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CONSIDERATIONS ON THE LONG-RANGE STRATEGY OF THE ISECG GLOBAL EXPLORATION ROADMAP

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The 1st iteration of the Global Exploration Roadmap (GER) was released in September, 2011 by the International Space Exploration Coordination Group (ISECG). The GER provides a framework for inter-agency dialogue in three areas: (1) common goals for space exploration, (2) the long-range strategy for exploration and (3) identification of near-term opportunities for coordination and cooperation in areas such as robotic missions, utilisation of ISS as a test-bed for exploration and analogue campaigns. Dialogue on the long-range strategy is informed through the development of notional mission scenarios which are technically feasible and programmatically implementable. Two mission scenarios were seen as responding to the long-range strategy: the "Asteroid Next and the "Moon Next" mission scenarios. Both take into account the short-medium term plans of the participating agencies. The long-range mission scenarios respond to the common goals and are driven by a common set of agency needs and drivers. In particular 6 common strategic principles have been adopted for the 1st iteration of the GER:

1. "Capability driven framework", implying the use and evolution of current capabilities as well as a gradual, step-wise development of new capabilities;
2. "Exploration value", underlining the need to generate public benefits and meet exploration objectives and to achieve this early and in a sustained manner;
3. "International partnerships", calling for enabling early and sustained contribution opportunities for all partners and at different levels;
4. "Robustness", stressing the need to provide for resilience to technical challenges and programmatic changes e.g. through dissimilar redundancy;
5. "Affordability", acknowledging current and future budget constraints;
6. "Human-robot partnership", emphasising the complementary role of humans and robots for meeting common exploration goals and specific mission objectives.

These principles will be further developed and applied for the 2nd iteration of the GER which is planned to be released in spring 2013.

This paper will provide a detailed analysis of the implications of these strategic principles on the future implementation of international exploration missions and review related aspects from a European perspective. It will furthermore analyse commonality aspects between ESA exploration plans and priority destinations for exploration (Low Earth Orbit, Moon and Mars) and the ISECG GER.

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

Space exploration is undergoing a major transition. All major space agencies are defining their space exploration strategy and plans and are investing in the development of critical capabilities and technologies for future space exploration missions.

ISECG has been set-up as a forum for agencies to share information on their policies and plans and develop collectively products informing the strategic and programme planning process. In particular the work on the ISECG Reference Architecture for Lunar Exploration and on the Global Exploration Roadmap (GER) has allowed agencies to identify common goals and objectives as well as general strategic views. The long-range strategy and associated mission scenarios described in the 1st iteration of the ISECG GER respond to common goals and strategic principles of all agencies which participated to the development of the GER.

This paper provides further insights on ESA's Strategic Guidelines for space exploration and ESA specific views of the ISECG GER strategic principles.

II. ISECG GER STRATEGIC PRINCIPLES

Agencies which participated to the development of the 1st version of the ISECG GER ([RD1]) recognised the need to develop a common set of key strategic principles, in addition to common goals, for guiding the development of long-range mission scenarios for space exploration. The development of the strategic principles has been informed by the ISS lessons learnt ([RD2]) and the participating agencies consider them as important.. The two optional long-range mission scenarios developed within the 1st iteration of the GER, the "Moon Next" and "Asteroid Next" mission scenarios, represent technically feasible and programmatically implementable pathways within the boundaries of these agreed principles.

Figure 1 shows the overall methodology and framework used for the development of the long-range mission scenarios. Common goals and strategic principles drive the development of optional long-range mission scenarios, which then provide the framework for the development of Design Reference Missions (DRM's), assessment of technology requirements and identification of the strategic knowledge gaps.

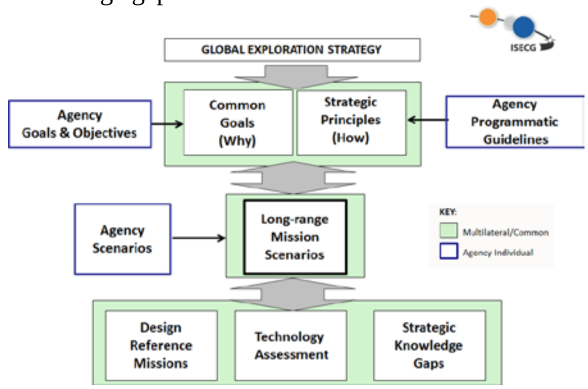

Fig.1: Methodology and Framework for Analysis of ISECG GER Long-range Mission Scenarios.

