Lunar ISRU P/L

Tipo Doc.: *Doc.Type:*	REPORT					N° DRD: *DRD N°:*	
N° Doc.: *Doc. N°:*	**LIMS-RP-OHBI-002**	Ediz.: *Issue:*	**1**	Data: *Date:*	**30/11/2018**	Pagina *Page* **1**	Di *Of* **9**
Titolo: *Title :*	Payload - Executive Summary Report (PL-ESUM)						

	Nome &Funzione *Name & Function*	Firma *Signature*	Data *Date*
Preparato da: *Prepared by:*	Study Team		
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Gestione documenti: *Data Management:*	Data management performed electronically by Ardis SW.	File:	LIMS-RP-OHBI-002 Iss1 (Payload Executive Summary Report (PL-ESUM)).docx

REGISTRAZIONE DELLE MODIFICHE / *CHANGE RECORD*			
EDIZIONE *ISSUE*	DATA *DATE*	AUTORIZZAZIONE *CHANGE AUTHORITY*	OGGETTO DELLA MODIFICA E SEZIONI AFFETTE *REASON FOR CHANGE AND AFFECTED SECTIONS*
01	30/11/2018		First Issue

LISTA DELLE PAGINE VALIDE / *LIST OF VALID PAGES*									
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1. INTRODUCTION

This document represents Executive Summary Report relevant to the work performed under ESA contract 40000123273/18/NL/JK, Lunar ISRU Demonstration Mission Definition Study – Segment 1 "ISRU Payload" by OHB Italia and the subcontractors Politecnico di Milano, OHB Systems and Blue Horizon.

The contract was part of the broader framework of two ESA-led mission study teams performing parallel and independent activities to establish the mission concept, considering the ISRU payload (Segment 1), the delivery service (lander, Segment 2) and the communication service (Segment 3).

In this context the scope of the OHB Italia contract activities was related to the definition of the ISRU Payload.

'ISRU' is the generic acronym for In-Situ Resource Utilization addressing the ways of exploiting local (lunar, planetary, asteroids) resources for the purpose of supporting and sustaining the future human exploration missions with material and consumables. For the mission addressed in this study the resource to be considered is the lunar regolith which can provide the oxygen it contains in its minerals. The in-situ production of oxygen (and thus also water) could eventually be used in life support systems in human exploration missions as well as for the production of propellants avoiding the need to transport these materials from Earth.

2. HIGH-LEVEL REQUIREMENTS

The objective of the mission and specifically of the ISRU Payload is the demonstration of the capability of extracting oxygen from the lunar regolith with a proper chemical process.

A target of about 100 g of oxygen (or water) represented the goal of the demonstration. Other requirements addressed the suitability of the process to any lunar location and the reference mission flight date in 2025 so that minimization of risk was a driving issue. A desired feature of the ISRU Payload was the scalability (to some extent) to larger systems, i.e. using solution and technologies adaptable for following pilot and operational systems.

In the first phase of the study activities, the reference landing site was selected in favour of the Shackleton connecting ridge in the south polar region where long periods of sunlight can be found; nevertheless, in terms of surface operations duration, the assumption has been to fulfill the demonstration task in the equivalent of one lunar daylight period (about 14 Earth days).

The ISRU Payload included as a secondary target the prospecting of volatiles contained in the regolith at the reference landing site.

The ISRU Payload is supposed to be carried on-board a lander (investigated under the Segment 2 activities of the overall ESA-led study) within the following general assumptions and conditions:

- the ISRU Payload will rely on the lander for electrical power supply and for the data link to/from Earth;
- the lander payload mass capability is up to 300 kg;

- the payload can be accommodated in two lateral positions, on the two opposite sides of the lander, minimizing the distance for access to the lunar soil;
- the envelope of each payload is about 1000 x 650 x 650 mm (tangential direction x radial x height).

To be highlighted that the mission approach was to avoid the implementation of mobility elements to minimize the complexity of the mission; thus the payload elements are fixed on the lander.

