

TOWARDS THE 2ND VERSION OF THE ISECG GLOBAL EXPLORATION ROADMAP

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The *International Space Exploration Coordination Group* (ISECG) was established in response to “*The Global Exploration Strategy: The Framework for Coordination*” developed by fourteen space agencies^{†††} and released in May 2007. This GES Framework Document recognizes that preparing for human space exploration is a stepwise process, starting with basic knowledge and culminating in sustained human presence in space. Robotic exploration is considered an important component of expanding human presence in space for increasing the knowledge of future destinations, taking steps to reduce risks to human explorers, and ensuring human missions can deliver maximum scientific discoveries.

The first version of the *ISECG Global Exploration Roadmap* (GER) has been released in September 2011. The development of the first version of the GER focused on developing the overall framework, consisting of common goals for exploration, the long-range strategy and associated optional mission scenarios and Design Reference Missions (DRM's) as well as near-term areas for coordination and cooperation. Through the development of the GER participating agencies demonstrate their commitment to coordinate near-term investments.

Work on the 2nd version of the GER has already started. Updates of the GER will be informed by evolutions of agency's exploration policies and plans, agency individual and coordinated analysis activities relevant for various elements of the GER framework as well as coordinated stakeholder engagement activities.

Areas which will be in particular further developed in the 2nd iteration include:

- A further refinement and definition of the optional mission scenarios, emphasizing the definition of near-term DRM's;
- A further elaboration of common goals and benefits resulting from global space exploration;
- The identification of agency plans for technology development, enabling the implementation of the ISECG DRM's; this assessment will identify technology gaps, opportunities for cooperation and coordination in developing and demonstrating technologies as well as opportunities technology pull.
- The definition and prioritisation of strategic knowledge gaps which need to be closed in preparation of the ISECG DRM's as well as an assessment of the contributions of planned robotic missions in addressing these gaps.
- An overview of planned terrestrial analogue activities related opportunities for coordination and cooperation and their contribution to enabling the ISECG DRM's.

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This paper will provide early insight in envisaged updates of the 2nd version of the GER and in particular assess the implications on the “Moon Next” mission scenario included in the GER.

I. INTRODUCTION

Together with the decision to release the 1st iteration of the GER, ISECG participating agencies have also agreed to maintain and further develop the GER and update it at least every two years. The need to update the GER is driven by the interest to maintain the value of the GER as an up to date tool for informing ISECG participating agency’s planning and programme preparation activities. Further updates will continue to reflect the status of ISECG participating agencies evolving space exploration plans and programmes.

ISECG participating agencies continue work on areas of potential coordination and cooperation. The current work, which will be reflected in the 2nd iteration of the GER, is focusing on refining selected areas providing opportunities for near-term coordination of space exploration preparatory activities. Furthermore, early DRMs included in the 1st iteration of the GER are further defined. Early DRMs are those which may take place before either the return of humans to the lunar surface or a first human mission to a Near Earth Asteroid (NEA). These missions play an important role in facilitating a transition from the current programmes, focusing on human operations in Low Earth Orbit (LEO) and robotic exploration of the exploration destinations, to early human missions beyond LEO.

One important goal for the publication of the GER and for sharing the status of agencies efforts to define a human space exploration roadmap has been to engage the broader stakeholder community in the planning

process. In this way, ISECG participating agencies hope to generate innovative ideas and solutions to meeting the challenges of complex space exploration missions. Since the publication of the GER more than 80,000 copies have been downloaded in the time period September 2011 to February 2012 from the ISECG and participating agency websites. This large number of downloads clearly demonstrate the interest of stakeholders to be informed about and engaged in the agencies planning activities. Some ISECG participating agencies have organised special events and put in place specific processes for introducing the ISECG GER to local stakeholders communities in order to get their feedback. An important aspect of the forward work on the 2nd iteration of the GER will therefore also include the review of stakeholders feedback brought forward by the individual agencies to ISECG. Stakeholders feedback will be discussed and, if consensus between ISECG participating agencies is achieved, reflected in the 2nd iteration of the GER.