Participating agencies reached consensus on the following 6 strategic principles :

1. "Capability driven framework", implying the use and evolution of current capabilities as well as a gradual, step-wise development of new capabilities;
2. "Exploration value", underlining the need to generate public benefits and meet exploration objectives and to achieve this early and in a sustained manner;
3. "International partnerships", calling for enabling early and sustained contribution opportunities for all partners and at different levels;
4. "Robustness", stressing the need to provide for resilience to technical challenges and programmatic changes e.g. through dissimilar redundancy;
5. "Affordability", acknowledging current and future budget constraints;
6. "Human-robot partnership", emphasising the complementary role of humans and robots for meeting common exploration goals and specific mission objectives.

Following the release of the 1st iteration and based on stakeholders' feedback received, participating agencies discussed further these principles with the goal to better explain and communicate the strategic relevance of these principles in the 2nd iteration of the GER planned for spring 2013. Initial discussions within ISECG and with the broader stakeholder community focused in particular on the 1st strategic principles which consequently has been renamed from "capability driven framework" to "capability evolution". This change reflects the need to better balance the evolution of existing capabilities with the step-wise development of new technologies and capabilities. Finding an appropriate balance is critical for enabling the implementation of regular, attractive and increasingly complex mission scenarios in a phased approach, thereby reducing risks and enhancing affordability.

Further explanation will also be provided on the other 5 strategic principles in the 2nd iteration of the GER.

III. ESA Strategic Guidelines for Space Exploration

Significant efforts have been undertaken in recent years in Europe and in particular within ESA to assess future perspectives for human spaceflight and exploration and for defining Europe's strategic orientation. Four consecutive Space Council Meetings[1] held in the time period September 2008 to December 2011 have addressed space exploration:

- The 5th Space Council recognised space exploration is a political and global endeavour and identified necessity for political dialogue;
- The 6th Space Council reaffirmed the need to assess possibilities offered by European Union policies to embed space exploration in a wider political perspective;
- The 7th Space Council identified major elements of a European space exploration involvement: enabling technologies, space transportation, space infrastructures and robotic missions;
- The 8th Space Council recognised potential of robotic and human exploration to produce societal, intellectual and economic progress and benefits for citizens.

The ESA Council at its meeting in June 2010 acknowledged furthermore that "Space Exploration is a global and continuous process which includes several destinations which cannot be explored with the same technologies. It is both robotic and human. Europe must build on its strengths, propose the set-up of a global political forum and base its short-term actions on the exploitation of the ISS, the robotic exploration of Mars and the demonstration of new technologies." In November 2011, the European Space Agency, the European Commission and their Member States initiated the High-level Political Dialogue on space exploration in Lucca (Italy).

More recently, the ESA Director General's Agenda 2015 published in November 2011 proposed some specific and directly relevant actions:

- Promoting human spaceflight as a factor of peace and a symbol of global cooperation. Human spaceflight needs a new driver. The future of human spaceflight and exploration worldwide should thus be built according to a different paradigm, based on interdependency and partnership. The current ISS partnership needs to evolve to include other space powers willing to join and bring their own capabilities and culture. Utilisation of ISS could be opened to scientists from all over the world.

- Supporting exploration as a continuous process of humankind. Space exploration concerns several destinations, from low-Earth orbit to planetary systems, including Moon and Mars. All currently considered missions are cooperative missions, cooperation being within different formats: bilateral, trilateral and multilateral, and with different partners. ESA can bring, in addition to its daily experience of cooperation, technologies and systems which, in some cases, are unique worldwide.

- Maintain a Mars Sample Return Mission as driving long-term goal for robotic Mars exploration. Mars continues to tantalise scientists with indications of potential habitats favourable to life. The evidence for abundant surface water in the past, dramatically shown by the wonderful views offered by Mars Express, together with the possible evidence for the presence of methane in its atmosphere, have more than ever convinced scientists of the importance of pursuing its study, with the long-term objective of bringing back a sample of Martian soil to Earth.

