

Definition of a Reusable Lunar Habitat to Extend Exploration Range

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The lunar ambitions of NASA's Artemis program outline multiple crewed missions to the Moon and later to Mars. A compact shelter able to sustain life for the typical duration of the missions, which could be deployed autonomously and reused either during the same mission or from one mission to the next, would greatly ease this purpose and expand the area of exploration. The aim of the Spaceship FR team at CNES (Centre National d'Etudes Spatiales - FRANCE) is to define this new habitat concept. This paper aims to presents the results of the concurrent design approach and the development logic for this habitat. Three different updates will step the development to achieve a shelter habitable by a crew. This logic makes it possible to meet different needs and to integrate more and more complex equipment. The first version of the shelter will be a charging station for a rover to power it and protect it during the lunar night. It will permit the feasibility of deployable pressurized structures, environmental and thermal control, dust mitigation and a new generation of batteries to be demonstrated. The second version will serve as a warehouse and possibly a greenhouse. It will allow the feasibility of radiation and micrometeoroid protection, airlock, equipment transfer and first level of ECLSS and autonomous supervision to be demonstrated. The third version will be a shelter consistent with the safety requirements with human in the loop integration. These different types of shelters can offer complements to the different Artemis missions from 2028 as the shelter will be brought to the Moon by EL3, the European Large Logistic lander, when this item is available for space flight. They will also allow to demonstrate the proper functioning of innovative technological bricks integrated before their transfer to a future Mars mission.

Nomenclature

<i>CNES</i>	=	Centre National d'Etude Spatiale (French Space Agency)
<i>E3P</i>	=	European Exploration Preparation Research
<i>ECLSS</i>	=	Environmental Control and Life Support System
<i>EL3</i>	=	European Large Logistics Lander
<i>ESA</i>	=	European Space Agency
<i>EVA</i>	=	Extra Vehicular Activity
<i>ExPeRT</i>	=	Exploration Preparation, Research and Technology
<i>GER</i>	=	Global Exploration Roadmap

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ISECG = International Space Exploration Coordination Group
ISRU = In Situ Resource Utilization
LISE = Lunar Integrated Shelter for Exploration
NASA = National Aeronautics and Space Administration
RFCS = Regenerative Fuel Cell System
Spaceship FR = Spaceship France project

I. Introduction

THE goal of NASA's Artemis campaign¹ is to send multiple crewed missions to the Moon beginning in 2028, to build a permanent base. After having tested the various technologies necessary to live on the surface of the Moon, the objective is to transfer them to Mars. To realize this strategy, given the constraints of surface exploration operations, CNES is proposing a new habitat concept. Three different versions of this habitat can cover the needs of agencies' goals and will sustain increasingly complex technologies.

The first version of the shelter will be a rover charging station to charge it and protect it during the lunar night. It will demonstrate the feasibility of deployable pressurized structures, environmental and thermal control, dust mitigation and a new generation of batteries. The second version will serve as a warehouse and possibly a greenhouse. It will allow for a feasibility demonstration of radiation and micrometeoroid protection, airlock readiness, equipment transfer, and the first level of ECLSS and autonomous supervision. The third version will be a shelter consistent with safety requirements and human in the loop integration.

II. Context

France signed the Artemis Accords on June 7, 2022^{2,3}. France is also member of ESA and participates in the Terra Novae 2030+ program (previously E3P)⁴. In this program, the ExPeRT (Exploration Preparation, Research and Technology) team integrates, coordinates, and manages the development of studies and technologies for future Exploration missions to low Earth orbit, Moon and Mars destinations. In the ExPeRT program, the Spaceships teams network works on innovative technological bricks for future Moon and Mars bases⁵. As part of this network, CNES created the Spaceship France⁶. The French team works on seven technical areas: Habitat, Robotics, Life Support Systems, Human Health & Performance, Energy, In-Situ Resource Utilization, and Digital Technologies⁷. The objective is to offer a part of the landed assets as well as innovative systems to CNES space partners from 2025 for the return of humans to the Moon.

