PROJECT

Lunar Mission One

Lunar Mission One

Request for Information (RFI)

WORK PACKAGE NUMBER

RGPI

DOCUMENT NUMBER

0261758

CUSTOMER ID NUMBER

LM1-MT-001

REVISION

1

REVISION OR RELEASE DATE

18 November 2015

STATUS

Issued

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DOCUMENT REVISION STATUS

Last Edited Date	Revision / Release Number	Status	Edited By	Pages / Paragraphs Affected	Change Ref
17 /11/ 2015	1	Issued	LM1 Mission Team	All (first issue)	

1 INTRODUCTION

1.1 Scope

This document is a statement of work for a Request for Information (RFI) issued by Lunar Mission One, in order to facilitate initial discussions with interested industrial partners.

The document includes the following:

- An overview of the Lunar Mission One main mission objectives.
- The associated programmatic and procurement approach planned by Lunar Mission One.

Lunar Mission One has issued this RFI in order to better understand possibilities for industrial management and implementation for the mission. In particular, the following are of high interest to the Lunar Mission One team:

- The proposed industrial consortia that could be put together to deliver the mission
- Preliminary mission architecture(s) which could meet the main mission objectives
- Non-binding, indicative price(s) for the mission architectures
- High-level delivery schedule
- Innovative ideas for cost reduction, schedule acceleration, and/ or increased value

The Lunar Mission One concept is still in a relatively early stage of its planning (pre-Phase A), and therefore the mission concept and mission requirements are not fully developed and consolidated. As such, Lunar Mission One does not expect a firm fixed price or a fully formed and detail technical proposal. The RFI is intended to capture early ideas and preliminary concepts for the management and delivery of the mission architecture, which will be refined though a formal Request for Proposals (RFP) which is planned for the second half of 2016 (see Figure 4).

Lunar Mission One welcomes innovative solutions that will deliver the mission objectives.

This document is structured as follows:

- Section 1.2 covers general project background.
- Section 2 provides an overview of the Lunar Mission One concept, the mission objectives and requirements, and the baseline implementation schedule
- Section 3 details the specific items to be addressed by any organisation responding to this Request for Information
- Appendix A outlines the preliminary drilling objectives and definitions.
- Appendix B outlines the preliminary strawman science payload for the mission.
- Appendix C outlines the preliminary strawman archive payload.

1.2 Project Background

Lunar Mission One is a plan for landing a vehicle on the Moon, expected to be near to the Southern Lunar pole, to use this vehicle to drill a deep borehole into the Moon's surface, and then to place inside the borehole an enduring time capsule – an archive payload consisting of digital media and DNA samples from Earth. In addition, the mission is required to enable highly valuable new science by performing detailed analyses of core samples returned to the lunar surface during the drilling process. Investigations to support manned lunar bases are also desirable. The mission has an innovative funding structure, based on self-financing through payments from members of the public in return for an allocation of the archive payload.

More information on the Lunar Mission One concept is available on the mission website (**https://lunarmissionone.com**). RD-2 links to a full list of project documents including the business case and market studies. Specifically, RD-1 can be consulted to obtain background information on the preliminary feasibility study performed in 2013 on the Lunar Mission One concept. It should be noted since that time some aspects of the mission concept may have changed, and therefore the information in this document should take preference in terms of a response to the questions in this RFI.

Lunar Mission One is also seeking to form a Public Private Partnership (PPP) between a Government agency, which will act as the political authority for the mission, and an industrial consortium with a lead company as the contracting authority for the mission's implementation. The objectives of the PPP will be expressed in terms of the transport, placement and servicing of the archive and science payloads. The industrial consortium would manage the programme for the selection and development of the technical solution and the subsequent space operations. The industrial consortium is expected to draw on a wide range of international capabilities.

