



Exploration Systems Mission Directorate Lunar Surface Systems Concepts Study

Lunar Surface Systems Overview

Lunar Surface Systems Overview - Introduction



Constellation Program established the Lunar Surface Systems Project Office at the Johnson Space Center in August of 2007.

Lunar Surface Systems Overview - Introduction (cont'd)



The LSS Project Office is focusing on several fronts:

- Supporting the ongoing Agency work to define a viable Lunar Architecture, the framework for defining how to return humans to the moon.

- Providing a program level focus for Lunar surface system activities
 - Ensure that Lunar surface activities are considered during the Initial Capability for human transport design activities.

- Participating in the definition and identification of technology needs and priorities working closely with the Exploration Technology Development Program

Lunar Surface Systems Overview - LCCR Outcome



At completion of the Lunar Concept Capability Review (LCCR) in Summer 08, NASA will have:

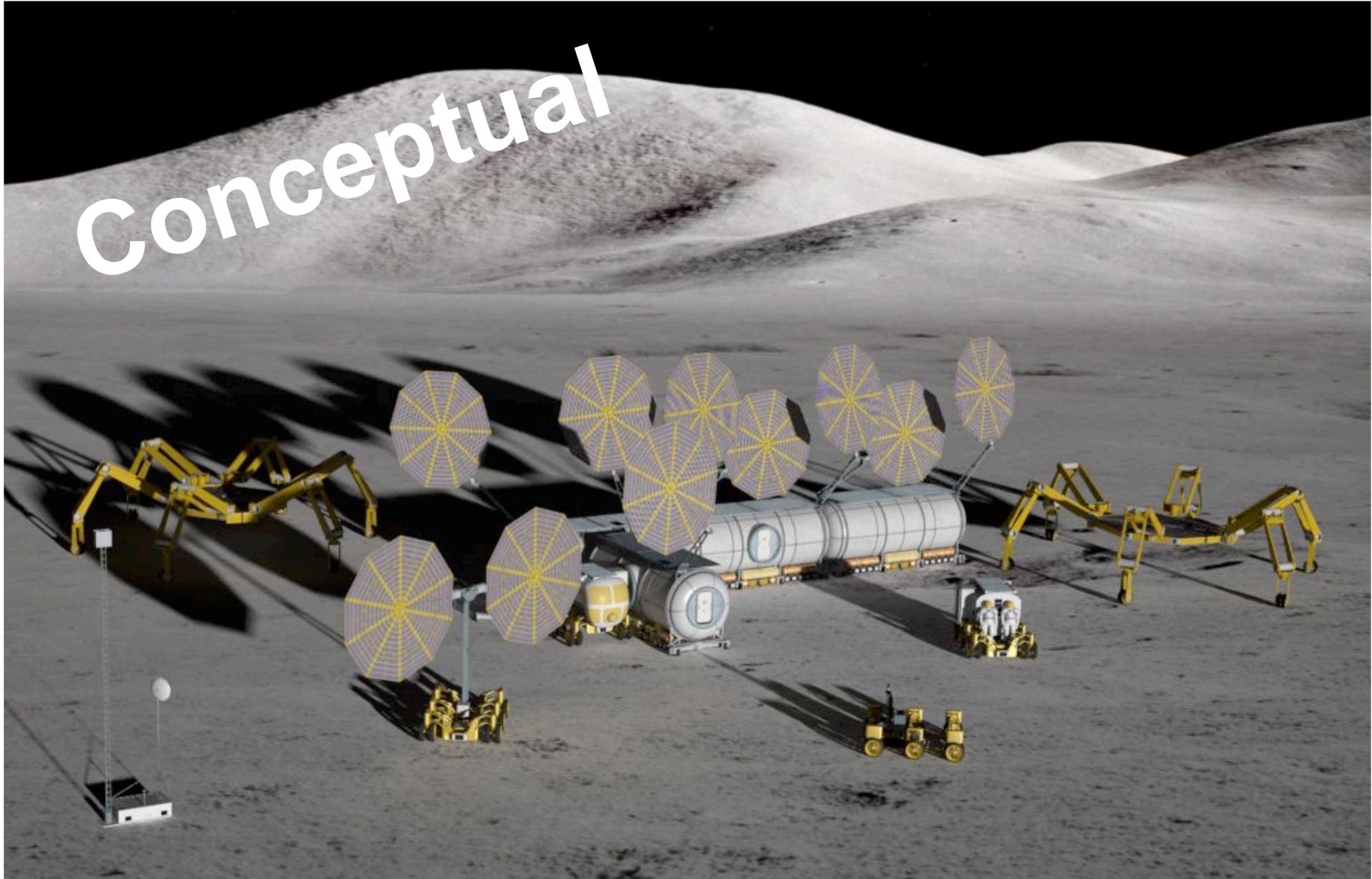
- a consistent, compatible definition of the transportation system
- Transportation system performance envelope to provide the framework for Lunar surface system concepts
- an assessment of the amount of risk associated with delivering the transportation system
- at least one viable concept of how that transportation system could be used to establish an Outpost capability

Lunar Surface Systems Overview - Next Steps



- **The Surface Systems team will support the continued refinement lunar architecture concepts**
 - Target surface system concept review in the 2010 or 2011 timeframe.
- **Continue to expand architecture participation with international and commercial entities.**
- **Focus on identifying innovative approaches, complementary concepts, and necessary technologies, not detailed designs of specific elements.**
- **Explore a wide variety of scenarios that**
 - Consider different ways to build up the Lunar capability over time
 - Assess multiple viewpoints on figures of merit for various lunar surface system capabilities.

Lunar Surface Systems Overview - Lunar Surface Architecture Concepts



Lunar Surface Systems Overview - Concepts for Basic Outpost Capabilities



- **Habitation systems**

- Support a crew of 4 for 180 days on the lunar surface

- **ISRU**

- Demonstrated ability to produce ISRU based oxygen at a rate of 1 mT per year

- **Rovers**

- Operated autonomously or by the crew
- Pressurized roving systems that can travel for hundreds of kilometers from the Outpost

- **Power**

- At least 35 kW of net power production and storage for crewed eclipse periods

- **Exploration and science systems**

- Surface based laboratory systems and instruments to meet exploration and science objectives