- Develop common enabling technologies. Some targeted key technologies, that will place ESA in a unique position in future partnerships and capitalise on industrial capabilities, should be developed and

[1] The Space Council is a joint and concomitant meeting of the Council of the European Union and the Council of ESA at ministerial level.

associated to missions. Four main domains were highlighted following several EU-ESA workshops organised in 2010 with key stakeholders: automation and robotics, novel energy production and storage (including nuclear), advanced propulsion, and life support systems. These technologies must represent breakthroughs in order to place ESA in a unique position in future partnerships be they for human spaceflight or exploration. They have also to capitalise on industrial capabilities, which have been developed in the recent past, and on on-going programmes.

- Promoting international cooperation. International cooperation must be based on mutual interest and, as a next step, on mutual dependence.

In line with the broader strategic objectives set by the Space Council and the ESA Director General's Agenda 2015, ESA has further developed some specific strategic guidelines for space exploration within the frame of the European strategy for space exploration called for by the Space Council addressing:

- Exploration Destinations;
- International Partnerships;
- Enabling Technologies;
- Synergies between exploration destinations.

IV. ESA View on Exploration Destinations

The space exploration destinations for the foreseeable future can be divided as follows:

1- LEO;
2- The Moon (Earth moon) and cis-lunar space;
3- The Mars system: the Red Planet and its moons;
4- Asteroids.

ESA proposal is to focus in the foreseeable future on the first three destinations considering criteria such as

- Accessibility,
- Ability to achieve human missions,
- Scientific interests and,
- The international context.

a) Accessibility

With the current capabilities, the foreseeable destinations are compatible with exploration programmes consisting of a series of robotic and/or human missions implemented incrementally, each mission building on the results achieved by the previous ones. LEO can be reached in less than one hour and the Moon in a few days. Due to celestial mechanics the Mars system can be reached at low energy approximately every 2.1 years in about 6-8 months. Considering that a space mission requires 5 to 8 years development time depending on its complexity, and that a few additional years are needed before for the mission definition and associated technology development, the three destinations are compatible with a dedicated exploration programme over a timescale of 1 to 2 decades. Concerning asteroids, a number of near Earth asteroids are accessible on a rather short time scale (2-3 years).

b) Ability to achieve human missions

The ISS is currently the sole destination of human space exploration. Considering technological readiness level and human health risks, cis-lunar space and the Moon are the destinations beyond LEO that could be reached by humans in the next two decades. Another reason for preferring Moon rather than Asteroids as next destination for human missions beyond LEO is the currently very limited number of known asteroids which are suitable targets for human missions, in particular within the next 10 to 15 years. The exploration of Mars with humans on its surface is generally considered by all partners as the long-term goal that could be achieved beyond 2040s following the gradual development of human spaceflight capabilities and their demonstration in LEO, on the Moon and possibly at intermediate deep space destinations. This would allow step-wise development of the needed capabilities, operations capacities and reduction of risks for human health and performance associated with a such demanding mission. A successful robotic exploration programme of the Red Planet consisting of multiple surface missions is also mandatory.

c) Scientific interests

Results obtained throughout the last decades in fundamental and applied research in LEO in a broad range of fields and the growing European stakeholder community exploiting LEO for scientific research demonstrate the high scientific value and interests of LEO. There is a wide scientific consensus that Mars exploration, with robotic missions in preparation of human missions, should be the driving goal for space exploration plans beyond LEO in the next decades. Exploring Mars and understanding its evolution will bring crucial elements for our understanding of the origin of life and of the Earth's evolution. The Moon, acting as an archive of the conditions during the early stages of Earth formation, can provide unique clues on Earth evolution which are not anymore available on Earth. The recent discovery of volatiles in the polar regions has further stimulated the interest in Moon exploration for scientific reasons (origin of these volatiles) and for the potential availability of resources to support human activities. Extended human surface operations on the Moon will also provide important scientific knowledge on human physiology, health and performance in conditions of low gravity and without the protection of the Van Allen belts.

It is worth noting that asteroids, outer planets and their moons do have a very high scientific interest and are being considered in the ESA Science Programme. JUICE (JUpiter ICy moons Explorer), to be flown in 2022 for the exploration of the Jupiter system and in particular of its icy satellite Ganymede, has been recently selected as a large class science mission. MarcoPolo R, an asteroid sample return mission, is a candidate for a medium class science mission, with a possible launch in 2024. Therefore, while there are well defined scientific and technological goals for robotic missions to asteroids, the interest in a programme intending for revisiting the same asteroid several times, or even for a programme to visit a large number of near Earth asteroids is limited.

d) International context

ESA's choice of destinations takes into account the international context. LEO is an important destination because of current ISS commitments and ISS utilisation activities delivering direct socio-economic benefits. The Moon is the preferred destination of several potential partners and could be the next destination for human missions beyond LEO. Concerning Mars, Europe is implementing the ExoMars Programme in collaboration with Russia (with some contributions from NASA). and is preparing to extend its Mars Programme. All major partners have declared interest in a Mars Sample Return mission as medium-term objective and consider human missions to Mars as the overarching long-term goal of exploration.