1.3 Reference Documents

RD-1	https://lunarmissionone.com/lunar-mission-one/the-business-case-technical-review
RD-2	https://lunarmissionone.com/lunar-mission-one/business-case

1.4 Acronyms and Abbreviations

The following abbreviations are used within this document:

COSPAR	Committee on Space Research
DNA	Deoxyribonucleic Acid
FRR	Flight Readiness Review
ITAR	International Traffic in Arms Regulations
PPP	Public Private Partnership
RFI	Request for Information
RFP	Request for Proposal
TBC	To be Confirmed
TBD	To be Determined
ΔV	Delta-Velocity

2 The Lunar Mission One Concept

2.1 Overview

Lunar Mission One is a UK-originated idea for an international robotic lunar drilling mission to land and drill a near-vertical borehole of a minimum 20 meters on the Moon. The project embodies a number of unique features, including:

- The first deep drilling mission on a solar system body other than Earth
- A commercial payload, contained in the archive, that enables the self-financing of the project
- Potential for unique science and exploration knowledge returns, as well as engineering technology demonstrations

The prime mission objective for Lunar Mission One is:

Land a vehicle safely on the surface of the Moon, expected to be in the southern lunar polar region, and use this vehicle to drill a deep vertical borehole into the lunar surface. The vehicle shall place an archive consisting of digital and DNA information into the hole that shall be able to survive undamaged on the Moon for one billion years. In addition the vehicle shall perform scientific analysis of lunar rock samples obtained during the drilling of the archival borehole and take measurements of the local surface environment.

This includes the following considerations:

- The mission *shall comply with all aspects* of the Committee on Space Research (COSPAR) Category II Planetary Protection Requirements
- The minimum surface lifetime for drilling and archive deployment is expected to be 6 months, based upon current understanding of the drilling capabilities.
- The minimum mission lifetime for potential extended science operations should exceed the lunar polar day.
- A non-polar site can be proposed. This will be evaluated in the same way as polar sites - in terms of the balance of cost, value and risks.

The mission will be split into several different phases, as illustrated at Figure 1 and outlined in more detail in Figure 2. The phases are shown in a nominally chronological order although scientific analysis may continue after the placement of the archive into the bore hole.

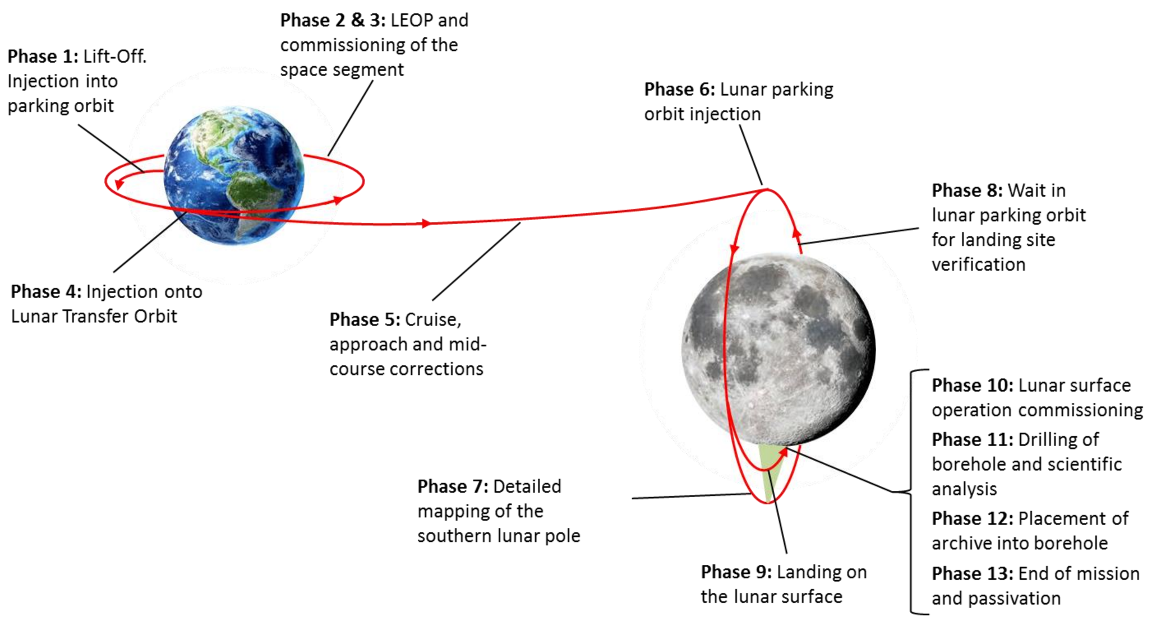


Figure 1: Notional Lunar Mission One mission phases (assuming southern lunar pole landing)