3. THE PROCESS FOR OXYGEN EXTRACTION

Under this set of general requirements, the concept elaborated for the oxygen extraction relies on the adoption of a carbo-thermal reduction process where the regolith minerals interact with methane at a temperature in the range of 900-1000°C; at this temperature the regolith remains solid, does not melt. This process was investigated by OHB-I and Politecnico di Milano in a past ESA contract, the ISRU Architecture and Technology Study, 2009-2011, where a TRL 3 has been reached on the process itself with lab demonstrations and a yield up to 7% (produced oxygen with respect to initial simulant mass).

The adopted carbo-thermal reduction process is able to reduce any oxide present in the lunar soil, in particular it can work with the silicates largely present (about 45% in mass) at any lunar location. This is one of the main advantages of this approach. The other is the relatively low complexity and easy operations with respect to other possible processes which involve molten phase.

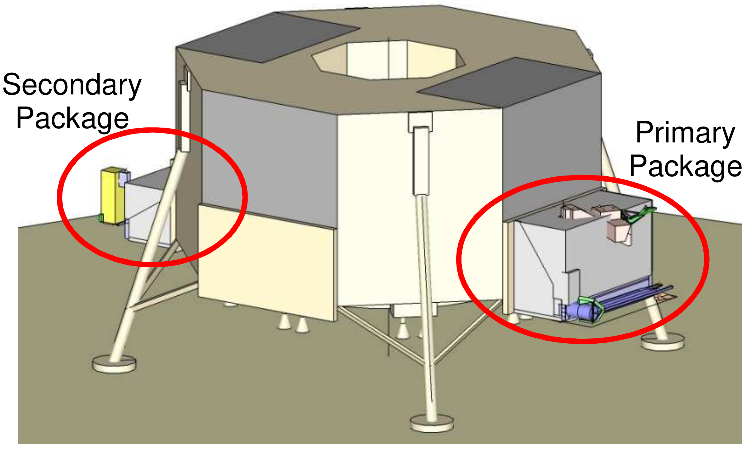
The chemical process in its implementation requires an additional step after carbo-thermal reduction where the produced gases (CO, CO_2 and H_2) are reacting in the so-called methanation reactor at about 250°C in presence of a catalyst to obtain water, methane and residual hydrogen. The methane can then be recycled and the water vapour condensed to the liquid phase. The water is composed by the oxygen extracted from the regolith and by hydrogen coming from methane or directly injected with the methane. The details of the process implementation are more complicated and depend on the tuning and optimization of several parameters.

The production of water calls for the consumption of hydrogen to be brought from Earth with a nominal ratio of 1 mass unit of hydrogen for 9 mass units of water produced on the Moon. In case hydrolysis is done on the water the hydrogen can be recovered so that nominally the gas brought from Earth is fully recycled (the hydrolysis step is not required in the frame of the ISRU mission of interest where the critical point are the demonstration of the extraction of oxygen and of the recovery, of methane).

The implementation of a reactor system able to perform the reaction in a lunar environment and with the limited resources available from the lander puts several challenges related to the management of the thermal conditions, required electrical power minimization, to the loading/ discharging operations which require valves able to handle the regolith flow and to seal the openings during operations with gas, to the characteristics on and the uncertainties of the regolith, to the need to be scalable, to some extent, to larger pilot and production plants.

