NASA Energy/Power System Technology

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Army Research Office Base Camp Sustainability Workshop

Synergies with Space Exploration

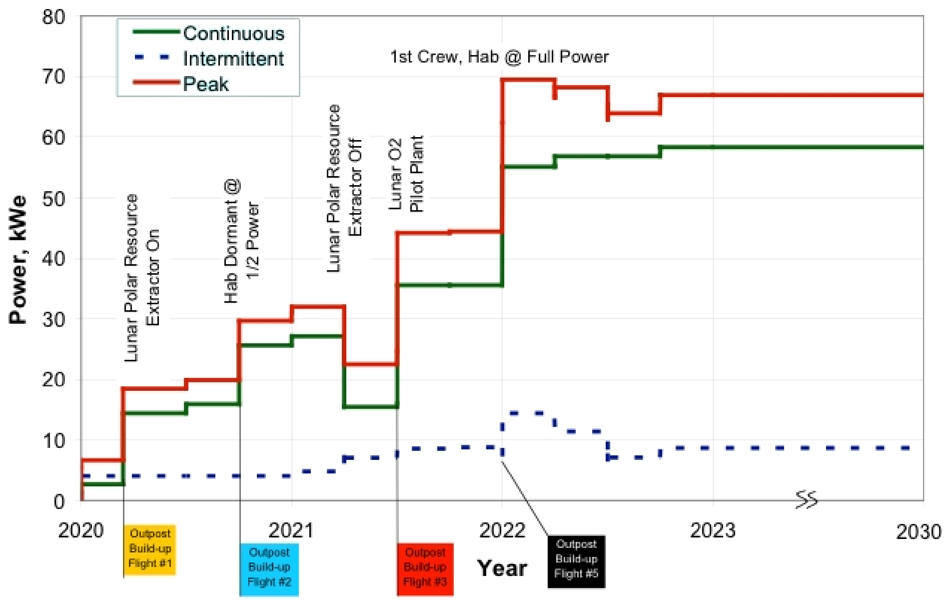
- Army base camps can use some of NASA’s technology developments that come from space exploration spin-offs – especially those relating to Lunar/Mars bases of the future.
  - Generation of sustainable (renewable) power – solar and nuclear
  - Hybrid systems
  - In Situ Resource Utilization
  - Energy storage
  - Power management and distribution
  - Harsh environment durability

Lunar & Mars Surface Bases

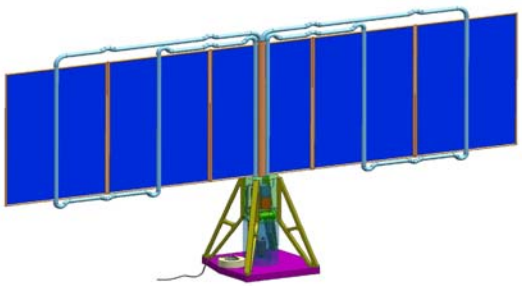
- Phased Development
  - Precursor: Robotic, Site Selection, Engineering Data Collection
  - Emplacement: First Humans, Multiple Sorties, Initial Outpost
  - Consolidation: Extended Stays, Centralized Base, In-Situ Resource Utilization Experiments
  - Operations: Continuous Occupation, Closed Loop Life Support, Resource Production

- Power System Options
  - Batteries and Fuel Cells (10’s to 100’s kW-hrs)
  - Deployable PV Arrays (kW’s to 10’s of kW)
  - Portable, Uninterruptible Radioisotope Generators (100’s of Watts)
  - Small, Deployable Reactor Power Systems (10’s of kW)
  - Large-Scale Reactor Power Plants (100’s of kW)
  - Hybrid Power System Architectures provide best reliability and fault tolerance

Exploration Systems Architecture Study



Power requirements reach 70 kWe within two years of initial outpost.



