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THE 2nd ITERATION 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[1] and released in May 2007. This 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.

ISECG has published in September 2011 the first iteration of the Global Exploration Roadmap (GER) [Ref 1]. ISECG has also taken on a commitment to maintain and update this roadmap at regular intervals for reflecting evolving policy and plans for space exploration. Consequently, in August 2013, the second iteration of the GER has been published. This second iteration reports on the status of work by agencies to develop a space exploration roadmap and describes major progress achieved in preparing for future human exploration missions beyond LEO. In particular, the second iteration of the GER reflects the following activities

- Further defining near-term human mission scenarios beyond LEO and understanding how these near-term missions prepare for future human missions to Moon, deep space and ultimately Mars.

[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.

- Refining the important role the ISS plays in preparing future exploration missions by acting as a test-bed for critical technologies and new operations techniques as well as by providing a unique platform for advancing research on human health and performance risks associated with future human exploration missions.
- Assessing the synergies between robotic missions to the exploration destinations and future human missions: Significant work has been devoted to defining and prioritising strategic knowledge gaps which, if closed through robotic missions, reduce the risks and enhance the return of future human mission scenarios.
- Reviewing plans for technology development and identifying opportunities for cooperation and/or areas which are possibly under-funded today in view of envisaged near-term mission scenario.

ISECG participating agencies have presented and discussed the first iteration of the GER with representatives of the global stakeholder community at numerous national and international events. The outcomes of these discussions have been thoroughly reviewed by agencies and within ISECG. Various stakeholder recommendations have been taken into account when drafting the second iteration of the GER.

The GER is non-binding, but expected to serve as important input to individual agency decision making, enabling agencies to assess their near-term investment priorities in view of their future role in and contribution to a long-term global exploration endeavor. For more information on ISECG please consult the ISECG website at www.globalspaceexploration.org or contact the ISECG Secretariat at: isecg@esa.int.

INTRODUCTION

The initial release of the Global Exploration Roadmap (GER) in September 2011 [Ref. 1] by the International Space Exploration Coordination Group (ISECG) marked an important milestone as it demonstrated the commitment of agencies participating to ISECG to work collectively on advancing the planning for future cooperative exploration missions. The updated GER, released in August 2013, reflects the feedback received and the progress made on agencies' policy and plans as participating agencies continue to share their work with the broader community.

As a non-binding, agency coordination forum, ISECG provides an effective forum for sharing views on topics considered important and timely. Information shared within ISECG and products generated by the international team are used by individual agencies to make decisions regarding their plans and activities.

The first release of the GER has been widely noted within the global stakeholder community. More than 75,000 copies have been downloaded from the ISECG and agency websites. The document has been translated from English into Japanese and French. The ISECG road-mapping exercise has also been acknowledged at political level at the first meeting of the International Space Exploration Forum held in Lucca, Italy, on the 10th of November, 2011.

Agencies have leveraged the strong interest in the GER by inviting the stakeholder community to provide feedback and suggest innovative ideas and concepts for meeting future exploration challenges, thereby strengthening the agencies planning effort [Ref. 2]. The opportunity provided by ISECG to inform consultations with stakeholders is valued by participating agencies. Stakeholders, such as national leaders, realize that developing durable international partnerships is necessary and will require political support and consensus. The GER is poised to play a role in building future consensus at political level.

Since 2011, space agencies have continued to advance their exploration plans, made progress in implementing preparatory activities and engaged in the inter-agency coordination process enabled by ISECG, including for maintaining and updating the GER. In August 2013 the second iteration of the GER has been released [Ref. 3]. This new release builds strongly on the foundations established by the initial release, but also includes some significant changes. Key changes have been introduced in three areas:

1. Mission Scenario: The initial roadmap identified two potential pathways toward the driving goal of human exploration of Mars: “Asteroid Next” and “Moon Next” [Ref. 4 and Ref. 5]. Each pathway was expanded through conceptual mission scenarios, which served as references to inform preparatory activities. Building on this work, the 2013 roadmap includes a single reference mission scenario that reflects the importance of a stepwise evolution of critical capabilities, which are necessary for executing increasingly complex missions to multiple destinations, leading to the human exploration of Mars. In this way, the new mission scenario is an international roadmap to Mars and acknowledges that multiple agencies will play their role to advance critical capabilities that extend human presence beyond LEO and eventually enable sustainable Mars exploration.