- **Safety**

- Sufficient functional redundancy to ensure safety and mission success

Lunar Surface Systems Overview - Examples of Surface Architecture Concepts



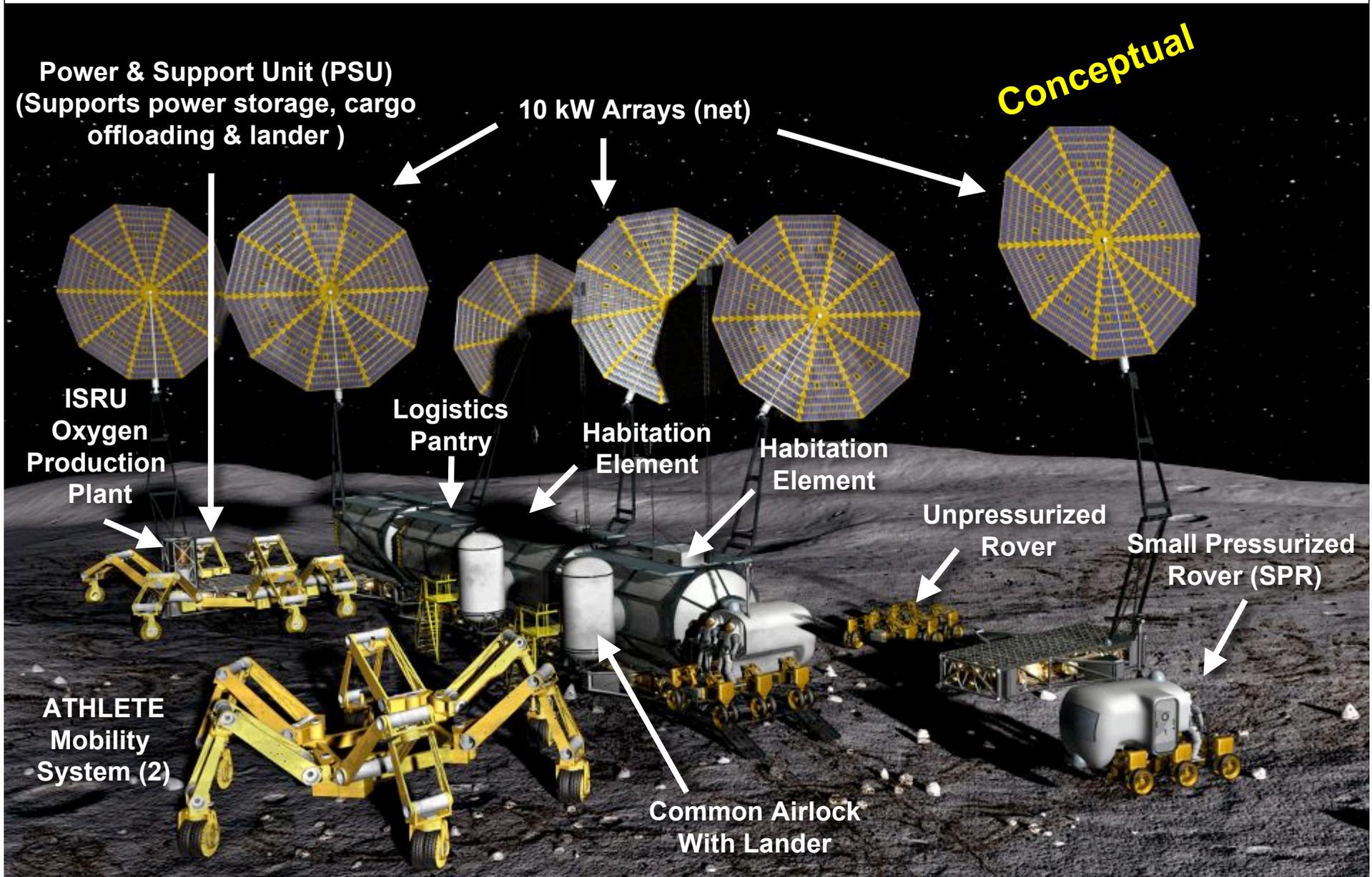
The team reviewed multiple surface system concepts, including:

- **Rapid development of output for long term crew stay capabilities**
 - Full outpost capability based on transportation system delivery capabilities
 - Outpost based on the recommendations from Lunar Architecture Team studies
 - Substantial robustness through element duplication

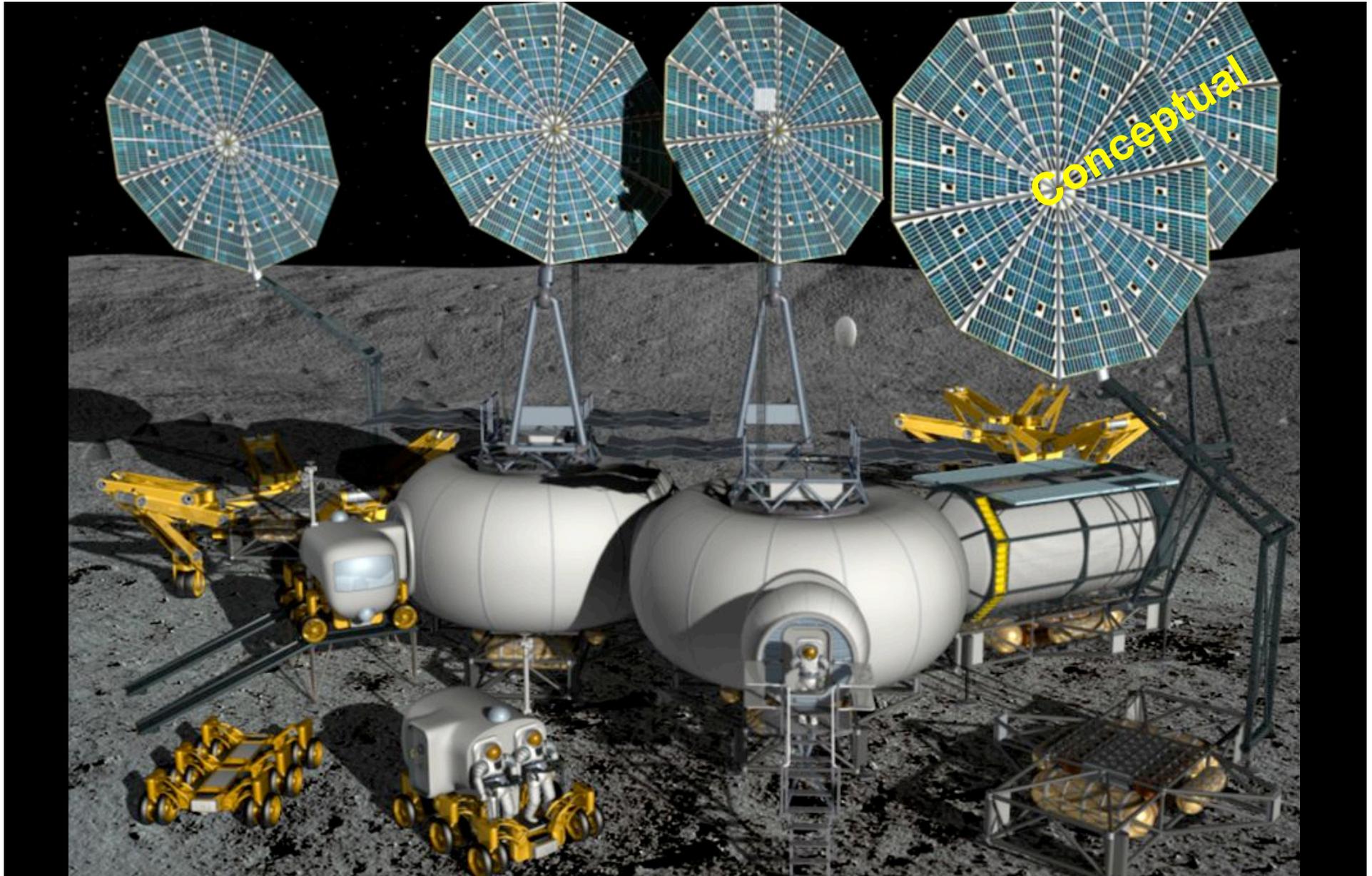
- **Initial Mobility Emphasis (Initial means not the full outpost functional capability)**
 - Temper outpost build-up based on affordability with initial emphasis on mobility capabilities
 - Final outpost has less volume and limited eclipse operating capability
 - Robustness achieved through functional reallocation
 - Assumed water scavenging