Lunar Mission One: Mission Phases		
Mission Phase	**Name**	**Description**
1	Pre-launch	The lunar lander vehicle is prepared for flight on the launch site, including its installation aboard the launcher, and correct functioning of the whole system is checked before lift-off
2	Launch and Early Operations (LEOP)	Starting with launcher lift-off and ending when the lunar lander vehicle is acquired by the LM1 ground segment and is shown to be safe (from the power and thermal point of view) and stable (from an attitude point of view)
3	Space Segment Commissioning	Systems on-board the lunar lander are verified for correct functionality and operating behaviour
4	Lunar Transfer Orbit Injection	The lunar lander vehicle is placed on an orbital trajectory that is compatible with the desired lunar parking orbit. This may come from the landers own propulsion, from an additional propulsion module, or from the upper stage of the launch vehicle (TBC)
5	Lunar Cruise & Approach	The lunar lander performs navigation updates and mid-course correction manoeuvres (if needed) towards the intended lunar parking orbit
6	Lunar Parking Orbit Injection	The lunar lander injects into a stable parking orbit around the Moon
7	Detailed Lunar Mapping Orbit	The lunar lander performs detailed surveillance of the Southern Lunar regions, for landing site hazard identification, and landing site confirmation
8	Lunar Parking Orbit	Once the potential landing sites have been surveyed, the lander will wait whilst the landing site imagery is checked and verified (on-ground)
9	Lunar Landing	Once the landing site suitability is confirmed, the vehicle orients itself to the desired attitude, uses on-board propulsion and sensing equipment to navigate towards the preferred landing site (within a defined error ellipsoid), performs course corrections and hazard avoidance manoeuvres as needed, and finally descends towards the lunar surface, landing safely within the error ellipsoid
10	Lunar Surface Operation Commissioning	Once on the surface, the functionality of the lander, including the drilling mechanism(s) and any science payloads shall be verified for correct functionality and operating behaviour
11	Drilling of borehole and Scientific Analysis	The lander shall employ a drilling device to dig the necessary borehole into the lunar surface. Core samples shall be periodically removed from the hole and shall be placed onto a separate payload on the lander for scientific analysis
12	Archive Placement into Borehole	Once the hole has been dug to the necessary depth, the lander shall place a DNA and Information Archive into the hole. (Note, if mission resources allow it, this phase could be extended for additional scientific measurements after the archive has been safely placed into the hole. This is TBC.)
13	End-of-Mission & Passivation	Once the archive has been placed into the hole, and all science observations have finished, the lander shall be fully passivated, and left in a safe non-volatile state

Figure 2: Lunar Mission One Mission Phases (assuming southern Lunar Pole landing)

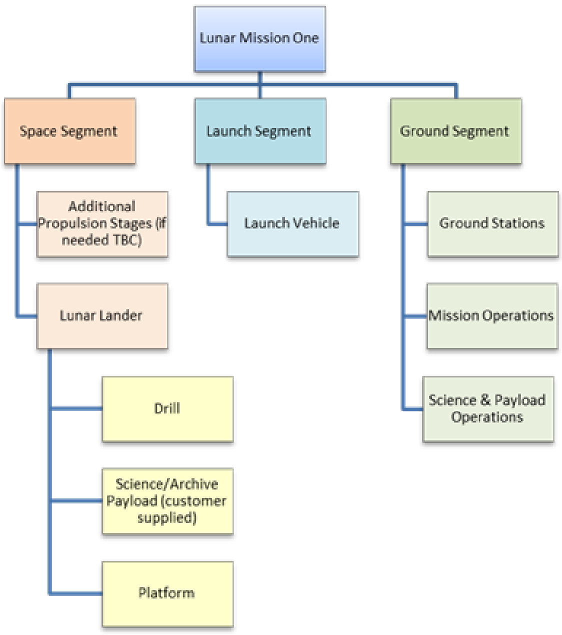


Figure 3: High Level Lunar Mission One Product Tree

Figure 3 shows the high level Lunar Mission One product tree, showing the key elements (the critical 'building blocks') of the mission.