V. ESA View on International Partnerships

Long-term international collaboration is nowadays a basic element of almost any space exploration programme. Even when Europe could technically implement autonomously a mission, international cooperation should be possibly considered to increase programmatic sustainability. Such collaboration would also represent an opportunity for strengthening existing or building-up new strategic partnerships to prepare for the implementation of more complex missions such as sample return missions and human missions.

However, the evolution of international collaboration schemes must also consider the following elements:

1- Lessons learnt throughout the ISS Programme, as developed and reviewed by the ISS Multilateral Coordination Board (MCB) in 2009. In particular the ISS cooperation framework based on an Intergovernmental Agreement (IGA) has helped to stabilise and continue the ISS programme despite budgetary problems of participating agencies and serious mishaps.

2- Lessons learnt from recent ESA/NASA collaboration difficulties for ExoMars must be taken into account for limiting the impact of a partner withdrawal during the implementation phase.

3- International collaboration does not exclude having European-led initiatives. On the contrary, a solid partnership for ambitious missions such as MSR or human missions can only be achieved when each partner effectively provides an essential piece to the edifice, and vice-versa a partnership is bound to fail if one is in a passive mode, driven by the decisions and investments of the other partners. It is therefore absolutely essential that Europe defines its own objectives and priorities and develops its own capabilities through dedicated Europe-led missions for being able to play an effective and visible role in future exploration endeavours. This should naturally be done by taking into account on one hand the existing heritage and the previous investments, and on the other hand the current financial constraints.

4- International cooperation does not exclude competition. While affordability constraints and strategic considerations lead to international cooperation on large infrastructures, e.g. on transportation, competition on science instruments and exploration enabling technologies has to be maintained in order to guarantee best science and innovation.

VI. ESA View on Enabling Technologies

Space exploration activities have a proven record as providers of new opportunities for research and innovation, with the techniques, technologies, products and systems developed having many applications on Earth in various domains such as aeronautics, energy, medical and life sciences to name a few. The "European space exploration path" encompasses the development of a robust set of exploration technologies, well-coordinated among the different programmes of ESA and other European players to enable a range of operational capabilities for future exploration activities.

ESA has initiated and will maintain a road mapping exercise on exploration technologies, coordinating inputs from all concerned ESA Directorates and European industry. Following the roadmap indications, the required resources for the technology procurement will be coordinated and optimised among all the different programmes, taking into account also major users outside space exploration and significant spin-in from other sectors. For exploration to be efficient and provide maximum return, drastic technology advances will have to be achieved and cooperation with terrestrial sectors will also be essential. The technology roadmaps prepared should be used also as the basis for the planning of possible international collaborations for future missions.

The ESA road mapping-exercise will allow developing at an appropriate pace European capabilities leading to an efficient implementation of missions.

VII. ESA View on Synergies between Destinations

While the exploration of each of the three destinations on which ESA proposes to focus (LEO, Moon and Mars), is driven by specific objectives and interests, and implemented with a unique set of capabilities, synergies between the three destinations exist at programmatic level. As outlined above, space exploration within the next decades will be driven by the long-term goal of the exploration of Mars with humans *in situ*. Each of the three destinations will play a crucial role in enabling the realisation of this long-term goal. LEO, Moon (and cis-lunar space) are important destinations for maturing and demonstrating selected technologies and capabilities, understanding risks for human health and performance and demonstrating mitigation measures as well as testing new operation techniques in preparation of a human mission on Mars. Robotic missions to Mars, including the return of Martian samples to Earth, allow for demonstrating technologies and acquiring scientific knowledge specific to the Martian environment and therefore contribute directly to enabling future human exploration of Mars.