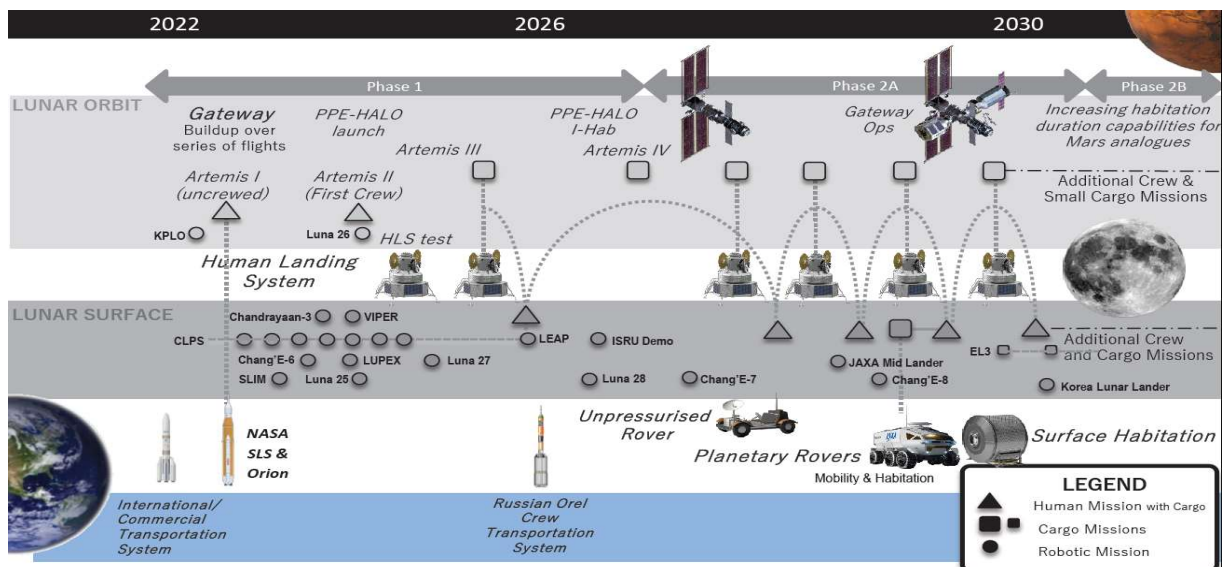


Figure 1. ISECG Lunar Surface Exploration in 2022. Credit: ISECG⁸

CNES follows NASA's strategy to offer technologies and landed systems for missions on the Moon to allow for testing before transferring them to Mars.

