SYMPOSIUM ON HUMAN SPACE ENDEAVOURS

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THE 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[1] 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 a sustained human presence in space. Robotic exploration is considered an important component of expanding human presence in space in order to increase the knowledge of future destinations, take steps to reduce risks to human explorers, and ensure the human missions can deliver maximum scientific discoveries.

Sharing this common understanding of space exploration, ISECG participating agencies have started concrete discussions on the purpose and goals of exploring different destinations. They have defined associated mission scenarios outlining the overall exploration sequence. Agencies have recognized that (a) different destinations and related mission scenarios require different challenges to be mastered and risks to be addressed and (b) opportunities exist to exploit synergetic capabilities linked to different destinations.

Senior agency managers representing agencies contributing to ISECG have agreed in June 2010 to start the development of the Global Exploration Roadmap (GER), recognizing that such a roadmap will be evolving and responding to new programmatic priorities, scientific discoveries and technological breakthroughs. The Global Exploration Roadmap is intended to serve as a tool or international reference framework for

- Facilitating the convergence of international human space exploration mission plans, programmes and policies and thereby enhancing opportunities for collaboration and coordination;
- Maximizing the benefits resulting from each planned mission, considering also opportunities it enables for the development of partnerships and follow-on mission scenarios;

[1] In alphabetical order: ASI (Italy), BNSC – now UKSA (United Kingdom), 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). "Space Agencies" refers to government organizations responsible for space activities.

- Encouraging timely and coordinated investments in the development of enabling technologies and their demonstration, with special emphasis on a near-term commitment to fully use the International Space Station (ISS) for preparing future human exploration missions.

Through the development of the GER, ISECG participating agencies demonstrate their interest in a globally coordinated space exploration effort along the principles of the vision described in the Global Exploration Strategy (GES) and for the benefit of the global society.

For more information on the ISECG please consult the ISECG website at www.globalspaceexploration.org or contact the ISECG Secretariat at: isecg@esa.int.

I. INTRODUCTION

In June 2010, ISECG participating agencies started the development of the Global Exploration Roadmap (GER) and released its first version in September 2011. As resource availability becomes critical at global level and interest in cooperation increases, agencies will benefit from the work in developing the GER by informing near-term investment decisions, identifying partnerships and renewing the spirit of exploration.

The GER serves as a common planning tool for participating agencies driven by the shared interest to enhance coordination and cooperation for exploration. Consistent with existing policies and plans of participating agencies, the GER introduces a long-range strategy for future human exploration mission scenarios. This common strategy leads to a sustainable human exploration of Mars. It begins with full use of the International Space Station to prepare for exploration. The ISS is not only an excellent in-space platform for demonstrating technologies and capabilities and performing research, but it is the current focus of the human spaceflight program for most nations. With this comes the opportunity to use the ISS to prepare for the next steps.

The GER will be regularly updated to reflect the evolving status of agency's policies and plans and outcome of additional assessments. The publication of the first version reflects work in progress and the decision to share this work early has been driven by the interest to engage the broader stakeholder community in the discussion. It is noted that the process put in place for developing and maintaining the GER may contribute to aligning exploration policies of participating agencies which is an essential condition for succeeding in the implementation of sustainable space exploration.

The development of the 1st version of the GER focused initially on developing the adequate framework. The framework includes three key elements:

- Common Goals: Many ISECG participating agencies have devoted significant effort in the last years to defining their goals and objectives for exploration, often engaging their stakeholder communities in this process. An initial assessment of individual agency goals and objectives was conducted during the development of the GES. This was followed by a dialog on lunar exploration goals and objectives during development of the ISECG Reference Architecture for Human Lunar Exploration (see Reference 1). Building on this body of work, the commonality assessment of exploration goals and objectives has been extended to all exploration destinations leading to development of eigth high-level common goals and associated objectives.