Achieving the long-term goal of human exploration of Mars requires an integrated plan which (a) foresees a gradual development, demonstration and maturation of the technologies and capabilities required, (b) reduces risks for human health and performance to an acceptable level, (c) acquires the knowledge about Mars required for implementing a safe and effective human mission scenario (i.e. filling the Strategic Knowledge Gaps) and (d) allows for establishing and maintaining the broad international partnership needed. The interagency work which led to the publication of the 1st iteration of the ISECG Global Exploration Roadmap provided some early insights in such an integrated planning process.

VIII. Alignment of ESA Strategic Guidelines and ISECG GER Strategic Principles

ESA fully recognises the strong merits of the principle of "capability evolution" and is currently defining different options for building new critical capabilities for future human spaceflight and exploration missions on the basis of the ATV heritage. ESA is in particular working together with NASA on the option for providing the Service Module for the Multi-Purpose Crew Vehicle (MPCV) for the demonstration missions (see [RD3]).

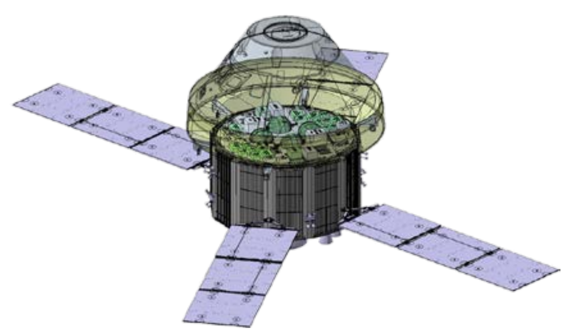

Figure 3: ESA Service Module Design for NASA MPCV.

The potential of space exploration to create public benefits has been recognised by the Space Council. This recognition clearly calls for implementing the global space exploration undertaking in such as manner as to optimise the public or socio-economic value provided. Therefore, further insights in the causal relationships between future space exploration activities and achieved socio-economic benefits is required for informing investment decisions.

Long-term international partnerships have been identified as an enabler of sustained space exploration activities. Further work is required on assessing and defining the appropriate governance and cooperation framework for future international undertakings. Such discussion need to take into account the general characteristics of space exploration (long-term, open ended process, targeting different destinations with different means), the boundaries and specific requirements of the programme intended to be implemented in partnership as well as the lessons learned from ISS and other past international partnerships.

Affordability constraints need to be better understood as affordability is not an absolute measure. Affordability depends largely on the attractiveness of a particular programme alternative and, in the case of ESA, the alignment of this programme with the strategic objectives and priorities of its Member States. International partnerships can help to counteract affordability constraints, but partnerships should not only be established for reducing costs to each partner or a single partner but primarily to reach common goals. Stable and sustained partnerships need to be structured such as not to reduce the long-term attractiveness of a particular undertaking for any partner.

ESA furthermore fully embraces the principle of human-robotic partnership. In this context it is worthwhile to note that ESA is not only assessing in detail how planned robotic missions, such as the ESA-Roscosmos ExoMars mission (see [RD4]) and the ESA Lunar lander mission (see **Error! Reference source not found.Error! Reference source not found.**), will support future human mission scenarios.

ESA is also looking into ways for increasing the return of human missions through robotic aids and an in-space capabilities for tele-operating automated assets on planetary surfaces. This latter aspect is addressed by the ESA METERON (Mission Concept Proposal for Preparation of Human-Robotic Exploration) project currently under preparation (see [RD5]).