The long-range strategy introduced in the 1st iteration of the GER proposed two optional pathways or mission scenarios as shown in Fig. 1: the “Moon Next” and the “NEA Next” mission scenario. Moon remains a priority destination for many agencies and a fleet of robotic missions to the Moon are under development or in the advanced planning stage. This paper will describe the work within ISECG related to the “Moon Next” mission scenario, with a view towards the 2nd iteration of the GER. A companion paper, GLEX-2012.06.1.2, does the same for ISECG’s “Asteroid Next” mission scenario.

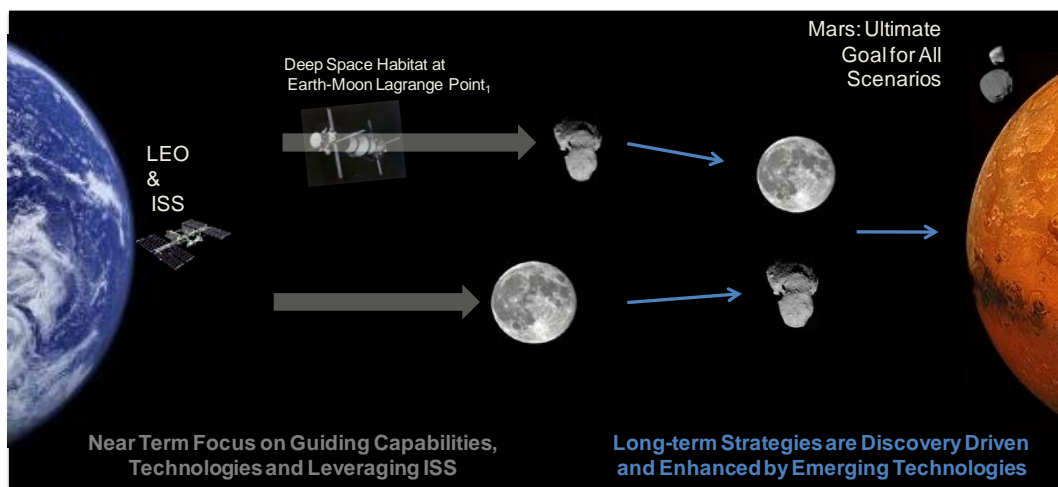


Fig. 1: Optional Pathways in a Common Strategy

II. PLANS FOR THE 2nd ITERATION OF THE GER

For the development of the 1st iteration of the GER significant effort has been devoted to developing the overall framework for interagency discussions as well as to defining and assessing optional long-range mission scenarios driven by the long-term goal of enabling a human mission to Mars. The development of the 2nd iteration of the GER will further advance the understanding of opportunities for coordination and cooperation on human exploration preparatory activities. The work is currently focusing on three areas: (a) the assessment of technologies enabling the implementation of the long-range mission scenarios, (b) the identification of the Strategic Knowledge Gaps (SKGs) which need to be addressed in preparation of human missions to the target destinations and, (c) the review of agencies' plans for analogue activities in preparation of future human exploration missions and identification of opportunities for international coordination and cooperation.

Agencies participating to the development of the 2nd iteration of the GER are sharing information on their plans to invest in technology development. These plans are mapped against the technologies needs for the different capabilities which enable the implementation of the long-range mission scenarios utilizing a common technology categorization. This allows for identifying (a) common interests of agencies in specific technology fields, providing possibly grounds for future cooperation, (b) critical technologies not sufficiently addressed by any agency today and (c) opportunities for considering innovative capability concepts driven by new technology developments.