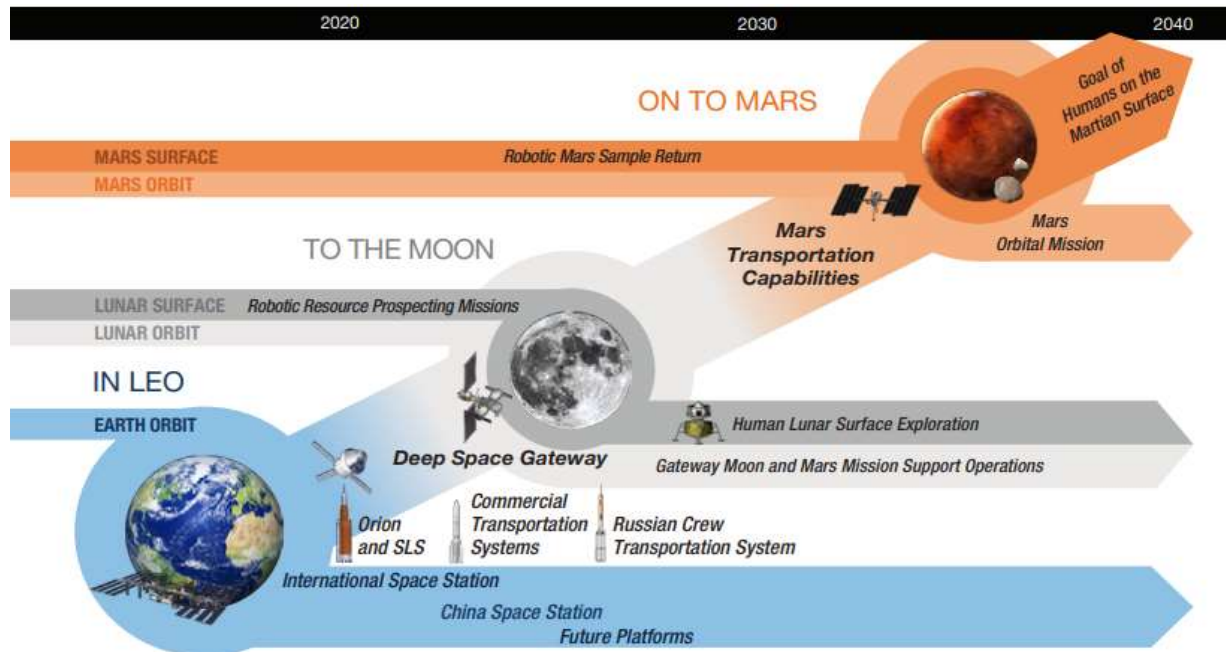


Figure 2. The GER 2018. Credit: ISECG⁹

III. Extending the range of Lunar Exploration

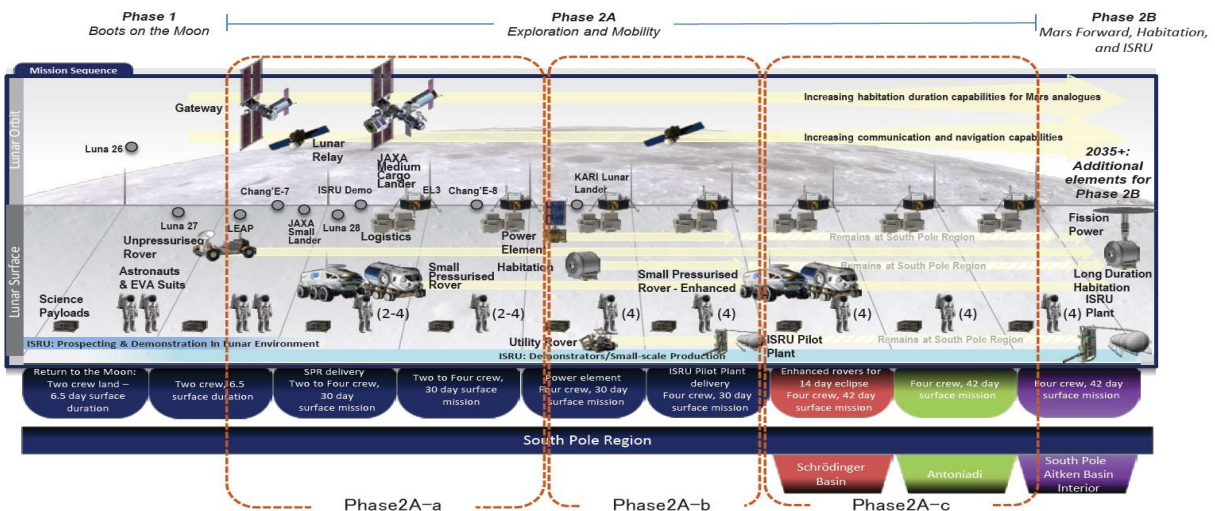


Figure 3. Mission Phases Summary. Credit: ISECG⁸

According to the Artemis program's strategy, the first operations on the surface of the Moon, named "Boots on the Moon", will take place in 2025. The surface mission will last 6.5 days. Then, Phases 2A and 2B will expand lunar exploration and build the necessary infrastructure for a permanent base. These will run from 2028 to 2034. Then, Phase 2B will provide sustained lunar opportunities from 2035 onward (see Figure 3).

Phases 2A-a and 2A-b's objectives are concentrated around the Shackleton^{10,11} crater. Each surface mission will last 30 days. Phase 2A-c will extend the exploration to the Schrödinger and the Antoniadi basins. Schrödinger basin is at a distance of 400 km from Shackleton crater¹² whereas Antoniadi basin is located at more than 400 km from Shackleton crater¹³.

EVA on the surface of the Moon is limited by the following recommendations issued from previous missions or actual on-going developments:

- Walking range is maximum two kilometers from a safe habitat (based on Apollo 14 experience),
- Unpressurized rover range is ten kilometers from a safe habitat (based on Apollo 17 experience),
- Single pressurized rover range is 12 kilometers from a safe habitat,
- Dual pressurized rover range is around 100 kilometers from a safe habitat.