2.2 Mission Implementation Timeline

The mission is envisaged to be implemented as a PPP, split into two stages. This first phase is a set-up phase where the management structure is established, procurement approach and legal responsibilities are defined, and discussions with industry occur, all leading to a competitive PPP contract. The second stage (implementation) deals with the development and procurement of the mission hardware and the execution of the actual mission itself.

Period		Stage	Mission Procurement	Technology Development
2015	Q4	Industry discussions	Initial expressions of interest	Mission risk identification
2016	Q1		Initial industry discussions & investment cases	Risk analysis
	Q2		Initial formation of consortiums	Preliminary mission outlines
	Q3		Procurement competition plan with initial RfP	Risk reduction planning
	Q4	Competitive procurement	Project planning, financial investment assessments	First stage risk reduction activity
2017	Q1		Candidate commercial offers, developed RfP	Mission planning & cost analysis
	Q2		Investment optimisation & contract development	Second stage risk reduction activity
	Q3		Best & final offers	Refinements to mission plan & cost analysis
	Q4	Contract negotiations	Bid selection	Negotiation support
2018	Q1		Contract decision & financial close	Prep for Development Stage
2018-2022		Mission development	Consortium sub-contracting	Detailed technology planning, design, development and build
2023			Flight readiness review	Assembly, integration & test
2024		Space ops	Extended mission options selection	Launch, spaceflight & lunar operations

Figure 4: Preliminary Mission Implementation Schedule.

The preliminary mission delivery schedule is shown in Figure 4. This is subject to change but is based upon the following key stages:

- **Industry discussions** – commencing with the issue of the Request for Information (RfI) Q4 2015
- **Competitive procurement** – commencing with the issue of the formal Request for Proposal (RfP) Q3 2016
- **Contract negotiation** – commencing with bid selection Q4 2017

Mission development – commencing with the contract kick off Q1 2018
Space Operations – commencing 2024

2.3 Mission Cost

Although the mission is not yet fully defined, a non-binding indicative mission price is requested as part of this RFI to support the high level trade-offs. This should highlight the high level mission architecture products that have been included such as the cost of the spacecraft, payload integration to spacecraft, launch vehicle, mission operations and provisions for launch services and which are not (refer to Figure 3).

2.4 Strawman Payloads

The drilling and science payloads will be handled via a separate call for proposals from 2016. The drilling is expected to be within the scope of the PPP mission contract with the industrial consortium.

The currently defined drilling objectives, science payloads and archive payloads for the Lunar Mission One lunar lander are shown in Appendix B and C respectively. These are preliminary definitions, and are subject to change, but should be used as the baseline for the payloads in terms of this RFI.

3 Request for Information

3.1 Specific Items Requested

The Lunar Mission One team has issued this RFI to begin the process of defining the industrial arrangements and implementation of the proposed mission concept. As such the Lunar Mission One team is interested in understanding the possible ways the mission development and implementation could be managed. Therefore Lunar Mission One specifically requests the responding organisation to address the questions shown below in their response[1]:

The key questions to be addressed are:

1. What would be the core industrial consortium that could be put together to deliver the mission?
    - This should include as a minimum the management teaming that would address the key aspects of the mission (e.g. the development and procurement of drilling, guidance navigation and control etc.) and an outline of the expertise and experience in the team.
2. What is the preliminary technical solution that could be envisaged by industry in order to meet the mission objectives of Lunar Mission One venture? This should include:
    - The overall high-level mission architecture proposed, and the space and ground segment design concepts, including a proposed launch solution (prime and backup).
    - Identification of mission drivers which have the capacity to be a particularly strong influence on the overall mission and project cost, complexity and risk. Highlight possible mitigation strategies and /or alternatives.
    - Any aspects of the design with particular heritage or potential to de-risk the mission should be clearly identified.
3. What would be the proposed programmatic implementation for the mission? This should include:
    - The proposed product and quality assurance approach and standards for the mission
    - The indicative non-binding price for delivering the mission solution to Lunar Mission One
    - The total mission schedule from kick-off to end-of-mission including any identified necessary critical technology pre-development or de-risking programmes
    - The proposed relationship between the proposed industrial consortia and any other organisations in terms of delivering the mission (e.g. relationships with space agencies, national government programmes etc.)
    - A first order assessment of the management of International Traffic in Arms Regulations (ITAR), or any other export or governmental restrictions that can be foreseen in terms of delivering the mission solution. This is particularly important given the expected international nature of the mission implementation.
4. What are considered the main risks to the project (both technical and programmatic)?
    - If feasible this should also include any associated mitigation strategies to minimise these risks.
5. Are there any innovative ideas for cost reduction, schedule acceleration, or any other aspects, that could bring significant value without damaging the key mission objective?

