INTERNATIONAL SPACE EXPLORATION COORDINATION GROUP ISECG

Summary Report

The ISECG Reference Architecture for Human Lunar Exploration

ISECG International Architecture Working Group, July 2010

Executive Summary

> ***For the foreseeable future, the Moon, Mars and near-Earth asteroids are the primary targets for human space exploration.***
>
> ***- The Global Exploration Strategy (GES)***

The **ISECG Reference Architecture for Human Lunar Exploration** envisions how the space-faring nations of Earth can collaborate in exploring the Moon using the coordinated assets of many space agencies. It marks the **first time that a group of space agencies has worked together to define a complex human exploration scenario.**

This document can be used to inform preparatory planning and decision-making within participating agencies. **It represents a concrete step towards realizing the vision of the Global Exploration Strategy,** which identified the Moon as one of the key destinations for future human space exploration.

While pioneered for lunar exploration, this study can serve as a useful model for designing multilateral architectures to explore Mars and other destinations in the solar system.

The Reference Architecture involves a **flexible, phased approach** for lunar exploration that demonstrates the importance of agencies working together early in program formulation. It is designed to achieve **significant exploration goals** while recognizing global realities and challenges.

The Reference Architecture is neither a lunar base, nor a series of Apollo-style missions. It is composed of phases that will deploy a range of international human-rated and robotic technologies over time on the lunar surface. It provides **continuous robotic and human exploration activity** in multiple locations on the Moon. These phases include:

- **robotic precursor phase**: This phase provides early technology demonstrations and engagement among international partners, the scientific community and the public. It highlights important activities intended to reduce the risks associated with human missions and to ensure sustainability of the architecture. These activities will also help target human missions toward the most promising objectives for scientific discovery and exploring Mars.
- **polar exploration and system validation phase**: This phase initiates human exploration of the Moon. It leverages the robotic precursor work to deploy and

test an international fleet of crew rovers and supporting robots in preparation for more aggressive human and robotic lunar exploration. This phase builds up confidence in operations and systems design through a series of human missions at a given lunar polar site.

- **polar relocation phase**: In this phase, the fleet of robots and rovers, controlled from Earth, will be relocated from the pole to new sites of interest. Along the way, they will perform scientific studies and enable interactive participation from the public. Once in place, they will meet and assist human crews landing at these new sites.

- **non-polar relocation and long-duration phase:** This phase may involve multiple short missions to various lunar sites of interest or long-duration missions of about 70 days at one site. Longer missions, which will require the addition of living modules or habitats, would be particularly useful for collecting data and testing technology for future Mars missions.

This summary document describes the specific **elements that comprise the Reference Architecture**:

- multilateral articulation of a set of **common lunar exploration goals**

- analysis of **strategic questions** that impact architecture definition, development and deployment;

- development of the Reference Architecture to include concepts for architecture elements, including identification of interfaces that would benefit from standardization;

- a **comparative assessment** of the Reference Architecture against the common lunar exploration goals;

- an assessment of **products and broader benefits** identified in the process of developing the Reference Architecture;

- recommendations for **future work**.

With a Reference Architecture in hand, forward work is now possible. The architecture can be developed as a **framework for a human lunar exploration program**. Alternatively, it is possible to **explore variations** in the architectural options for human transportation that could provide different and potentially creative approaches for future international human exploration missions. Finally, the work pioneered here can be applied to studying additional exploration destinations, such as Near Earth Objects, Lagrange Points, and Mars and its satellites.

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1 Introduction

> ***For the foreseeable future, the Moon, Mars and near-Earth asteroids are the primary targets for human space exploration.***

The Global Exploration Strategy (GES)[1] identified the Moon as one of the key destinations for future exploration missions. Just three days from Earth, it has low gravity, a dusty environment and natural resources that make it an ideal location to prepare people and machines for venturing farther into space. As a repository of four billion years of solar system history, and as a vantage point from which to observe the Earth and the universe, it also has great potential as a base for scientific research.

Near the end of 2008, it became clear that many space agencies[2] associated with the International Space Exploration Coordination Group (ISECG) were engaged in plans and preparations for missions beyond Earth orbit that could benefit from early coordination in the spirit of the GES. In early 2009, the ISECG endorsed the development of a Reference Architecture for Human Lunar Exploration and invited interested agencies to participate. To further the goal of cooperation, it established the International Architecture Working Group (IAWG) and the International Objectives Working Group (IOWG) to analyze the lunar exploration objectives of participating agencies.

This first study focusses on the Moon, not only because it is expected to play an important role in future exploration endeavors, but also because of the large number of countries having expressed an interest for the Moon in their future exploration plans. Moreover, NASA has invested a significant effort in

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[1] *The Global Exploration Strategy: The Framework for Cooperation*, http://www.nasa.gov/pdf/178109main_ges_framework.pdf, 2007.

[2] "Space Agencies" refers to government organizations responsible for space activities. Those involved in the ISECG include, in alphabetical order: ASI (Italy), CNES (France), CNSA (China), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA (European Space Agency), ISRO (India), JAXA (Japan), KARI (Republic of Korea), NASA (United States of America), NSAU (Ukraine), Roscosmos (Russia), UKSA (United Kingdom).

understanding human lunar architectures in furtherance of the US Space Exploration Policy. Therefore, the participating agencies recognized that collaborating on a Reference Architecture for Human Lunar Exploration (the "Reference Architecture") would help introduce multilateral consensus to preparations for future space exploration.

This Summary Report is arranged to address the specific work objectives that comprise the Reference Architecture:

- articulating a set of common lunar exploration goals;
- analysing strategic questions that affect architecture definition, development and deployment;
- development of the Reference Architecture to include concepts for architecture elements, including identification of interfaces that would benefit from standardization;
- comparing the Reference Architecture against the common lunar exploration goals;
- assessing products and broader benefits identified while developing the Reference Architecture;
- identifying future multilateral work that would advance preparations for human lunar exploration.

This study can serve as a useful model for designing multilateral architectures to enable enhanced international coordination and cooperation for sustainable space exploration.

The ISECG Reference Architecture for Human Lunar Exploration envisions how the space-faring nations of Earth can collaborate in exploring the Moon using the coordinated assets of many agencies. This vision can inform preparatory planning and decision-making within participating agencies and thus represents a concrete step toward realizing the goals of the Global Exploration Strategy.

2 Architecture Development Process

The development of the Reference Architecture marks the first time that a group of space agencies has worked closely together to create a conceptual definition of a complex human exploration mission scenario. Interested agencies were invited to define and assess architectures for human exploration of the Moon that would allow implementation of common lunar exploration goals.

The space agencies represented include: ASI (Italy), CNES (France), CSA (Canada), DLR (Germany), ESA (Europe), JAXA (Japan), KARI (Republic of Korea), NASA (United States), and UKSA (United Kingdom). Annex A describes the international teams and how the work was done.

Figure 1 provides an overview of the process utilized:

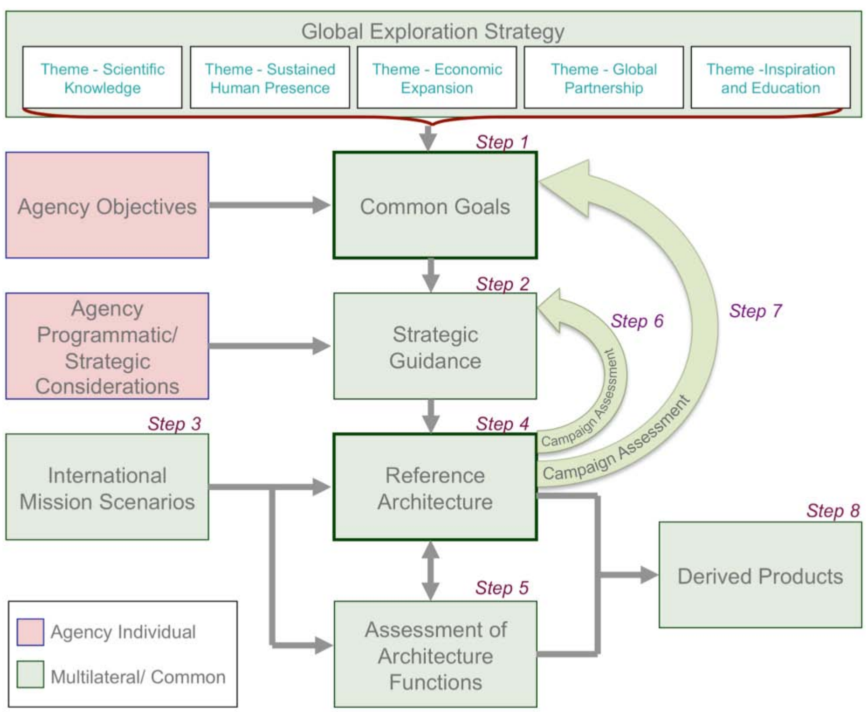


Figure 1: Reference Architecture Development Process.