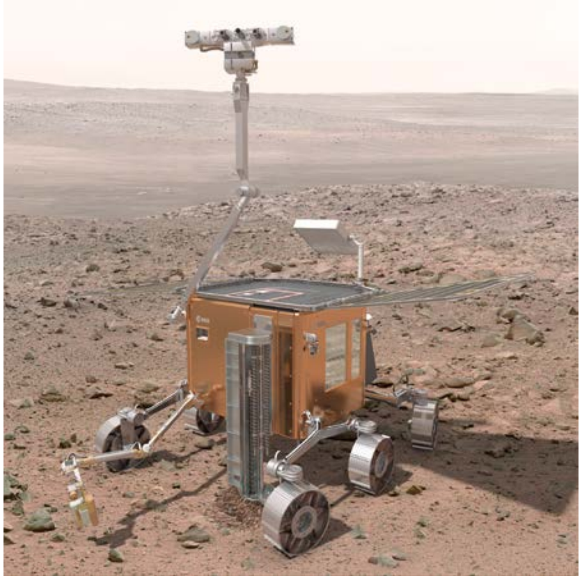

Figure 3: The ExoMars Rover

Figure 3: ESA Lunar Lander, currently in Phase B

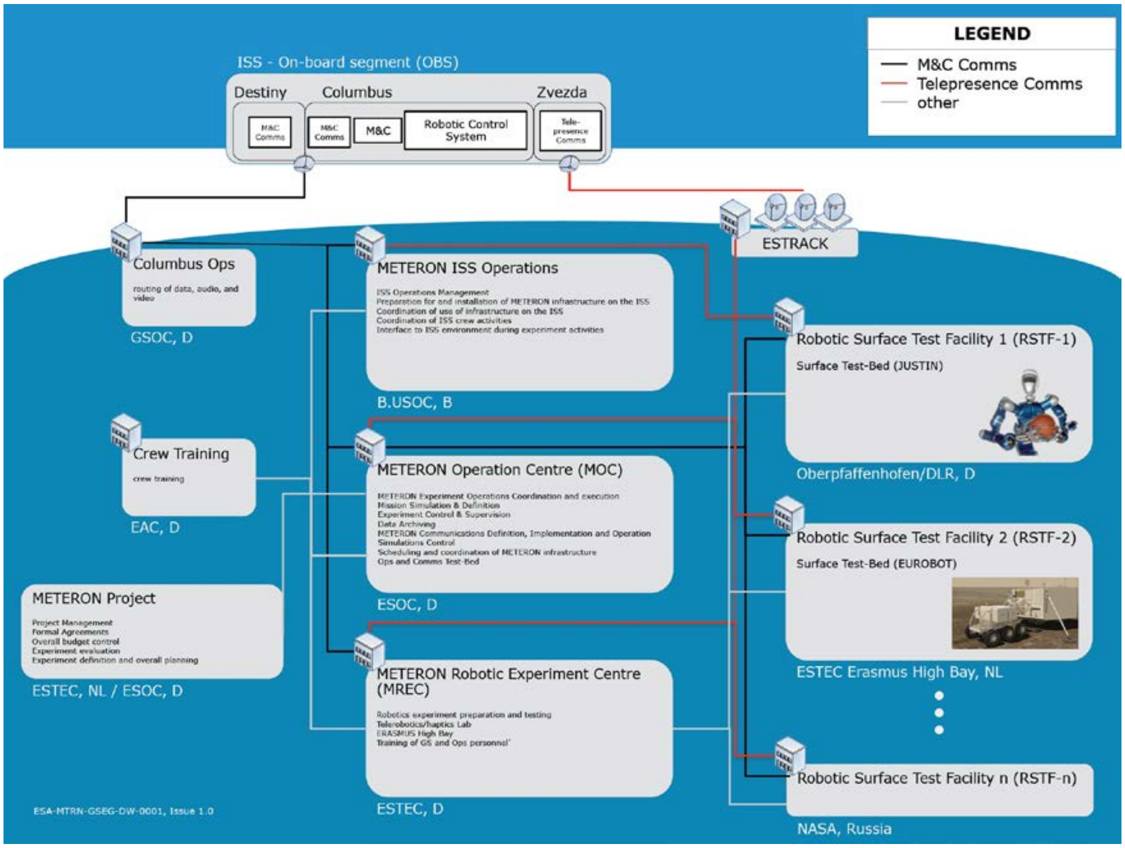

Figure 4: METERON Architecture

IX. Conclusions

The ISECG GER Strategic Principles and ESA Strategic Guidelines for Space Exploration show a high degree of alignment. This is due to the fact that ESA has been an active contributor to the development of the 1st iteration of the GER.

What may appears as a disconnect between the ESA strategic guidelines and the ISECG GER is the clear identification of Moon as the preferred next destination for human spaceflight beyond LEO, while the ISECG GER identifies two technically feasible and programmatically sustainable pathways: “Moon Next” and “Asteroid Next”. The ISECG GER reflects plans and policies of all agencies which have contributed to the development of its 1st iteration. The ESA strategic guidelines define ESA priorities. Obviously, the international space exploration undertaking will be successful if all Partners are enabled to contribute in line with their capabilities and if a pathway integrating the main priorities and interests of all participating agencies is developed. Further effort towards this goal is still needed. Work is currently underway within ISECG to better understand the two pathways and seek for commonalities. The 2nd iteration of the ISECG GER is therefore intended to represent a next steps towards aligning agency priorities.

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