2. Preparatory Activities: Further details on preparatory activities are included which have been categorized into five activity areas in the first iteration: ISS utilisation, robotic missions, advanced technologies, next generation capabilities, and analogues. The second iteration provides an update on agency progress and accomplishments in these areas, but also includes an expanded chapter on the importance of using ISS for exploration preparation and a new section on “human health and performance risk mitigation”. More detail on the ISECG technology assessment is provided in a separate paper (Ref. 7).

3. Human-robotic Coordination: The first iteration of the GER included the observation that “Steps should be taken by space agencies to explore the natural synergies between the objectives of robotic planetary science programs and those of the human-robotic exploration strategy. Coordinating future mission of mutual benefit should leverage common interest and create new opportunities for both communities”. Driven by this observation, significant efforts have been devoted to assessing how robotic missions provide opportunities for delivering knowledge, which is strategic for human mission planners. And beyond this, innovative mission concepts leveraging on the unique and complementary capabilities of robots and human in space for advancing exploration goals have been identified and assessed.(Ref 6)

This paper focuses on highlighting the changes introduced in the second iteration of the GER . It also assesses how observations of the first iteration have led to these changes and introduces the motivations for including some new observations.

SINGLE REFERENCE MISSION SCENARIO

Key Features of the ISECG Mission Scenario

The ISECG conceptual mission scenario depicted in Figure 1 depicts missions in the next 20 years which significantly advance exploration objectives on the path to Mars. It reflects an integrated approach to human and robotic exploration.

It articulates the near-term initiatives in implementing the common strategy, namely: 1) fully utilizing the ISS, 2) continuing efforts to expand on synergies between human and robotic missions, and 3) discovery-driven missions in the lunar vicinity that evolve capabilities and techniques needed for Mars, while enabling discoveries on the Moon and near-Earth asteroids. The scenario reflects a coordinated international effort to advance common goals and objectives while enabling interested agencies to pursue their priorities and prepare for critical contributions to human Mars missions.

The mission scenario chart shows on-going and planned human and robotic activities which are critical for preparing future exploration missions, such as the utilisation of ISS and robotic missions to the envisaged exploration destinations (Asteroids, Moon and Mars). It introduces new mission concepts, which provide new opportunities for advancing the realisation of common exploration goals by enhancing coordination between human and robotic capabilities, such as human-assisted sample return and tele-presence. And finally, it introduces three themes for near-term human mission beyond LEO on the path to human Mars missions including (1) exploration of a Near-Earth Asteroid, (2) extended duration crew mission in lunar vicinity and (3) human lunar surface missions. The multi-destination transportation capabilities under development and required to implement these mission themes are identified at the bottom of the chart. The missions are achievable if multiple agencies contribute capabilities which build on their expertise, enabling common and individual agency goals and objectives to be met.

The chart illustrates opportunities for transitioning from exploration to sustained utilisation, in particular in Low Earth Orbit, but at a later stage also in the lunar vicinity (a.k.a. cis-lunar space). Sustained utilisation is also enabled by private sector initiatives which strongly benefit from institutional programmes leading the way and successfully demonstrating technologies and capabilities required for sustained operations at current and future exploration destinations.