- The Long-range Strategy: The development of the long-range strategy has been informed by detailed work done by ISECG participating agencies. This common long-range strategy reflects ISECG participating agency's policies, as far as existing, and builds on ISECG participating agency's preparatory activities and plans. As said previously, it reflects a common desire to fully utilize the ISS and progressively develop and demonstrate the capabilities necessary for humans to sustainably explore the surface of Mars. The strategy is elaborated through mission scenarios driven by the common goals. To further guide the development of mission scenarios, high-level strategic principles have been developed. These principles reflect strategic considerations of ISECG participating

agencies which have been informed by individual agencies studies, lessons learned from the ISS programme (see Reference 2) and previous work on the ISECG Reference Architecture for Human Lunar Exploration.

- Near-term areas for Coordination and Cooperation: Preparatory activities currently implemented by participating agencies have been grouped into five areas:

    - Robotic precursor missions;
    - Development of enabling technologies;
    - Use of ISS for preparation of exploration missions beyond low Earth orbit;
    - Development of new systems and infrastructure;
    - Analogue activities.

    The activities performed in each of these areas are designed to prepare for human missions in the future. It is recognised that the existence of a common long-range strategy can facilitate coordination of these preparatory activities and processes have been put in place to enable this to happen. At the same time, early sharing of information on these activities areas will help to establish cooperative projects already in the preparation phase and thereby foster early partnerships.

II. COMMON GOALS

Exploration must be driven by goals and objectives. These provide the basis for organizing and focusing our efforts to explore the solar system. The success of the Global Exploration Roadmap in preparing for human space exploration will be based on the recognition of individual partner goals and the acceptance of common goals which are both realistic and compelling. These goals should reflect common purpose but also enable individual agencies to achieve their national objectives.

Informed by a detailed assessment of agency's individual goals and objectives, eight high-level goals have been developed. These goals are not destination specific. Individual missions, whether human or robotic, will often address a combination of these goals, which is a specific characteristic of exploration missions.

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- **Search for Life:** Determine if life is or was present outside of Earth and focus on understanding the systems that support or supported it.

- **Extend Human Presence**: Extend human presence beyond low-Earth orbit with a focus on continually increasing the number of individuals that can be supported at these destinations, the duration of time that individuals can remain at these destinations, and the level of self-sufficiency.

- **Develop Exploration Technologies and Capabilities**: Develop the knowledge, capabilities, and infrastructure required to live and work at destinations beyond low-Earth orbit through development and testing of reliable and maintainable technologies, systems and operations in an off-Earth environment.

- **Perform Science to Support Human Exploration**: Reduce the risks and increase the productivity of future missions in our solar system by characterizing and mitigating the effect of the space environment on human health.

- **Stimulate Economic Expansion**: Support or encourage provision of technology, systems, hardware, and services from commercial entities and create new markets based on space activities that will return economic, technological, and quality-of-life benefits to all humankind.

- **Perform Space, Earth, and Applied Science:** Engage in science investigations of and from solar system destinations and engage in applied research in the unique environment at solar system destinations.

- **Engage the Public in Exploration**: Provide opportunities for the public to engage interactively in human space exploration.

- **Enhance Earth Safety:** Enhance the safety of planet Earth by following collaborative pursuit of planetary defence and orbital debris mitigation mechanisms.

Reference 3 provides further details on the Common Goals.

III. LONG-RANGE STRATEGY

The Global Exploration Roadmap introduces the destinations beyond low Earth orbit (LEO) which can possibly be visited by humans in the foreseeable future. These destinations include Moon and the cis-lunar space (The cis-lunar space includes destinations such as Earth Moon Lagrange Points and Moon orbits.), Near-Earth Asteroids and the Mars system (Mars and its moons). Figure 1 highlights key driving objectives for visiting these destinations and some key considerations. Clearly, each of these destinations represents a target for human missions in its own right, but the complexity and risks associated with human missions to these destinations varies considerably and provides insights into destination sequencing.

The long-range strategy represents a common understanding of the approach for extending human presence into space. The long-term goal of this strategy is to enable a human mission to and the human exploration of the surface of Mars. In the near-term the ISS is utilized for preparation of exploration missions beyond LEO through demonstrating technologies, advanced capabilities and performing enabling research. Recognizing the risks associated with and significant amount of new technologies and capabilities required for a human mission to Mars, human presence into deep space is extended in a step-wise approach. Two interim destinations are visited gradually demonstrating those capabilities required for the human exploration of the Martian surface while meeting other destination specific objectives: Near Earth Asteroids and the Moon. Two optional pathways for implementing this long-range strategy have been defined, which differ primarily with regard to the sequence of visiting the interim destinations.

