EXPLORATION TECHNOLOGY PRIORITIZATION

NASA INTEGRATED TECHNOLOGY PLAN INPUT

REVISED PRIORITIZATION CRITERIA FOR THE NEAR-TERM SEI TECHNOLOGIES

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

**Mission Leverage**
- Performance leverage of technology to system, mission, and crew
- Ability of technology to reduce risk to crew and mission
- Ability of technology to reduce cost by reducing Earth delivered mass and life cycle costs
- Evolution capability
- Ability to support multiple missions (commonality)

**Timing**
- Development time to reach TRL 5 (years)
- Time needed before project start (years)

**Special Factors**
- Transportability/spin-off to commercial sector
- Ability to stimulate universities and public for support of mission

**Rating**
- High
- Medium
- Low

**1992 - 1995 CRITICAL TECHNOLOGIES**
PRELIMINARY CRITICAL TECHNOLOGY PRIORITIZATION

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 + )
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

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: $\geq 5$ yrs
- Duty cycle: $\geq 200$ days/yr @ 6-8 hrs/day
- Suit oper. pressure: 3.8 - 6 PSIA
- Lunar EVA system mass: $\leq 110$ Kg venting $\leq 125$ Kg regen.
- Mars EVA system mass: $\leq 90$ kg venting $\leq 70$ 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: \( \frac{670 \text{ W-hr}}{\text{kg}} \) (Lunar)
  \( \frac{200 \text{ W-hr}}{\text{kg}} \) (Mars)
• System efficiency: 65% FC, 90% electrolyzer
• Lifetime: 500 - 4000 hrs (SOA)
• PMAD: 20 kg/kW
• Generation: PV arrays 300 W/kg (Lunar)
  80 W/kg (Mars)

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

- 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: \( \leq 100 \text{ m} \)
• Hazard avoidance: \( \geq 1 \text{ m} \) (surface hazards)
• Hazard endurance: \( \leq 1 \text{ m} \) (surface hazards)
• Reliability: \( \geq 99\% \) 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

Technology Category

- NASA

• 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

TECHNOLOGY NEEDS

Technology Category

- NASA

• 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

NASA

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

TECHNOLOGY NEEDS

NASA

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**
- **Mobile applications:**
  - Lifetime:
    - 5 W/kg @ 300 We (RTG)
    - 7 W/kg @ 2.5 kWe (DIPS)
  - 7 - 15 yrs

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

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**Technology Needs**

**Technology Category**
- Surface hab and construction

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

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

**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

**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

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

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

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

Need dates:
- Lunar: 2000
- Mars: 2000

TECHNOLOGY NEEDS

Technology Category:
Telerobotics

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

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

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

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

Need dates:
- Lunar: 1996
- Mars: 2000
# 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:**
  - \( \geq 10 \)M (early)
  - \( \geq 100 \)M (interim)
- **Mobility** (obstacle endurance): \( \leq 1 \)M
- **Power system:** \( \geq 5 \)W (kg (robotic))
- **Lifetime:** 1-2 years
- **Life support requirement:** TBD
- **Range robotic:** 100 km
- **Range manned:** \( \leq 100 \) 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\%
- **L/D ratio:** 0 to 1.5 (Varies with mission application)
- **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