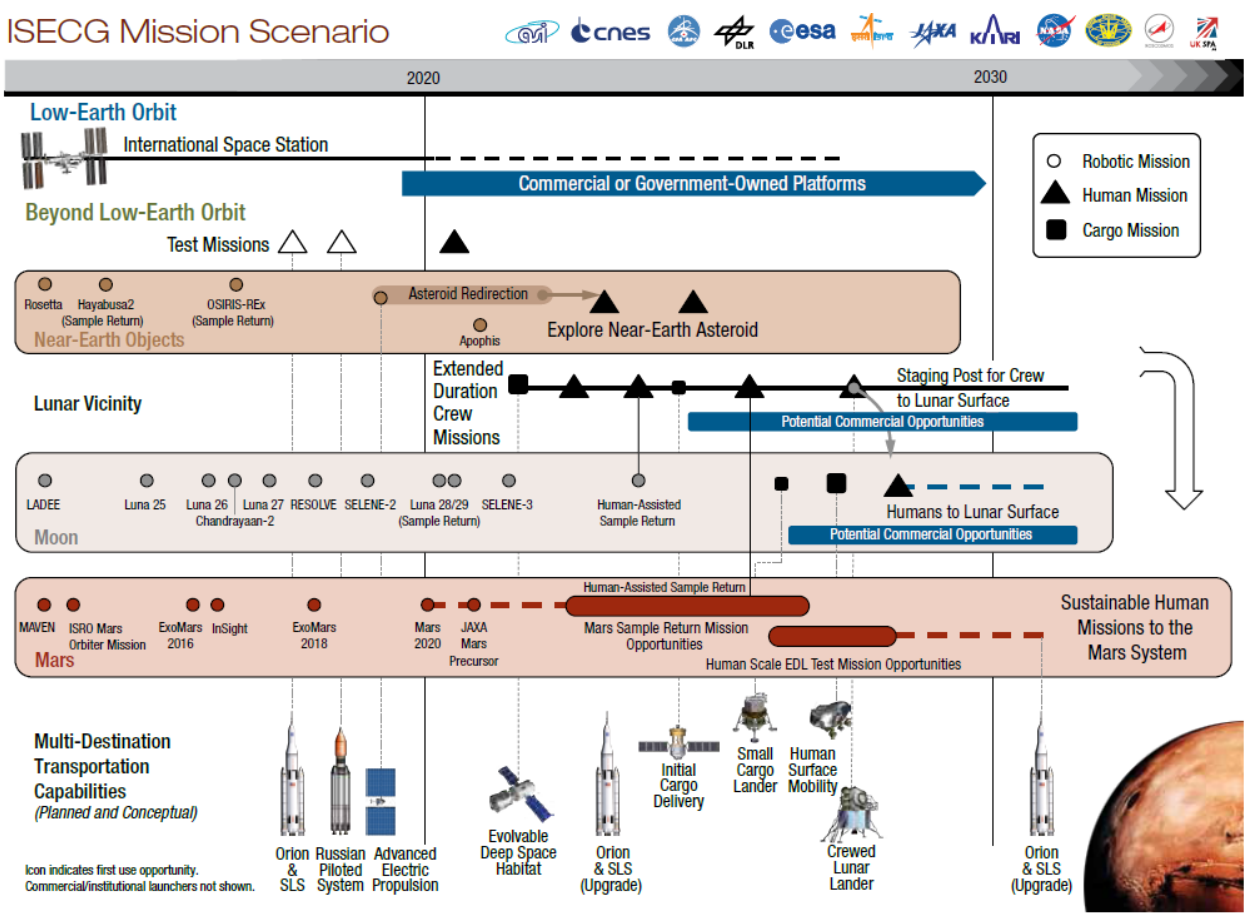

Figure 1 – ISECG GER Reference Mission Scenario

Approach for Converging on a Single Scenario

The definition of a single reference mission scenario has been enabled by acknowledging that

- Enabling the implementation of human missions to Mars within a global partnership is the commonly shared long-term objectives for all agencies participating in ISECG;

- A human missions to Mars can best be realized in a step-wise approach, which enables to gradually reduce mission risks and allows all partners to develop and demonstrate capabilities they envisage to contribute to future international human Mars missions;

- Near-term robotic and human missions on the pathways to Mars, implemented in cooperation or by individual agencies, provide significant opportunities to prepare for the implementation of future human Mars missions while responding to national policies and mission specific goals and objectives;

Following this approach, the work of ISECG has focused on assessing the relevance of planned missions in preparing for future human Mars missions. In addition, near-term human mission scenarios (time-period 2020 to 2030) beyond LEO have been conceptually defined, which would enable significant progress towards human Mars mission, while allowing for advancing common exploration goals and objectives. Figure 2 shows the Mars mission risk reduction table which has been used as key tool for performing this assessment.