50 kWe Fission Surface Power System

11 MT* (Self-Shielded)

8 MT* (Regolith Shielded)

120 m^2 Radiator

25 kWe PV/Regen. Fuel Cell System

16 MT* (Cryo Storage, Global), 492 m^2 Array

8 MT* (Cryo Storage, Shackleton), 184 m^2 Array

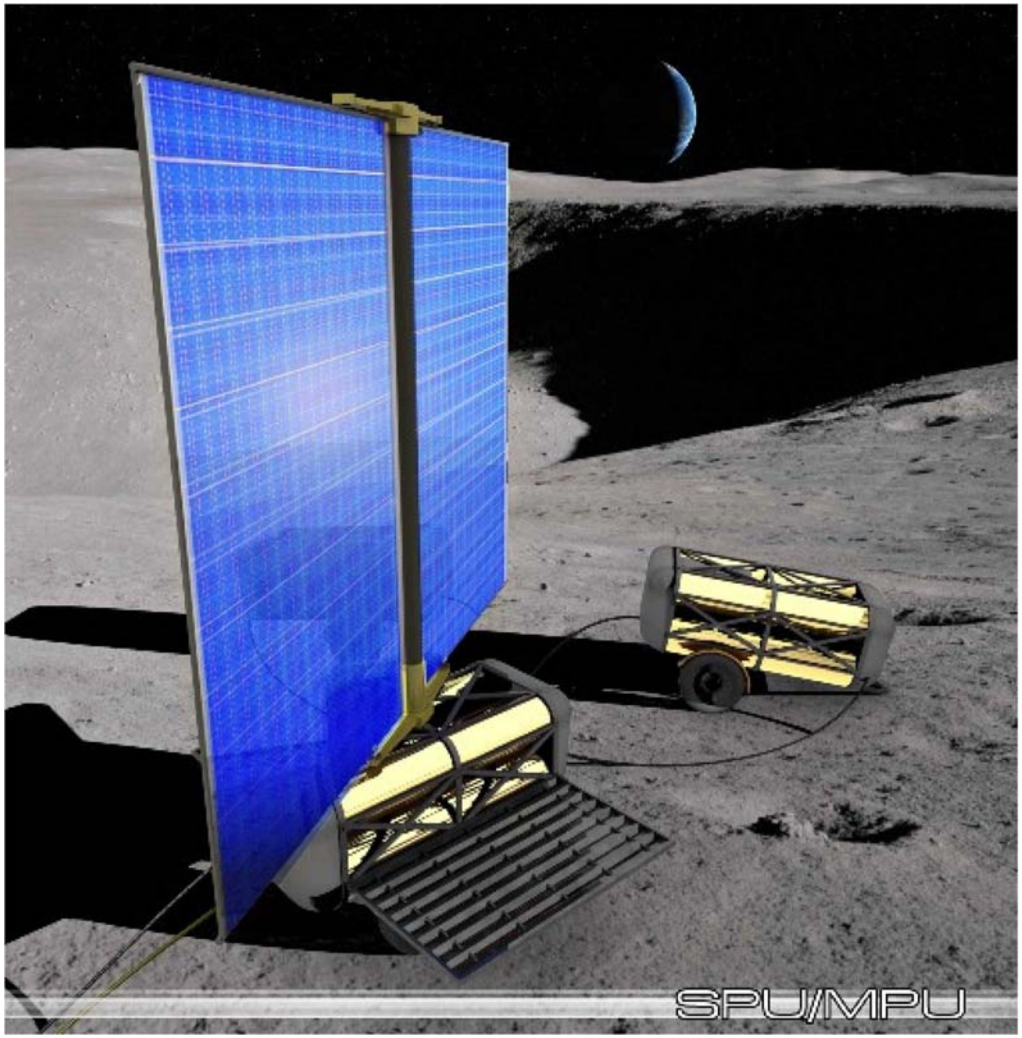
* All Masses include 20% Margin

Ref: "NASA's ExplorationSystems Architecture Study, Final Report" NASA-TM-2005-214062, November 2005.

Technology Thrusts

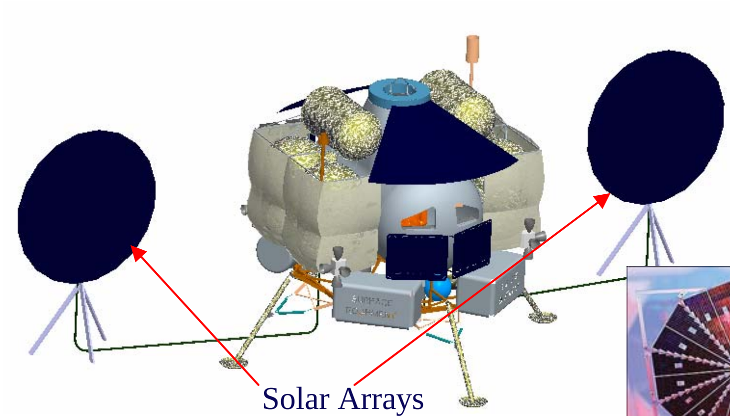
- Solar Power
  - Lunar and Mars Solar Arrays
  - Regenerative Fuel Cells
- Radioisotope Power Systems
  - Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)
  - Advanced Stirling Radioisotope Generator (ASRG)
  - Plutonium Alternatives
- Fission Surface Power
  - Terrestrial-Derived Reactor Technology (UO_2, Stainless, Pumped Liquid Metal, 900K Peak Coolant Temperature)
  - Multi-Kilowatt Stirling or Brayton Power Conversion
  - Heat Rejection (including Deployable Radiators)
  - Power Conditioning & Distribution (including High Voltage Power Transmission)

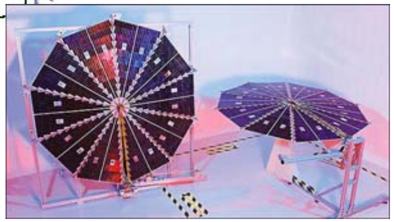
Solar Power Unit & Make-up Power Unit for Shackleton Crater



Photovoltaic/Regenerative Fuel Cell Concepts for Lunar Surface Power Systems

Photovoltaic-Regenerative Fuel Cell (PV-RFC) power systems provide near-term, low-cost options for a wide variety of lunar sortie, outpost and rover missions.