- **Initial Habitation Emphasis (Initial means not the full outpost functional capability)**
 - Temper outpost build-up based on affordability with initial emphasis on core habitation & exploration capabilities
 - Final outpost has less volume and limited eclipse operating capability
 - Robustness achieved through functional reallocation
 - Assumed water scavenging

Lunar Outpost Surface Systems Concepts (Hard-shell habitation)



Lunar Outpost Surface Systems Concepts (Inflatable Habitation)

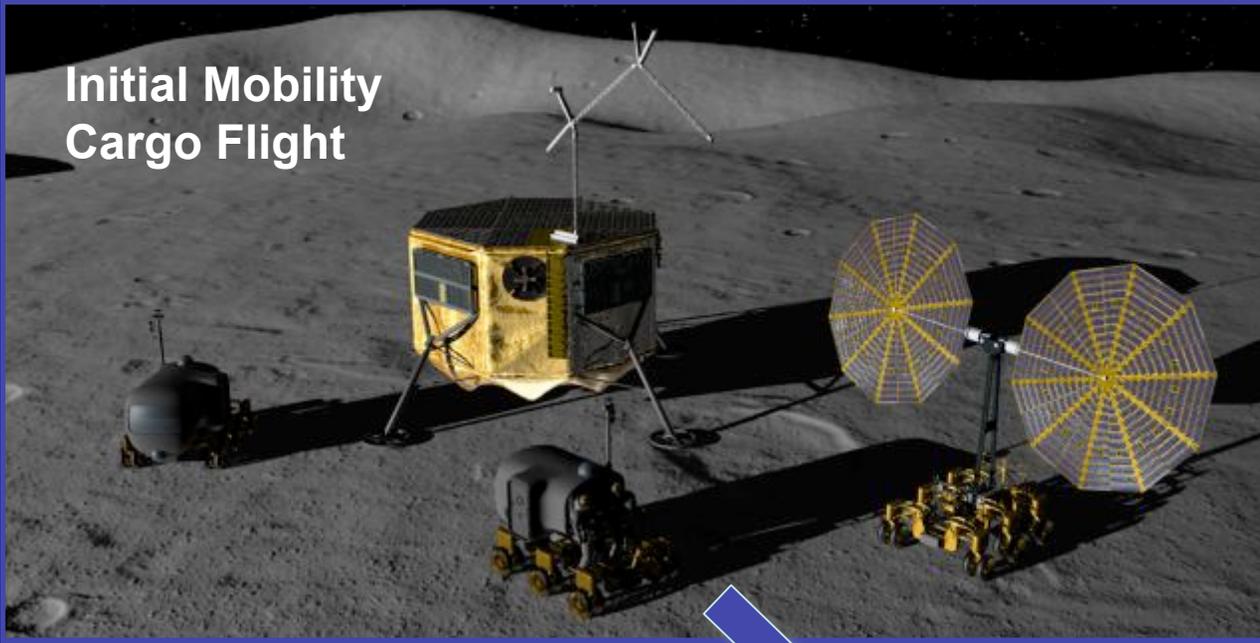


Lunar Surface Systems Overview - Evolution toward full Outpost (Conceptual)



- **Phasing options were developed for full outpost capability tempered by affordability**
 - Regardless of early emphasis (mobility or habitability)
- **Started with limited early outpost capabilities using these assumptions:**
 - Core volume for habitation no more than LAT-2 minimum, uses a suitlock
 - Capability to increase volume by
 - Attaching habitation modules from international and commercial entities
 - Attaching minimally outfitted logistics modules
 - No requirements for crew occupation during worst five months of the year but outpost must be able to be augmented to eventually support permanent occupation
 - Long range mobility from the Outpost is performed by Small Pressurized Rovers augmented by mobile power/logistics carriers
 - Scavenged water from the landers is assumed as part of the logistics train