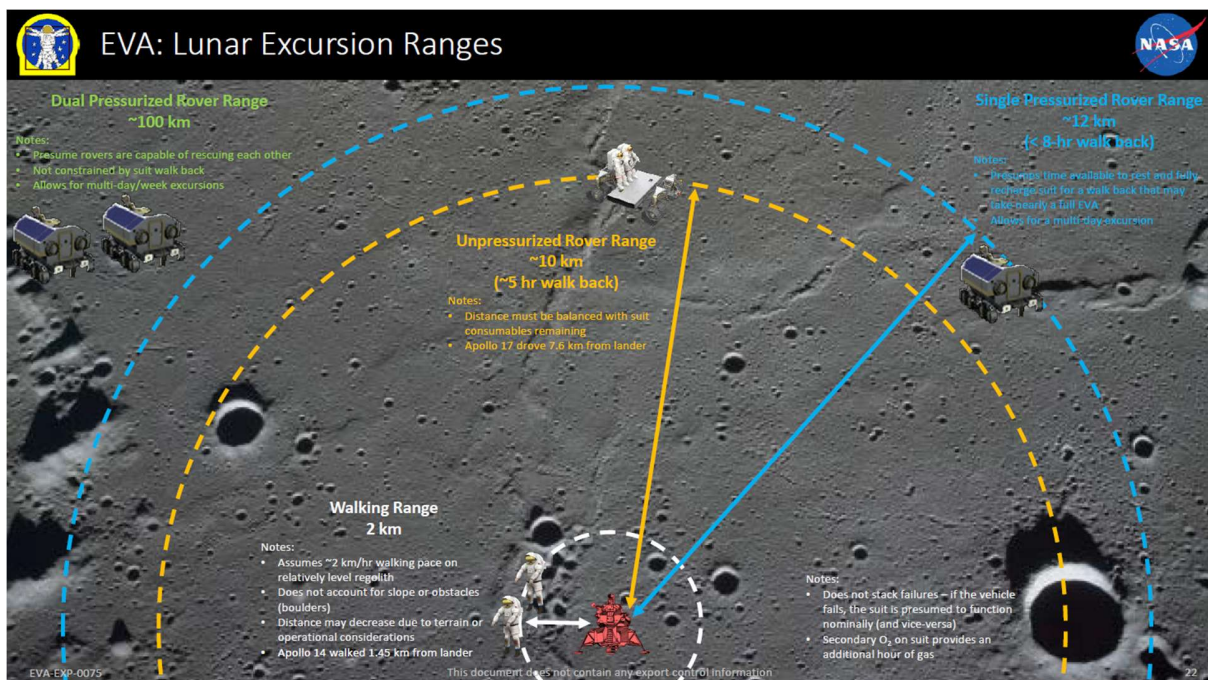


Figure 4. Exploration Ranges.
Credit: NASA¹⁴

Shackleton crater's diameter is 21 kilometers, its perimeter is around 66 kilometers. Exploring all around the crater may require two pressurized rovers.

To extend the range of exploration and reach the furthest points as foreseen in the Artemis program as soon as possible, CNES has proposed to provide a small module called LISE : Luna Integrated Shelter for Exploration. This system will be compacted when brought to the surface of the Moon by an EL3 lander. It will then be deployed and started automatically and will remain on standby awaiting an astronaut crew, ready to be utilized according to a planned schedule or in emergency conditions.

The goal is to use this shelter in the same way as a mountain refuge is used to reach the summit of the highest mountains, e.g. Everest or as an outpost to reach the Poles on Earth. It can provide a safe haven for astronauts from Phase 2A-a. Four LISE modules placed around Shackleton crater would allow to explore all its perimeter with an unpressurized rover. This shelter can provide a habitat near ISRU infrastructures for maintenance or resource-gathering operations.

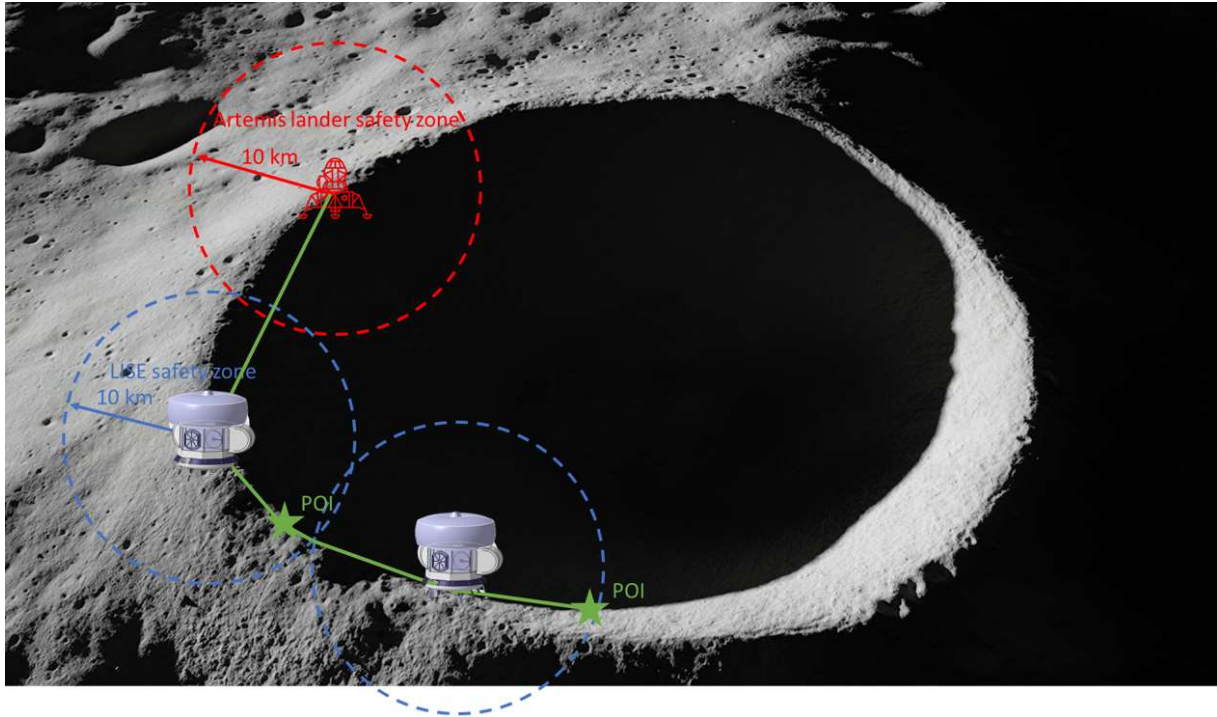


Figure 5. Example of potential extension of the Exploration Ranges *This figure shows an example of a possible strategy to use LISE as an inhabited shelter for surface exploration. The crew can reach LISE A and check and prepare it, then return to the lander. After this first phase, the crew may go to LISE A to explore the first point of interest to prepare a way to the bottom of the crater. Then, the crew may reach LISE B to explore the second point of interest to install solar panels on an elevated point.*

Having LISE as an intermediate step between EVAs expands the radius of exploration and makes the extension of the scope of action and the duration of the mission feasible. It will provide possible rest and increase the availability of resources to the crew.