> ***This development process -- pioneered for human lunar exploration -- can be employed to seek collaboration among space-faring nations interested in future exploration destinations, such as Mars and other bodies in the solar system.***

The steps illustrated in Figure 1 are detailed below.

1) Review of individual agencies' lunar exploration objectives and the themes of the Global Exploration Strategy, resulting in common goals (Chapter 3).

2) Development of guidance based on strategic and programmatic considerations that are important to participating agencies (Chapter 4)

3) Identification of reference human lunar exploration mission scenarios in order to scope the range of exploration approaches: Three mission scenarios had been defined upfront: polar lunar outpost, lunar sortie and extended stay as defined in Annex B. These were used to guide the development of elements and strategies that combine to create the reference architecture (Chapter 5).

4) Development of the Reference Architecture for Human Lunar Exploration describing a sequence of missions over time (Chapter 5).

5) Conceptual definition of the elements required to implement the architecture (Chapter 5).

6) Development and assessment of variations of the Reference Architecture to improve responsiveness to the strategic guidance and common goals (Chapter 5).

7) Evaluation of the Reference Architecture against the common goals. The strategy and campaign accepted as the ISECG Reference Architecture was deemed the option best able to achieve the common goals (Chapter 6).

8) Development of derived products, including identification of critical architecture functions, critical technologies and interfaces that would benefit from international standardization (Chapter 7).

While these steps are related (e.g. step 7 requires completion of step 1 through 6), many can be performed in parallel (e.g. step 1, 2, 3, 4, 5 were initiated together) and some require iterations (e.g. step 4 and 5). One important lesson learned is the importance of early agreement on definitions used throughout the work.

3 Common Goals and their mapping to GES themes

The IOWG first collected and integrated an initial set of existing and emerging national lunar exploration objectives from CNES, CSA, DLR, ESA, JAXA, KARI, NASA, NSAU, and UKSA. Many agencies are still developing their objectives and will be for some time to come, so the initial set is expected to grow and evolve as national objectives do, and as discussions on commonality proceed.

More than 600 national objectives were collected, representing the spectrum of what is currently thought to be important for humans and robots to achieve in lunar exploration. Described in both broad, sweeping terms and very specific, contextual terms, they provided insight into similarities in the goals identified by individual nations.

The next step was to compare these objectives to the five themes of the Global Exploration Strategy and to come up with a set of common goals for human lunar exploration that could be used to define a Reference Architecture. The five primary themes of the GES are:

- new knowledge in science and technology
- sustained human presence in space
- economic expansion
- global partnerships
- inspiration and education

A series of workshops resulted in the development of a set of common lunar exploration goals. These goals, which are listed in Fig. 2, were accepted by the ISECG in December, 2009. ***They represent the shared interests of the participants and provide the rationale and guidance for developing and evaluating an international architecture for human lunar exploration.***

The participants' individual objectives require further consolidation and will evolve over time based on discoveries made along the way. Participants recognize that as they plan future cooperative undertakings, further dialogue on common objectives will be needed.

- Theme 1: New Knowledge in Science and Technology
- Theme 2: A Sustained Presence - Extending Human Frontiers
- Theme 3: Economic Expansion
- Theme 4: A Global Partnership
- Theme 5: Inspiration and Education

■ Primary Themes
◣ Secondary Themes

Common Goals for Human Lunar Exploration

Traced to "GES: The Framework for Coordination"

Theme 1	Theme 2	Theme 3	Theme 4	Theme 5	Common Goals for Human Lunar Exploration
	Primary		Primary		1: Embrace a long-term strategic view for enhancing and expanding global partnerships for sustainable exploration of the Moon and beyond.
	Secondary		Primary		2: Maximize early international partnership opportunities for lunar exploration.
Primary	Primary		Secondary		3: Use lunar exploration as a stepping stone for the demonstration of technologies, operational concepts, and cooperation approaches for Mars and other destinations.
Primary	Primary		Primary		4: Take maximum advantage of ISS assets and other opportunities in LEO to advance technologies and capabilities for exploration beyond LEO.
Primary	Primary	Secondary		Secondary	5: Develop, demonstrate and apply innovative capabilities, technologies and processes for improving resource and energy management and environmental protection, driven by the challenge of sustaining human life and operations in the hostile environment of space and the lunar surface.
Secondary	Primary		Primary		6: Develop a flexible, robust and reliable architecture that allows humans to safely explore the moon.
	Secondary	Primary		Secondary	7: Stimulate economic development and industrial innovation to enhance global economic prosperity via exploration of the Moon.
Primary			Secondary	Secondary	8: Understand the origin and evolution of the Moon
Primary			Secondary	Secondary	9: Interpret the uniquely preserved record of solar system evolution on the Moon and its relation to the origin and evolution of life
Primary	Primary		Secondary	Secondary	10: Extend human presence in the solar system and improve the health of humans on Earth, by understanding and mitigating the risks to astronaut health in the lunar environment.
Primary	Secondary		Secondary	Secondary	11: Maximize science return by leveraging human presence on the Moon and/or capabilities developed for lunar exploration
Secondary		Secondary		Primary	12: Develop innovative tools, means and methods to enable the public to engage interactively in human exploration.
Secondary				Primary	13: Inspire the next generation to embrace the tools of exploration: science, technology, engineering, mathematics and a sense of curiosity.
	Primary			Primary	14: Engage the public on the broader rationale and benefits of exploration.
	Secondary		Primary	Primary	15: Achieve early, frequent and inspiring milestones relevant to the partnership, and to the public.

Figure 2: Common Goals for Human Lunar Exploration mapped to the GES Themes.

4 Strategic Guidance

While the common goals were developed to guide the Reference Architecture, they are independent of any particular architectural approach or solution. Indeed they may inspire many potential architectural solutions that could meet the goals in a variety of ways.

To drive a *specific* architectural approach, it was necessary to develop guidelines that express the strategic considerations shared by the participating agencies. These guidelines emphasize some specific goals, provide balance among others and emphasize particular aspects of some. They also capture concerns such ensuring timely development of program phases to improve affordability.

The strategic guidelines followed in developing the Reference Architecture are:

- advance the principles of programmatic and technical sustainability and ensure their early incorporation in the architecture. While these concepts are reflected in the goals, they are especially important in developing the architecture. There was particular emphasis on methods of incorporating these principles:
    - apply a phased approach to exploration, with interim milestones to accommodate evolving mission objectives and changes in program priorities, while demonstrating the performance of delivered systems;
    - include a phase involving robotic missions to the Moon in preparation for human lunar surface operations;
    - maximize the synergies between human and robotic activities.
- consider affordability in laying out approaches. The analysis includes a normalized cost assessment of all assessed campaign types but a quantified affordability assessment was not needed at this point.
- balance compelling science and Mars-forward objectives, understanding that specific Mars-forward and science priorities will evolve. Both the common goals and the guidelines emphasize the long-term strategic importance of lunar exploration in the context of other destinations (Mars) and the need to accomplish important scientific objectives in parallel. A robust architecture must also allow for evolution in scientific

and Mars-forward objectives resulting from new discoveries and technologies;

- take due consideration of ISS Lessons Learned.[3] For example, the principle of dissimilar redundancy in critical systems is important to ensure the sustainability of exploration programs and technical capability. The ISS was sustained by using the Russian Soyuz and Progress spacecraft during the hiatus in Space Shuttle flights after the loss of the Shuttle Columbia in early 2003.

A combination of common goals and strategic considerations were used to guide and evaluate the Reference Architecture.