	Mars	Moon	Near Earth Asteroid	Cis-Lunar Space
Key Objectives	Search for Life Advance understanding of planetary evolution Learn to live on another planetary body	Characterise availability of water and other resources Test technologies and capabilities for human space exploration Advance understanding of solar system evolution Utilise the Moon's unique importance to engage the public	Demonstrate innovatiive deep space exploration technologies and capabilities Advance understanding of role of these primitive bodies in solar system evolution and origin of life Test method to defend the Earth from risk of collisions with NEA's	Expands capability of humans to operate in this strategic region beyond LEO Drives innovations in deep space exploration technologies and capabilities
Considerations	Significant technology advancements essential for safe and affordable missions Radiation risks and mitigation techniques must be better understood Highly reliable space systems and infrastructure needed Demonstrated ability to use local resources is essential	Expenses associated with extended surface activities	Need to better understand and characterize the NEA population Technology advancements are needed before missions to NEA	Need to better understand role and value of humans in cis-lunar space

Figure 1: GER Destinations

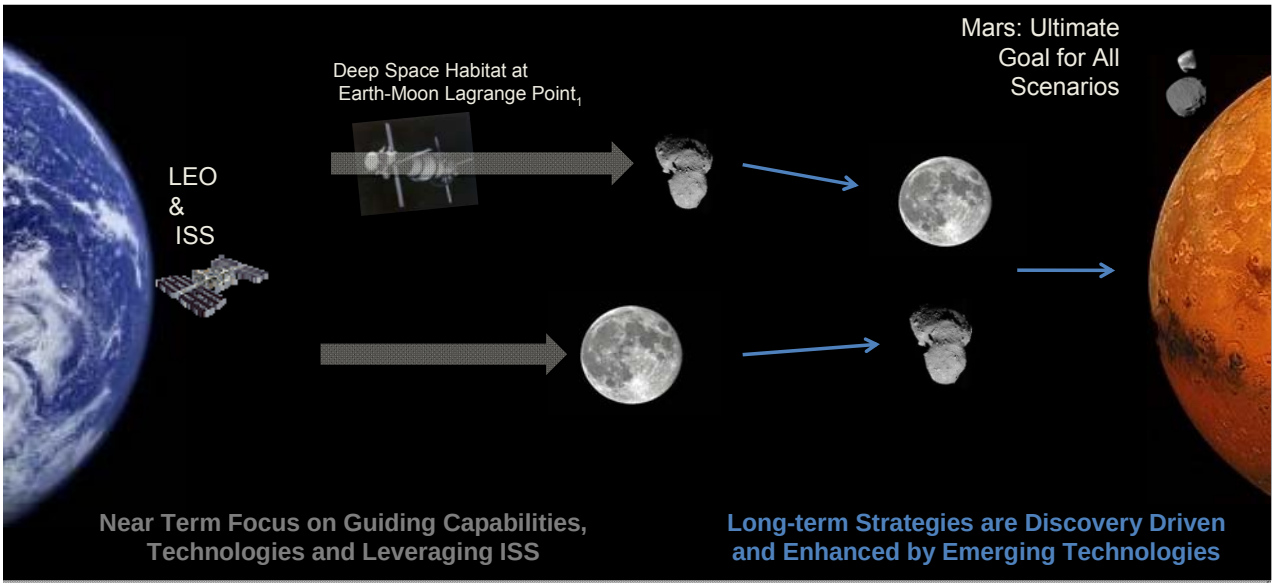

Figure 2: Long-range Strategy

IV. OPTIONAL MISSION SCENARIOS

Two pathways have been defined and evaluated as shown in Figure 2. These pathways are further elaborated in mission scenarios which describe at a high level a sequence of Design Reference Missions to LEO, cis-lunar space, Moon and near Earth asteroids which increase gradually in complexity. Reference 4 provides further details on the mission scenarios and Design Reference Missions analysed.