This type of shelter will also be used to store equipment and resources to avoid their transport by unpressurized and pressurized rovers.

LISE can be used as an electric charging station for rovers that will be used to assist astronauts on surface operations or for preparing infrastructures before their arrival.

After feasibility demonstrations and some operations around Shkelton crater, LISE will be used during the surface operations of phases 2A-c and 2B.

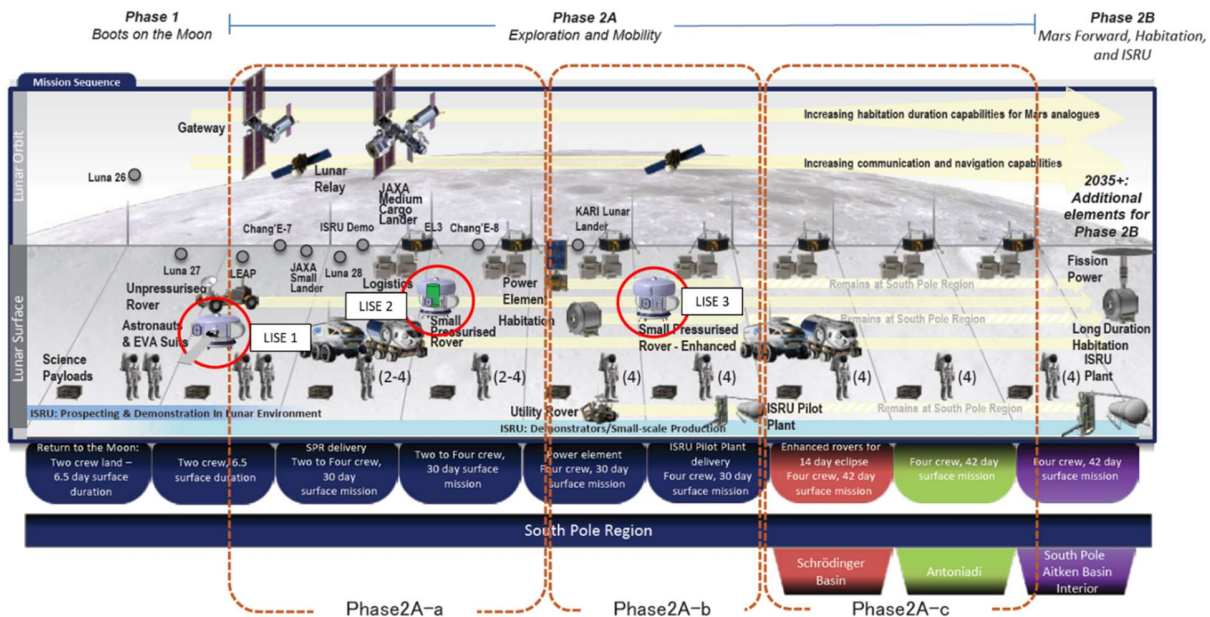


Figure 6. LISE in the Mission Phases

IV. Lunar Integrated Shelter for Exploration (LISE)

Spaceship FR's project strategy is to develop three different versions of LISE. This makes it possible to cover the different needs and to increase the technological level and complexity step by step. The first two versions will demonstrate the feasibility of the different technologies brought into play before the third step which will complete the manned version.

LISE version 1 is a pressurized shelter for small and medium size rovers. It will provide both internal and external electrical charging stations and protection during the lunar night.

It is composed of a deployable pressurized volume with a hatch. This will demonstrate the feasibility of the deployable structures, the ramp and walls, and the management of the structure tightness.

A simple thermal and environmental control will manage the atmosphere. It will validate the management of the future airlock and its behavior when faced with lunar dust. The energy will be generated by a RFCS (Regenerative Fuel Cell System) of 100 W and by low temperature batteries powered by deployable or re-rollable photovoltaic panels. This power system will be supplemented by a rover-compatible electrical interface.

The supervision and communication systems will be implemented to command and control the shelter from the Earth and to test the first autonomous functionalities.

A first model of LISE version 1 will be useful for the first surface missions of phase 2A-a involving rovers.

LISE version 2 is a pressurized warehouse. It will provide a pressurized volume to store samples, equipment, and resources.

It will re-use the technologies developed for LISE version 1 and the deployable structures will include radiation and micro-meteoroid protection.

A first level of ECLSS will be developed to manage an atmosphere compatible with the stored material and fire prevention constraints. A dedicated interface will be added to transfer the equipment and an airlock will be installed for maintenance. The astronauts who will carry out the maintenance operations will wear their spacesuits. Outer interface interface plugs will be added for fluid transfers and services.