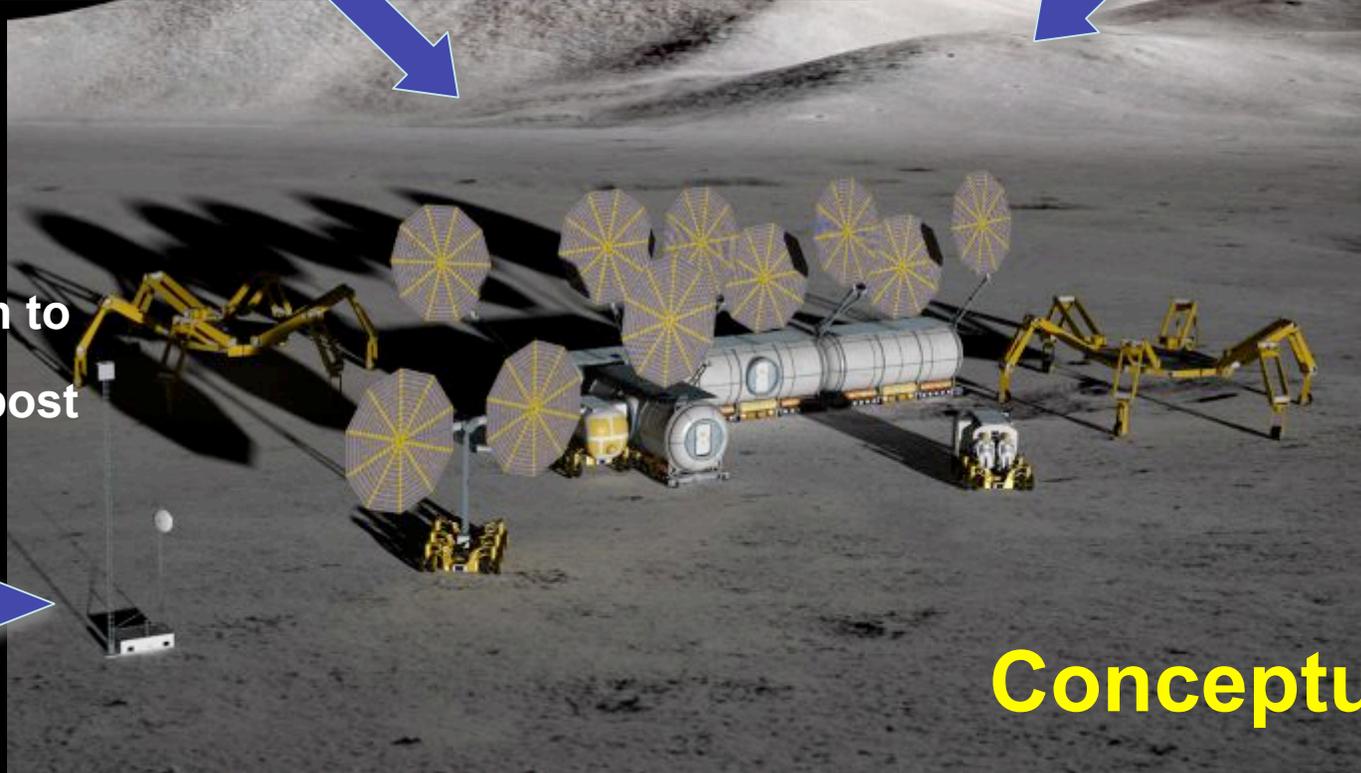
**Initial Mobility
Cargo Flight**



**Initial Habitation
Cargo Flight**



**Initial Mobility &
Habitation growth to
common full outpost
Configuration**



Conceptual



Exploration Systems Mission Directorate Lunar Surface Systems Concepts Study

Topic 1: Alternative Packaging Options

Topic 1: Alternative Packaging Options – Objective



Objective:

Improve the efficiency of loose equipment packing. Identify alternative packing options that eliminate or minimize waste generation from packing materials and allow optimal utilization of available stowage volume.

For example:

- Concepts that require NO packing material
- Materials that can be volume-reduced after use
- Materials with secondary application

Alternative Packaging Options – Challenges



Challenges:

- Loose equipment items require special packing to attenuate vibration and loads experienced during launch.
- Historically, approximately 30% of stowage volume lost due to fit mismatch and need for packing foam.
- Much of this packing material is not needed once on orbit – becomes a substantial component of the waste stream.
- Packing of clothing and similar items that are not affected by launch environment do not require supplemental packing material and are nearly 100% volumetrically efficient.



Existing Packaging Practices

- **Baseline packing foam for Shuttle**
 - PYRELL produced by FOAMEX
 - Some issues with long term durability

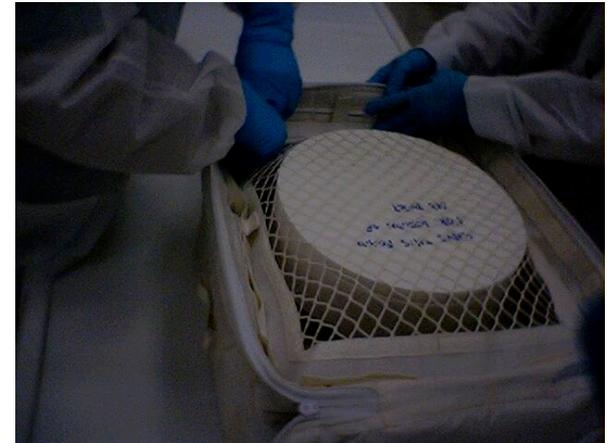
- **Baseline packing foams for ISS**
 - “Minicel” foam (type L200) produced by Voltek, LLC
 - Closed-cell chemically cross linked polyethylene
 - Some coverage of Minicel with Nomex for flammability and debris control
 - Zotek™ F30 by ZOTEFOAMS
 - Kynar® PVDF Fluoropolymer (poly vinylidene fluoride)
 - Good flammability resistance



Current Examples of Packaging



Example: Packing of GPS antenna in Crew Transfer bag (CTB)



Current Examples of Packaging



Alternative Packaging Options – Constraints on packing materials



Functional capability

- Vibration attenuation
- Key properties: density and compressive strength
- Minicel L200: $\rho = 1.5 - 2.5$ pcf, 4 – 7 psi @ 25% compression
- Zotek™ F30: $\rho = 1.9$ pcf, 6.8 psi @ 25% compression
- Testing currently being performed to better understand threshold values

• Materials requirements

- Materials must be capable of meeting the test requirements of NASA-STD-(I)-6001A (approved 04-21-08)
 - Test 1 – Flammability (O_2 environments : 30% @ 10.2 psi, 32-34% @ 8 psi)
 - Test 7 - Off-gassing

• Attribute – ambient pressure sensitivity

- Open-cell material: adapts to ambient pressure – more compatible with vacuum environment
- Closed-cell material: internal gas leaks out during vacuum exposure, then material compressed when exposed to pressurized environment

• Goal – mass of packing material should not exceed the mass of the item being packed

Alternative Packaging Options – Topic Specific Technical Requirements



Contract deliverables must specifically address the following:

- define the proposed alternative options
- address compliance with functional and compatibility requirements
- define the unit mass of proposed materials, and
- define secondary uses of materials, as applicable



Exploration Systems Mission Directorate Lunar Surface Systems Concepts Study

Topic 2: Minimum Functionality Habitation Element

Topic 2: Minimum Functionality Habitation Element



- **Objective**
- **Ground Rules and Assumptions**
- **Topic Specific Technical Requirements**

Minimum Functionality Habitation Element - Objective



The primary objective of this study is to produce a conceptual design for a minimum functionality habitation element based on a minimum set of functions that are required to perform the reference mission. The minimum functionality habitation element includes basic required safety features but does not protect for contingency situations. This element may never realistically fly, but the minimum set of functions identified would provide the backbone for crew accommodations on the surface, as well as provided growth options for the Lunar Surface Systems.

- “Minimum Functional” is a design philosophy that begins with an element that deliberately meets only the minimum set of functions required to perform the mission, and no more than that.
 - Does not consider contingencies, nor does it have added redundancy (i.e., it is a single string implementation).
 - Enables a process that can add safety, reliability and other functionality to the element with informed cost, risk and performance Deltas
- A “Minimum Functional” element does not need to meet full operational standards. This is for concept development.