The Mars mission risk reduction table identifies key areas where solutions are needed to reduce the risk of human missions to an acceptable level. They have been derived from Mars mission architecture studies done by participating agencies and external groups in the past. The table reflects an assessment of opportunities to demonstrate the maturity of a technology, capability or operations to enable a human mission to the Martian surface and the respective risk reduction. The level of maturity was divided into three broad categories:

- Full utilization in relevant environment: same level of maturity required for a Mars surface mission.
- Sufficient risk reduction in relevant environment: not identical to requirement for a Mars surface mission, but ample in reducing risk for the Mars surface mission.
- Initial feasibility validation/partial validation: capability, technology or operational approach may be mature, but not in a relevant environment or partial demonstration of a capability, technology or operation.

Missions in the lunar vicinity provide both the environment and key elements to significantly reduce most Mars mission risks. For example, a series of extended-duration crew missions would enable both transportation and habitation risks to be reduced. A crewed mission to an asteroid increases confidence in crew transportation and spacewalk capabilities. Lunar surface missions address habitation, mobility and other capabilities, which are unique to operations on planetary surfaces. Following the conclusion of the lunar surface campaign, sustainable missions into deep space and Mars would be possible. If an orbital or fly-by mission to Mars or its moons were desired, that mission could effectively retire all but the key atmospheric and surface risks. And while crewmembers are vital for many of the Mars risks, an un-crewed medium-to-large scale robotic mission to the Mars surface would be sufficient for the residual atmospheric and surface risks.

🟢 Full utilization in relevant environment ● Sufficient risk reduction in relevant environment ⊙ Initial feasibility validation/partial validation	Earth	ISS/Low-Earth Orbit	Lunar Vicinity (Earth-Moon Lagrange Point (EML), Moon Orbit)	Moon Surface	Mars Vicinity	Mars Surface (Robotic Mission)
Beyond Low-Earth Orbit Crew Transportation			●	●	🟢	
Heavy Lift Launch			⊙	●	🟢	
Reduced Supply Chain		⊙	●	●	🟢	
Autonomous Crew Operations	⊙	⊙	●	●	🟢	
Deep Space Staging Operations			🟢		🟢	
Mars Ascent	⊙			⊙		⊙
Space Radiation Protection/Shielding		⊙	●	●	🟢	
Life Support & Habitation Systems		●	●	●	🟢	
Entry, Descent, & Landing Systems	⊙			⊙		●
Surface Power and Energy Management	⊙			🟢		🟢
Surface Mobility	⊙			●		●
Human Robotic Integration	⊙	●	🟢	🟢	🟢	🟢
Mars In-Situ Resource Utilization	⊙			⊙		●
Long Duration Human Health	⊙	●	●	●	●	
Deep Space Operation Techniques	⊙	⊙	●		🟢	

Note: This table assumes critical capabilities will be provided by multiple agencies.

Figure 2 – Human Mars Mission Risk Reduction Table

Mission Themes

The GER describes at a high-level the three mission themes for near-term human missions beyond LEO:

(1) Exploration of a Near-Earth Asteroid – robotically deflecting an asteroid to enable its exploration in the lunar vicinity to demonstrate advanced electric propulsion, crew transportation and operation capabilities. This mission theme responds to a NASA initiative and includes opportunities for partnership.

(2) Extended Duration Crew Missions – long-duration missions in the lunar vicinity for advancing deep space exploration capabilities and creating innovative opportunities for exploration of the Moon through a human-robotic partnership. This mission theme represents an achievable near-term step and has been defined with the goal to directly advance capabilities for future exploration missions targeting the Moon and deep space. This mission definition has been advanced collectively by representatives of ISECG agencies.

(3) Humans to the Lunar Surface – missions to the lunar surface providing opportunities to address priority lunar exploration objectives benefiting from human presence on the surface and advancing habitation, mobility and other planetary exploration capabilities. This mission theme addresses one of the exploration destinations. Many agencies consider human missions to the lunar surface as an essential step in preparation for human Mars missions. Lunar surface mission scenarios have been studied by ISECG agencies, individually and collectively, for several years.