[1] Responding organisations are free to respond in which ever format they consider the most appropriate, e.g. document, presentation slide pack etc.

3.2 Size of Submission

Lunar Mission One anticipates responses limited to a **maximum** of 20 pages in length, although this is not a strict requirement. However, responses significantly over this limit may not be read or acted upon.

3.3 Response Deadlines

3.3.1 Registration of Interest

Potential respondents are asked to register their interest in this RFI by email by 09:00 GMT on 7th December 2015.

RFI@lunarmissionone.com

Registration of interest does not create an obligation to respond to the RFI, but will allow the LM1 team to disseminate any additional details to the interested parties.

3.3.2 RFI Submissions

RFI responses should be sent electronically (preferably in PDF format) to the following email address:

RFI@lunarmissionone.com

The response should be contained within a single file, and should reach the stated email address by **17:00 GMT on the 25th January 2016.**

3.3.3 Questions

Respondents may send questions to the LM1 team via the following email address:

RFI@lunarmissionone.com

All questions and answers will be made available to those who register their interest. The source of the questions shall be held confidential. Questions and answers that contain information unique to a respondent's proprietary approach will not be shared if they are identified as such.

3.4 Other Items

The responding organisations are free to add any other information to their response if they feel it adds value to their proposal, and will be of benefit to Lunar Mission One (noting the target page count stated in section 3.2).

3.5 Disclosure of Information

Any responses received by Lunar Mission One will be treated as commercially sensitive and treated as in-confidence information.

APPENDIX A. DRILLING OBJECTIVES & ASSUMPTIONS

High Level Drilling Objectives:

The drilling objectives should be phased. The following are recommended:

a) A cased 10 metre vertical borehole is the mission objective for success

b) 20 metres is the target depth, uncased hole below 10 metres

c) 100 metres is a stretch target based on uncased hole below 10 metres

Working Assumptions:

1. The lunar sub-surface shall be assumed to be a mix of basalt and breccia in a heterogeneous mix. See section on stratigraphy. This will require further iteration with the Science Team.
2. The diameter of the borehole will be optimised for drill performance, but is expected to be 0.045m. This will require iteration with the Drilling Team.
3. The lunar lander shall place the archive payload into the hole once the final hole depth has been reached.
4. The drilling system shall allow for the return to the lunar surface of core samples for scientific analysis. This will require iteration with the Science and Mission Teams.
5. The arrangements and responsibilities for robotic sample handling will need co-ordination with the Science Team.
6. Measurement While Down (MWD) – Critical engineering data on the drilling whilst drill is active in the hole will be required but is still to be defined.
7. Logging While Down (LWD) - Mainly science data on the drilling whilst drill is active in the hole is desirable, but is still to be defined.

Stratigraphy

LM1 currently has three working scenarios for the drill site stratigraphy:

a) Homogeneous anorthosite breccia scenario
b) Homogeneous crystalline anorthosite scenario
c) Heterogeneous scenario

a) Homogeneous anorthosite breccia scenario

A top layer of lunar soil up to a depth of 10 metres below which are anorthositic breccias to a depth of >100 metres.