For assessing the optional mission scenarios, common strategic principles for extending human presence into space have been defined. These principles reflect a shared view on strategic considerations which inform the approach on how to extend human presence into deep space. The strategic principles together with the Common Goals provide a guiding framework for the definition of mission scenarios and their evaluation.

The following strategic principles have been defined:

1. Capability Driven Framework: follow a phased/step-wise approach to developing capabilities applicable to multiple destinations.
2. Exploration Value: Generate public benefits and meet exploration objectives.
3. International Partnerships: Provide early and sustained opportunities for diverse partners.
4. Robustness: Provide for resilience to technical and programmatic challenges.
5. Affordability: Take into account budget constraints
6. Human-Robotic Partnership: Maximize synergy between human and robotic missions

Figure 3 shows other mission scenarios considered and the reason for deselecting each. In particular, a human mission directly to the Mars system has been excluded considering the strategic principles 1, 4, 5.

The two maintained mission scenarios are described in Figure 4 and 5.

This “Asteroid Next” scenario pursues human exploration of near-Earth asteroids as the next destination. It offers the opportunity to demonstrate many of the capabilities necessary to send astronauts to Mars orbit and return them safely to the Earth. The mission scenario includes deployment of a deep space habitat in cis-lunar space to advance the capabilities necessary for travelling and living in deep space. Missions to asteroids, using the very same deep space habitat deployed in cis-lunar space, will then allow us to learn more about these primordial objects, and examine techniques and approaches that may one day serve for planetary defence purposes.

The success of this scenario depends on the availability of suitable near-Earth asteroid (NEA)

human mission targets. Suitability includes such factors as achievable mission trajectories, acceptable physical characteristics for crewed operations, and scientific interest. Since only a small percentage of the total NEA population has been discovered and catalogued, identifying targets which provide flexibility in selection of crewed mission opportunities to achieve most objectives will be essential to the viability of this strategy as a pathway to eventual human missions to Mars.

This scenario develops the capabilities necessary to demonstrate crewed missions in space for longer durations at increased distances from Earth. Also demonstrated are critical capabilities, such as radiation protection and reliable life support systems, to support the longer duration trip times required to send astronauts to Mars orbit and return them safely to Earth. Successful human exploration of near-Earth asteroids will necessitate mastery of advanced propulsion technologies, which are essential for the safe and affordable exploration of Mars.

