Assumptions

- Two prioritized list are developed: one for early manned Lunar missions and one for permanently manned Lunar missions and Mars
- No priority is implied within a group
- First Lunar outpost, missions and design guidelines dated 1/7/92 and SEI Strategic Plan Dated 12/10/91 are used for mission requirements
- Early manned Lunar mission by 1999 with up to 45 day stay capability for a crew of 4
- No long-term cryo storage required for initial Lunar missions (storable return propulsion)
- Emphasize common Lunar mission - Mars mission technology and H/W and S/W
- All technology will be developed to TRL 5 or 6 prior to project start (Phase C/D)
- Required permanent Lunar and Mars technology/advanced development will be initiated between now and 2000
- All technology/advanced development must have clearly defined cost/benefit justification or mandatory mission need rationale
- NTR development in critical path for manned Mars mission
- Mars missions will include stays of up to 500-600 days at Mars
- For each project advanced development starts before project start at Phase C/D and terminates within the year PDR is held
# Prioritization Criteria

**NASA Office of Exploration**

**NOTE:** This chart is used to develop the technology needs for the SEI missions.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mission Leverage</strong></td>
<td></td>
</tr>
<tr>
<td>• Performance leverage of technology to system, mission, and crew</td>
<td>High</td>
</tr>
<tr>
<td>• Ability of technology to reduce risk to crew and mission</td>
<td>Medium</td>
</tr>
<tr>
<td>• Ability of technology to reduce cost by reducing Earth delivered mass and life cycle costs</td>
<td>Low</td>
</tr>
<tr>
<td>• Evolution capability</td>
<td></td>
</tr>
<tr>
<td>• Ability to support multiple missions (commonality)</td>
<td></td>
</tr>
<tr>
<td><strong>Timing</strong></td>
<td></td>
</tr>
<tr>
<td>• Development time to reach TRL 5 (years)</td>
<td></td>
</tr>
<tr>
<td>• Time needed before project start (years)</td>
<td></td>
</tr>
<tr>
<td><strong>Special Factors</strong></td>
<td></td>
</tr>
<tr>
<td>• Transportability/spin-off to commercial sector</td>
<td></td>
</tr>
<tr>
<td>• Ability to stimulate universities and public for support of mission</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Long</th>
<th>Medium</th>
<th>Short</th>
</tr>
</thead>
<tbody>
<tr>
<td>T≥8</td>
<td>3&lt;T&lt;7</td>
<td>T≤3</td>
<td></td>
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**1992 - 1995 CRITICAL TECHNOLOGIES**
PRELIMINARY CRITICAL TECHNOLOGY PRIORITIZATION

Office of Exploration

Category 1 Priority (Near Term)

- Lunar EVA Systems
  - Durable, lightweight, high mobility suit and EVA gloves
  - Lightweight, serviceable, PLSS
- Autonomous Terminal Landing
  - Sensors
  - S/W algorithms
  - Hazard avoidance
- Life Support
  - Contamination and particulate control
  - Trash & waste/collection & processing
  - Loop closure

Category 1A Priority
(Mars and Permanently Manned Lunar Missions)

- NTP
  - Fuel development
  - Turbo pumps
  - Test facility
  - Reactor development
- Surface Habs and construction
  - Radiation shielding
  - Dust control

- Surface Power - Non Nuclear
  - High efficiency thermal to electric conversion
  - Heat rejection
  - Long-life energy storage

- Cryo Fluid Systems
  - Cryo storage
  - Cryo transfer (zero-g)
  - Quick disconnect couplings
  - Zero-g gaging

- Surface nuclear power
  - Power conversion
  - Radiators

- ISRU (Technology demo capability)
  - Oxygen process chemistry
  - Mining
  - Construction material test

CRITICAL TECHNOLOGIES

(1995 + )
**PRELIMINARY CRITICAL TECHNOLOGY PRIORITIZATION**
**PERMANENTLY MANNED LUNAR AND MARS MISSIONS**
**(1995 +)**

**Category I (Highest Priority)**

- NTP
- Mars EVA Systems
  - Durable, lightweight, high mobility suit and EVA gloves
  - Lightweight, serviceable, PLSS
- Surface Power - Nuclear
  - Life Support Systems/Thermal Control Systems (Long-term use)
  - Radiation Protection
    - Light weight shielding
    - SPE prediction
    - Transport code validation
- ISRU
  - Liquefaction
  - Materials compatibility
  - Electrolysis technologies