Minimum Functionality Habitation Element – Ground Rules and Assumptions



- **General**

- Element demonstrates ability to support 4 crew for 28 days, and eventually (with growth option) support continuous 4-crew, 180-day surface stays with surge (+4 crew = 8) during a crew change-out
- Element will support a 30-day contingency stay beyond the scheduled mission
- Element will operate at a pressure of 8.0 psia at an O₂ concentration of 30%
- Element will protect the crew from the radiation environment

- **Consumables / Resupply**

- Element will accommodate logistics required for 4 crew with a surface stay of 28 days

- **Dormancy**

- Element will be able to verify (back to Earth) “initial safe operational mode” post descent to lunar surface and prior to first crew Earth departure
- Element will accommodate dormancy by providing health status prior to any crew Earth departure

- **Mass**

- Element is constrained to a total mass not to exceed 7,000 kg

Minimum Functionality Habitation Element – Ground Rules and Assumptions



- **Element will provide all human habitability accommodations**
- **required for the lunar surface crews.**
 - Human waste management
 - Trash management (includes food waste)
 - Surface EVA support
 - Life support
 - Air revitalization
 - Thermal control
 - Humidity control
 - Pressurization

Minimum Functionality Habitation Element – Topic Specific Technical Requirements



- **Contract deliverables must specifically address the following:**
 - Identify and define the proposed minimum required functions
 - Provide rationale for the proposed minimum required functions
 - Provide a conceptual design (topology, layout, sections, 3D) that accommodates the minimum required functions
 - Provide mass, power and volume estimates of the concept
 - Provide potential growth options utilizing the concept



Exploration Systems Mission Directorate Lunar Surface Systems Concepts Study

Topic 3: Innovative Avionics Architectures & Sparing Strategies

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- **Objective**
- **Ground Rules and Assumptions**
- **Topic Specific Technical Requirements**

Innovative Avionics Architectures & Sparing Strategies - Objective



Objective:

*The objective of this study is to investigate **innovative** avionics **architectures and sparing strategies** that maximize **commonality** of avionics components and enable/facilitate in-situ repair strategies while **minimizing mass** of spares. Critical to deployment of a **sustainable avionics** architecture are reductions in mass including indirect reductions via reductions in power, packaging, and maintenance spares.*

Technical Challenges:

- Severely mass (and power) constrained
- Initial deployment to eventually coexists with subsequent generation hardware
- Surface networks are highly sparse but must still be robust

Innovative Avionics Architectures & Sparing Strategies - Ground Rules and Assumptions



- **Architectures provide command and control, data handling, systems health monitoring, network connectivity for heterogeneous lunar surface elements**
- **Architectures, or systems, will be 1-fault tolerant at a minimum and fail operational**
- **Architectures will facilitate maintenance and “management” of spares**
- **Architectures provide a holistic approach to commonality, interoperability, and flexibility**
 - Commonality – modular reuse of cards and boxes
 - Interoperability – system ambivalent and software compatible
 - Flexibility – systems that can be adapted for various different missions at different lunar surface locations across the lifespan of lunar surface exploration
- **Systems will operate in a vacuum and radiation environment**
- **Systems will operate autonomously when unmanned**
- **Systems will accommodate dormancy by providing health status prior to any crew Earth departure**

Innovative Avionics Architectures & Sparing Strategies - Topic Specific Technical Requirements



Contract deliverables must specifically address the following:

- What figures of merit are used to evaluate various trade options?
- At what levels are commonality enabled (hardware, communications, software)?
- How can the sparing mass be reduced while meeting mission safety requirements?
- Where could technology development promote increased commonality and facilitate reconfiguration and repair?
- How does the architecture enable an evolvable and maintainable infrastructure?



Exploration Systems Mission Directorate Lunar Surface Systems Concepts Study

Topic 4: Long-term Lunar Energy Storage Systems Concepts



The lunar surface is a unique location from the perspective of energy storage

- **Earth surface: ~12 hours without sunlight**
- **Earth orbit: ~36 minutes without sunlight (ISS)**
- **Lunar orbit: ~46 minutes without sunlight (Orion)**
- **Mars surface: ~12 hours without sunlight**
- **Mars orbit: ~45 minutes without sunlight (MRO Science)**

- **Lunar surface: typically >350 hours without sunlight**
- **Some lunar polar locations: ~120 hours without sunlight**

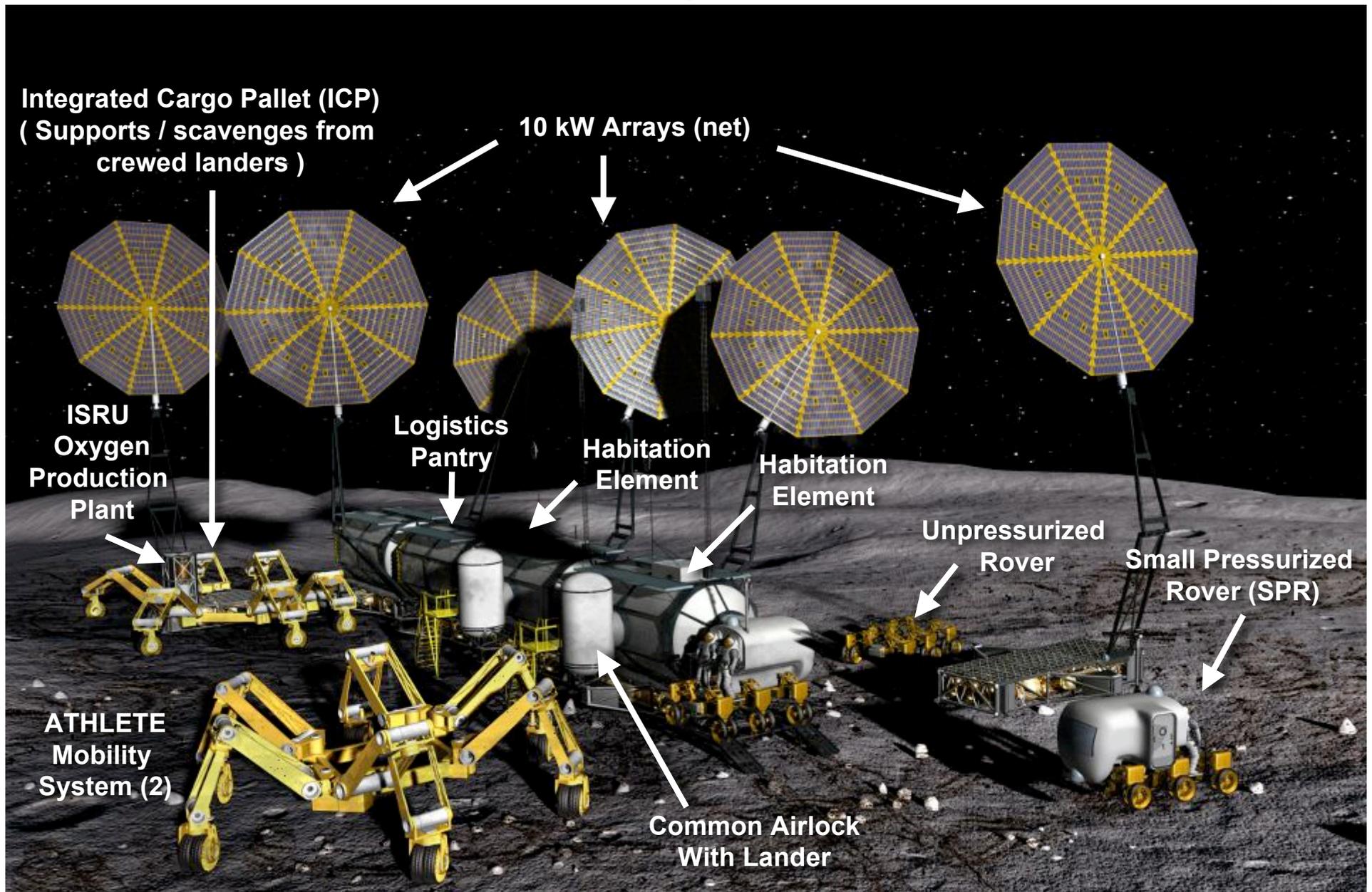
- **At any power level, lunar energy storage becomes significant**