[3] ISS Multilateral Coordination Board. *International Space Station Lessons Learned as Applied to Exploration*, 2009

5 Reference Architecture

5.1 Overview

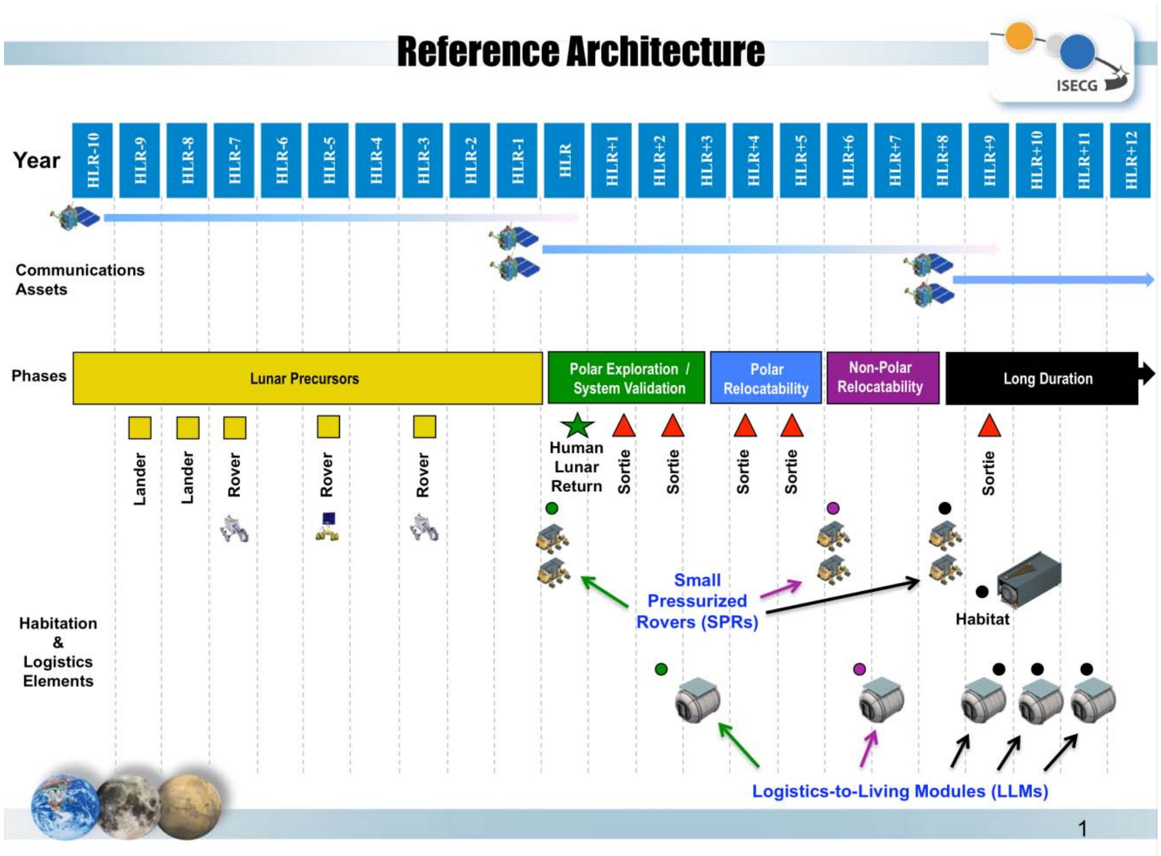
The Reference Architecture is neither a lunar base nor a series of Apollo-style (i.e. sortie) missions. It employs a flexible approach to lunar exploration that can accommodate changes in technologies, international priorities and programmatic constraints as necessary.

It relies on NASA's Constellation architecture for crew and large cargo transportation but is robust to variations (increases or decreases) in landed mass. It shows flexibility and redundancy will be improved by also using small cargo launch vehicles to deliver scientific payloads and logistics (e.g. laboratory and excavation equipment and crew support items like food, water and clothing.)

Key aspects of the architecture's robustness include opportunities for multiple partnerships and a phased approach that provides space agencies with diverse opportunities for scientific discovery and participation in exploration missions. Fig. 3 illustrates the phased approach, which employs an inventory of international human-rated and robotic assets over time to explore the Moon. Figure 4 illustrates notational locations on the Moon for these phases:

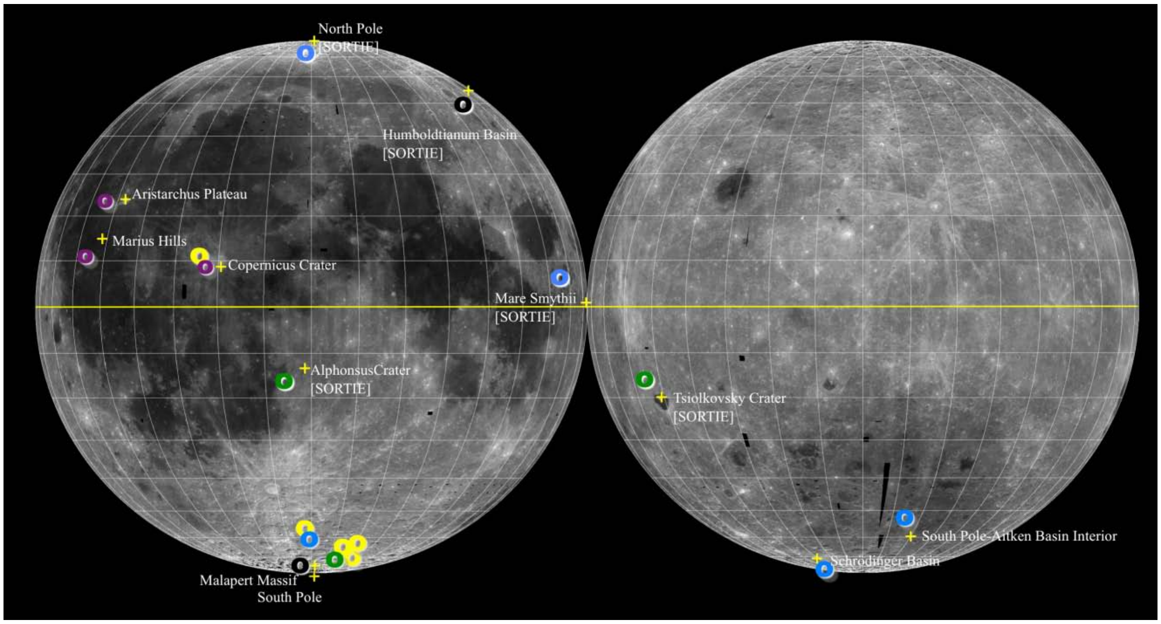
- robotic precursor phase
- polar exploration and system validation phase
- polar relocation phase
- non-polar relocation and long-duration phase

The Reference Architecture represents a flexible, phased approach to lunar exploration that demonstrates the importance of agencies working together early in program formulation.



The years across the top of the figure indicate years before or after Human Lunar Return.

Figure 3: Reference Architecture Overview, illustrating phased approach.



Colours correspond to the phases in Fig. 3.

Figure 4: Map of the Moon showing notional destinations for the Reference Mission.

5.2 Robotic Precursor Phase

A Human exploration mission can be performed in human-robotic partnership, where a robotic phase prior to human missions provides benefits in enhancing the efficiency of the human exploration phases. In the Reference Architecture, robotic precursor operations are included explicitly. Additionally, robotic operations do not stop after human lunar return and play an important role in subsequent phases, both during crew surface stays and in between landing.

The primary objectives of this phase include: characterizing the polar and non-polar lunar environment, resource prospecting, materials testing, and demonstrating technology and operations concepts. The precursor missions also provide an opportunity to deploy operational infrastructure, conduct science that may yield particular value prior to the human exploration phases, and offer opportunities for interactive public engagement in real time. This phase will also give existing and emerging space agencies opportunities to consolidate international partnerships.

The knowledge gained during the robotic phase will be used to help select future exploration sites, improve safety and reduce the cost and risk of human exploration missions.

Based on a preliminary analysis of necessary functions and tasks needed to accomplish these objectives, a six-mission robotic precursor phase was developed, beginning 10 years before Human Lunar Return (HLR). (Figure 3, yellow bar) The phasing and sequencing of these activities is intended to inform the design and development of architectural elements for subsequent human lunar missions.

The robotic phase will begin with a lunar orbiter mission that deploys a communication relay capability, and builds on mapping and reconnaissance data collected by recent missions, including the Lunar Reconnaissance Orbiter (NASA), Kaguya (JAXA), Chandrayaan (ISRO) and Chang'e 1 (CNSA) spacecraft. Data from these orbital missions will be used to design robotic surface exploration missions to sites of high interest.

The surface missions will include three landers to the south pole region that perform ground-truth measurements to characterize the local environment, conduct resource prospecting and perform long-duration materials testing. They will also demonstrate a variety of technologies, including advanced systems for automated precision landing, long-duration thermal management and surface mobility. These missions also include high-priority science investigations and transmission of 3-D images and video from the lunar surface.

The next robotic missions will feature mobility and site-survey functions at a nearby site (e.g. Malapert plateau), and then a site further from the pole. The selection of the robotic mission destinations is based on human landing sites in subsequent phases. The latter mission will also focus on resource discovery, characterization and extraction, as well as a demonstration of thermal control systems for the extreme non-polar lunar environment.

The robotic precursor phase is designed to provide an early demonstration of technological capability and early engagement among international partners, the science community and the public. This phase highlights important precursor activities designed to reduce risks to human missions, enhance sustainability of the architecture, and assist in targeting human missions toward the most promising scientific and Mars-forward objectives.

5.3 Polar Exploration and System Validation Phase

This phase (Fig. 3, green bar) will take place at one of the lunar poles due to favourable solar and thermal conditions in these regions and their inherent scientific value. Once the systems have been successfully deployed and tested at the pole, exposure to the harshest operational environment (including full ~15-day lunar eclipse periods) at lower latitudes will begin.