**Category II**

- Telerobotics
  - Sensors
  - Vision
  - End effectors
- Aerobraking
  - TPS
  - CFD codes
  - High temperature structural material
  - Adaptive GN&C
- Planetary Rovers
  - Motors lubricants (Long-term use)
  - Dust control
  - Power

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**TECHNOLOGY NEEDS**

**Technology Category**

- EVA Systems

**Technology Areas**

- Durable lightweight dexterous high mobility suit
- Lightweight, serviceable PLSS
- Environmental dust control
- Highly dexterous gloves

**Benefits/Leverage**

- Increase crew safety and EVA productivity
- Reduce suit servicing time
- Enabling for use on surface
- Lower life cycle cost
- Evolvable technology baseline for Mars

**Performance Goals**

- EVA system lifetime: ≥ 5 yrs
- Duty cycle: ≥ 200 days/yr @ 6-8 hrs/day
- Suit oper. pressure: 3.8 - 6 PSIA
- Lunar EVA system mass: ≤ 110 Kg venting
  ≤ 125 Kg regen.
- Mars EVA system mass: ≤ 90 kg venting
  ≤ 70 kg regen.

**Technology Readiness Dates**

- Current TRL: 3 - 4
- Required time to reach TRL 5: 3 years

Need dates: Lunar: 1996
  Mars: 2000
### Technology Needs

#### NASA

**Technology Category**
- Surface power - non nuclear

**Technology Areas**
- Long-life energy storage, e.g., regenerative fuel cells (RFCs)
- Power management and distribution (low mass, long duty cycle, low maintenance)
- Thermal control (high efficiency, long duty cycle, long-lived, low maintenance)
- Generation: solar PV

**Benefits/Leverage**
- Reduced mass
- Reduced maintenance
- Improved reliability, lifetime
- Increased performance
- Applications to terrestrial systems

**Performance Goals**
- RFCs: Specific energy: $670 \text{ W-HR} / \text{ kg}$ (Lunar)
  
- Specific power: $250 \text{ W/kg}$ (Lunar and Mars)
- System efficiency: 65% FC, 90% electrolyzer
- Lifetime: 500 - 4000 hrs (SOA) ≥20,000 hrs (advanced)
- PMAD: 20 kg/kW
- Generation: PV arrays 300 W/kg (Lunar) 80 W/kg (Mars) ≥40,000 hr. lifetime

**Technology Readiness Dates**
- Current TRL:
  - Storage: 3 - 4
  - PMAD: 4
  - Thermal: 4
  - Generation: 4
- Years to TRL 6: 4 - 6

### Technology Needs

#### NASA

**Technology Category**
- Autonomous terminal landing

**Technology Areas**
- Hazard avoidance
- Sensors
- S/W algorithms
- Adaptive mechanisms and effectors

**Benefits/Leverage**
- Reduce ground support
- Reduce EVA support for vehicle mating
- Allow landing if crew unable to manually perform task
- Land at predefined coordinates
- Robotic Mars missions to return samples from rover is enabled

**Performance Goals**
- Landing accuracy: ≤ 100 m
- Hazard avoidance: ≥ 1 m (surface hazards)
- Hazard endurance: ≤ 1 m (surface hazards)
- Reliability: ≥ 99% probability of safe landing

**Technology Readiness Dates**
- TRL: 3 - 4
- 2 - 4 years to TRL 5

Need dates:
- Lunar: Robotic: 1993
- Outpost: 1995
- Mars: 2000
TECHNOLOGY NEEDS

NASA

Technology Category
- Cryogenic Fluid Systems

Technology Areas
- Cryo storage (Thermal & Pressure Control)
- Cryo management for propellant slosh control and acquisition
- Cryo transfer for in-space fueling/refueling
- Cryo zero-leak quick disconnect coupling and zero-G gaging system
- Cryo production on planet surface

Benefits/Leverage
- Enabling for in-space assembled space transfer vehicles (all Mars concepts)
- On-orbit fueling/refueling enables reusable vehicle concepts and significantly reduces vehicle departure mass
- IMLEO reduction of 25-30% for cryogenic propulsion system used for return from Lunar surface when compared to storables for direct Lunar injected missions