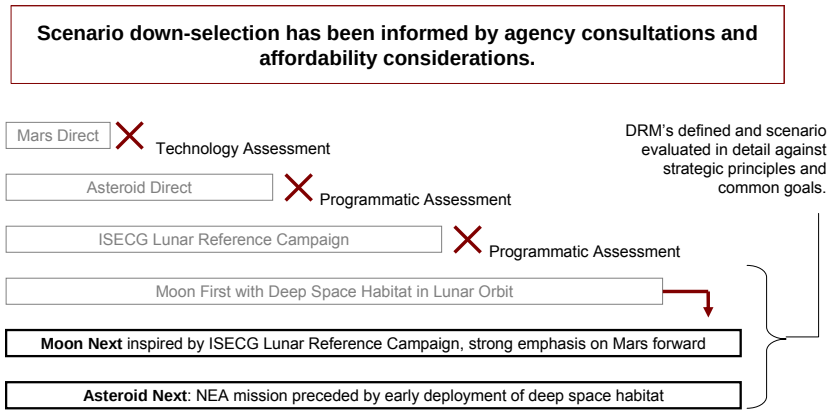

Figure 3: Deselected Mission Scenarios

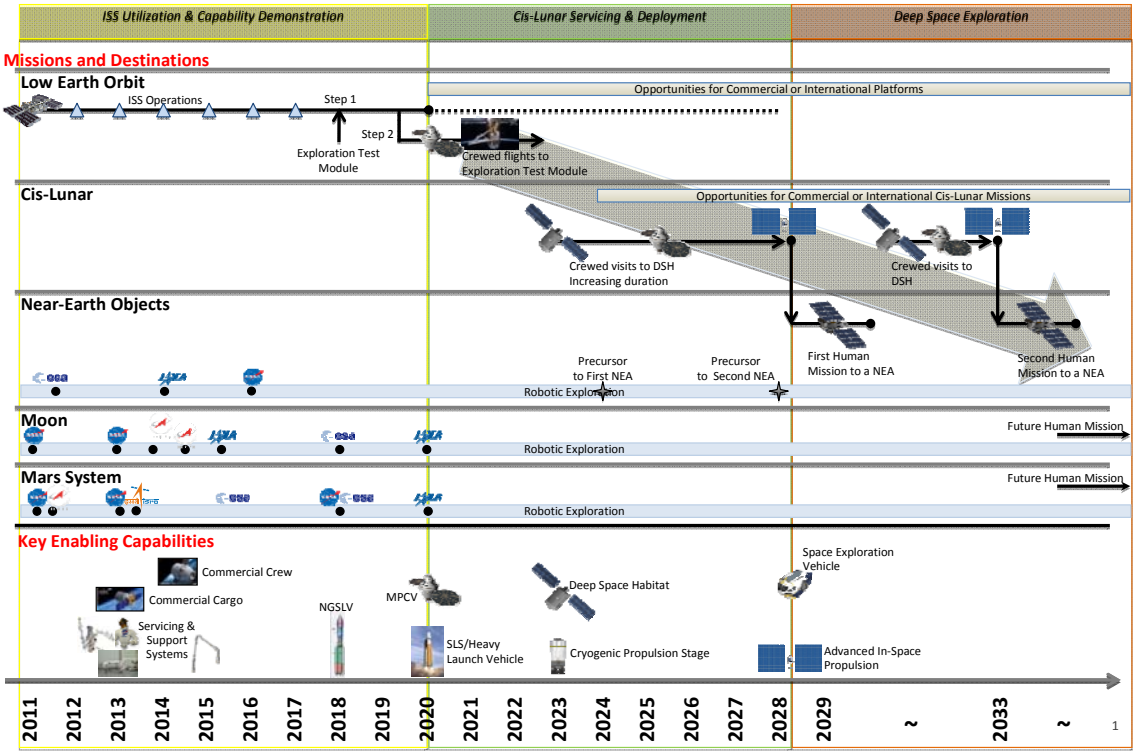

Figure 4: "Asteroid Next" Scenario

This "Moon Next" scenario pursues human exploration of the Moon as the next destination. The Moon is seen as an ideal location to prepare people for learning how to live and work on other planetary surfaces. It also holds a wealth of information about the formation of the solar system, and its proximity and potential resources make it an important destination in expanding human presence.

This scenario develops the capabilities necessary to explore and begin to understand how to live self-sufficiently on a planetary surface. Also demonstrated are certain capabilities to support Mars mission landings, such as precision landing and hazard avoidance. Initial flights of the cargo lander not only demonstrate its reliability but deliver human-scale robotic systems that will conduct science and prepare for the human missions to follow. The period between the initial delivery of human-scale robotics and human missions will allow target technologies to be demonstrated and human/robotic operational techniques to be developed. When humans arrive, they will perform scientific investigations of the polar region, travelling enough terrain to master the technologies and techniques needed for Martian exploration. They will also aid the robotic assessment of availability and extractability of lunar volatiles.

After the lunar missions, exploration of near-Earth asteroids would follow. These missions require additional capabilities, yet are an important step in preparation of future missions to the Mars. In-space systems with increased ability to support longer missions at increased distances from Earth would be necessary to reaching Mars orbit and surface.