Near-term Lunar Missions

Larger-scale Outpost Power System

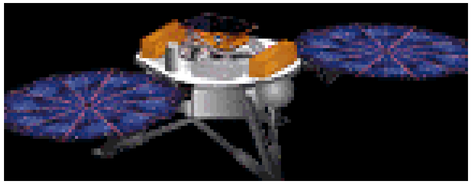
- High modularity allows for redundancy and ease in increasing power/energy capacity as power needs grow
- Use of existing/near-term technology lowers cost while providing high reliability
- GRC has world-class expertise and facilities in photovoltaic and energy storage technology
  - PV space calibration & test cells
  - Lead for “Energy Storage/Fuel-Cells for Surface Power” with RFC operational test bed

Photovoltaic (PV) Cell and Array Research & Development at NASA

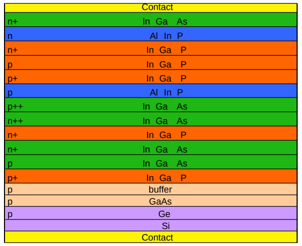
Advanced photovoltaic cell and array technology development, and its interaction within the space environment, has supported/enabled numerous NASA and other Government missions.

Advanced R&D primary conducted at Glenn Research Ctr. (GRC). Specific mission requirements/flight programs supported at other NASA Centers:
- JPL (Mars-optimized solar cell, dust mitigation)
- GSFC (electrostatically clean solar arrays)
- MSFC (space environmental effects)

Advanced PV Blanket and Array Technologies



Solar Cell Measurement and Calibration



High Efficiency III-V Photovoltaic Development

ATK UltraFlex array base-lined for CEV

Recent focus on supporting NASA Exploration mission needs.

- PV R&D supports generic future needs as well as specific science & exploration programs
- Program highly coordinated with other programs (AFRL, NRL, DOE, etc.)
- GRC POCs
  - Roshanak Hakimzadeh (216-433-8738)
  - Michael Piszczor (216-433-2237)

Photovoltaic Cell/Array R&D at NASA

NMP ST8 Flight Experiment UltraFlex-175

New Millennium Program (NMP) ST8 solar array flight experiment of UltraFlex design

- managed by JPL NMP Office
- array designed & built by ATK Space Systems
- UltraFlex Patent # 5,296,044

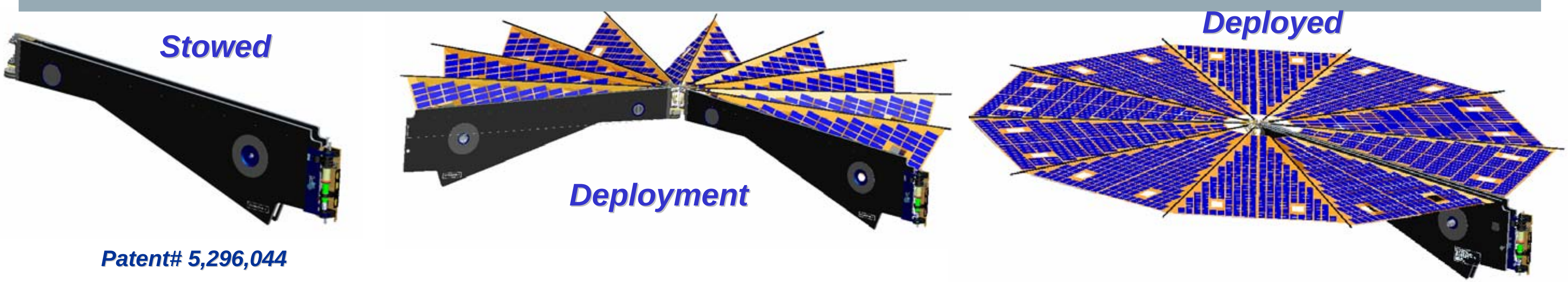
ST8 Experiment Goals

- **Deploy and operate in space an UltraFlex solar array and measure first mode frequency and photovoltaic power production**
- **Validate analytical models, which will allow for scale-up performance predictions applicable to solar arrays producing up to 7 kW**

- UltraFlex-175 (UF-175) is an accordion fanfold flexible-blanket solar array comprised of ten interconnected triangular shaped ultra-lightweight substrates (gores)
- During deployment each interconnected gore unfolds & becomes tensioned to form a shallow umbrella-shaped high-stiffness membrane structural platform for the PV cells

UltraFlex-175 technology advance provides extraordinary solar array performance

Ultra-lightweight (>175 W/kg), compact stowage volume (>40 kW/m^3), and high deployed frequency



Photovoltaic Cell/Array R&D at NASA

NMP ST8 Flight Experiment UltraFlex-175

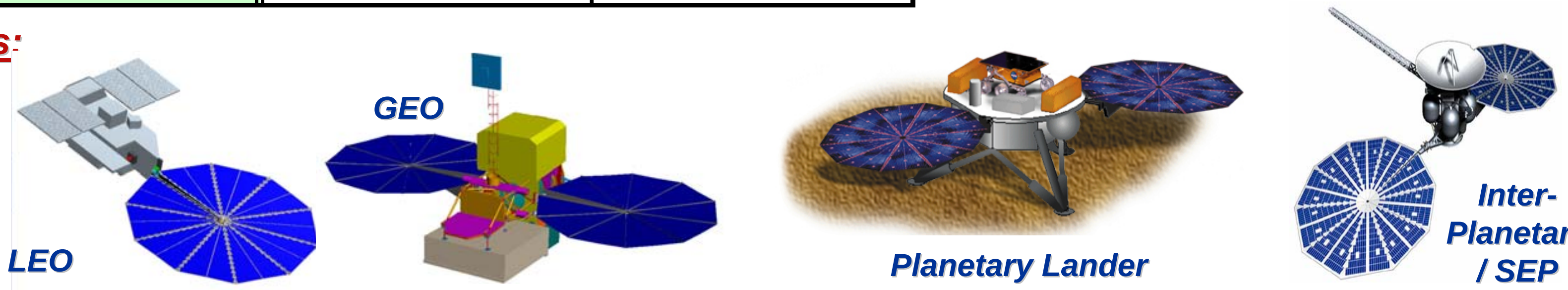
Mission-enabling performance benefits:

Performance Parameter	*7 kW UltraFlex-175*	*State-of-Art Rigid Array*
BOL Specific Power	**175-220 W/kg (depending on PV / circuit technology)**	60-70 W/kg
Stowed Packaging Efficiency	**> 40 kW/m^3**	7-10 kW/m^3
Deployed First Mode Frequency	**>0.4 Hz**	0.1 Hz
Operational Limitations	**None**	None
Reliability	**High**	High
Normalized Cost	**Low (post-technology development)**	Low

- Ideal for mass and stowage volume-critical applications
- Allows mission planners to maximize payload, reduce launch costs, or simply enable a mission because of exceptional performance metrics

UltraFlex-175 is easily interchangeable with rigid array technology and usable in all normal S/C operational modes

Applications:



Electrochemistry Branch – Batteries

Overview

- Batteries provide a versatile, reliable, safe, modular, lightweight, portable source of energy for aerospace applications.
- Batteries have demonstrated the life and performance required to power current missions.
- Li-Ion batteries offer improvements in specific energy, energy density, and efficiency

Products/Heritage

Li-Ion: Lithium-Ion, Ni-Cd: Nickel-Cadmium, Ni-H_2: Nickel-Hydrogen, Ni-MH: Nickel-metal hydride, Ag-Zn: Silver-Zinc, Na-S – Sodium Sulfur, LiCFx: Lithium-carbon monoflouride

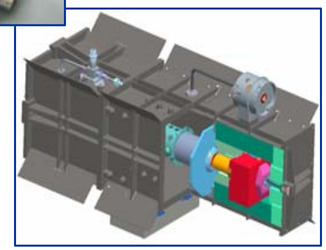
Experience

- Jointly sponsored Li-ion battery development program with DoD
- Lead for NASA Aerospace Flight Battery Systems Steering Committee –agency-wide effort aimed at ensuring the quality, safety, reliability, and performance of flight battery systems for NASA missions.
- Evaluated flight battery technologies for ISS
- Developed and validated designs for nickel hydrogen cells adopted for NASA missions and employed by cell manufacturers and satellite companies.
- Developed lightweight nickel electrodes, demonstrated the feasibility of bipolar nickel hydrogen battery designs

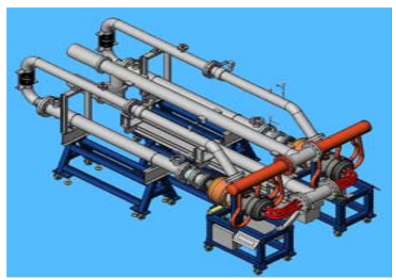
Thermal Energy Conversion

Description

- Thermal energy conversion
- Dynamic Power: Brayton, Rankine and Stirling
- Fission & Isotope Power Generation (partner w/DOE)
- Radiator System Development
- Modeling and Conceptual Design
- System Performance Modeling
- End-to-End System Testing



Stirling Convertor & Generator



Dual Closed-Brayton Test Loop

Facilities/Labs

- Brayton & Alternator Test Facilities
- Heat Pipe Laboratory
- Stirling Research Laboratory
  - Ambient test stand (6)
  - Thermal Vacuum Facility (small)
- Large Thermal-Vacuum Facility
  - 24 meters x 8 meters diameter
  - Solar Simulator
  - Integrated end-to-end testing
- Lunar PMAD Facility
- Polymer Composites Laboratory
- High Temperature Creep Lab

Focus Areas

- Brayton and Stirling Energy Conversion
- Heat Rejection Systems
- Electrical Controllers
- Power Management and Distribution
- Reactor & Isotope Heat Sources (partner with DOE)
- Component Development: Organics, Alternators, Heat Exchangers, Composites, Magnets, etc.
- High temperature materials
- Reliability and endurance testing

High temperature water heat pipe lab

Accomplishments

- Over 100,000 continuous hours of operation (24/7) on eight (8) 100 watts electric Stirling convertors (2006)
- Demo of high efficiency Stirling Convertor (~40%) (2006)
- Demo of 50 kilowatts Brayton Alternator Test Unit (2006)
- Demo of 30 kilowatts Dual Closed Brayton test system (2006)
- Long-term life testing at 500K Titanium-Water Heat Pipes (2006)
- Demo of 230 ^{o}C Polymer-Matrix Composite Radiator Panels (2006)

Lunar Environment
Effects, Durability Evaluation, Prediction and Mitigation

Accomplishments

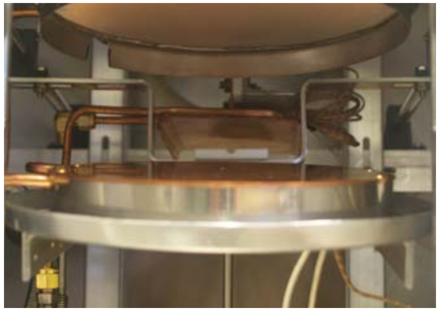
- Participation on MSFC-led study team for lunar surface access module - recommended design strategies to mitigate lunar dust effects
- Provided lunar environment support for GRC Lunar Surface Power design study
- Completed Lunar Dust Adhesion Bell Jar, a high fidelity lunar simulation chamber
- Initiated high fidelity lunar simulant work