Addressing and closing priority SKGs associated with potential human destinations timely will contribute to enabling safe, effective, and efficient human exploration. Agencies participating in the development of the 2nd iteration of the GER are sharing information on identified SKGs and optimum approaches for closing them either through terrestrial or in space research and testing or through robotic missions to the target destinations. The role of planned robotic missions in addressing SKGs is assessed and remaining priority SKGs are identified for informing the definition of potential future robotic missions. The work on the SKGs underlines the important role of robotic missions and is an example of the human-robotic partnership required for exploration.

The 2nd iteration of the GER will also discuss agencies' considerations on how to enable a gradual transition from current ISS and LEO focused human spaceflight activities to early human missions beyond LEO. Further definition work on near-term DRMs to the Moon and NEAs is performed to inform these considerations. Finally, the 2nd iteration of the GER will reflect updates and progress in agencies' plans and policy formulations.

III. MOON NEXT MISSION SCENARIO

The Moon Next Mission Scenario considers the Moon as the next destination for human exploration. The Moon provides an ideal environment for preparing the tools and systems needed to enable humans to live and work on other planetary bodies. The lunar exploration will allow to perform a broad range of major scientific experiments and to achieve objectives of value to nearly every agency involved in the ISECG. The Moon may also enable initial examinations on how humans can utilise the resources of our Solar System to sustain life and extend human presence.

In the 1st iteration of the GER, the Moon Next Mission Scenario defined the initial system concepts necessary for an effective campaign to explore the lunar surface in the polar regions. This work also demonstrated some of the key capabilities needed to support Mars mission landings, such as precision landing and hazard avoidance. The "Moon Next" scenario started with a series of missions that deploy human-scale robotic systems to prepare for eventual human missions and perform other important activities. The period between the initial delivery of human-scale robotics and human missions allowed target technologies to be demonstrated and human/robotic operational techniques to be developed. When humans arrive, they perform scientific investigations of the polar region, travelling enough terrain to master the technologies and techniques needed for Mars exploration. They also aid the robotic assessment of availability and extractability of lunar volatiles.

The landing systems required to deploy these human scale systems can be developed in two stages; an initial landing stage element that allows the delivery of large cargos to the surface of the Moon, followed later by the development of an ascent or return stage that provides accommodation for crew and the propulsion system to return the crew to lunar orbit for eventual return to Earth.