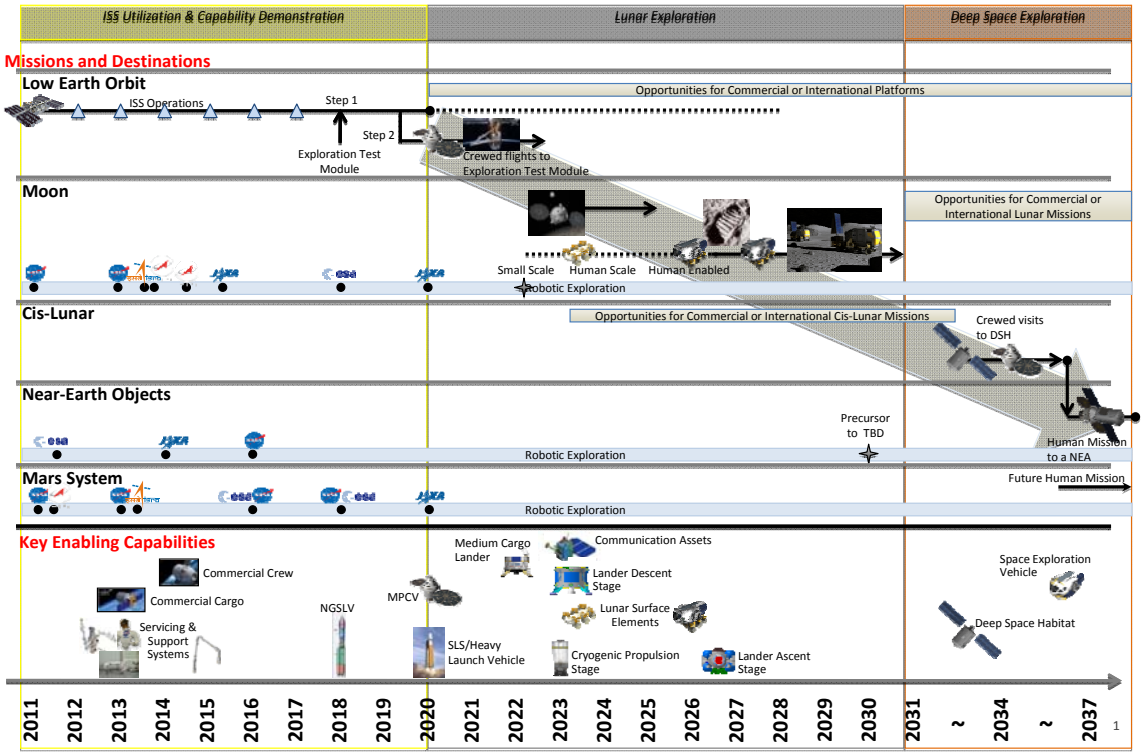

Figure 5: "Moon Next" Scenario

None of the mission scenarios defined can be realised without the development of strong and robust international partnerships, which makes accepting multiple partners on the critical path strategically important as it increase the chances to successfully implement these missions. Working together on the long-range strategy, space agencies have therefore realised the importance for taking concrete steps to define and manage the factors affecting interdependency at the architecture, mission, infrastructure, systems and operations level, in order to enable a successful implementation of this strategy.

V. NEAR-TERM OPPORTUNITIES FOR COORDINATION AND COOPERATION

Agencies participating to the development of the GER consider the work on the long range mission scenarios useful in guiding and coordinating near-term investment priorities, thereby enhancing near- and medium-term opportunities for cooperation.

Participating agencies invest currently in five categories of exploration preparatory activities:

- Use of ISS for preparation of exploration missions beyond LEO;
- Implementation of robotic precursor missions to the Moon, asteroids and Mars;
- Development of advanced technologies enabling future mission scenarios;
- Definition and development of systems and infrastructures forming part of a future international exploration architecture;
- Implementation of analogue activities to validate mission requirements, systems and technologies.

These areas offer concrete opportunities for near-term and medium-term coordination and cooperation. The long-range strategy and its optional mission scenarios provide a common reference for informing requirements for preparatory activities, thereby aligning and these activities towards the realisation of common future mission scenarios and de facto coordinating the ongoing activities of the agencies.

The Global Exploration Roadmap provides furthermore a mapping of existing plans of ISECG participating agencies which helps each agency to identify potential partners for near-term activities. Processes have been put in place within ISECG for further building on the developed long-range strategy and deriving information essential for the coordination of preparatory activities in these five areas.

VI. FORWARD WORK

A significant effort has been dedicated in 2010-2011 to the development of the overall framework for the Global Exploration Roadmap. Version 1 of the GER has been published mid September and can be downloaded from the ISECG website (see www.globalspaceexploration.org).