Figure 3 shows how the realization of these mission themes can be achieved through a gradual evolution of transportation capabilities, starting from those developed for ISS operations. The figure shows also synergies between the different mission themes, e.g., the implementation of human lunar surface missions could be support by the evolve deep space habitat deployed for enabling extending duration crew missions in lunar vicinity and repurposed to function as international staging post. Human lunar surface mission architectures supported by such an international staging post have some inherent advantages such as overall increase of mission robustness, easier integration of international transportation capabilities as well as opportunities for implementation of innovative missions concepts (e.g., re-usable lander).

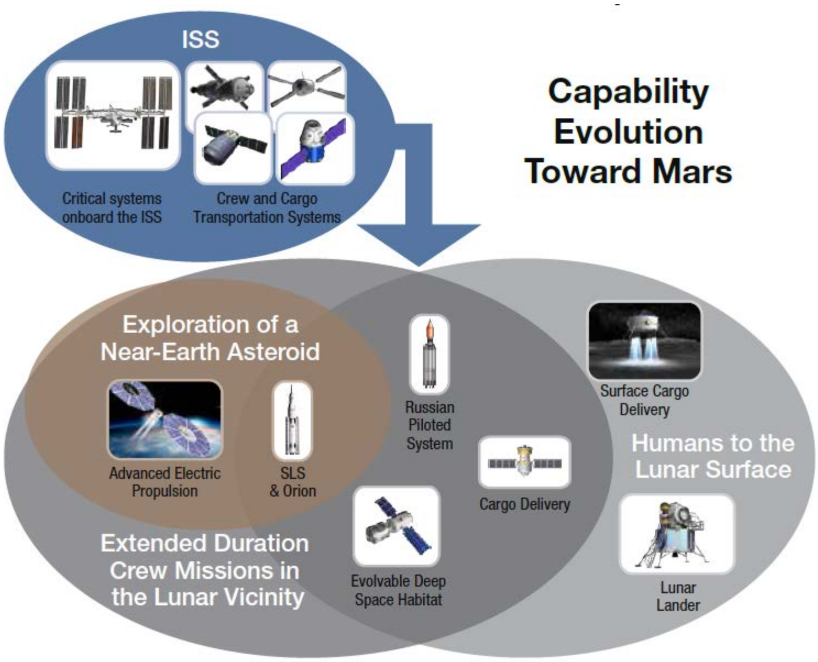

Figure 3 – Evolution of Transportation Capabilities

USE OF ISS FOR EXPLORATION

Significant work has been undertaken by the ISS partnership to further define the role of the ISS for preparing exploration and coordinate the implementation of related activities, recognising that the ISS serves global research interests in many other fields unrelated to exploration.

Four focus areas for using ISS in preparation of exploration have been identified:

- Exploration Technology Demonstrations: On-orbit demonstration or validation of advanced and promising technology that enables or improves exploration mission readiness.
- Maturing Critical Systems: Driving evolution in capabilities supporting the ISS today, such as increased reliability, reduced mass and reduced power consumption.
- Optimizing Human Health and Performance: Research to understand and reduce risks to human health and performance.
- Operations Simulations: Furthering the understanding of the operations challenges associated with exploration missions.

The ISS partners have started to share detailed information on their respective plans for using the ISS in preparation of exploration. This enables stronger coordination of and cooperation on envisaged activities, thereby optimising the use of limited ISS resources.

A good example is the plan of the ISS partners to extend the stay of two crewmembers beyond the current six-month expeditions to 12 months in 2015. This one-year mission will provide the opportunity to look for relevant threshold effects in health and performance and to validate physical countermeasures applied to maintain bones, muscles, and overall fitness, and use modern analysis techniques to identify any new areas of concern. Only four cosmonauts spent more than one year in space so far, namely on board the Russian MIR space station. The longest mission, lasting 438 days, was conducted by Valery Polyakov from 1994–95. Since that time, significant advances in habitability systems and physiological response have been made. Countermeasures against the debilitating effects of microgravity on the human body have advanced considerably, with effective strategies for counteracting bone and muscle losses being employed.