These missions are different than Apollo

- **Apollo surface time was much shorter**
 - 21 hours to 3 days, all during lunar day
- **Power requirements were lower**
 - Smaller crew and vehicle
- **Batteries are adequate for these durations and power levels**
 - Non-regenerative fuel cell (with potable water as dual-use) was on Service Module in orbit

Long-term Lunar Energy Storage Systems Concepts – One version of a lunar outpost



Long-term Lunar Energy Storage Systems Concepts – System Requirements



- **Power level**

- 2 - 5 kW net discharge electric power
- Modular approach: several 2 - 5 kW modules can be used together
- Net power: after any ancillary or support power loads

- **Energy storage**

- 100 - 2000 kWhr net energy storage per module, e.g.:
 - For 120 hours without sunlight, 0.8 - 17 kW net capability
 - For 400 hours without sunlight, 0.25 - 5 kW net capability

- **Technology Readiness Level (TRL) 6 by 2015 - 2018 timeframe**

- (see backup slide for TRL explanation)
- Provides time for flight hardware fabrication, testing, and integration for Lunar Surface timeframe

Long-term Lunar Energy Storage Systems Concepts – System Requirements



- **5-10 year calendar life on lunar surface**
 - Not related to operational life but still may be challenging requirement in lunar environment
- **10,000 - 15,000 hour operational life**
 - Depends on location on surface and operational needs
- **100 - 2000 charge/discharge cycles**
 - Also depends on location and operational needs
 - May be some flexibility on depth-of-discharge requirements
 - Energy storage will most likely be oversized for nominal operations so nominal depth-of-discharge will be less than 100%

Long-term Lunar Energy Storage Systems Concepts – System Requirements



- **Able to withstand high dust, radiation, and widely varying thermal environment**
 - Dust
 - Lunar dust was identified as major challenge from Apollo missions
 - Will be more challenging for longer-term missions
 - May have multiple landings at a single site which increases dust activity
 - May have more mobile vehicles at outpost which also increases dust activity
 - Radiation
 - More significant problem for longer lunar missions
 - Galactic cosmic background radiation
 - Solar particle events
 - Thermal environment
 - Dependent on location but potentially 100K to 400K

Long-term Lunar Energy Storage Systems Concepts – Topic Specific Technical Requirements



Contract deliverables must specifically address the following:

- **Present the conceptual design(s) and their figures-of-merit, including estimated mass, volume and recharge efficiency**
- **Discuss any potential issues affecting cycle and calendar life, reliability, maintainability, and cost**
- **Discuss the sensitivity of the energy storage system design and its requirements on the figures-of-merit**
- **Discuss potential impacts on other outpost subsystems, including thermal, communications, and logistics needs**
- **Discuss any concepts for dual use, such as capturing and using waste heat, or other hybrid approaches**



Long-term Lunar Energy Storage Systems Concepts

Backup



Technology Readiness Levels

- **Basic principles observed and reported**
- **Technology concept and/or application formulated**
- **Analytical and experimental critical function and/or characteristic proof-of-concept**
- **Component and/or breadboard validation in laboratory environment**
- **Component and/or breadboard validation in relevant environment**
- **System/subsystem model or prototype demonstration in a relevant environment (ground or space)**
- **System prototype demonstration in a space environment**
- **Actual system completed and “flight qualified” through test and demonstration (ground or space)**
- **Actual system “flight proven” through successful mission operations**