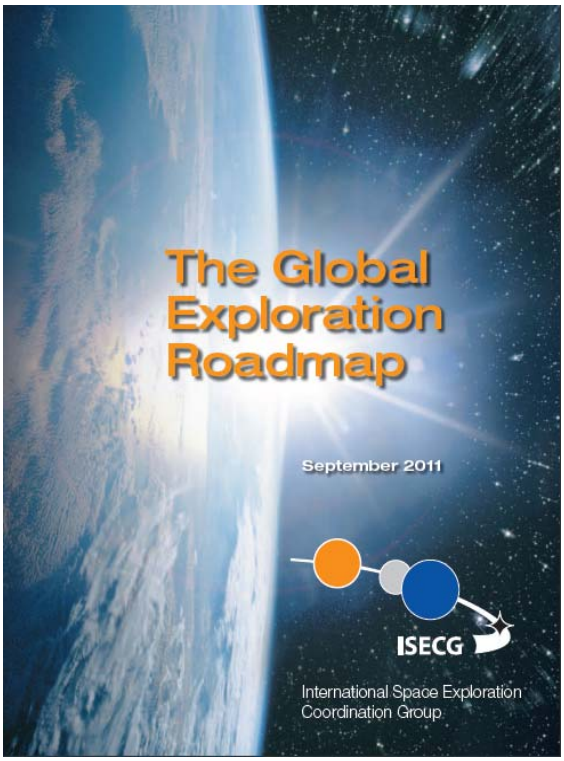

Figure 6: Cover of the Global Exploration Roadmap

For fully exploiting the potential of the roadmap as a tool for informing the setting-up of partnerships and aligning agencies exploration policies, plans and programmes, ISECG participating agencies have decided to update the GER within one year and develop the 2nd version by August 2012. Forward work will in particular focus on

- Advancing the assessment of near-term opportunities for coordination in particular in the domains of robotic missions, use of ISS for exploration preparation and development of enabling technology.
- Engaging stakeholder communities and reflecting in the next version of the GER collected input on innovative approaches for GER implementation. ISECG participating agencies will engage stakeholder communities individually and collectively. The Global Exploration Conference, organized jointly by IAF, AIAA and ISECG and planned for May 2012, will be a major

milestone of the coordinated stakeholder engagement process.

- Further defining near-term design reference missions for better understanding the transition from ISS to the first human mission to Moon surface or asteroid mission.

- Further assessing, articulating and substantiating the benefits of space exploration and the implementation of the GER in particular.

VII. CONCLUSIONS

Agencies participating to the development of the GER have demonstrated their strong commitment to coordinate near-term investments in preparatory space exploration activities. The long-range strategy defined in the GER and the associated mission scenarios provide a common framework which can help to inform the formulation of objectives for robotic precursor mission, investment strategies in enabling technologies, the definition of future system and infrastructures for exploration and the requirements for analogue activities. With the development of the GER a process has been put in place which may ultimately aid agencies in aligning their exploration policies and plans, which is a prerequisite for sustained human exploration missions beyond LEO.

Figure 7 summarises at a high-level the key content of the GER, including information on agency plans related to early robotic missions and illustrating the long-range strategy leading to human exploration of Mars through a step-wise approach.