ROBOTIC AND HUMAN MISSION COORDINATION

Efforts have been made to further identify concrete opportunities for coordination of human and robotic missions. Work within the ISECG focused on two aspects:

1. The analysis of the so called Strategic Knowledge Gaps (SKG's) which identifies specific knowledge human mission planners need about exploration destinations for increasing the safety, efficiency and effectiveness of future human missions. Robotic missions provide opportunities to enhance the specific knowledge about exploration destination required by human mission planners.

2. The review of innovative mission concepts building on complementary capabilities of human and robots in space for advancing exploration goals.

Regarding point 1, a detailed list of SKGs has been defined and then prioritized on the basis of crew/mission risks, relevance to the ISECG mission scenario, and applicability to more than one destination. The list identifies specific measurements which would contribute to filling the gaps. It also gives insights into how recent and planned robotic missions and ground-based activities will contribute information related to the gaps and where additional measurements will be useful to fill the gaps. Figure 4 shows an excerpt of the list. The full list can be downloaded at the ISECG website.

The SKG work is intended to inform the definition of objectives for future robotic missions and ground-based activities and it is hoped that availability of this information will contribute to further strengthen coordination between the communities planning robotic and human missions and thereby increase the value of space exploration investments to our global stakeholder community.

Regarding point 2, two mission concepts have received attention as well: tele-presence and human-assisted sample return.

The concept of human-assisted sample return is based on the assumption that human missions in the lunar vicinity will take place for advancing broader exploration goals and taking the first steps toward enabling human missions to the Moon, deep space and Mars. The presence of crew can enhance the value of sample return missions in various ways:

- Increased science return with a larger and more diverse set of samples;
- Reduced complexity of robotic mission, transferring sample handling responsibilities to the crew and Earth re-entry capabilities to the crew system;
- Better opportunities for public engagement due to astronaut involvement;
- Broader opportunities for international cooperation.

This concept provides opportunities to revisit the approach for sample return missions targeting asteroids, Moon and Mars. Future work should focus on identifying and analysing with the science/-exploration community unique mission objectives which could be enabled with such an approach as well as defining conceptually Design Reference Missions.

Tele-presence can be defined as tele-operation of a robotic asset on a planetary surface by a person who is relatively close to the planetary surface, perhaps orbiting in a spacecraft or positioned at a suitable Lagrange point. Tele-presence is a capability which could significantly enhance the ability of humans and robots to explore together, where the specific exploration tasks would benefit from this capability and the reduced time delay. These tasks could be characterized by high-speed mobility, short mission durations, focused or dexterous tasks with short-time decision-making, reduced autonomy or redundancy on the surface asset as well as contingency modes/failure analysis through crew interaction. The concept of tele-presence is currently advanced within the ISS partnerships. Various technology demonstration on-board ISS are planned leading ultimately to simulating operations of robots on planetary surfaces from space.

Destination	Knowledge Domain	Strategic Knowledge Gap: Description and Priority	Target Measurement	Mission or Ground Based Activity Addressing the SKG	Additional Measurements: R = Robotic Mission SR = Sample Return G = Ground Based Activities
Moon	Resource Potential	**Lunar Cold Trap Volatiles:** Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps.	In-situ measurement of volatile characteristics and distribution within permanently shadowed lunar craters or other sites identified using remote sensing data (e.g., from LRO)	Roscosmos Luna-25/ Luna-27/Luna-28 and 29 NASA-CSA RESOLVE	R, SR
Near-Earth Objects (NEO)	Human Mission Target	**NEO Composition/Physical Characteristics:** Rotation State	Light curve and radar observations from different ground (Earth based telescopes) and space based assets.	Examples include: Goldstone Observatory (US); Bisei Spaceguard Center (Japan), Observatoire du Pic du Midi (France)	G, R
Mars	Atmosphere	**Atmospheric Modeling:** The atmospheric models for Mars have not been well validated due to a lack of sufficient observational data, and thus confidence in them (for use in mission planning, including entry, descent and landing) is limited.	Density, pressure, temperature, and wind data, trajectory performance information	NASA Viking, Pathfinder, MGS, MERs, Phoenix, MRO, MSL ESA Mars Express ESA-Roscosmos ExoMars 2016, 2018	R

