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Lunar Volatiles and their characterisation by L-VRAP (the Lunar Volatiles Resources Analysis Package)

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1. Introduction

Although it's more than 40 years since space missions landed on the Moon and brought back samples, both through human exploration and by robots, the volatile inventory of our satellite is still uncertain. The unanswered questions are both scientifically significant and the presence and abundance of lunar volatiles is an important consideration for ISRU (In Situ Resource Utilisation) since this is likely to be a part of a strategy for supporting a long term human presence and for the wider exploration of the solar system. The Lunar Volatile Resources Analysis Package (L-VRAP) is part of the provisional payload for the ESA European Lander [1] and aims to measure the abundance and chemical/isotopic composition of volatiles from regolith samples and the lunar exosphere.

1. Lunar Volatiles

Soon after the first Apollo samples were returned to Earth it was believed that the Moon (as represented by primary lunar rocks) was almost completely devoid of what is probably the most important volatile – water. However, it was well known that the Moon as a whole was exposed to the solar wind. Consequently conditions existed under which water might be synthesised from solar hydrogen impinging on target oxygen containing minerals. Water with a very low abundance of deuterium could be liberated from lunar soils by stepped fashion heating experiments identifying the solar wind as a provenance for the hydrogen [5].

Other volatiles including CH₄, CO, N₂ and CO₂ were also liberated but since the isotopic abundance of light elements was (and still is) unknown the involvement of the solar wind in their synthesis remains speculative.

Possible evidence for gases of solar origin being liberated from the lunar regolith (probably loosely bound/trapped rather than within soil grains) at natural temperature (ca 140°C) has been obtained from analysis of the lunar exosphere by LACE (Lunar Atmospheric Composition Experiment) [2] an experiment that was part of the ALSEP (Apollo Lunar Surface Experiment Package) left by Apollo 17. The data (ions corresponding to methane, carbon dioxide etc.) from the LACE nude source mass spectrometer can be interpreted as the gases being evolved from the soil as the terminator crossed the Apollo 17 landing site at the dawn of the Moon's day (every 28 Earth days).

There is however currently no evidence to demonstrate the origin of these species is the solar wind. Indeed there is another potential major source of lunar volatiles to be considered – comets and primitive meteorites.

It has been proposed since the 1960s that volatiles on the Moon resulting from impacts might migrate to cryogenic traps, permanently shaded areas, at the lunar poles. Recent results from the L-CROSS mission confirm that water is present at the lunar surface near the south lunar pole verifying results from orbiting experiments and telescopic radar observations.

To investigate the feasibility of autonomous guided landing on the Moon, the Human Spaceflight and Exploration Directive of ESA is proposing the send a robotic mission to a south pole target with a launch by 2018. A science payload aboard such a feasibility demonstrator lander offers a tremendous opportunity to carry out science activities related to lunar volatiles and thus addressing the possible involvement of processes occurring as a result of solar wind bombardment and cometary impacts.

2. L-VRAP design

The L-VRAP concept is based on instruments flown for other lander missions (e.g. GAP[6], TEGA[3], and Ptolemy[4]). Regolith samples are loaded into one of 24 ovens on a carousel whereupon the volatiles are extracted by either pyrolysis or combustion to temperatures of least 800°C. The abundance and chemical composition of volatiles released is determined by an ion trap mass spectrometer. The volatiles are then chemically processed to be suitable for isotopic analysis by a magnetic sector mass spectrometer. L-VRAP also contains reference gases of known chemical and isotopic composition to enable precise isotopic measurements. The CAD layout is shown in figure 1.

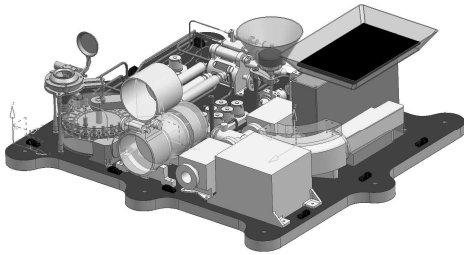


Figure 1: CAD model of the internal layout of L-VRAP. Dimensions 430 mm × 400 mm, ht 160 mm.

The Lunar Lander includes a robotic arm capable of scooping samples from up to 3.5m from the lander centre and to a nominal depth of 10cm. A timeline has been developed to analyse volatiles at various depths and locations as well as their variation over time and changing illumination conditions. The possible inclusion of a mobile payload element with a mole would allow a much larger range (depth and lateral displacement from lander) of samples to be acquired.

In addition to analysing volatiles released from regolith samples, L-VRAP can directly analyse the tenuous lunar exosphere by opening the mass spectrometers to the lunar environment. The ion trap MS (table 1) can rapidly monitor the full mass range to detect transient events (e.g. during changes of illumination) whereas the magnetic sector MS (table 2) has greater sensitivity and can detect the less abundant volatiles. The housing for the Ion Trap MS also includes a material which passively traps the exosphere. Hence the exosphere can be collected

Table 1: Summary of ion trap capability

Ion trap mass spectrometer	
Ring electrode size, r_0	8mm
RF trapping frequency	1 MHz
Mass Range	10-150 amu
Mass Resolution	unit

Table 2: Magnetic Sector Mass Spectrometer

Magnetic sector mass spectrometer	
Magnet radius	6 cm
Mass range	2-150 amu
Mass Resolution (M/ Δ M)	65
Precision nmol samples	1‰
Precision μ mol samples	0.1‰

over a long time scale.

An important consideration for this study is the effects of contamination from the Lander. The landing sequence will use about 1000 kg of propellant, with a large fraction directed onto the landing site. Initial modeling indicates that uncontaminated samples will be accessible by the robotic arm at depths of several cm. Knowledge of the contamination composition and distribution will allow the identification of surface volatiles, either by subtracting the contamination or by identifying protected areas such as surface shielded by small rocks

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