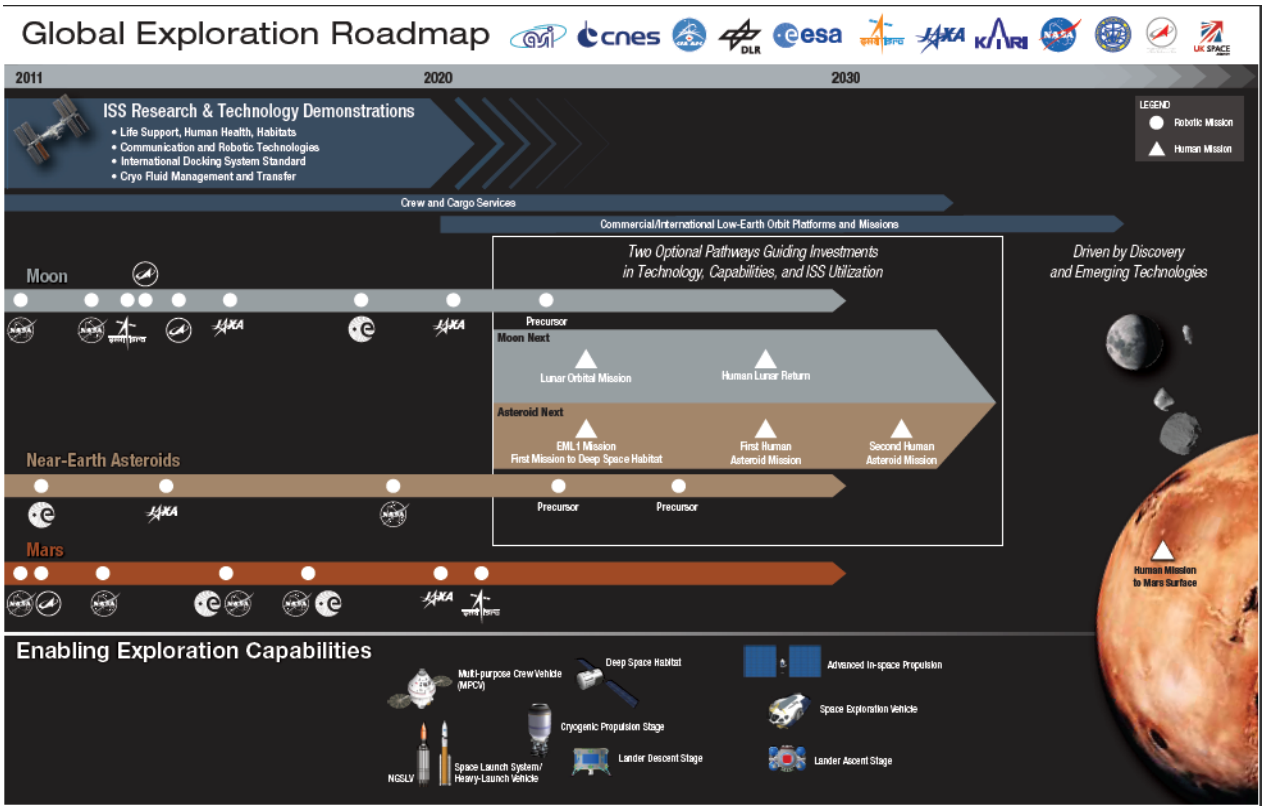

Figure 7: High-level Illustration of GER

VIII. REFERENCES

Ref. 1: International Astronautics Congress (2010), Laurini, K; Hufenbach, B.; Kawaguchi, J.; Piedboeuf, J.C.; Schade, B.; Lorenzoni, A.; Curtis, J.; Hae-Dong, K.; " An International Strategy for Human Exploration of the Moon: The International Space Exploration Coordination Group (ISECG) Reference Architecture for Human Lunar Exploration" IAC-10.A5.2.9, Prague, September 2010

Ref. 2: International Astronautics Congress (2011), Laurini, K,; Karadbajak, G., Satoh N.; Hufenbach, B.; "International Space Station (ISS) Lessons Learned and their Influence on Preparations for Human Exploration Beyond Low Earth Orbit", IAC-11.B3.2.1, Cape town, October 2011

Ref. 3: International Astronautics Congress (2011),Common Goals Suzuki, N; Matsumoto, K; Hufenbach, B.; Piedboeuf, J. C.; Carey,W.; Cirillo,W.; "ISECG Space Exploration Goals, Objectives and Benefits", IAC-11.A5.4.2, Cape Town, October 2011

Ref. 4: International Astronautics Congress (2011), Culbert, C; Mongrard, O; Martin, E.; Satoh, N.'Goodlif, K.; Troutman, P.; "ISECG Mission Scenarios and Their Role in Informing Next Steps for Human Exploration Beyond LEO", IAC-11-D3.1.2, Cape Town, October 2011