“Moon Next” Scenario Near-term Design Reference Missions

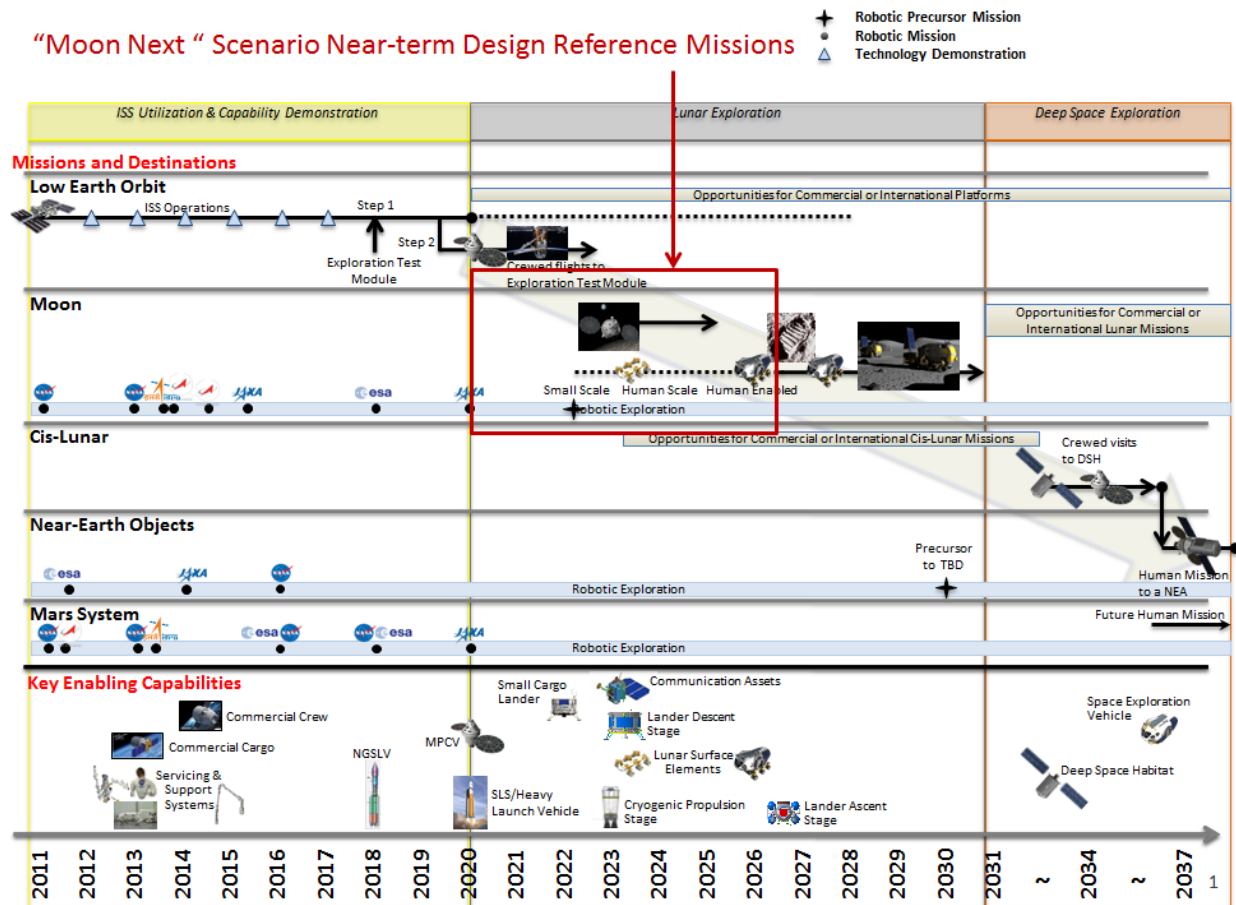


Fig. 2 Near-term Design Reference Missions of “Moon Next” Mission Scenario

The series of human missions to the surface of the Moon are unchanged in the 2nd iteration of the GER. These missions are defined using previous ISECG work to develop a reference architecture that enables extensive exploration of the lunar surface. These missions were specifically designed to prepare for Mars exploration and be consistent with the strategic principles, using a robust campaign that relies upon international partnerships to enable affordable missions. Human robotic partnerships are integral to the surface activities and should allow a broad range of science objectives to be met.

For the 2nd iteration of the GER, much of the scenario work has focused on providing more definition of the early DRMs; the series of missions leading up to humans returning to the lunar surface. They are characterized by the ability to send crew to various locations in cis-lunar space using NASA’s crew transportation systems. These early missions pave the way for the eventual human missions and provide a wide variety of opportunities for international

participation on many different levels. Considerable discussion has been held over the merits of various technology demonstrations and examining the best sequence for delivering both science assets and technology demonstrators. The trades between different approaches for demonstrating resource detection and exploitation have been reviewed and multiple approaches are being considered. Different options for delivering payloads to the surface of the Moon have been discussed though many of these concepts await further definition of future launch capabilities.

Also of interest are opportunities for tele-operation of robotic assets, such as In-situ Resource Utilisation (ISRU) hardware. Early deployment of robotic systems to be operated by humans in lunar orbit may increase science return and improve our understanding of how to best utilise surface assets. These opportunities should also prove to be interesting for public engagement, peaking interest in the eventual human missions to the surface.

The work to define these early activities in the Moon Next Mission Scenario will enable a more robust mission definition and should enable all of the agencies participating to better plan for eventual roles. It will also enable a better understanding of the needed technologies and illuminate where and how these technologies can be prepared for future human missions.