Figure 4 – Excerpt of Strategic Knowledge Gaps Table

HUMAN HEALTH AND PERFORMANCE RISK MITIGATION

The 2013 release of the GER includes a new section which identifies the main risks for crew health and performance associated with long-duration and planetary missions. The current status of understanding the risks and developing adequate mitigation strategies is shown in Figure 5. Inclusion of this paragraph acknowledges the significant research conducted on ground or on-board the ISS in this area. Finding solutions for these risks will require scientific and technological breakthroughs in clinical and industrial applications, many of which will have relevance to health issues on Earth as well. The ISS partners are developing an international approach for addressing these risks, using all available assets and leveraging on existing working groups, such as the International Space Life Sciences Working Group. Agencies are also increasing efforts to share operational medical and biomedical science data, to standardize techniques and methodologies as well as to share hardware and crew subjects on-board the ISS.

Red (Unacceptable): A risk with one or more of its attributes (i.e., consequence, likelihood, uncertainty) currently exceeding established human health and performance standards for that mission scenario.
Yellow (Acceptable): A risk with all of its attributes (i.e., consequence, likelihood, uncertainty) well understood and characterized, such that they meet existing standards but are not fully controlled, resulting in "acceptance" of a higher risk posture. Lowering the risk posture is important, but the risk is not expected to preclude a mission.
Green (Controlled): A risk with all of its attributes (i.e., consequence, likelihood, uncertainty) well understood and characterized, with an accepted mitigation strategy in place to control the risk. It is still helpful to pursue optimized mitigation opportunities such as compact and reliable exercise devices.