Approximately one year before any large infrastructure is sent to the Moon, small cargo landers will ferry several small servicing robots and a pilot In-Situ Resource Utilization (ISRU) plant to the surface. These systems will benefit from the experience gained during the precursor technology demonstration missions. They will be designed to operate for many years because they are key parts of the human/robotic team that will explore the Moon for hundreds of kilometers from the lunar pole in later phases.

The servicing robots will support the deployment and operation of the ISRU plant, practice maintenance operations, scout the region for future crew and cargo landing areas, and deploy landing aides. All robots will relay data and video, including the descent and touchdown of future crew and cargo landers, back to engineers and scientists on the Earth.

Once the primary Human Lunar Return landing site has been sufficiently investigated by the small servicing robots, the deployment of the large-scale exploration infrastructure will begin in preparation for human missions. Approximately one year after the initial robotic missions, but before the first human mission, a large cargo lander will arrive on the surface, directed by the landing aides placed by the robots. It will contain two unpressurized rovers, offloading equipment and a large regenerable fuel cell system with solar arrays.

These human-scale rovers will be tested by remote control from Earth and then sent out on excursions, beyond the range of the small robots, to identify opportunities and optimal paths to be used by human explorers. Within a few months, the first flight crew will arrive to use the fully-tested rovers. Their initial surface exploration mission will last up to 28 days and will likely include exploration of the near-polar region, practice operations for upcoming traverses and preparation of support systems for relocation.

> ***The polar exploration and system validation phase initiates human exploration with human lunar return (HLR). It leverages the robotic precursor work to build confidence in operations and systems design in preparation for more aggressive human and robotic lunar exploration.***

5.4 Polar Relocation Phase

During the Polar Relocation phase (Fig. 3, blue bar), the international team of robots, rovers and surface systems deployed to the lunar polar region will be relocated to the next site of interest for human exploration. On their journey, they will conduct scientific observations and provide opportunities for interactive engagement with the public.

When the equipment reaches the new, near-polar, exploration site (Malapert plateau, for example), the initial exploration and reconnaissance operations will begin again – months before the next crew lands. About a year after their exodus, they will greet the next human crew at the new exploration site.

As before, the crew will arrive in the lander and explore the region for approximately 28 days. The advance scouting done by the robots will increase the efficiency and productivity of the human crew's exploration activities. This relocation cycle can be repeated, based on emerging priorities, until the technological systems reach the end of their useful lives.

> ***The Reference Architecture strategy provides continuous human and/or robotic science collection activity at multiple locations on the Moon, starting from at least one year before the first flight crew arrives.***

5.5 Non-Polar Relocation and Long Duration Phase

At this point, there are several options in the Reference Architecture. Priorities will be influenced by the scientific, technical, operational and programmatic experiences and knowledge gained to this point. The two most promising approaches include:

- **Non-polar relocation**: A new/upgraded set of hardware can be launched to another region of interest (Aristarchus crater, for example) to support multiple 28-day missions, or short-duration sortie missions to specific sites of interest may be performed.

- **Long-duration missions**: Alternatively, a series of ~70-day human missions may occur at the same site. This would require the addition of several small logistics-to-living modules or larger habitats delivered on large cargo landers. These longer missions will satisfy Mars-forward objectives and will provide a better understanding of the effects of partial gravity and radiation exposure on crew and life support systems.

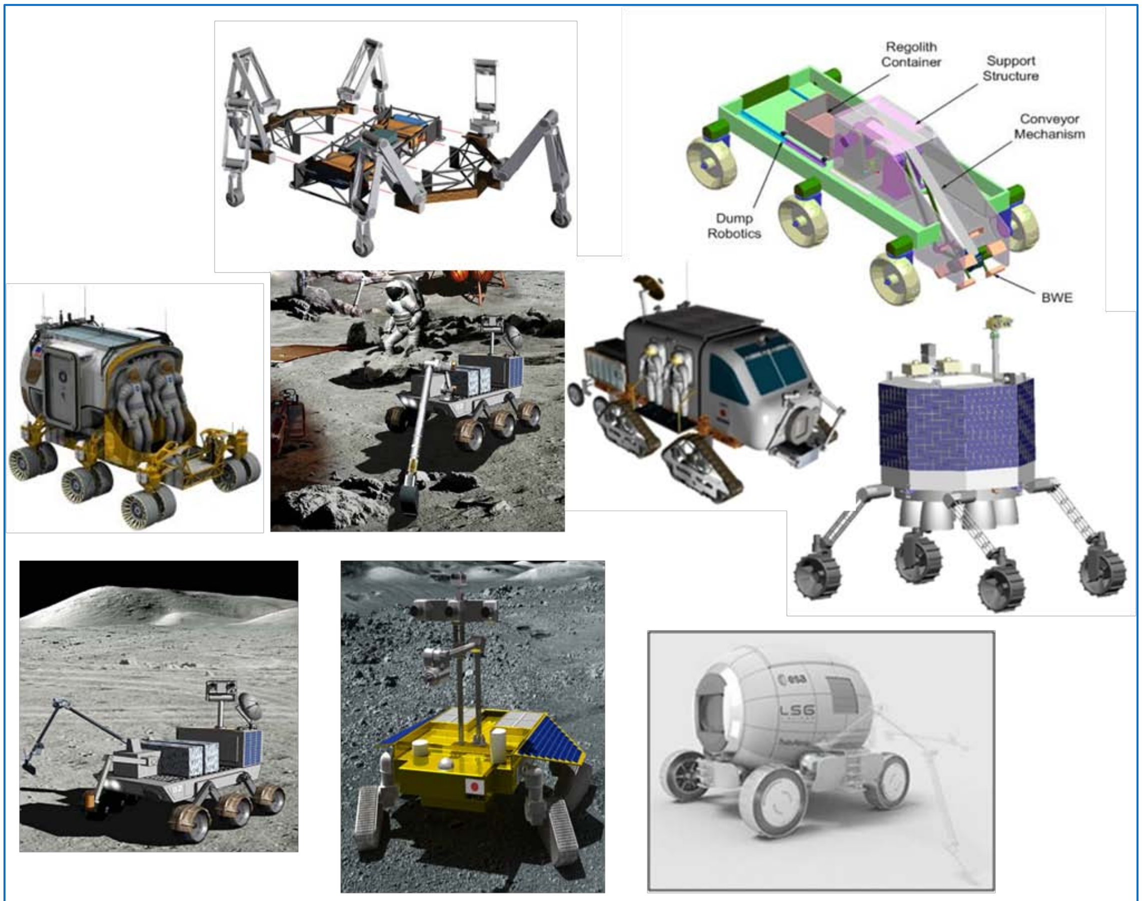
The Reference Architecture can support any combination of the above mission types, independent of the order in which they occur.

5.6 Element Descriptions

The Reference Architecture requires many systems to be developed and deployed on the Moon, providing numerous opportunities for international space agencies, large and small, to develop dedicated systems in areas of their core interest. There will also be many opportunities for agencies to work together to develop larger systems, allowing effective use of limited resources.

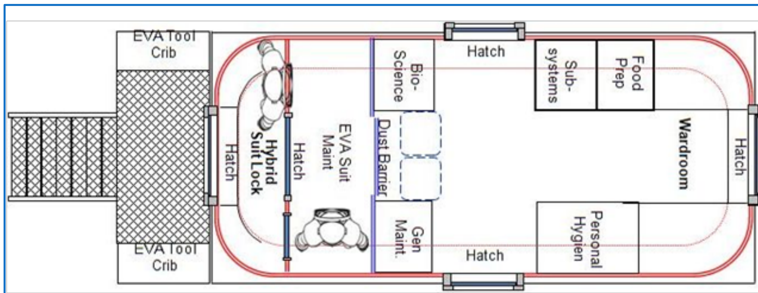
While developing the Reference Architecture, the international team proposed a wide array of elements, support mechanisms and transportation systems at a conceptual level. The selected assets provide a robust set of resources offering long-range mobility and the ability to survive the lunar environment over several lunar day/night cycles.

In addition, much of the critical infrastructure may be relocated and reused at different exploration sites as required. The following figures illustrate a representative sampling of some proposed elements.