IV. ENABLING TECHNOLOGIES

Technology assessment in the context of the GER will help to facilitate leveraging investments in technology development efforts of individual ISECG agencies. While preparing the GER, agencies have already begun sharing information on their technology development investment areas and priorities. The GER already features in its current version a high-level categorization of the technology development input of participating agencies, providing a general overview of the applicable challenges.

As the ISECG exploration scenarios mature, work is underway to prepare additional levels of analysis for the next release of the GER. The goal for this next step is improving the coherence and level of detail of the collected inputs by adding high-level performance characteristics and identifying the applicability to exploration scenarios. This is achieved through a mapping process of the individual technology development activities to the specific elements and capabilities of the ISECG DRMs.

It is important to note that individual technology development activity inputs of the ISECG participating agencies to this *GER Technology Development Map* (GTDM) are guided by varying constraints and assumptions. While one agency might have identified a technology development activity in great detail, others might not yet have broken down their entries to the same level. To allow for a high-level analysis, the various agencies technology development inputs have been categorized based on the Technology Areas developed by NASA's Office of the Chief Technologist.

As a result, individual agencies can identify gaps as well as overlapping areas that could spur innovative competition and yield a more robust architecture. Joint activities, on the other hand, can create partnership opportunities not only related to technology demonstration missions or platforms but also to the usage of unique ground facilities or capabilities. The overall goal is to create opportunities for cooperation while recognizing agencies' autonomy in investment

decisions and for allowing each agency to find promising technologies in the global exploration effort. The NRC⁺⁺⁺ defines three Technology Objectives. Two of them are closely tight to the GER, namely

- Technology Objective A: *Extend and sustain human activities beyond low Earth orbit.* Technologies to enable humans to survive long voyages throughout the Solar System, get to their chosen destination, work effectively, and return safely; and
- Technology Objective B: *Explore the evolution of the Solar System and the potential for life elsewhere.* Technologies that enable humans and robots to perform in-situ measurements on Earth (astrobiology) and on other planetary bodies.

That report identifies a number of priority technologies for each of those objectives. The mapping of the technology development activities of the individual participating agencies identified in the GTDM against those "Final Prioritization of Top Priority Technologies" for Objectives A and B shows that all those top technology have associated development activities identified by multiple agencies. For instance three to five out of the six currently agencies participating in the GTDM have identified technology development activities in the area of Radiation Mitigation for Human Spaceflight (4), Long-Duration Crew Health (4), ECLSS (4), GNC (5), Lightweight & Multifunctional Materials & Structures (5), Solar Power Generation (3), Electric Propulsion (4), In-Situ Instruments and Sensor (4), and Extreme Terrain Mobility (5). On the other hand, Fission Power Generation for instance is only identified by one agency.

More details on the technology assessment activity and a preliminary analysis can be found in GLEX-2012.09.3.1x12269.

⁺⁺⁺ The Steering Committee for NASA Technology Roadmaps; National Research Council of the National Academies identifies in its report entitled *NASA Space Technology Roadmaps and Priorities: Restoring NASA's Technological Edge and Paving the Way for a New Era in Space*, 2012 (http://www.nap.edu/catalog.php?record_id=13354)

V. STRATEGIC KNOWLEDGE GAPS

In order to prepare for safe, effective, and efficient human exploration beyond LEO, system and mission planners will need access to data that characterizes the engineering boundary conditions of representative exploration environments, identifies hazards, and assesses resources. The knowledge developed from this data will inform the selection of future destinations, support the development of exploration systems, and reduce the risk associated with human exploration. Such data can be obtained on Earth, in space, by analogue, experimentation, or direct measurement by remote sensing or in situ. In order to accomplish this, it is necessary to identify the Strategic Knowledge Gaps (SKGs) associated with potential destinations for human exploration, what measurements or data are needed to fill those gaps, how the knowledge is best obtained, and when the knowledge is needed.