The RFCS will be upgraded to reach 1 kW. The power distribution will be refined to save energy and distribute it intelligently according to production and needs. The exterior electrical interface will be retained to recharge rovers or various equipment.

The autonomous functionalities will be upgraded for supervision and communication systems. In particular, they will automatically manage inventory and command and control a robotic storekeeper which will manage the storage of items.

A first model of LISE version 2 will be useful for the surface missions of phase 2A-b involving logistics.

LISS version 3 is a pressurized inhabited shelter. It is envisioned to provide a pressurized volume and resources to accommodate a crew of four astronauts for six days. The interfaces' requirements taken into account on the landing asset come from the lander EL3 (European Large Logistics Lander). The launcher interfaces' requirements come from Ariane 6.

This third version will re-use the technologies developed for LISE version 2 and the deployable structures will include radiation and micro-meteoroid protection compatible with human safety requirements.

ECLSS will be developed to handle a human-breathable atmosphere. The final version of the airlock will be installed. This airlock has to be compatible with any spacesuit regardless of its country of origin.

A waste management system will be integrated and the exterior interfaces for fluid transfers and services will be maintained. Medical, ISRU, and science equipment will be added for the various crew missions. The power generation and distribution will be adapted to cope with the needs of the different sub-systems of LISE version 3.

The autonomous functionalities of the supervision and communication systems will be developed to be compatible with future martian operations. A digital assistant will supervise the shelter during the inhabited period and support the astronauts during lunar operations. A first model of LISE version 3 will be useful for the surface missions of phase 2A-b and 2A-c for long distance exploration.

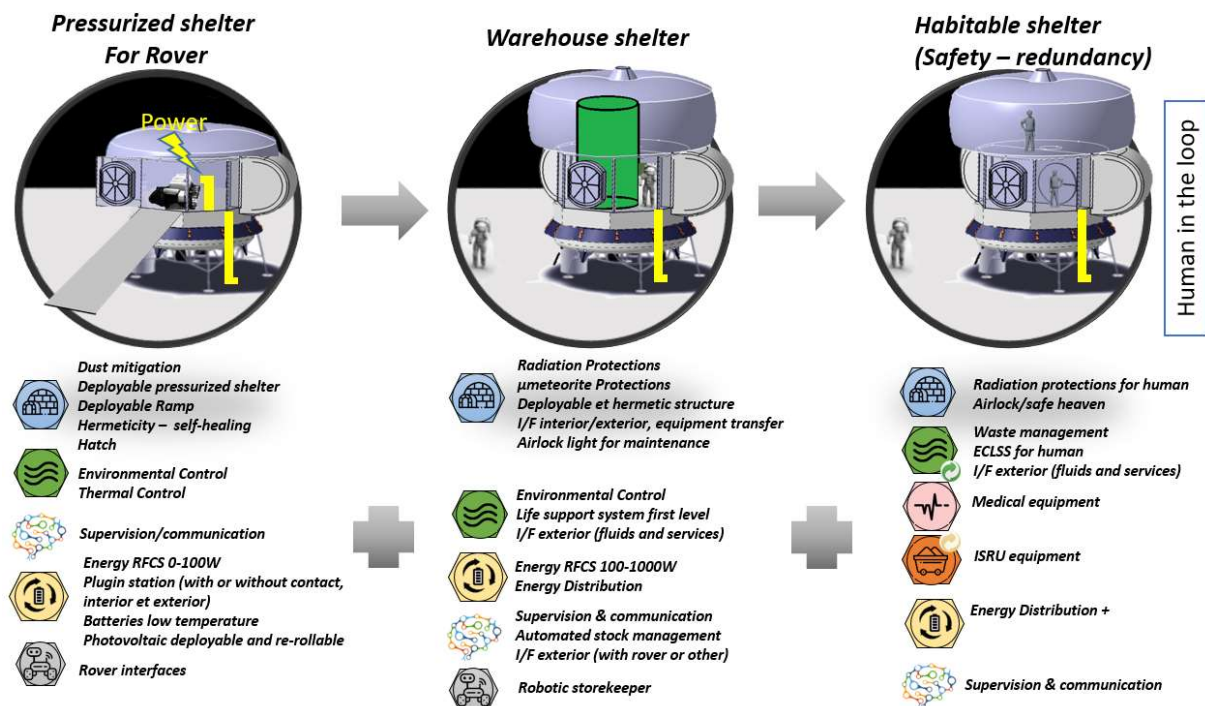


Figure 7. Synthesis of LISE development logic.

In 2023, the definition of the mission specification and the system specification is in progress. At the same time, CNES will consult its partners to integrate LISE into the existing scheme defined by ISECG.

This phase 0 will define the technical infrastructure and the development plan, establish the requirements, and define the interfaces with partners. It will give a first evaluation of the costs. These inputs will be used by CNES to launch an Intention To Tender by the end of the year 2023 to complete phase 0/A of the development of the three versions of LISE.

