Nuclear Electric Propulsion Options for Piloted Mars Missions

Nuclear Propulsion Technical Interchange Meeting
LeRC Plum Brook Station
October 22, 1992

Jeff George
Advanced Space Analysis Office

NEP for SEI Mars Missions

- Synergy with Surface Power Technology
- "Fast" Piloted Missions
- Efficient Cargo Delivery
- Fewer and/or Smaller (135 MT) Launch Vehicles
- Continuous Abort Mode
- Continuous Earth Return Window
- Technology:
  - Existing Reactor Technology Program
  - Need Potassium Rankine Power Conversion
  - Need Multimegawatt Ion Thrusters
Why not NEP?

- Long Earth spiral escape times
  - Impractical piloted lunar missions
  - Chemical crew taxi for piloted Mars
- Long operating times
  - High reliabilities necessary
  - Complications for artificial gravity
- Multiple technologies
  - Reactor
  - Power Conversion
  - Thrusters

NEP Technologies

- Reactor
  - 2 yr life, 25 MWth SP-100
  - Li cooled, fast spectrum, UN fuel, Nb-1Zr clad
  - Technology developed in current SP-100 program
- Power Conversion
  - 1400 K Potassium Rankine
  - SNAP-50 tested components at 1420 K for 10,000 hours
    - 3-5 life projected from turbine erosion
- Thrusters
  - Argon ion engines, 5000 sec. lsp, 69 % efficiency, 10,000 hour life
  - Efficiency and life demonstrated at lsp but lower power
  - EP will be used on upcoming Telstar IV
2 x 5 MWe Reduced Life Growth SP-100 NEP System

Reactor Power Conversion Power Output Full Power Life Propulsion
Li-cooled pin-type fast reactor Potassium Rankine 5 MWe/Module 5 yrs Ion

Cycle Characteristics:
Turbine Inlet Temp. 1400 K
Condenser Temp. 975 K (Min. mass)
Thermal-Electric Eff. 20.5%

Reactor:
Spectrum Fast
Coolant Lithium
Fuel UN pins
Cladding PWC-11
Structure PWC-11

Man-rated Shadow Shield:
Dose Constraint 5 rem/yr
Materials W/LiII
Dose Plane Diameter 30 m
Separation Distance 100 m

Heat Rejection:
Type Heat Pipe Radiators
Geometry Planar
Specific Mass 6 kg/m²
Total Radiator Area 683 m²/Module

System Mass Breakdown:
Reactors 6390 kg
Shielding 12000 kg
Power Conversion 19060 kg (4x2 T-G units, 50% redundancy)
Radiators 8320 kg
Power Cond. & Dist. 20000 kg
Ion Propulsion 60000 kg
Total (2 Modules) 72770 kg
Specific Mass 7.3 kg/kWe

15 MWe Multi-Reactor Nuclear Electric Propulsion Vehicle for a Piloted Mission to Mars

Advanced Space Analysis Office

Advanced Space Analysis Office
Groundrules

- Systems
  - Modular/Multiple Power Systems
    - Growth SP-100 Reactor
    - 1400 K Potassium Rankine Power Conversion
  - Argon Ion Engines
    - 5000 sec Isp
    - 68.9 % efficiency
    - 10,000 hour life
    - 7.3 kg/kWe
  - 10 % Tankage Fraction
  - 10 MT Inert/Structure Mass

- Orbits
  - SSF Altitude Earth Departure Orbit
  - Crew boards at HEO
  - Areosynchronous Orbit at Mars
  - ECCV return at Mars (8.4 km/sec V= Limit)

Payload Assumptions

<table>
<thead>
<tr>
<th>ECCV</th>
<th>7 MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Habitat</td>
<td>55 MT</td>
</tr>
<tr>
<td>Piloted MEV</td>
<td>65 MT</td>
</tr>
<tr>
<td>Cargo MEV</td>
<td>65 MT</td>
</tr>
</tbody>
</table>

- Unless otherwise noted - all Piloted NEP missions presented carry return propellant
10 MWe Piloted Mars NEP with ECCV