Potential lunar polar illumination profile

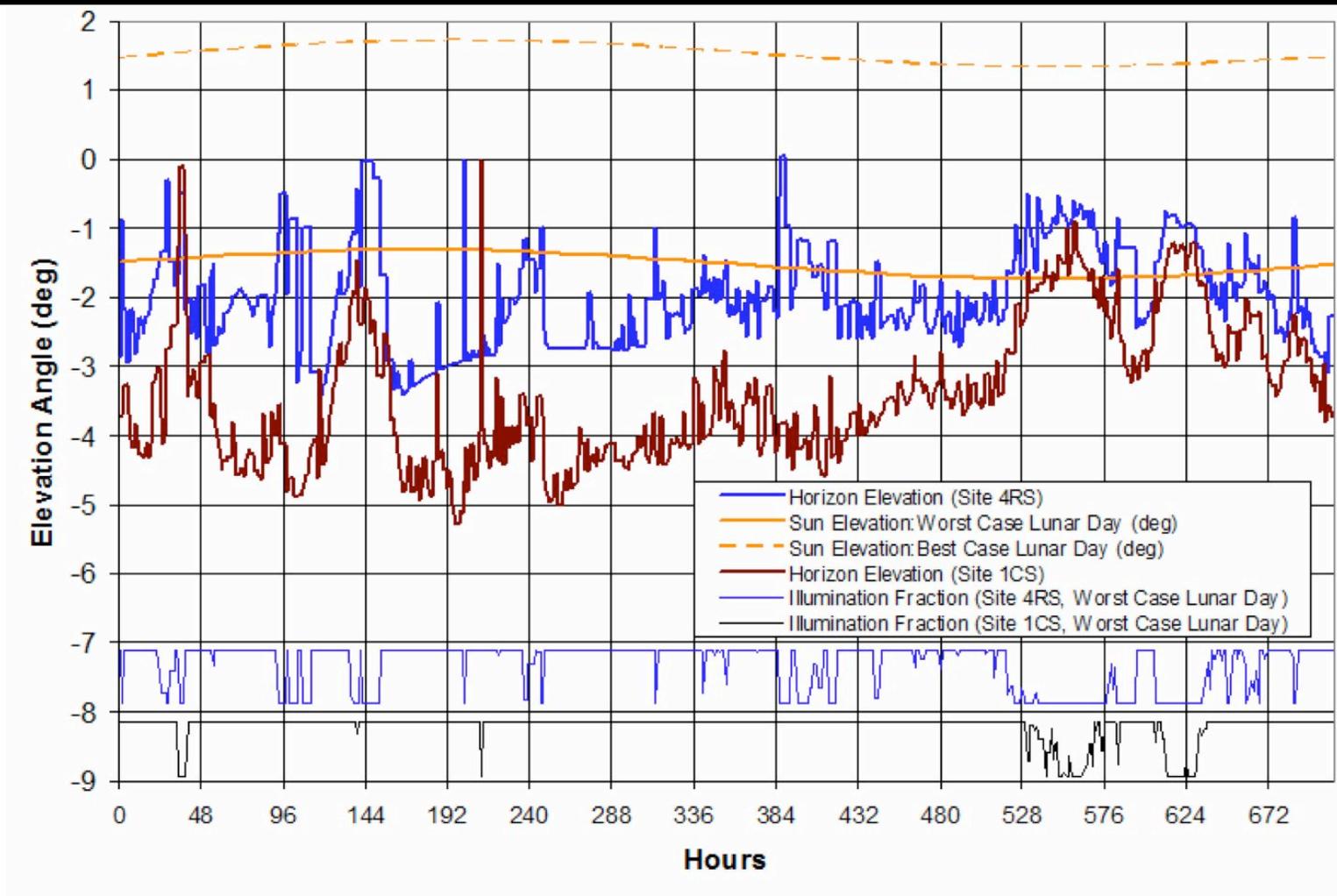


Figure 36. Elevation and illumination profiles for south pole Sites 4RS and 1CS.

(from J. Fincannon, Characterization of Lunar Polar Illumination from a Power System Perspective, AIAA 2008-0447)



Exploration Systems Mission Directorate Lunar Surface Systems Concepts Study

Topic 5: Alternative Software Architecture Development Approaches

Topic 5: Alternative Software Architecture Development Approaches



- **Objective & Technical Challenges**
- **Ground Rules and Assumptions**
- **Topic Specific Technical Requirements**

Alternative Software Architecture Development Approaches - Objective & Technical Challenges



The primary objective of this study is to identify alternative approaches for lunar surface systems software architecture and development that may result in robust software performance and reliability at a lower cost than traditional development methodologies.

Technical Challenges:

- Portions of the lunar software systems will be safety critical - can these be minimized or otherwise done more cost-effectively ?
- Developing a trade space that includes both traditional aerospace approaches and approaches informed by relevant analogues for software in human-occupied vehicles and habitats in hazardous environments.
- Models for software reuse (including off-the-shelf) both across lunar systems and from previous systems.

Alternative Software Architecture Development Approaches

- Ground Rules and Assumptions



- **Architectures provide software for lunar habitat, both pressurized and unpressurized rovers, communication and navigation infrastructure, solar and/or nuclear electric power management, and in-situ resource utilization. Architectures should also include software concepts for modeling and simulation used in verification and validation of lunar software systems.**
- **Architectures will be 1-fault tolerant at a minimum and fail operational for safety-critical functions.**
- **Software architectures will enable automated operations when unmanned. Software will provide automated checkout and test capabilities from dormant operations in preparation for new phases of human habitation.**
- **Software architectures will provide the capability for both earth-mediated operations and autonomous operations.**
- **Software for the different lunar surface systems will interoperate to flexibly support a variety of concepts of operations.**

Alternative Software Architecture Development Approaches - Topic Specific Technical Requirements



The following areas must be addressed in the contract deliverables for each architecture / development approach investigated:

- Conceptual design and FOMs including estimated software cost.
- Approach to achieving human safety through architecture, developmental processes, and suitable V&V.
- Both software DDT&E costs (development and test) and software maintenance costs based on extrapolating actual cost data from analogues or well-defined software cost estimation method.
- Qualitative description of potential issues impacting reliability and life-cycle costs.
- Conceptual approach to reuse including off-the-shelf.



Exploration Systems Mission Directorate Lunar Surface Systems Concepts Study

Topic 6: Lunar Regolith Moving Methods & Techniques

Topic 6: Lunar Regolith Moving Methods & Techniques - Objective



The primary objective of this study is to provide viable and innovative methods and techniques for moving lunar regolith in order to deploy and operate a lunar outpost. These methods and techniques should be focused on providing novel approaches while leveraging off terrestrial technologies that are promising for lunar environments.

Lunar Regolith Moving Methods & Techniques - Potential Benefits of Excavation and Surface Preparation



- **Surface Systems**

- Landing area clearing, surface hardening, and berm building for surface systems
- Landing risk and exhaust plume mitigation
- Protect emplaced assets from subsequent blast damage during landings
- Provide a better surface capability for Outpost deployment
- Prepare pathways for transferring cargo from lander
- Dust Mitigation
- Radiation Shielding for crew and assets
- Excavation for Outpost Emplacement
- Reduce life cycle cost and operations risk of operating an outpost

Lunar Regolith Moving Methods & Techniques - Potential Benefits of Excavation and Surface Preparation



- **Altair Lander**

- Provide an enhanced landing capability
- Reduce landing risk
- Reduce turnaround issues / potential damage to lander
- Provide a landing facility with associated support equipment
- Level surface and controlled launching conditions

- **Science**

- Provide a trenching access capability for Lunar Geologic / Stratigraphy studies
- Provide geotechnical methods for deploying instruments

Lunar Regolith Moving Methods & Techniques - Topic Specific Technical Requirements



Contract deliverables must specifically address the following:

1. A comprehensive study and operational assessment, with benchmarking, assessing areas *such as*:
 - Earth soil moving techniques, devices, implements and lessons learned with applicability to moving lunar regolith
 - Specifically, in relation to regolith flow and interaction with excavation devices, beneficiation devices, wheel traction, input hopper design and regolith transport systems
 - Performing tasks *such as*:
 - » Landing / Launch Pads
 - » Blast Protection Berms
 - » Electrical Cable Trenches / Stratigraphy Trenches
 - » Utility Roads / Clearing Obstacles
 - » Foundations / Leveling
 - » Trenches for Habitat & Element Burial
 - » Regolith Shielding on Roof over Element Trenches