For LISE version 1, a condensed development will be set up. The objective is to develop it in five years. Some critical technologies studies at Spaceship France are in progress to accelerate the process. A first prototype of 100 W RFCS is being tested and the definition of a generic interface between LISE and a rover assistant is in progress. A first dimensionning of a deployable ramp has been carried out and shows that a mixture of conventional and innovative materials could save mass. Studies of self-healing materials were launched in 2022 to bring this functionality to the future envelope of the shelter¹⁵. LISE version 1 will be used to provide a charging service for the rovers which will contribute to the scouting, sampling and installing of infrastructures during the first steps of the Moon's exploration.

The objective is to plan the development of LISE version 2 over 6.5 years. The priority will be the definition of the deployable structure and the airlock. Both are essential for the rest of the developments. Studies of 1 kW RFCS will start in 2023. First studies of the robotic storekeeper and the ECLSS are in progress. The flight of LISE version 1 will provide important feedback and improve LISE version 2's systems. LISE version 2 will be used to provide shelters for equipment storage and for science activities. This system will facilitate the installation of the various infrastructures in anticipation of the future permanent base.

The objective is to plan the development of LISE version 3 over 7.5 years. It will benefit from the feedback of LISE version 2's flight. The feedback on the deployable system, the ECLSS, and the radiation protection are the most important for improving the habitable shelter of the habitat. They will be injected into the development at the start of phase D. The development of the first bricks of the autonomous supervision began in 2021. A PHD thesis, cofunded by [TRAD Tests & radiations](#) and [CNES](#), at [ISAE-SupAero University](#), began in 2022 to bring more knowledge on the effect of radiation on the human body and on appropriate protection solutions.

LISE version 3 will be used to provide habitable shelters for the astronauts near areas of interest. This system, that can be deployed before the crew's arrival, will offer extensions of the exploration ranges as well as provide a safe haven.

Thanks to the agreements made between CNES and its partners, a Memorandum Of Understanding could be established and signed in 2024. So since the "Boots on the Moon" phase, the various feedback is planned to be used to improve LISE from phase B.