2 x 5.0 MWe Modular "Hydra" NEP Vehicle

2 x 181 MT HLLV Launches

2010  2018

Piloted Transit Time:
193 d  154 d
+180 d  +106 d
373 d  280 d

IMLEO:  310 MT  285 MT

NASA Lewis Research Center
Advanced Space Analysis Office

10 MWe Modular NEP Piloted Mars Vehicle
10 & 15 MWe Piloted Mars NEP with ECCV & MEV

2 x 5.0 MWe Modular "Hydra" NEP Vehicle

3-4 x 132 MT HLLV Launches

<table>
<thead>
<tr>
<th>Power:</th>
<th>15 MWe</th>
<th>10 MWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piloted</td>
<td>200 d</td>
<td>177 d</td>
</tr>
<tr>
<td>Transit</td>
<td>±180 d</td>
<td>±105 d</td>
</tr>
<tr>
<td>Time:</td>
<td>380 d</td>
<td>283 d</td>
</tr>
<tr>
<td>IMLEO:</td>
<td>479 MT</td>
<td>367 MT</td>
</tr>
</tbody>
</table>

* - Optimal leg distribution 221±134=355 d & 518 MT

Lewis Research Center
Advanced Space Analysis Office

5 MWe Piloted Mars NEP with ECCV

5.0 MWe Piloted NEP Vehicle

1 x 190 MT HLLV Launch

<table>
<thead>
<tr>
<th>Power:</th>
<th>15 MWe</th>
<th>10 MWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piloted</td>
<td>233 d</td>
<td>191 d</td>
</tr>
<tr>
<td>Transit</td>
<td>±200 d</td>
<td>±125 d</td>
</tr>
<tr>
<td>Time:</td>
<td>433 d</td>
<td>306 d</td>
</tr>
<tr>
<td>IMLEO:</td>
<td>189 MT</td>
<td>190 MT</td>
</tr>
</tbody>
</table>

Lewis Research Center
Advanced Space Analysis Office

NP-TIM-92 1091
5 MWe Mars Cargo NEP with 2 MEVs

5.0 MWe Cargo NEP Vehicle

1 x 242 MT HLLV Launch

242 MT
46 m x 12 m

2007
One-Way

Transit Time: 416 d
IMLEO: 242 MT

NASA Lewis Research Center
Advanced Space Analysis Office

2.5 MWe Mars Cargo NEP with MEV

2.5 MWe Cargo NEP Vehicle

1 x 135 MT HLLV Launch

135 MT
46 m x 10 m

2007
2007
One-Way Round Trip

Transit Time:

<table>
<thead>
<tr>
<th></th>
<th>One-Way</th>
<th>Round Trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit</td>
<td>405 d</td>
<td>460 d</td>
</tr>
<tr>
<td>Time:</td>
<td>405 d</td>
<td>669 d</td>
</tr>
<tr>
<td>IMLEO:</td>
<td>135 MT</td>
<td>135 MT</td>
</tr>
</tbody>
</table>

NEP: Systems Modeling

NASA Lewis Research Center
Advanced Space Analysis Office
NP-TIM-92
Launch Vehicle Requirements

<table>
<thead>
<tr>
<th>Launch Vehicle Size</th>
<th>Mission Mode</th>
<th>Piloted</th>
<th>Cargo</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Small&quot; (135 MT)</td>
<td>10 MWe Piloted with ECCV</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>10/15 Piloted with MEV</td>
<td>3-4</td>
<td>3</td>
<td>6-7</td>
</tr>
<tr>
<td>&quot;Medium&quot; (180 MT)</td>
<td>5 MWe Piloted with ECCV</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10 MWe Piloted with ECCV</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>10/15 Piloted with MEV</td>
<td>3-4</td>
<td>3</td>
<td>6-7</td>
</tr>
<tr>
<td>&quot;Large&quot; (220 MT)</td>
<td>5 MWe Piloted with ECCV</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>10 MWe Piloted with ECCV</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>10/15 Piloted with MEV</td>
<td>3-4</td>
<td>2</td>
<td>5-6</td>
</tr>
</tbody>
</table>

Future Work

- Preliminary trade studies completed
  - EXPO '92 NEP Mars Scenario
- Select reference mission/system scenario
- Perform focused studies
  - System design
    - Krypton propellant
    - Advanced reactor/power conversion technologies
  - Launch manifest
  - Aborts/Window Assessment
  - 10 MWe out/15 MWe back
  - Radiation Protection

NASA Lewis Research Center
Advanced Space Analysis Office

NP-TIM-92 1093 NEP: Systems Modeling
Summary

- NEP meets EXPO trip time requirements (5-10 MWe)
- NEP enables reduction of number and/or size of HLLV's
- NEP has inherent flexibilities and abort capabilities not afforded by high thrust systems
- Synergy exists between NEP, surface, and spacecraft power technologies
- NEP could be ready to support 2010 Mars mission - No technological "show-stoppers" exist