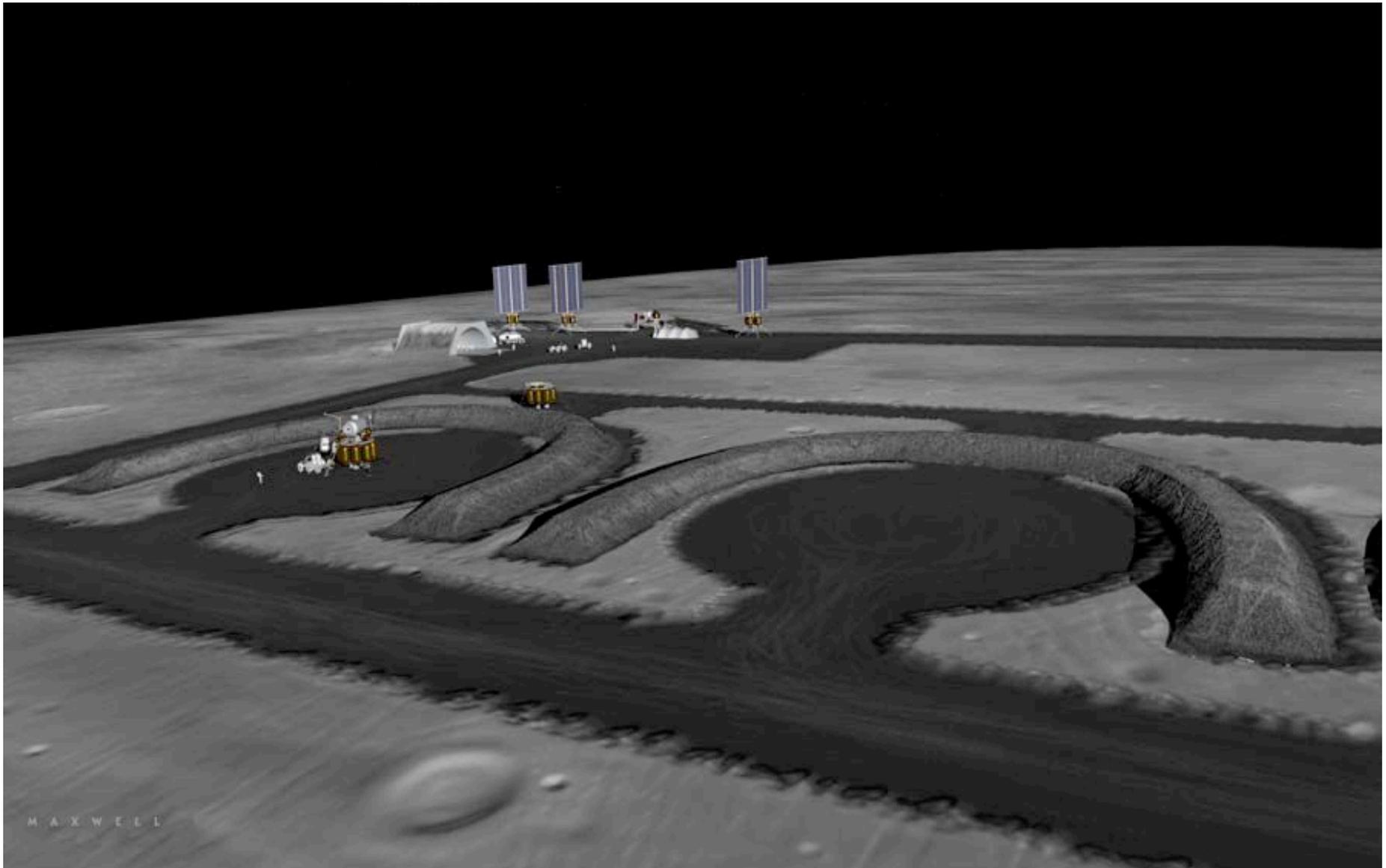
Lunar Regolith Moving Methods & Techniques - Topic Specific Technical Requirements



Contract deliverables must specifically address the following (Cont'd):

2. A trade study of concepts for collecting loose surface regolith including:
 - Regolith found at depths less than 2-3 cm on the moon
 - Compacted regolith found at depths greater than 20-30 cm on the moon
3. Identify viable lunar regolith moving and surface stabilization methods and techniques as well as regolith size sorting and mineral beneficiation methods that can be integrated into proposed systems.
4. A life cycle cost study of regolith moving systems and Earth-based lessons learned from a variety of industries to identify the key drivers and applicable components of life cycle cost with associated wear mitigation and cost reduction techniques and suggestions.

Lunar Outpost Concept (Artistic)





Exploration Systems Mission Directorate Lunar Surface Systems Concepts Study

Overview of Strategy & Schedule

Overview of Strategy & Schedule – Questions?



Questions you may have:

- Are the concept study topics prioritized?
- Are there any constraints on number of proposals?
- How many contracts will be awarded? ...per study topic?
- When will selections be made?

- Will the contracts be awarded & managed out of JSC?
- What's the period of performance for the studies?
- What if I have relevant proprietary information that would be applicable to address some of the requirements of the study?

Overview of Strategy & Schedule



- **Topics are NOT prioritized – all are important to us.**
- **Prioritize proposals. Submit no more than 3 proposals.**
- **Based on the quality of the proposals, NASA may make no award on a topic or may make multiple awards on a study topic.**
- **Number of awards will be a function of the quality, value and price of the proposals.**
- **Maximum price and duration of a proposed study is \$250,000 and six months.**
- **Contracts will be awarded & managed by the Center with the expertise most pertaining to the study topic.**

Overview of Strategy & Schedule



- Goal is to not limit the sharing of useful information that may be proprietary, but to utilize a different avenue to convey it, for example: providing supplemental info in your proposals marked proprietary, conducting face to face meetings, etc.
- Results of the studies will be shared with this community through a 2-3 day workshop within approximately a month after the final reports have been submitted/received.
- In parallel with the approximately 6-month LSS Concept Studies duration, EMSD will continue to engage industry in our lunar exploration effort through the USCC Space Enterprise Council (SEC).
- The USCC-SEC and the Space Transportation Working Group (STWG) are our primary contacts for these interactions.

ESMD Lunar Surface Systems Concept Studies – Schedule at a Glance



June 6, 2008	Release ESMD LSS Concept Studies BAA
July 7, 2008	Proposals submitted / received
July-August 2008	Proposal selections & contract awards
Early-mid Nov 2008	Mid-term report and face-to-face meeting
Early-mid Feb 2009	Final reports submitted / received
Early-mid March 2009	Community workshop