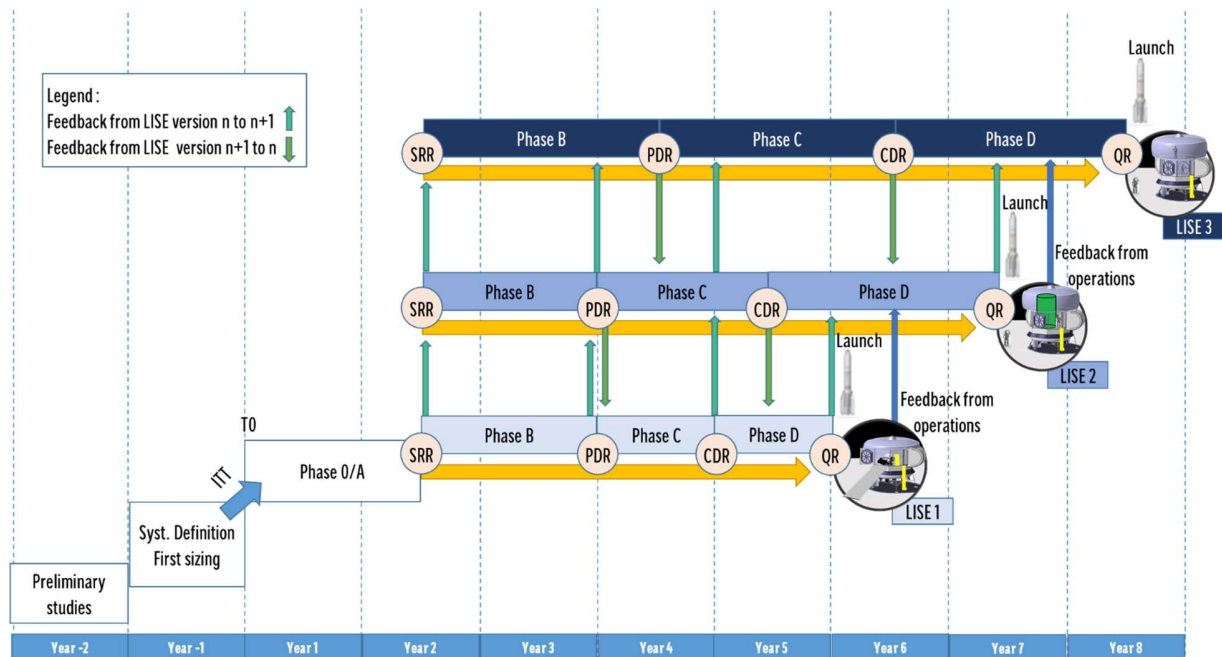


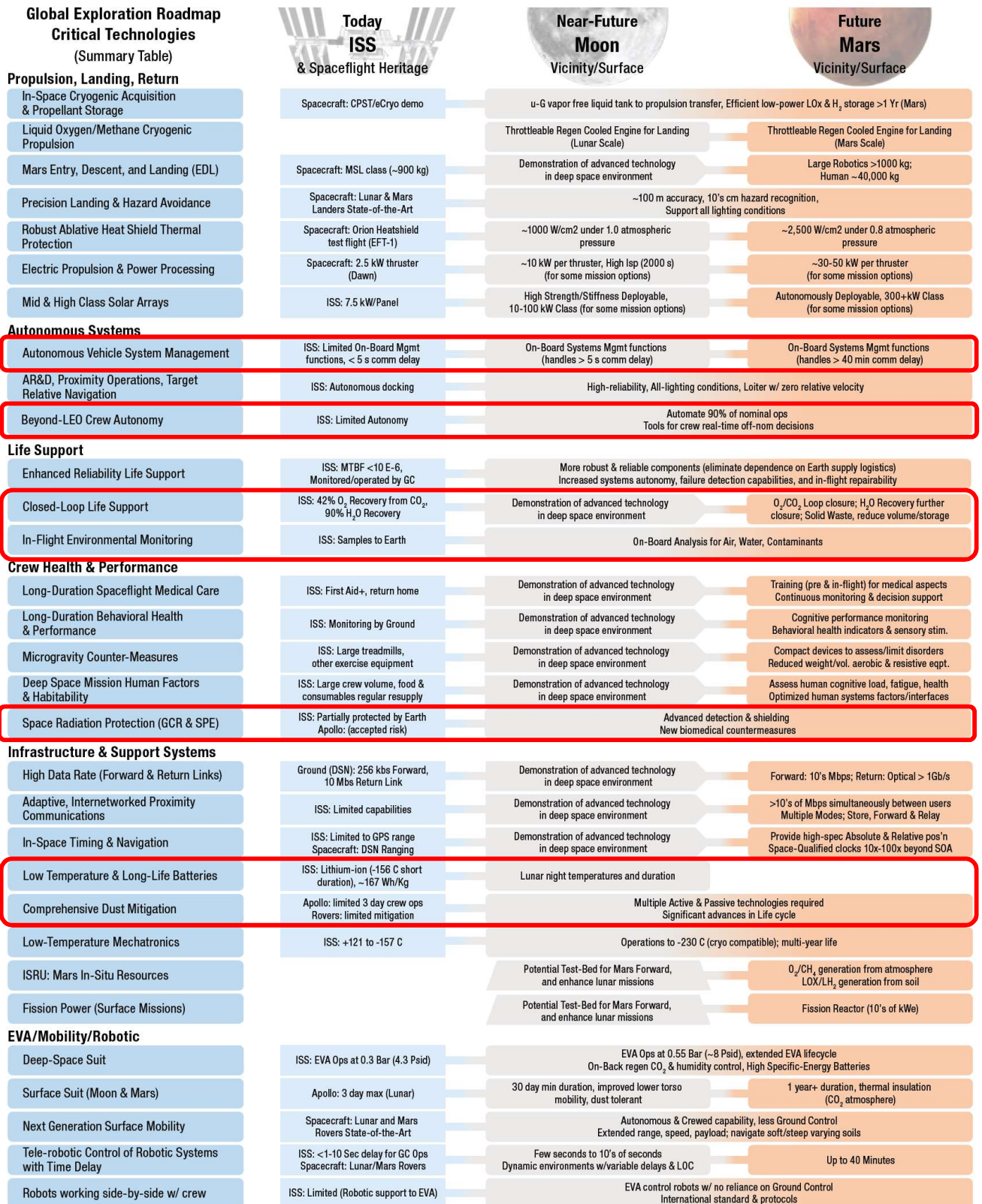
Figure 8. Objective planning for the development of LISE.

V. Conclusion and Perspective

To complete the various systems involved in the Artemis program, CNES offers an inhabited module LISE to be developed in three incremental versions. This approach of the Spaceship FR project makes it possible to cover the different needs and to increase the technological level and complexity version after version. As a pressurized shelter for small and medium sized rovers, LISE version 1 will provide both an internal and external electrical charging station and protection during the lunar night. As a pressurized warehouse, LISE version 2 will provide a pressurized volume to store samples, equipment or resources. And as a pressurized inhabited shelter, LISE version 3 will provide a pressurized volume and resources to accommodate a crew of four astronauts for a duration of six days.

The definition of the mission specification and the system specifications is in progress. The next step is launching an Intention To Tender in 2023 to start the Phase 0/A as soon as possible. In accordance with CNES's decision, the objective is to develop LISE version 1, then 2, and then 3, and to land them on the Moon in accordance with Artemis, Ariane 6, and EL3 programs. Various studies are underway to develop critical technologies, mainly for the power subsystem, ECLSS, micrometeoroid and radiation protection, deployable structures, and autonomous supervision. In parallel, the Spaceship FR project has started a study to anticipate the transfer of LISE to Mars.

Appendix: critical technologies covered by GER



Acknowledgments

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