Performance Goals
- Cryogens: Hydrogen and oxygen
- Cryo system acceleration environment: 0 to high G level
- Lunar boil-off rate: 2 to 6%/month (mission dependent)
- Mars boil-off rate: ≤ 1%/month
- Transfer losses: ≤ 5%
- Unusable propellants (residuals): ≤ 2%

Technology Readiness Dates
- Thermal control is TRL 4/5
- All other areas are TRL 2/3
- Cryo transfer and 0-G pressure control are 8 yrs. to TRL 6
- Thermal control is 3 yrs. to TRL 6
- All other areas require up to 5 yrs. to TRL 6

Need dates:
- Lunar: 1998
- Mars: 2000

NASA

Technology Category
- Life support systems/crew accommodations

Technology Areas
- Contamination and particulate control
- Trash and waste collection and processing
- Water management
- Bio regeneration
- Food management and biomass production

Benefits/Leverage
- Saves up to 40 lbs/day resupply
- Reduce trash build-up
- Integration of biological and physiochemical regenerative systems

Performance Goals
- System lifetime: 7 - 15 yrs (Lunar)
  3 + yrs (Mars)
- System closure (water): 95%
- System closure (air): 95%
- System closure (total): TBD
- System power req: TBD kW/person
- Operating environment: Lunar/Mars Minimal servicing

Technology Readiness Dates
- TRL: 2 - 4
- Development to TRL 5: 5 - 6 yrs

Need dates:
- Lunar: 1995
- Mars: 2000
## Technology Needs

### Technology Category
- **ISRU**

### Technology Areas
- Oxygen process chemistry
- Mining
- Electrolysis technologies
- Materials compatibility
- Liquefaction
- Construction material test

### Benefits/Leverage
- Reduce resupply
- Make up oxygen for safety and redundancy
- Increase stay time

### Performance Goals
- Equipment life time: ≥10 years
- Liquid oxygen production:
  - Initial: 5 - 10 mT/yr
  - OPS: 10 - 25 mT/yr
- Regolith mined annually: ≤5 KMT/yr
- Duty cycle: ≥90% (day/night)
- System mass: OPS ≤15 mT
- Power: TBD KWe

### Technology Readiness Dates
- TRL: 2 - 4
- 4 - 6 years to TRL 6

**Need dates:**
- Lunar: 1995
- Mars: 2000
- Lunar robotic (demo): 1993

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### Technology Needs

### Technology Category
- **NTP (Solid core)**

### Technology Areas
- Fuel development
- Turbo pumps
- Test facility design/construction
- Shielding and control systems
- Pressure vessels and nozzle technology
- High temperature materials
- Reactor development

### Benefits/Leverage
- Significant reduction in Earth delivered mass
- Reduce Mars trip times
- Crew safety
- Operational flexibility

### Performance Goals
- Lifetime: 5 - 15 years, multiple flights
- Thrust: 25 - 75 k lbs
- Specific impulse: 900 - 1000 sec
- Specific mass: 120-240 kW/kg
- Thrust-to-mass: >3 to 30
- Space base, limited servicing, multiple restart

### Technology Readiness Dates
- TRL: 4-5
- 5-10 years to TRL 6 (uprated NERVA technology)

**Need date:** Mars: 2000
TECHNOLOGY NEEDS

Technology Category
- Surface power - nuclear

Technology Areas
- High efficiency thermal to electric conversion
- Power conditioning and transmission
- Heat rejection/radiator concepts
- Dust effects on system performance
- Generation: Reactor and isotope/Heat sources

Performance Goals
- Stationary applications:
  - 50 kg/kWe @ 100 kWe (static conversion)
  - 25 kg/kWe @ 500-800 kWe (dynamic conversion)
- Mobile applications:
  - 5 W/kg @ 300 We (RTG)
  - 7 W/kg @ 2.5 kWe (DIPS)
- Lifetime:
  - 7 - 15 yrs

Benefits/Leverage
- Increase crew living/working area
- Allow building of large structures
- Prepare landing site
- Enhance crew productivity/safety
- Reduce launch mass/volume

Technology Readiness Dates
- Current TRL:
  - 3 - 4 SP - 100
  - 4 - 5 DIPS
  - > 5 RTG
- Years to TRL:
  - 6 - 10 depending on system, subsystem