Mobility and Rover Concepts

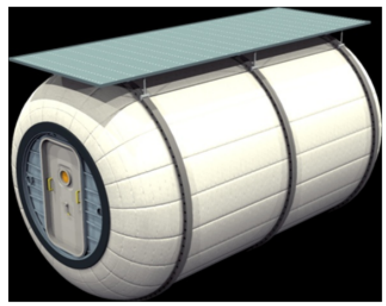
Transportation: Possible Landers



Habitation Module Layout

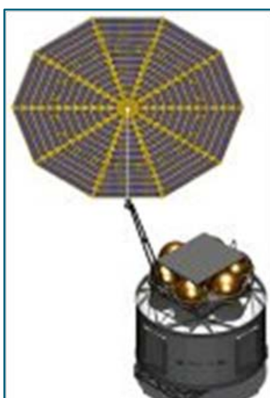
Inflatable Airlock

Habitation Module Offloading via ATHLETE

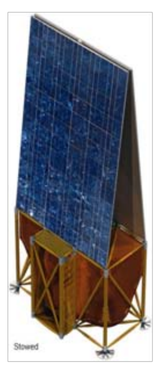


Logistics-to-Living Module

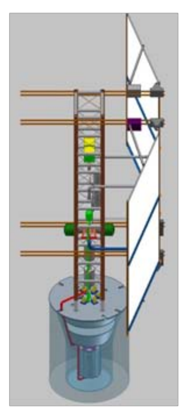
Habitation Concepts



Power and Support Unit

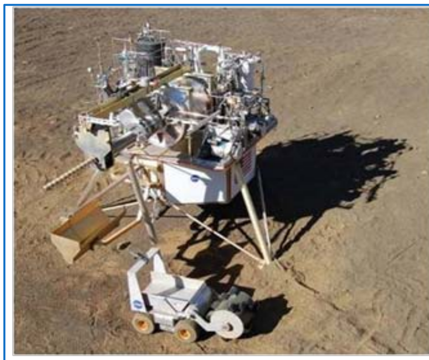


Portable Utility Pallet

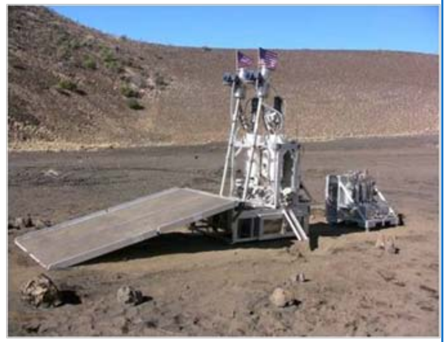


Nuclear Power

Power Concepts



Precursor Integrated Lunar Oxygen Testbed



Oxygen System

In-Situ Resource Utilization Concepts

Reconfigurable Adapter for Deployment of Large Elements

Lunar Surface Manipulator System

Servicing Concepts

Communication and Navigation Concepts

5.7 Implementation of the Strategic Guidance

The Reference Architecture was specifically developed to respond to the strategic guidance described in Section 4. This section addresses how that was accomplished.

Programmatic and Technical Sustainability: Sustainability was a primary focus in developing the Reference Architecture. The architecture was structured to maximize flexibility and robustness and to allow for changes over time, primarily through the adoption of a phased approach.

In addition, the phases are structured and timed so that the experience and lessons learned from each one can be used to improve subsequent phases. This approach allows participating agencies to meet evolving goals and objectives and to optimize the achievement of exploration goals.

Figure 5 illustrates the structure of the phases and the flexibility and robustness this provides in element design. Because developing and modifying surface elements requires significant detailed design, testing, and production periods, a commitment to the preliminary design of these elements must occur years before they are deployed.

Figure 5 illustrates these periods for each phase and also shows the approximate date by which commitments to element design must be made. It shows that the Reference Architecture allows for significant operational experience to be accumulated prior to the commit dates for later phases. This means that elements can be modified and customized in response to actual long-term operational experience and exploration discoveries.

The different phases of the Reference Architecture also allows for large-scale restructuring. The decision points in Fig. 5 allow for major adjustments, including but not limited to: switching the order of the phases, introducing new elements and operational concepts, adjusting mission locations, and adding utilization.

The Reference Architecture is composed of five phases of exploration on the lunar surface. While each phase builds on previous ones, and elements are re-used between phases, each phase involves a different realm of exploration.

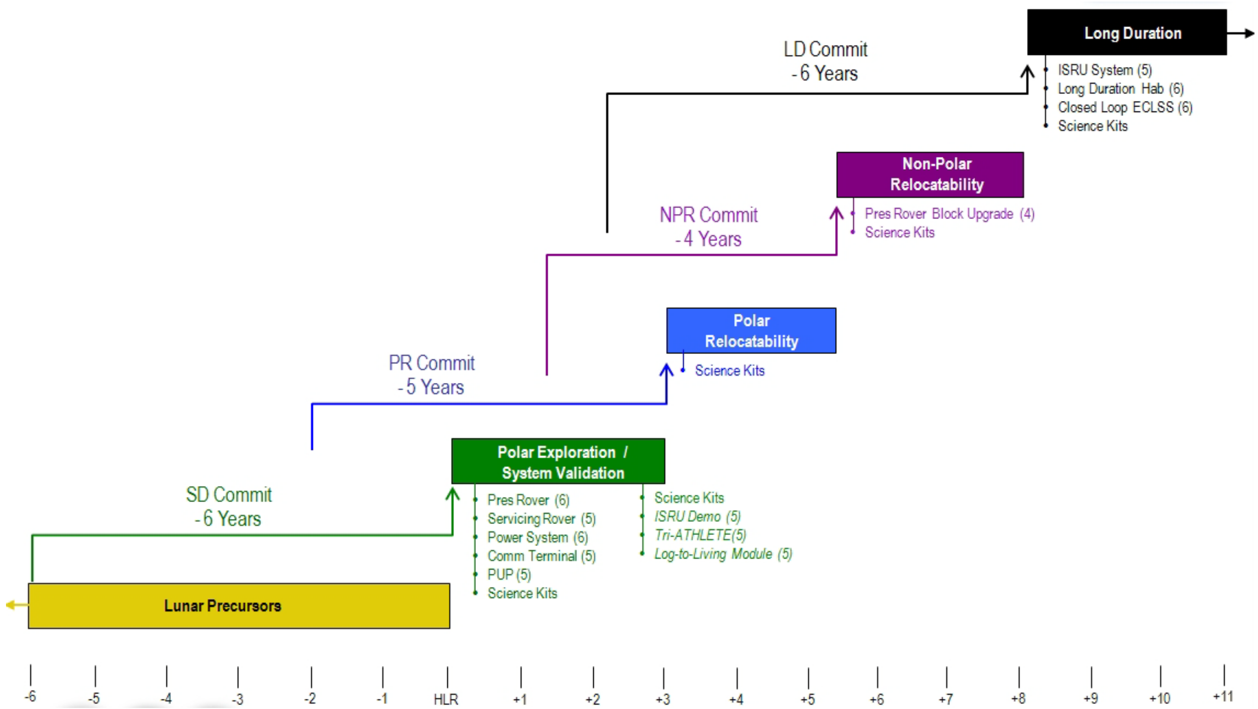


Figure 5: Design Commit Points for Reference Architecture Phasing, illustrating flexibility that supports sustainability.

Affordability: Because budgetary data for each of the agencies was not compared, true affordability analysis was not completed as a part of the structuring of the Reference Architecture. However, the intent of the strategic guidance was taken into account by introducing new elements and evenly loading the development and production costs of the surface infrastructure over time.

Balance of Science and Mars-forward Objectives: Each phase will involve increased capabilities and an expanded scope of exploration. New elements directly applicable to Mars exploration will be introduced over time. A balance of science and Mars-forward objectives will be achieved by using these new technological capabilities to explore and conduct science on the Moon in a way that mimics modes of exploration that might take place on Mars. The extensive use of mobile assets such as rovers is a key feature that responds to both Mars-forward and science needs.

This plan allows for significant time to be devoted to science and other utilization activities. Some examples of such activities include:

- **fieldwork:** mapping; collecting and analyzing rock and soil samples; measuring the Moon's gravitational, atmospheric and radiation environment; surveying for geological resources and landing sites; education and public outreach events.
- **human health risk reduction:** measuring radiation doses and cardiovascular function; analyzing blood and urine samples; studying astronaut behaviour and performance.
- **flight test and demonstration:** testing navigation and other systems to improve the ability of spacecraft to orbit the Moon, make precise landings on the surface and avoid landing hazards.

Incorporation of ISS Lessons Learned: Experience from the ISS provided valuable lessons that were incorporated into the Reference Architecture.

The Reference Architecture allows for significant delivery capacity and crew time to be devoted to utilization activities during each phase using a progressive build-up of capabilities. This will allow partner agencies to engage in scientific research, resource extraction, demonstration exercises, public outreach and other utilization activities while the lunar infrastructure is being assembled. They won't be forced to wait until everything is in place to start this work. This will enable them to phase their assets according to national interest.

On the ISS, science and other utilization activities were significantly delayed by the protracted construction phase and this was a source of frustration to space agencies and the scientific community.

The Reference Architecture incorporates redundant transportation systems, particularly for logistics. The activities planned for the lunar surface require a regular flow of logistics from Earth and if a single launch system were used, any failures or delays would severely restrict or curtail these activities, limiting the benefits for all partners.