Current Work

- Lunar dust adhesion bell jar facility continued development (EVA support)
- GRC dust characterization/mitigation (Level II support)
- High fidelity lunar simulant fabrication (IR&D support)
- Dust mitigation techniques (Congressional Earmark for Power Systems support)
- Lunar environmental effects on system designs (Constellation support)

Lunar Dust Adhesion Belljar

Exterior View of Chamber



Inside View of Sample Holder

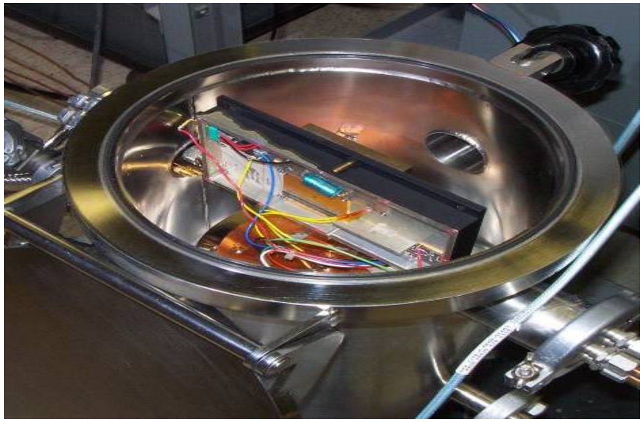
Extreme Temperature Electronics

Accomplishments

- Completed qualification tests on 4 RF preamplifiers for use on Shuttle for signal amplification from GPS satellites. Work done for JSC & Boeing
- Completed evaluation of new precision voltage reference chips under cryogenic temperatures. Data was provided to GSFC JWST Mission engineers so that proper selection can be made of extremely stable voltage references for deployment behind sun shield.
- Performed evaluation of several prototype SiGe power transistors that were developed by GPD Optoelectronics, Inc. under a NASA SBIR Program.

Current Work (Customer/Funding)

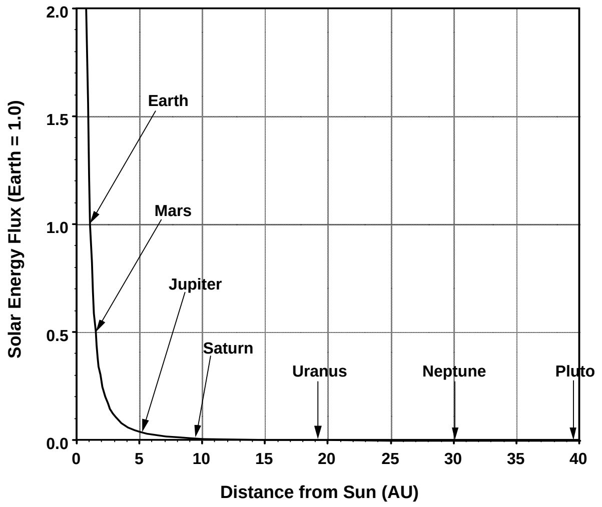
- Device evaluation for NASA Electronic Parts and Packaging Program
  - Identification and acquisition of commercial & mission-related devices
  - Extreme temperature screening testing and combined thermal/electrical testing
  - Submit reports and disseminate information through NEPP
- Develop high temperature instrumentation for jet engine distributed control

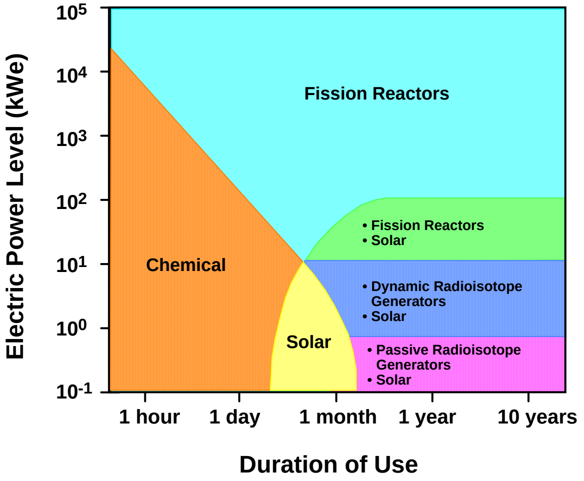


Space Shuttle GPS Preamp in cryogenic/vacuum chamber

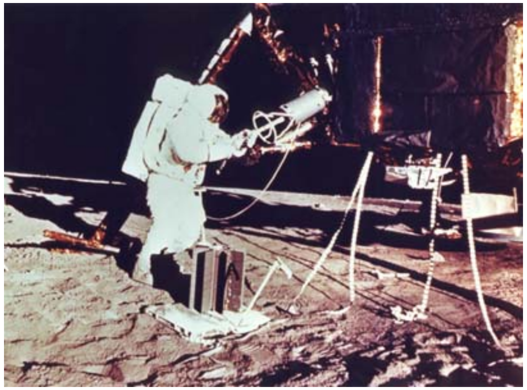
Why Nuclear?