4. PAYLOAD DESCRIPTION

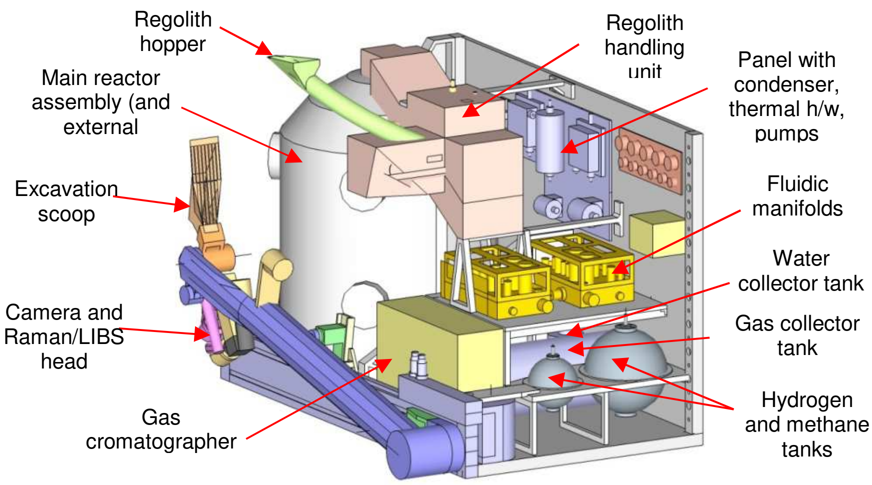
The ISRU Payload is accommodated on the lander on two 'packages' mounted on the sides of the lander in the proximity of the lunar surface as depicted in figure (the Lander configuration shown in the figures is only generically representative of Lander geometries and layout).



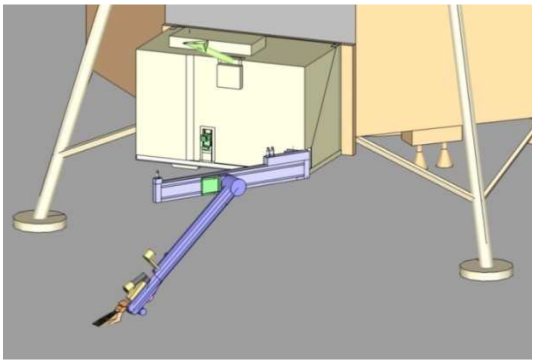
The Primary Package carries the carbo-thermal reduction payload, which extracts oxygen from the regolith and produces water; the internal layout is shown below.

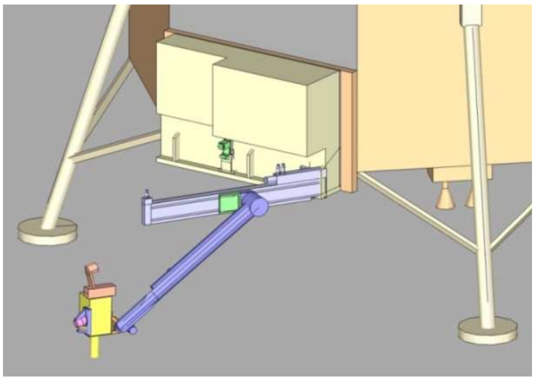
The Secondary P/L Package hosts the volatile prospecting payload and most of the electronic units supporting both packages.

The overall mass of the two packages is 161 kg including the design maturity margins and the envelope is about 1000 x 850 x 650 mm for the Primary Package, with the Secondary Package smaller and lighter. The difference in mass between the two element may create un unacceptable unbalance for the lander flight operations which has to be compensate with ballast or with possible additional auxiliary payload(s) on the Secondary Package.



An important part of the effort has been devoted to the trade-off, definition, sizing and analysis of the carbo-thermal reactor, the core element of the ISRU Payload. The reactor operates in a batch mode; it is loaded from the upper side with regolith filling (about 1 kg); discharge of spent regolith occurs by gravity from the lower side, to the lunar surface; for these functions a system of solid/sealing valves able to work in hot environment (hundreds °C) is required. The regolith excavated by the robotic arm is unloaded in a hopper which carries the regolith to the handling unit where it is sieved, characterized by a microscope and a Raman/LIBS instrument and moved to the reactor. A fluidic subsystem is in charge of all operations for handling the gas flows feeding the reactor and the syngas out of the reactors, for condensing the water, for sampling the gases for analysis by a gas cromatographer.





Each package includes a robotic arm which, for the oxygen extraction payload, is dedicated to the excavation of regolith and, for the volatile prospecting payload, carries the instrument in proximity of the surface for operations. The surface area reachable by each arm is about 2.4 m^2.