Employing multiple transportation systems to deliver logistics will help ensure that surface operations can continue even if one transportation system fails. This strategy allowed the ISS to survive the loss of Space Shuttle services for more than two years after the loss of Columbia.

6 Comparative Assessment of Alternatives

The proposed Reference Architecture was evaluated against each of the common goals through the use of both qualitative considerations and quantitative metrics. Since satisfaction of the common goals is, in most instances, not directly measurable, both qualitative and quantitative factors were considered.

Methodology: A relatively simple but effective methodology was used to assess the degree to which the Reference Architecture was able to meet the common goals. A pair-wise comparison technique – a process for determining preference among options by comparing those options against quantitative properties[4] – was then undertaken for three options under consideration.

In addition to the proposed Reference Architecture, two campaigns based on previously defined mission scenarios (see annex B) were used as the basis for comparison:

- **a sortie-based campaign** involving stand-alone flights to the Moon with little or no dependence on pre-deployed assets;
- **a outpost-based campaign** focussed on developing a permanent human presence in a single location (a lunar pole) as rapidly as possible.

The sortie-based campaign relies solely on the sortie mission scenario. The outpost campaign relies mostly on the outpost mission scenario but includes also some sortie missions. The Reference Architecture incorporates aspects of all three mission scenarios (sortie, outpost and extended stay).

The primary objective of this process was to identify which was best suited to meet the 15 common goals.

Ratings were determined by consensus as to how well particular pairs under comparison best met each goal.

A sample of the pair-wise comparison tool is included below. The results show that the proposed Reference Architecture best met the set of common

[4] Saaty, Thomas L. (2008-06). "Relative Measurement and its Generalization in Decision Making: Why Pairwise Comparisons are Central in Mathematics for the Measurement of Intangible Factors - The Analytic Hierarchy/Network Process". RACSAM (Review of the Royal Spanish Academy of Sciences, Series A, Mathematics) 102 (2): pp. 251–318.

goals and provides for a robust and flexible exploration strategy for the Moon.

Partnership-related Goals: The Reference Architecture offered clear advantages in terms of opportunities for international partnerships (Fig. 2, Goals 1 and 2). Both the Reference Architecture and Outpost included more elements and therefore greater opportunities for partner contributions, while a series of sortie missions would most likely involve repetitive use of similar hardware across multiple sites. Also, the phased approach of the Reference Architecture enabled multiple entry points for diverse contributions from existing and new partners.

The Reference Architecture was also the preferred choice for financial reasons. Both the robotic precursor phase and the phased delivery of hardware enabled a greater diversity of contributions, large and small, to be made over time compared with the outpost option. Affordability was also enhanced by the delayed commitment to long-duration stays, which allowed for innovative technology advancements to minimize the high-cost supply chain from Earth.

Mars-forward Goal: In terms of preparing for future human missions to Mars (Goal 3), both the Reference Architecture and the outpost were strongly preferred over sorties; they offered superior opportunities to test and demonstrate Mars-forward technologies and to accumulate experience in the long-term operation of these technologies. The outpost option had an advantage over the Reference Architecture because it provided for significantly greater operational experience with human on the surface over time. Sortie missions had limited capability to deliver systems for test and demonstration and had no ability to provide for long-term operational experience.

Technology-related Goal: The Reference Architecture and the outpost were rated equally, but significantly higher than the sortie option, in terms of driving investments in technologies with potential applications on Earth, particularly in the areas of energy, resources and environmental management (Goal 5). The Reference Architecture requires advances in energy storage beyond 150W-hr/kg in order to accommodate the lunar night (two week stay periods) without access to solar power. The 180 day nature of the outpost requires a closed life support system, reduction and recycling of logistics and consumables, and nuclear power generation, all with significant spin-off potential on Earth.

Science-related Goals: In terms of science considerations such as understanding the origin and evolution of the Moon (Goal 8), both the sortie and Reference Architecture offered advantages over the outpost option since staying at one location would severely limit collecting the diversity of samples required to address the scientific objectives. However, the sortie missions would not provide the ability to dig and investigate beneath the lunar regolith, so both the outpost and Reference Architecture were preferred for this purpose.

The Reference Architecture was also advantageous because it allows science to be conducted during periods without human presence. It also allows examination of the preserved record on the Moon (Goal 9) to gain a better understanding of the evolution of the solar system, a goal that requires access to multiple locations. However, the outpost would allow more time to study the preserved lunar record, and both the Reference Architecture and outpost might allow access to materials trapped in permanently-shadowed regions of the Moon.

The Reference Architecture was considered preferable to sorties since it combined the advantages of site diversity and longer stays for analysis of the lunar record.

In terms of human health (Goal 10), both the outpost and Reference Architecture were strongly preferred over sortie missions because they best support key metrics such as time on surface, number of crew and return mass.

Human-robotic Partnership Goal: The Reference Architecture also scored best when measured against the goal of maximizing science return through leveraging human-robotic partnerships (Goal 11) since the use of robotics is inherent in the Reference Architecture. While robotics can be integral to both the outpost and sortie scenarios, they're used in very different ways, making it difficult to favor one campaign over another.

Public Outreach-related Goals: Finally, with regard to the goals related to public engagement (Goals 12-15), both the outpost and Reference Architecture fared well. They offer increased opportunities for diverse interactive engagement, an ability to demonstrate the benefits of exploration to people on

Earth, and a higher likelihood of being considered inspirational. The stronger emphasis on repeated technologies in the sortie scenario will reduce opportunities for continuous public inspiration and new visible milestones.

Figure 6 below shows the results of the pair-wise comparison. Each coloured bar represents a goal. The relative size of the bar represents the degree to which the proposed architecture met that goal (larger bars indicate a higher preference for meeting a goal). This provided assurance that the proposed Reference Architecture was best able to satisfy the common goals and strategic considerations.

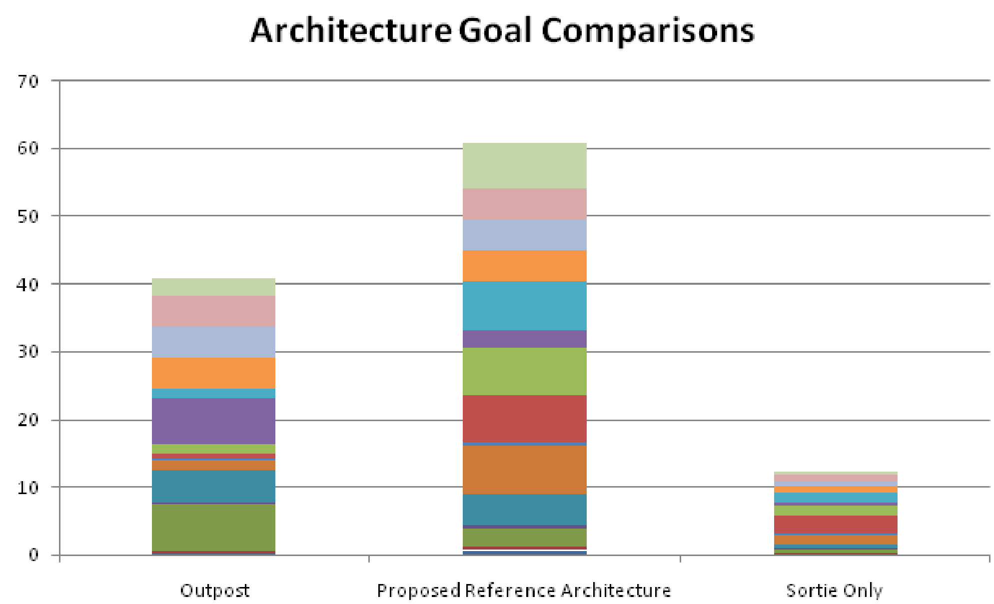


Figure 6: Pair-wise Comparison Results.

7 Broader Benefits and Derived Products

7.1 Broader Benefits

Using the Reference Architecture as a foundation, ISECG agencies can:

- share views on opportunities and challenges associated with meeting shared exploration goals, objectives, and priorities
- identify strategic issues and barriers
- use multilateral forums to generate a greater diversity of ideas and concepts
- demonstrate the value of collective work for defining initial concepts
- use a common reference for their individual and joint planning and decision-making; which may
    - inform policy
    - inform scientific research roadmaps
    - inform element-level concept studies (e.g. rovers, landers)
    - prioritize technology development
    - define robotic precursor missions
    - prioritize ISS research and technology demonstration
    - prioritize objectives for Earth-analogue demonstrations
    - inform the development of international interface standards
    - identify critical functions to assess major risks
    - identify critical technologies that are barriers to further exploration
- use a common reference for dialogue with political, industrial, scientific and educational stakeholder communities and the public
- enable a focused dialogue on partnerships and cooperation frameworks
- assess the value of innovative technologies and concepts.