- High Power
- Long Life
- Compact
- Low Mass
- High Power Density
- High Reliability
- No Dependence on Sunlight
- Environmentally Robust
- Proven Technology
- Safe for Humans
- Safe for All Mission Phases

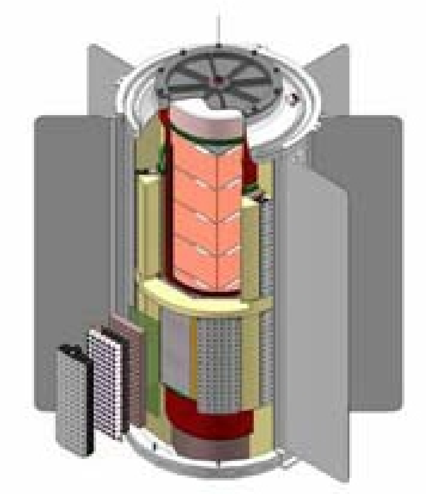




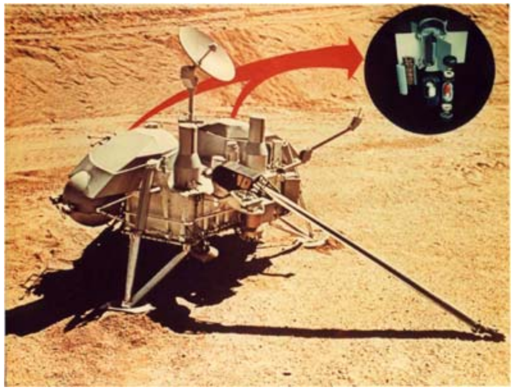
Radioisotope Generators



SNAP-27 (Apollo)

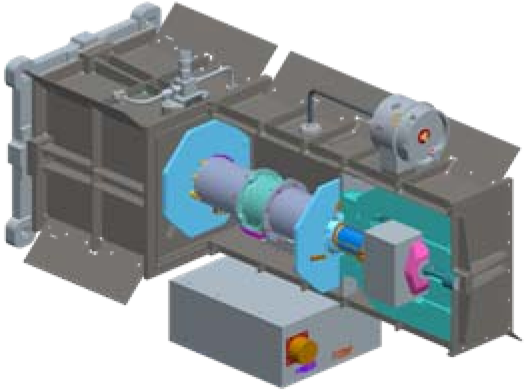


Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)

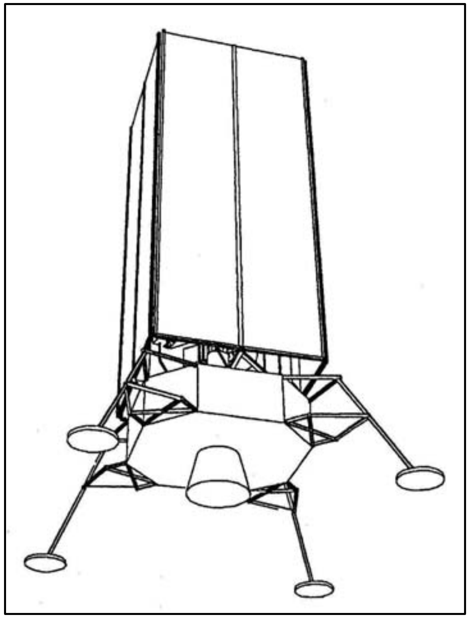


SNAP-19 (Viking)

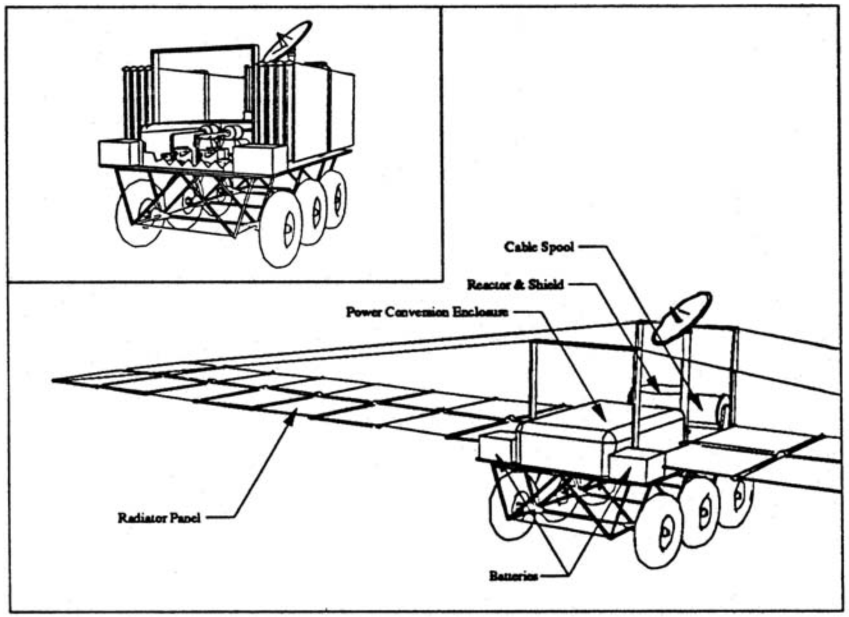
Advanced Stirling Radioisotope Generator (ASRG)