Technology Category
- Surface hab and construction

Technology Areas
- Autonomous deployment of systems
- Surface/stability determination
- Dust control
- Hab to Hab IVA interface
- Inflatable structures

Performance Parameters
- Habitat lifetime: ≥ 10-15 years
- Habitat environmental pressure: TBD
- Heat rejection requirement: TBD
- Construction equipment load: TBD
- Set up time: TBD
- Crew required for set up: TBD

Benefits/Leverage
- Increase crew living/working area
- Allow building of large structures
- Prepare landing site
- Enhance crew productivity/safety
- Reduce launch mass/volume

Technology Readiness Dates
- TRL: 1-2
- 4-5 years to TRL 5
Need dates:
- Lunar: 1997
- Mars: 2000
TECHNOLOGY NEEDS

Technology Category:
- Radiation protection

Technology Areas:
- Shielding materials (light weight)
- Prediction of SPE and monitoring
- Crew high Z, high energy limits
- Transport codes enhancement & validation
- Active crew personal dosimeter
- Particle Spectrometer for GCR and solar flare particles
- Tissue Equivalent Proportional counter for charged particle detection
- Neutron Energy Spectrum spectrometer

Performance Goals:
- Shielding lifetime: > 10-15 years
- Shielding requirement: 20 gm/sq. cm. (200 gm/sq.cm. sleep quarters)
- Prediction error: <20% (initial) <10% (final Mars)
- SPE prediction: TBD hrs. prior to occurrence

Benefits/Leverage
- Crew protection from solar and cosmic radiation during transit and on surface
- Data to determine appropriate shielding strategy for crew and electronics to reduce mass

Technology Readiness Dates
- TRL: 3
- Development to TRL 6: 5-7 years

TECHNOLOGY NEEDS

Technology Category
- Telerobotics

Technology Areas
- Joint actuators
- Sensors
- Vision
- Man-machine interface
- End effectors
- Intelligent controls

Performance Goals
- Manipulator dexterity: TBD
- Manipulator loading: TBD
- Radiation field: TBD

Benefits/Leverage
- Reduce crew exposure to EVA
- Perform operations at a distance
- Servicing of hazardous systems

Technology Readiness Dates
- TRL: 3-4
- 3-5 years to TRL 5
## TECHNOLOGY NEEDS

### Technology Category
- Planetary Rovers (Long-term autonomous use)

### Technology Areas
- Motors/lubricants (Long-term use)
- Dust control
- Power

### Performance Goals
- Semi-autonomous traverse: \( \geq 10 \text{M (early)} \)
- \( \geq 100 \text{M (interim)} \)
- Mobility (obstacle endurance): \( \leq 1 \text{M} \)
- Power system: \( \geq 5 \text{W (kg (robotic))} \)
- Lifetime: 1-2 years
- Life support requirement: TBD
- Range robotic: 100 km
- Range manned: \( \leq 100 \text{ km} \)

### Benefits/Leverage
- Allow extended operations from base
- Support science investigation

### Technology Readiness Dates
- TRL: 2-3
- 4-6 years to TRL 5

Need dates:
- Mars: 2000

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### TECHNOLOGY NEEDS

### Technology Category:
Aerobraking

### Technology Areas:
- Reusable and ablative TPS material
- Validated CFD Codes
- Adaptive GN&C
- Lightweight, launchable structures

### Performance Goals:
- Entry velocity range
  - Lunar return -- 11 km/s
  - Mars entry -- 5 to 6 km/s
  - Mars aerocapture -- 6 to 10 km/s
  - Mars return to Earth -- 12 to 15 km/s
- Aerobrake mass fraction < 20% (Varies with mission application)
- L/D ratio: 0 to 1.5
- Reuse for lunar permanent base - 7 flights

### Benefits/Leverage
- Required for Mars entry/landing and Earth entry/landing
- Enables Mars quick return trajectories
- Enhances all-chemical propulsive mission performance, reduces IMLEO
- Can backup or compliment NTP

### Technology Readiness Dates
- TRL: 3 - 4
- Lunar: 4 years to TRL 6
- Mars: 8 years to TRL 6

Need dates:
- Lunar early: 1995
- Lunar permanent: 2000
- Mars: 2000

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