EXPLOITING HUMAN-ROBOTIC PARTNERSHIP MISSIONS TO OBTAIN A PRISTINE SAMPLE FROM PREVIOUSLY INACCESSIBLE SITES ON THE MOON M. Landgraf[1], H. Ueno[2], O. A. Sprykin[3], [1]Markus.Landgraf@esa.int, European Space Agency, European Space Agency, ESA/ESTEC, Postbus 299, 2200 AG Noordwijk, The Netherlands, [2]Japan Aerospace Exploration Agency, JAXA Space Exploration Center, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa , JAPAN 252-5210, [3]Tsniimash, Central Scientific Research Institute for Machine Building, 4 Pionyerskaya Street, Kaliningrad, 141070 Moscow Region, Russia.

Introduction: In the frame of the strengthening global lunar exploration program the natural partnership of human and robotic components is looked at as an opportunity to implement exploration-driven scientific missions that were not deemed feasible before. In particular the challenging aspects of accessing, selecting, collecting, and preserving a delicate pristine sample of lunar material (e.g. intact polar ice deposites) benefits from the less constrained mission scenario of a human-robotic lunar partnership mission compared to a fully autonomous stand-alone lunar sample return mission [1]. Classical survey missions that are currently operating or planned to be implemented in the near future [2,3,4] will provide information about where to find such a sample, so now is the appropriate time to consider the next step. With the example of a human-assisted multi-mission lunar sample acquisition and preservation system we assess the enhanced science and exploration knowledge return at equal or lower cost compared to conventional systems that are based on non-robotic unmanned systems or robotic "autonomous" systems.

Currently there are multiple international space agencies investing in studies to define an end-to-end mission scenario of a human-robotic partnership architecture. The objective of those studies is to determine the performance and requirements of the mission scenario vis-à-vis the objective to obtain a pristine lunar volatile sample.

Mission Objectives and Scenario: The ESA-lead study focuesses objectives with a balanced weight on the technology and operations preparation for a future human lunar surface mission and the science objectives of obtaining lunar sample return. Besides the ambitious mission statement of obtaining an unaltered lunar ice sample a number exploration-related objectives exist, therefore, that address the need of the broader global exploration roadmap [5]. An initial set of top-level mission objectives has been identified:

- Provide access to samples from previously inaccessible sites on the lunar surface
- Preserve lunar surface samples in their pristine state
- Implement, demonstrate, and certify technology elements for human lunar landing
- Demonstrate an optimised human-robotic partnership and tele-operations achitecture with a high-agility surface element (rover)
- Consolidate a true multi-lateral partnership for the implementation of exploration missions

This preliminary set of mission objectives incproporates the three general goals in exploration: knowledge gain, technology development, and international cooperation.

In the first cycle of architecture design, a preliminary mission scenario has been developed that calls for exploiting the presence of a crew in cis-lunar space, most likely near the far-side libration point (EML_2) of the Earth-Moon system approximately 60,000km from the lunar surface. Alternative mission scenarios that are studied e.g. by Roscosmos consider a staging location in low lunar orbit (LLO). The ESA-studied architecture comprises a launch of a 10t-class landing vehicle into a lunar transfer orbit together (or at the same time) with a crew. While the crew transfers to the cis-lunar habitat, the landing vehicle carries the rover and an ascent vehicle to the lunar surface after a short stay in low lunar orbit. On the surface, the rover is deployed and then tele-operated by the ground as well as the crew from EML_2 to obtain samples. A protective sample container is transferred robotically from the rover to the ascent vehicle, which takes it to the cis-lunar habitat. The crew transfers the sample container to their Earth return vehicle, which guarantees a return in a benign thermal and mechanical environment. Once back on Earth the samples are added to a curation and analysis laboratory.

While the mission operational concept is still to be defined, the study shows already the most promising roles for the crew in the human-robotic architecture (in decending order of consolidation):

- Return of sample container in human-rated vehicle (benign thermal and mechanical environment), avoiding Genesis scenario [6]
- Telecontrol of the robotic surface mobility element during critical operations on the far side

- Refurbishment of robotic element in preparation for next mission cycle
- Sample reception, curation, and selection for return in the cis-lunar habitat
- Landing operations in challenging terrain

Key Technologies: One result of the on-going study activity within ESA is a list of key technologies that are required to fulfill the objective of retrieval of an intact solid volatile sample. These key technology elements are: tele-operated sampling process for increased human decision making while sampling, efficient surface mobility and improved global sample access through tele-operations, non-solar power systems for operations in permanently shadowed regions, cryo-cooler for sample thermal management, Earth return in crew capsule for benign thermal and mechanical environment during reentry, orbit choice for line-of-sight from operator console to mobility element on the surface for tele-operations.

Affordability: Another study objective was to measure the benefits of reusing the lunar ascent element of the space segment. The laws of staging and rocket propulsion do not allow to gain a significant savings in launch mass even for many reusability cycles if the components and fuel are delivered particularly for this mission. However, reusability strategies allow the exploitation of more flexible staging scenarios. An example for such an exploitation is the use of contingency fuel of arriving vehicles that is no longer needed after a successful inbound transfer. An interesting aspect is the utilization of the EML_2 habitat as fuel depot. Some preliminary requirements for such a fuel depot can already be established. Ultimately, the cost benefit of a reusabiliy scenario have to be determined taking into account an established cost model for the mission. At this stage we can only predict that the reuse of complex system hardware (data handling, AOCS, payload) and the refurbishment of less complex hardware as well as fuel will bring a cost beneft. Future studies are needed to test this prediction.

We predict further affordability and performance increase of a human-robotic partnership mission scenario to be achievable by exploiting the problem-solving capabilities of the human component to avoid overly complex non-robotic systems (e.g. fail-safe automated assembly and servicing) as well as the advanced robotic capabilities existing today to allow more elaborate staging scenarios. These claims will have to be confirmed by operational tests and performance analysis.

Next Steps: The mission objectives, architecture, and preliminary end-to-end system design are subject to further study in the frame of an international human-robotic partnership design reference mission. Two high-priority objectives of such a study are the definition of interfaces between the various elements (lunar ascent element and cis-lunar habitat, crew and lunar landing element, ….), as well as an end-to-end operational concept. An immediate preparatory activity of an international study is to determine the amount of convergence of the various architectures considered by various partners, as well as the aspects that are different. Once a common point of departure will be found, it it will be proposed to define an international design reference mission for human-robotic sample return. The goal of this study will be to enable all partners to identify the roles vis-à-vis their stakeholders in preparation of phase-A project proposals. If successful, the human-robotic lunar partnership mission could be the first truly international exploration mission that lies the foundation for the next steps in the global exploration program in terms of programmatics, science, technology, and operations.

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