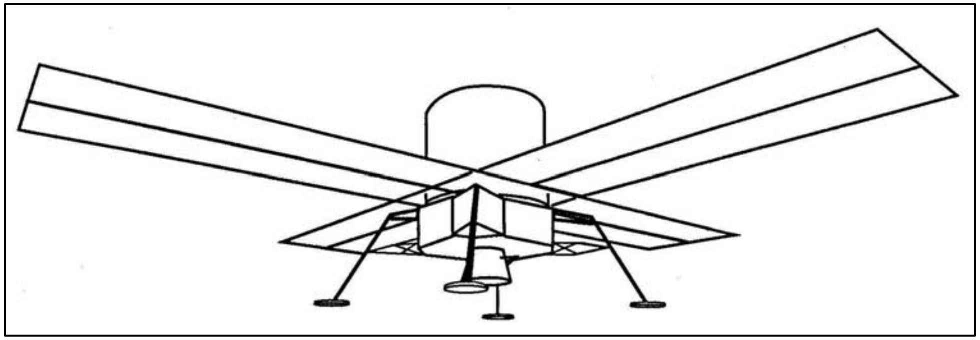


Self-Deployed Reactor Systems



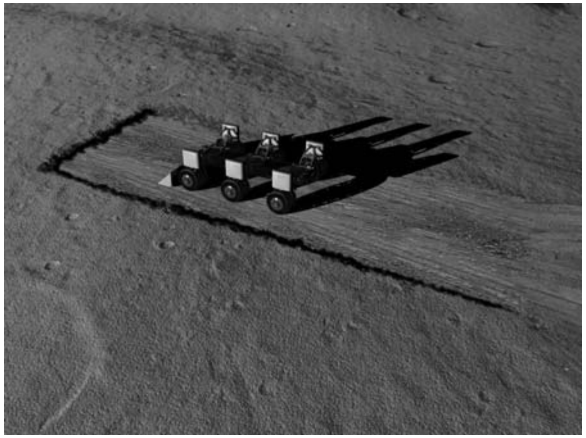
Landed Reactors



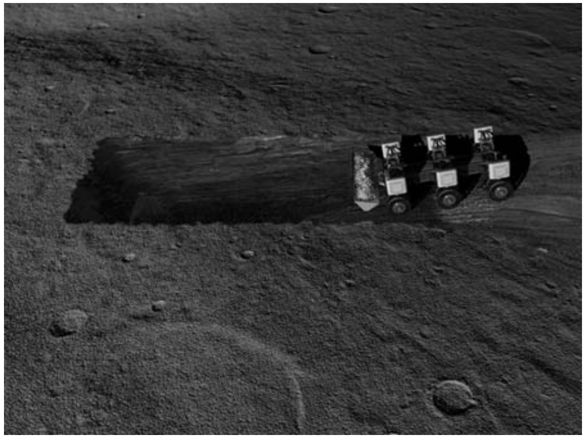


Mobile Reactors

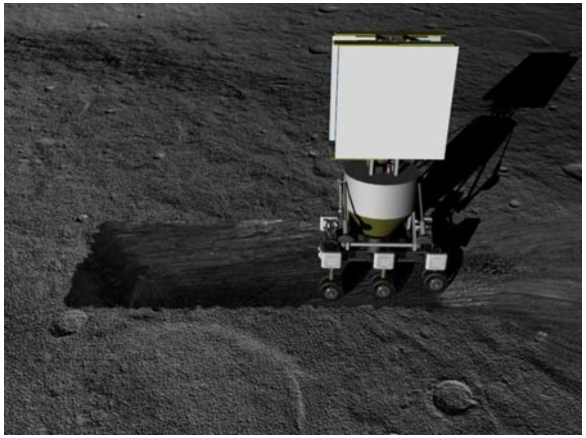
Emplaced Reactor Systems



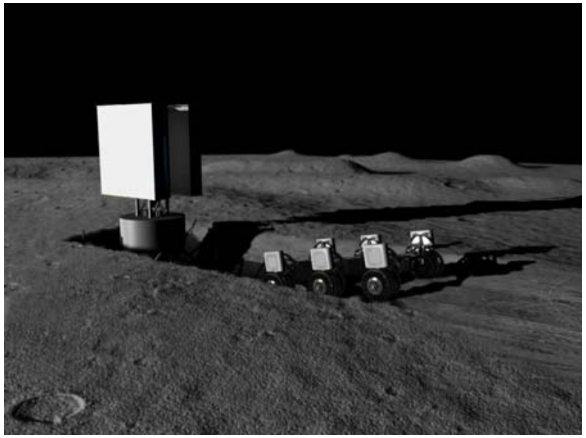
1. Site Selection



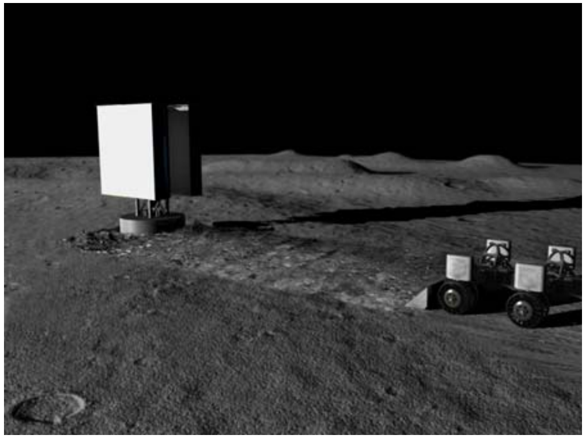
2. Excavation



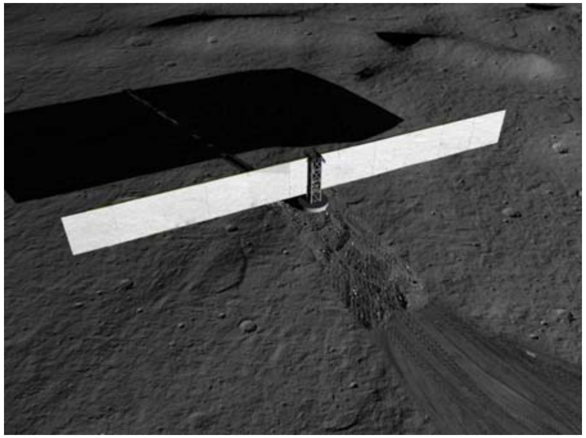