A Strategic Knowledge Gap Assessment Team (SKGAT) has been formed and charged with developing an internationally integrated set of SKGs to inform our joint efforts at planning human and robotic precursor exploration of asteroids, the Moon, and Mars and its moons. This comprehensive set of knowledge gaps is based on inputs provided by DRMs elements designers and the scientific community.

The effort also includes articulating how currently in orbit or planned science driven and robotic precursor missions such as among others the NASA GRAIL and LADEE missions, Selene 2 (JAXA) or the ESA Lunar Lander will contribute to filling the SKGs and elucidation of potential future precursor robotic missions that complement those currently planned and could provide robust opportunities for international cooperation. Some examples of destination specific SKGs are listed below:

- Asteroid: Near-Surface Mechanical Stability, Surface Morphology & Compaction

This knowledge is needed to inform effective anchoring to and safe interaction with the body during a human exploration mission.

- Moon: Detailed Characterization of Polar Cold Traps and Nearby Sunlit Areas

This knowledge is needed to inform the identification of potential landing sites at the lunar poles that take best advantage of local resources (e.g. near-continuous sunlight) and

are scientifically compelling (e.g. lunar polar volatiles).

- Mars: Atmospheric Aspects (Characteristics) that Affect Aerocapture, Entry Descent and Landing and Launch from the Mars Surface

These observations/measurements directly support engineering design and also assist in numerical model validation.

The SKGAT is in the process of consulting with international experts in order to establish the priority gaps for the two GER Mission Scenarios. It is the intention of ISECG to document the internationally integrated set of priority gaps, as well as information on how planned robotic mission fulfill these gaps, in the second iteration of the GER.

VI. ANALOGUE ACTIVITIES

Analogue activities represent one method used by many ISECG agencies to test of system designs and mission concepts at a location mimicking key features of a chosen Solar System destination. These terrestrial analogue activities also provide an important opportunity for public engagement in a setting that brings together students, astronauts, scientists, and engineers.

Tests conducted at terrestrial analogue locations are designed to be a cost effective means of helping engineers and decision makers to better understand how well chose hardware concepts and operations meet exploration objectives. Consequently, tests must be designed and analogue locations must be chosen to address questions that arise from the ISECG DRMs.

As part of the GER refinement, ISECG participating agencies are taking a number of steps to make the most effective use of analogue activities. One of the first steps in this process is to review the evolving DRMs and identify questions or uncertainties that analogue activities could help resolve. In parallel with this is a review of technologies that have been linked to these DRMs, looking for opportunities where testing in an analogue environment (preferably in conjunction with other analogue tests) are possible. With this collection of questions and uncertainties in mind, a next step will be to review analogue activities currently planned by ISECG agencies to identify any opportunities to address DRMs-related or technology-related uncertainties that have not already been taken into account. For those questions or uncertainties not accounted for in currently

planned analogue activities, an assessment will be made of the scope and scale of additional analogue activities that could address these open issues. Potential locations for these analogue activities, and some description of the feature(s) that are of the most benefit for these activities, are being collected by ISECG participating agencies. These assessments of possible analogue activities, along with the collection of candidate analogue sites, will be available for ISECG agencies to use to plan activities in future years.

VII. CONCLUSIONS

ISECG participating agencies are committed to update the GER and maintain its strategic value as tool for informing agencies' planning and program formulation activities, for informing the establishment of future partnerships for exploration and for communicating the long-term scenario and value of space exploration to the

broader stakeholder community. While significant efforts have been devoted during the development of the 1st iteration of the GER to the definition of the overall GER framework and the analysis of optional long-range mission scenarios, current work concentrates more on the analysis of coordination opportunities related to the implementation of space exploration preparatory activities and the further definition of near-term Design Reference Missions which may be implementable within the next 10 to 15 years. The 2nd iteration of the GER is currently planned to be published end 2012/early 2013. The continued work on the GER demonstrates the commitment of ISECG participating agencies to coordinate their space exploration plans and preparatory activities such as to enable a step-wise implementation of the vision described in the Global Space Exploration Strategy published in May 2007.