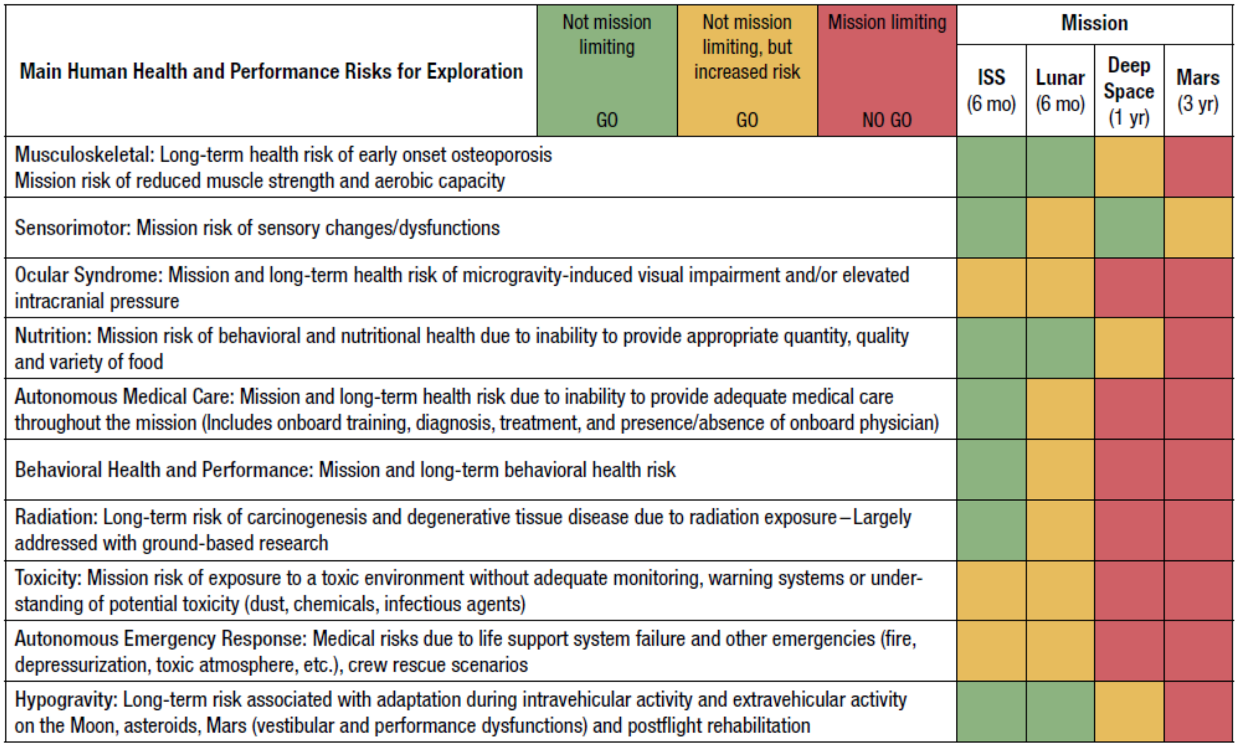

Figure 5 – Main Human Health and Performance Risks for Exploration

<u>GER OBSERVATIONS</u>

The first iteration of the GER included some key observation which served as guidelines for advancing coordinated exploration planning. Similar, the second iteration includes some new observations and these observations provide some early insight on areas where progress can be expected over the next few years. The table below list these new observations and highlights their significance.

Observation	Significance
In order to build a sustainable human space exploration endeavour that lasts decades, agency leaders should maintain a focus on delivering value to the public.	Demonstrates commitment of space agencies to deliver societal benefits. The importance of this must guide agencies formulating and implementing specific programs and missions. Forward work will focus on further improving reporting on benefits.
With the goal of enabling several partners to contribute critical capabilities to future human missions, agencies note that near-term collaborative missions on the ISS, in the lunar vicinity, on the lunar surface, and robotic missions may be used to simulate and better inform preparations for future international missions to Mars.	Recognizes that human missions to Mars will only be possible if multiple agencies contribute reliable capabilities. Demonstrates commitment of space agencies to advance readiness for implementing human Mars missions by considering evolution strategies for transportation capabilities as well as opportunities for enhancing the human mission preparation value of robotic Mars missions and near-term human missions beyond LEO. Forward work will focus on defining near-term Design Reference Missions, but also on increasing international coordination on the analysis of

	approaches and mission concepts for human Mars exploration
New mission concepts, such as human-assisted sample return and tele-presence should be further explored, increasing understanding of the important role of humans in space for achieving common goals.	Demonstrates commitment of space agencies to further coordinate human and robotic missions for enlarging the return of future missions to the global exploration community. Forward work will focus on advancing the definition of related Design Reference Missions and the development of associated technologies.
Robotic science missions provide an important technique for obtaining the data needed to prepare for human exploration beyond low-Earth orbit. It is generally accepted by both the science and exploration communities that measurements and data sets obtained from robotic missions support both the advancement of science and preparation for human exploration.	Demonstrates commitment of space agencies to consider Strategic Knowledge Gaps when defining future robotic missions. Forward work will focus on prioritization of the gaps to further inform robotic mission planners.
Agencies should increase efforts to pursue a coordinated approach to mitigation of the human health and performance risks of extended duration exploration missions, putting priority on efforts to reduce countermeasure mass and volume and drive risks to an acceptable level	Demonstrates commitment of space agencies to coordinate research on human health and performance risks. Forward work will focus on addressing priority risks though ground and ISS-based research.

CONCLUSIONS

The 2013 release of the GER demonstrates the commitment of space agencies participating in ISECG to continue coordinating their planning for future space exploration missions. The latest release includes some important changes as it marks the introduction of a single reference mission scenario and reports significant progress and recent accomplishments in coordinating preparatory activities for space exploration. Road-mapping is an important planning tool for exploration and as such international coordination on the road-mapping process will continue within ISECG. The release of the first iteration of the GER has served as an effective tool for engaging the broader stakeholder community into a dialogue on how to best address future exploration challenges. The feedback received from stakeholders allowed to strengthen the strategic planning for future global space exploration. Space agencies plan to follow this path and use future conferences as well as dedicated events for fostering a sustained dialogue with the global exploration community.

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