The Reference Architecture is not intended to be self-contained. Indeed, it was developed primarily to spawn products needed in the broader ISECG community and to provide an example of dialogue among ISECG members that will help them pursue the exploration programs envisioned by the GES.

7.2 Derived Products

The broader benefits listed in section 7.1 can be further expanded and result in derived products. This section highlights several products of particular interest in the pre-program formulation phase. Participating agencies see the value of coordinating their activities in these areas to prepare for human space exploration.

***Interface Standards*:** Interface standards were recognized early on as a critical matter for the international community to consider in developing the Reference Architecture. Agreeing on an international standard interface is a resource intensive effort, so participating agencies look to the Reference Architecture to inform priorities for such discussions.

There are two issues that deserve equal focus: The interfaces that will physically interact and the standards that will be used to develop different functional areas in a common way for all participating agencies. Both are needed to ensure the Reference Architecture provides the most robust design with dissimilar redundancy and cross-partner compatibility.

Interfaces: The physical interfaces of the Reference Architecture have been identified. They fall into three categories:

- an interface is already under development or it does not benefit the architecture through early standardized definitions;
- the interface does not clearly show a current need for development of a standard;
- standardizing the interface will clearly benefit the architecture and it does not appear that a standard is currently being developed.

Items in the third category are ripe for future work that would greatly benefit the ISECG community.

Standards: Standards offer a way to ensure that elements developed by different participants meet common functionality and performance requirements and integrate well into the larger system.

A catalogue of standards important to the Reference Architecture was developed. It identifies international standards that have already been developed or are in development and contains consensus recommendations about others that need development or modification. Future work in this area would also benefit the ISECG community.

Critical Functions: The Reference Architecture defines critical functions as those that are essential for crew safety throughout all mission phases. Critical functions requiring certainty of operation at all times during the mission are typically identified via a systems engineering process later in a design cycle.

However, the Reference Architecture was reviewed to ensure that critical functions are as well understood as possible at this early definition stage. There was an assessment of risks associated with three categories: a loss of crew members and/or destruction of surface systems; early crew return; and crew health. Based on this high-level review, the Reference Architecture identifies mitigation approaches for most types of failures within these categories.

Areas in which the current Reference Architecture has critical functions requiring further mitigation work are:

- failure of the lunar ascent stage, requiring a redundant stage or a crew rescue system. Neither are parts of the Reference Architectures.
- failure in radiation protection systems that provide a safe haven for crew members against exposure to space radiation

Risk-mitigation solutions for these few identified areas should be considered for follow-on work.

Critical Technologies*:* The Reference Architecture has identified key technology challenges associated with the lunar mission as currently defined. The success of meeting these challenges requires key enabling technologies. In the context of the Reference Architecture, “critical” technologies are those required to implement the defined mission architecture and operational concepts.

Critical technologies have been identified by system discipline. Some representative examples include: advanced life support systems, long duration habitation modules, water/hydrogen/oxygen extraction from regolith, advanced lunar space suit, portable communication tower, advanced power storage systems, surface nuclear power and long-life mobility systems.

There are potential ISS and lunar precursor mission opportunities that could advance the readiness levels of some of these critical technologies prior to their integration into the final flight systems for the Reference Architecture.

Innovative Approaches and Concepts: In the course of developing the Reference Architecture, some new technical approaches were identified. Most have not been completely defined, but they represent areas where collaboration has already spawned new ideas and improved the technical foundation of the architecture. Examples include:

- **Logistics-to-living concept**: This involves using a modular approach to building pressure vessels that deliver logistics, then reusing those volumes for living quarters. This furthers commonality among airlocks, rover cabs, mobile habitats, etc. for habitation systems.

- **Waste and trash management approaches:** It is necessary to avoid as much as possible leaving trash on the Moon. In developing technologies for lunar exploration, resource extraction, environmental control and life support, it's important to identify approaches that will use local resources (e.g. water), minimize the creation of waste and encourage reuse and recycling.

- **Integrated ISRU:** In-situ resource utilization is not a stand-alone activity; it is intended to generate products (e.g. minerals, oxygen, water etc.) that are used by other systems (e.g. life support.) It's important to make the best use of the resources on the Moon to avoid having to launch any more than necessary from Earth. In short, lunar operations should, as much as possible, "live off the land." Achieving this goal will require study to identify ways to integrate the different lunar systems; this is an opportunity for future cooperative architecture development.

8 Next Steps

The ISECG Reference Architecture for Human Lunar Exploration is a concept for human and robotic exploration of the Moon designed to deliver important scientific discoveries and prepare for more challenging and distant planetary exploration aspirations. It was developed to encourage the international partnerships needed to prepare and execute human lunar exploration.

Coordination at this stage is considered important for exploring concepts that reflect common goals and maximize the opportunities to achieve the objectives of the individual partner agencies. It enables leveraging the preparatory activities of individual agencies but it is not mature enough to begin traditional Phase A program formulation activity.

The Reference Architecture can be the foundation for important multilateral work leading to the implementation of the Global Exploration Strategy (to be performed by ISECG or other mechanisms identified by participating agencies). The following areas are suggested for follow-up if agencies decide to pursue lunar exploration collectively:

Partnership interests: The Reference Architecture represents early dialogue on the roles and interests of partners in contributing to an international lunar exploration undertaking. It recognizes that some overlap of interest can enhance the robustness of the venture and it facilitates early identification of significant gaps that are not being addressed by any partner. Further dialogue should be undertaken when the formulation status of exploration policies and plans of ISECG members is mature.

Cooperation Framework: The international space agencies have been discussing the development of a cooperation framework founded on the GES to manage the next phase of lunar exploration. This framework will be built from the ground up through the participation of all involved agencies. This has never been done before so there is no existing management structure to turn to.

The development of this framework will depend on the nature of the lunar exploration architecture that is ultimately adopted by the international community. This architecture must meet the goals and needs of individual partner agencies, but must also meet the common goals that have been identified. It must also ensure that lunar missions will be conducted efficiently and effectively to achieve those goals.

It is impossible to predict exactly what form the management structure will take until the architecture is clearly defined. A Reference Architecture will influence this dialogue since partner goals and objectives, interdependencies (or lack thereof), development schedules, etc., are framed by the architecture under consideration.

Evolve Common Goals and Objectives: As discussed previously, a relatively simple but effective approach was chosen for comparative assessment. Further work is needed to support more detailed architectural evolution. Beyond the conceptual level, participating agencies will require a deeper understanding of, and ultimately agreement upon, common objectives in all of the areas addressed by the common goals. An understanding of the degree to which objectives can be met, based on measurable criteria of objective satisfaction, will be needed to support this dialogue.

Opportunities for Private Sector Engagement: The Reference Architecture helps to identify opportunities for private sector engagement and investment by giving an idea of the market potential in developing products and services for lunar exploration. Areas that could benefit from private sector investments are those with recurrent production and service demands, such as communication/navigation, cargo transportation and logistical services. An enabling international legal and policy framework is needed to encourage private sector engagement and ensure a market size above the critical level.

Collaborative Earth Analogue Missions: By identifying enabling research and technology development and critical international interfaces, the Reference Architecture may help to foster early and focussed collaborative activities among the partners. Earth analogue missions represent one important method partners can use to advance and demonstrate the capabilities needed for lunar exploration.

Engaging Stakeholder Communities: The Reference Architecture represents an excellent tool to engage stakeholder communities: it outlines utilization opportunities for the scientific communities, tells an inspiring story to the interested public, engages the private sector with technical challenges and possibly new markets, and can engage academics and educational institutions in related enabling research. Tailored messages and communications must be developed for different audiences.

Transportation Systems: In the current Reference Architecture, the capabilities of the transportation system were treated as an invariable constant since NASA had established a transportation architecture that provided crew and large cargo access to the Moon. While this simplified the task of developing a surface-focussed international architecture, it also narrowed the possibilities for discussion of other options. Reviewing and optimizing architectural options for human and cargo transportation to the surface of the moon should be done building on transportation systems envisioned for other destinations.

The benefit of having a reference is that it provides a framework to measure progress and discuss specific ideas for improvement of the architecture. The Reference itself can certainly be improved. One good way to do this would be to issue an open call to international academics, educational institutions and the private sector to contribute innovative ideas.

Having established an efficient and effective collaborative method of identifying common goals and developing a Reference Architecture for Human Lunar Exploration, the ISECG can undertake similar work for additional exploration destinations identified in the GES, such as Near Earth Objects, Lagrange Points, and Mars and her satellites.

Annex A: The International Team and Work Process

Nine ISECG agencies were represented on the international team that developed the ISECG Reference Architecture for Human Lunar Exploration. Not all of the agencies participated in all working group activities; their involvement was based on individual interests and expertise. However, whether they were large or small, all agencies gained important insights and were active and influential in the overall development of the Reference Architecture.