3. Delivery



4. Emplacement

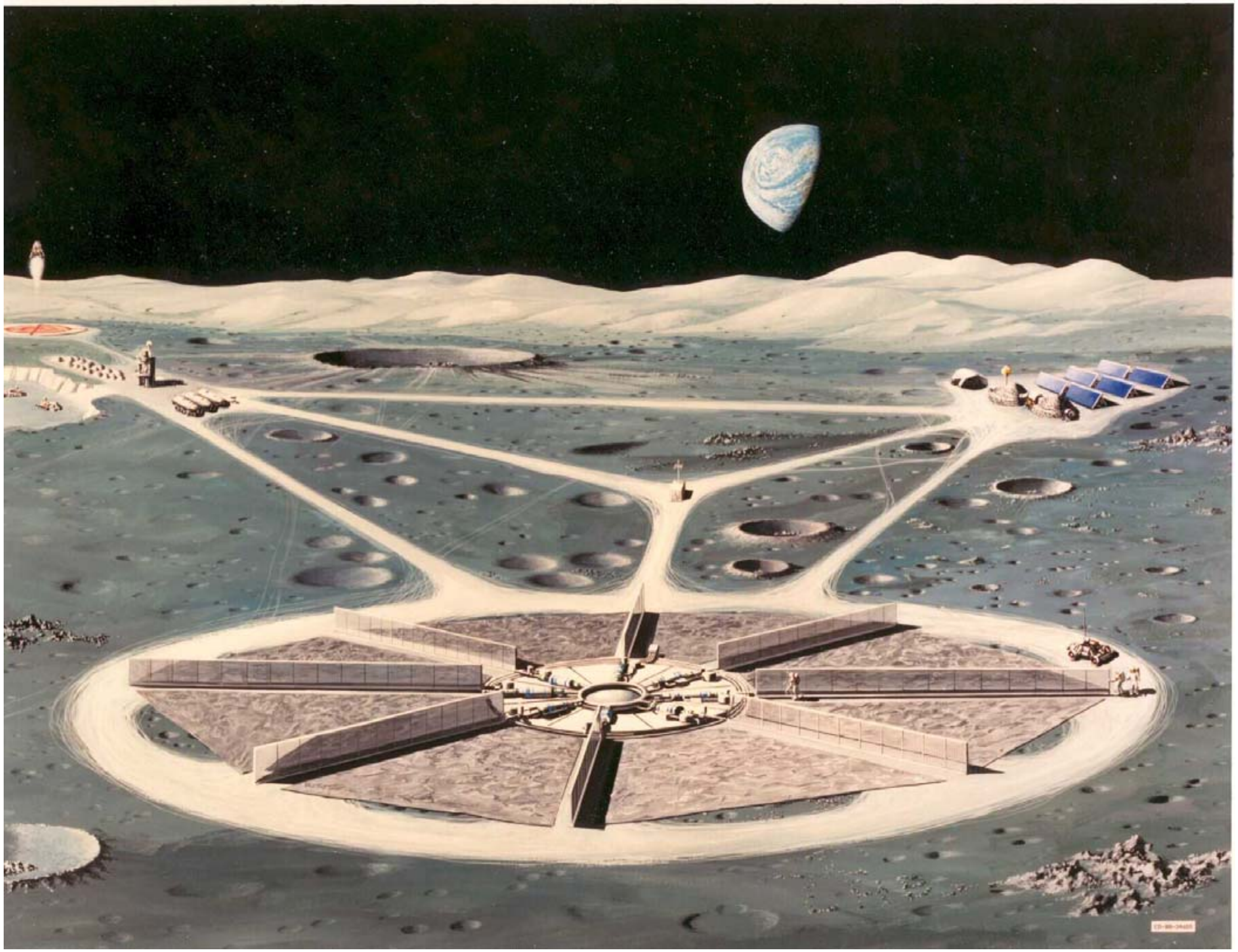


5. Back-filling



6. Startup

Large-Scale Reactor Power Plants



Summary

- NASA goals of developing equipment for use in remote Lunar and Mars bases offers technology that can be used for remote, autonomous bases on earth.
- NASA encourages partnering with external organizations to achieve technology and product development for supporting its missions.