As said, the Secondary Payload aims at prospecting volatiles contained in the regolith. For this purpose the payload considers as reference the LUVMI instrument which is being developed up to TRL 5 in the frame of a larger EU Horizon 2020 programme. The instrument includes a driller able to reach up to 20 cm into the regolith; a heating element mounted inside the drill heats the regolith generating the release of the volatiles which are brought to a miniaturized mass spectrometer installed above the drill.

The robotic arms aids the drilling operations providing a pushing force; the Secondary Payload is completed by a camera and a Raman/LIBS instrument for characterization of the regolith where the drilling operations are done.

5. CONCEPT OF OPERATIONS

The payload operations on lunar surface aim at reaching the mission objectives within one lunar daylight period, meaning that in this timeframe at least 3-4 water production batches are performed and volatile prospecting is performed in some sampling spots. When accounting for payload commissioning time, the initial survey of the excavation area and of the volatile prospecting area (with instrumentation - camera, Raman/LIBS - mounted on the arm ends) and the needed margins for unexpected events and uncertainties and actual time of landing with respect to daylight beginning, the remaining time for actual payloads operations could be very short.

The typical duration of a full batch production cycle, from excavation to spent regolith discharge, has been estimated to about 2.5 Earth days. For the volatile prospecting payload the cycle time, including sampling in one spot at different depths, has been assumed at 8 hours.

In terms of required electrical power, the most demanding phases are the regolith heating, from ambient to the reaction temperature, with peaks of some hundreds Watts, and the process reaction running, at lower required power levels. During these activities, because of the large power consumption is has been assumed that no other operations are performed by the ISRU Payload. For the remaining phases an operational timeline which foresees parallel operations has been envisaged: basically excavation, regolith preparation and loading operations relevant to one production batch are combined with the final operations of the previous batch (cooling, discharge) and with the operation of the Secondary Payload. In this way the overall ISRU Payload cycle duration is less than two days.

The approach to operation control from ground foresees semi-automatic operations where low level tasks or sequences of low level tasks are autonomously performed by the payload after being instructed and initiated from ground; operations are continuously monitored by the ground control center. In this way a relatively low downlink data rate is possible, not requiring continuous real-time video images. It has been assessed that about 100 kbit/s would be the minimum data rate required to perform the payload operations.

The situation where a continuous datalink could not be assured at mission level was investigated from the point of view of the payload. In this sense the operational modes relevant to the core reactor functioning (heating, production, cooling) are suitable for automatic operations without continuous monitoring, implementing a proper FDIR system. On the other side, modes related to excavation, regolith handling and loading/discharge, being more complicated and more susceptible to possible unexpected and unforeseen situations, as well as the secondary payload operations would require a continuous datalink and possibility of rapid intervention. The downlink data rate in this case increases to about 160 kbit/s.

The datalink with Earth is not performed directly by the ISRU Payload but it runs through the lander systems.

6. TECHNOLOGY READINESS

The carbo-thermal reduction process has been demonstrated at laboratory level (TRL 3) but the development of a lunar demonstrator faces lower TRL's in some critical areas which have been identified in frame of the Study:

- the reactor in itself is a novel system where the proper architecture and solutions have still to be consolidated; ground breadboards and development models are necessary in this sense.
- all aspects related to handling of regolith, (i.e. excavation, sieving and in general regolith flow/motion in ducts and surfaces); these aspects depend on the regolith handling properties which are not well known nor adequately investigated yet. In particular electrostatic behavior which causes the sticky behavior of regolith is only marginally addressed by research. Technological criticality of this issue is also depending on the relatively large quantities to be handled with respect to past exploration missions and on the difficulties in ground testing under earth gravity and use of simulant analogue materials.
- high temperature solid/sealing valves for regolith flow in/out of the reactor are considered other components with very low TRL. The functioning requirements for these valves are peculiar and implementation of non-space technologies and solutions is not straightforward; operating temperature for these valves has to be minimized by a proper payload concept and architecture where figures above 250-300 °C may result in high risks for a development of mechanical devices suitable for the mission to be flown in 2025.