Study leads are listed below and were supported by key personnel from each agency. In addition to the primary working groups, function teams were formed to advance concepts in key functional areas (e.g. habitation, transportation, logistics, etc.) and the Campaign Integration Team integrated this work into an architecture.

Overall Study Lead
NASA Kathy Laurini, IAWG Chair

Agency Study Leads
ASI Andrea Lorenzoni
CNES Jean-Jacques Favier
CSA Jean-Claude Piedboeuf
DLR Britta Schade
ESA Bernhard Hufenbach
JAXA Junichiro Kawaguchi, Kohtaro Matsumoto*
KARI Hae-Dong Kim
NASA Chris Culbert**, Jennifer Rhatigan*
UKSA Jeremy Curtis

* IOWG Co-chairs
**Campaign Integration Chair

Work was conducted primarily via teleconference, using collaborative web-based tools. Workshops were held to conduct planning and collaborative decision-making. Workshops are listed in the following table.

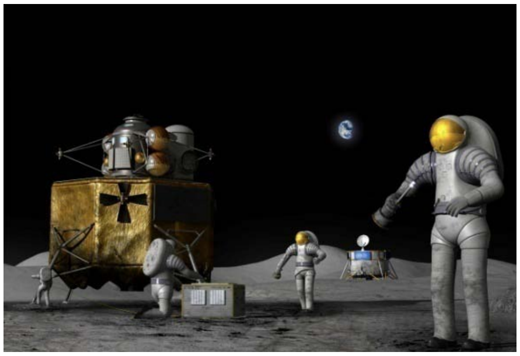
Workshop	Date and Location	Lunar Architecture Development Tasks
IAWG	October 2008 – Bremen, Germany	Formulated high level plan to define common architectural interests
IAWG	February 2009 – Houston TX, USA	Identified three distinct scenarios worthy of more detailed analysis: polar outpost missions, sortie missions, and extended-stay missions.
ISECG	March 2010--Yokohama, Japan	Reviewed three scenarios; formed IOWG
IAWG/IOWG	June 2009 – The Hague, Netherlands	Identified a preliminary list of elements for each lunar scenario and started development of high-level requirements. Developed strategic guidance to focus work in key areas. Assessed commonality of agency objectives collected and defined criteria for common goals.
IOWG	July 2009 – Tokyo, Japan	Processed collected common objectives, developed draft common goals.
IOWG/CIT/IAWG	September 2009 – Flagstaff, Arizona, USA	Developed candidate reference architecture. Agreed on common goals for human lunar exploration, and traceability to GES Themes.
IOWG/IAWG	November 2009 – Noordwijk, Netherlands	Began development of a campaign manifest and finalized the element requirements.
ISECG	December 2009 – Noordwijk, Netherlands	Reviewed common goals and architectural approaches with full ISECG
CIT	December 2009 – Montréal, Canada	Further developed candidate reference architecture.
IOWG/IAWG	January 2010 – Houston, Texas, USA	Compared the candidate reference architecture to other scenarios using a pair-wise comparative methodology. Selected a recommended ISECG Reference Architecture for Human Lunar Exploration.
CIT	February 2010 – Langley, Virginia, USA	Consolidated reference architecture, and reviewed robotic precursor mission strategy, worked on derived products (critical technologies and architecture functions, interfaces benefiting from international standards).
IOWG/IAWG	March 2010 – Montréal, Quebec, Canada	Further refined reference architecture. Formulated the outline of the reports, describing entirety of work performed.
ISECG	June 2010 –Washington, DC, USA	Obtained agency's senior management feedback on ISECG Reference Architecture.

Annex B: Lunar Exploration Mission Scenarios

Advancing the Global Exploration Strategy:

Human Exploration of the Moon

Summary of Discussions at
International Space Exploration
Coordination Group
Yokohama, Japan



1.0 Introduction

In *The Global Exploration Strategy: The Framework for Cooperation,* fourteen international space agencies [5] expressed their common interest in "creating a common language of exploration" to "enhance mutual understanding among partners and to identify areas for potential cooperation." It was in this spirit that in July 2008 the members of the International Space Exploration Coordination Group (ISECG) agreed to collectively explore ideas and plans for human exploration of the Moon.[6] From the latter half of 2008 through early 2009 interested agencies[7] participated in a series of Lunar Architecture Workshops to begin the process of discussing human exploration of the Moon in the international community.

Workshop participants have begun to study the means by which lunar exploration objectives can be met, examining the many kinds of spacecraft and other systems that can be developed over time to enable human exploration of the Moon. These systems are often referred to as architecture elements, and the members of the ISECG that participated in the workshops have considered how the innovative utilization of these elements can provide the necessary functions for lunar exploration – including habitation and life sup-

[5] In alphabetical order: ASI (Italy), CNES (France), CNSA (China), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA (European Space Agency), ISRO (India), JAXA (Japan), KARI (Republic of Korea), NASA (United States of America), NSAU (Ukraine), Roscosmos (Russia), UKSA (United Kingdom). "Space Agencies" refers to government organizations responsible for space activities.

[6] The ISECG held its second meeting in Montreal, Canada, on July 9-10, 2008.

[7] ISECG members that participated in at least one workshop include ASI, BNSC, CNES, CSA, DLR, ESA, JAXA, KARI, NASA, and Roscosmos (Russia)

port, transportation, and scientific investigation. A critical aspect of the successful functioning of these elements, if they are to be provided by multiple international space agencies, is the interfaces that enable the necessary level of interoperability. Participants have begun to formulate recommendations regarding these interfaces, highlighting the importance of standards, which can promote robustness across a global exploration architecture.

This multilateral lunar architecture study is planned to continue through mid-2010, with a goal of developing a reference lunar surface architecture which may be used to inform subsequent decision milestones of individual agencies.

2.0 The Lunar Architecture Workshops

Three Lunar Architecture Workshops, open to all ISECG members, were conducted between September 2008 and February 2009.[8] During the workshops, participating agencies reviewed their respective lunar exploration objectives and, where applicable, the status of ongoing or completed lunar exploration studies. The workshops gave participants the opportunity to share plans, look for common themes and objectives and begin the multilateral process of examining coordinated lunar exploration. Together, the group identified common objectives for exploration of the Moon, such as science of and from the Moon, preparation for human Mars exploration, and engaging the public through the course of lunar exploration. The group also considered International Space Station lessons learned, opportunities for private industry, as well as other strategic considerations which may impact a lunar exploration architecture.

Through the course of the workshops, participants considered how to best satisfy the lunar exploration objectives of the international community, ultimately identifying three distinct scenarios worthy of more detailed analysis: polar outpost missions, sortie missions, and extended-stay missions. These scenarios are explained further below, and provide the framework for the continued development and analysis of the international exploration of the Moon. The participants will conduct this analysis through additional workshops planned between now and mid-2010.

3.0 Lunar Exploration Scenarios

Workshop participants examined architectures associated with three major types of lunar exploration scenarios: establishment of a polar outpost, sortie, and extended-stay missions. Each scenario requires at a minimum the provision of crew and cargo transportation, communications from the Moon to Earth, and support for extravehicular activity.

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[8] The first workshop was September 17-18, in Bremen, Germany. The second workshop was October 29 – 30 in Cocoa Beach, Florida, USA. The third workshop was February 3-5 in Houston, Texas, USA.

Participants discussed the key parameters of potential architecture element in order to understand how they may be utilized in each scenario.

3.1 Polar Lunar Outpost Scenario

A human lunar outpost at one of the poles can be described as the build up of capabilities and elements that enable the opportunity for continuous presence of astronauts on the Moon, with individual stays of up to 180 days. It is envisioned that a completed outpost can be accomplished with a relatively small number of missions. An outpost can begin satisfying science, public outreach and other objectives during its construction phase and upon completion. A major attribute of a lunar outpost is to allow the international community to develop the systems and capabilities with sufficient reliability to consider undertaking an international mission to Mars.

3.2 Lunar Sortie Mission Scenario

A lunar sortie mission can be described as one or more short duration flights to any location on the Moon. These missions will satisfy a range of science objectives as well as public engagement and others. The main characteristic of this type of mission is that the crew lives out of the NASA Altair lander (or another human lunar lander) and can conduct up to seven days worth of scientific or other activities with the resources brought with them. Pre-deployment of resources is not necessarily precluded in this scenario.

3.3 Extended-Stay Mission Scenario

Workshop participants recognized that significant enhancement of sortie mission scenarios can be achieved if elements in addition to a human lunar lander are in-place on the lunar surface. The participants characterized an extended-stay scenario by the pre-deployment of elements that may extend the sortie mission crew time, provide additional capability for crew habitation, science or demonstration of capabilities and technologies necessary for human missions to Mars.