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EXPLORATION TECHNOLOGY PRIORITIZATION

NASA INTEGRATED TECHNOLOGY PLAN INPUT

REVISED PRIORITIZATION CRITERIA FOR THE NEAR-TERM SEI TECHNOLOGIES

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- **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

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

	Rating		
• Mission Leverage	High	Medium	Low
- 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	Long	Medium	Short
- Development time to reach TRL 5 (years)	T>=8	3<T<7	T<=3
- Time needed before project start (years)	T>=8	3<T<7	T<=3
• Special Factors	High	Medium	Low
- Transportability/spin-off to commercial sector			
- Ability to stimulate universities and public for support of mission			

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1992 - 1995
CRITICAL TECHNOLOGIES

PRELIMINARY CRITICAL TECHNOLOGY PRIORITIZATION
FIRST LUNAR OUTPOST (1992 - 1995)

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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
- **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

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 nuclear power**
  - Power conversion
  - Radiators
- **ISRU (Technology demo capability)**
  - Oxygen process chemistry
  - Mining
  - Construction material test

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(1995 +)
CRITICAL TECHNOLOGIES

PRELIMINARY CRITICAL TECHNOLOGY PRIORITIZATION
PERMANENTLY MANNED LUNAR AND MARS MISSIONS

(1995 +)

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Category I (Highest Priority)

- NTP
- Mars EVA Systems
  - Durable, lightweight, high mobility suit and EVA gloves
  - Lightweight, serviceable, PLSS
- Surface Power - Nuclear
- Telerobotics
  - Sensors
  - Vision
  - End effectors
- Aerobraking
  - TPS
  - CFD codes
  - High temperature structural material
  - Adaptive GN&C
- 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

- Planetary Rovers
  - Motors lubricants (Long-term use)
  - Dust control
  - Power

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TECHNOLOGY NEEDS

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Technology Category

- EVA Systems

Technology Areas

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

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.

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

Technology Readiness Dates

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

Need dates: Lunar: 1996
Mars: 2000

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Ver 1/1-31-92

TECHNOLOGY NEEDS

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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

Performance Goals
- RFCs: Specific energy: $670 \frac{W\text{-}HR}{kg}$ (Lunar)

  $200 \frac{W\text{-}HR}{kg}$ (Mars)
- Specific power: 250 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

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

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

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TECHNOLOGY NEEDS

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Technology Category
- Autonomous terminal landing

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

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

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

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

Need dates: Lunar: Robotic: 1993
Outpost: 1995
Mars: 2000

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TECHNOLOGY NEEDS

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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

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%

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

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

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TECHNOLOGY NEEDS

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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

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

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

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

Need dates: Lunar: 1995
Mars: 2000

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TECHNOLOGY NEEDS

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Technology Category

- ISRU

Technology Areas

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

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

Benefits/Leverage

- Reduce resupply
- Make up oxygen for safety and redundancy
- Increase stay time

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

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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

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

Benefits/Leverage

- Significant reduction in Earth delivered mass
- Reduce Mars trip times
- Crew safety
- Operational flexibility

Technology Readiness Dates

- TRL: 4-5
- 5-10 years to TRL 6 (uprated NERVA technology)

Need date: Mars: 2000

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TECHNOLOGY NEEDS

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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

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

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Technology Category
- Surface habs 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

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TECHNOLOGY NEEDS

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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

Need dates: Lunar: 2000
Mars: 2000

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Ver 2

TECHNOLOGY NEEDS

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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

Need dates: Lunar: 1996
Mars: 2000

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Ver 1/1 31-92
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TECHNOLOGY NEEDS

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

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

Performance Goals
- Semi-autonomous traverse: ≥ 10M (early) ≥ 100M (interim)
- Mobility (obstacle endurance): ≤ 1M
- Power system: ≥ 5W {kg (robotic)}
- Lifetime: 1-2 years
- Life support requirement: TBD
- Range robotic: 100 km
- Range manned: ≤ 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: Lunar: Outpost: 1996
Mars: 2000

TECHNOLOGY NEEDS

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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