b) Homogeneous crystalline anorthosite scenario

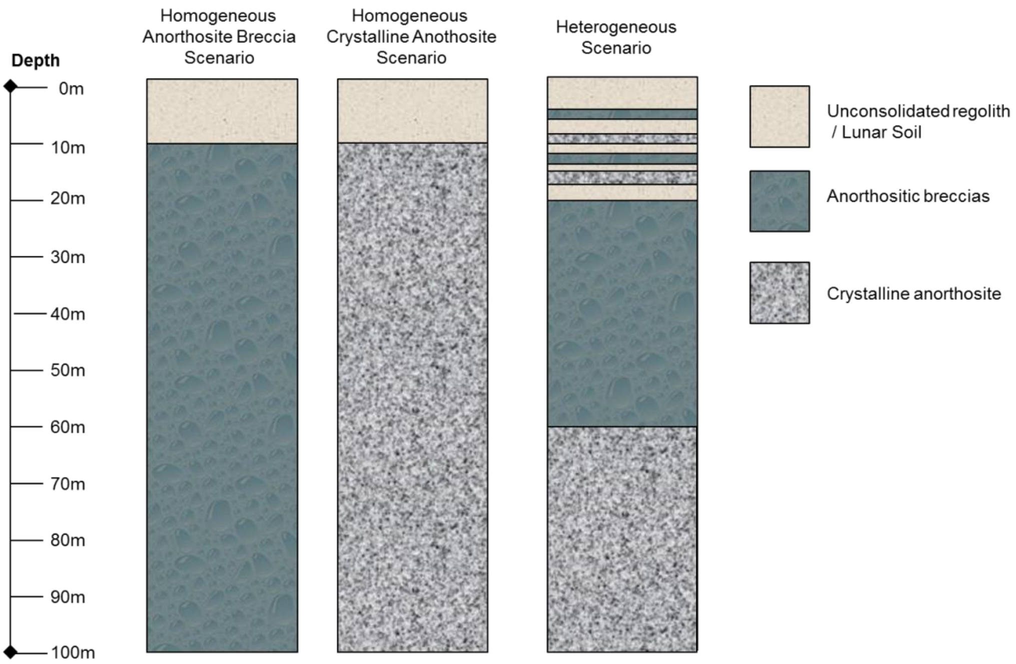
A top layer of lunar soil up to a depth of 10 metres below which are crystalline anorthosite to a depth of >100 metres.

c) Heterogeneous scenario

A top layer of lunar soil up to a depth of 5 meters followed by alternating layers of regolith breccia and crystalline anothosite separated by maximally compacted regolith (lunar soil)

At circa 20 metres to circa 50 metres homogeneous anorthosite breccia.

At circa 50 metres to > 100 metres, homogeneous crystalline anorthosite.



Sources: Prof Ian Crawford & Mr Phil Bustin

APPENDIX B. STRAWMAN SCIENCE PAYLOAD

The following model payload is indicative of one that would achieve the proposed science goals within a notional 30 kg allocation. At present this is purely conceptual but is based on instrumentation that has an appropriate level of technical maturity. It will be refined as a result of future studies.

- Descent Imager – part of landing system images of the landing site at various heights to place the landing site into the local context. Some other instruments required for navigation/landing (e.g. landing LIDAR) may also provide data of scientific value.
- Landing Site Imager – multi-spectral imaging mineralogy for landing site characterisation. If possible, obtaining images of Earth from the landing site will also be desirable for outreach purposes and for studies using the Earth as an analogue for habitable exoplanets.
- Infra-Red Imaging Spectrometer – to characterize the local mineralogy.
- X-ray Diffraction/X-ray Fluorescence (XRF)/Gamma-ray spectrometer/Densitometer – to determine elemental composition, mineralogy, trace elements and radio-nuclides. Note: It is important to ascertain the thermal conductivity (e.g. via density) of the rock to accurately determine heat flow (a densitometer could be incorporated within the drill).
- Raman-LIBS (Laser Induced Breakdown Spectrometer) – to determine elemental composition and mineralogy at the landing site and of drill samples.
- Neutron spectrometer – for the determination of hydrogen concentrations in the local regolith for comparison with orbital measurements.
- Mass Spectrometer – for determination of the chemical composition of sampled materials, especially of volatiles and (ideally) stable isotopes. This would give potential for K-Ar age dating (when combined with K data from XRF or LIBS [8]), and characterization of volatiles trapped in the regolith. Requires a sample handling system and a carousel of ovens.
- Seismometer – for determination of internal lunar structure and characterization of natural moonquakes (might also be used to monitor drilling activities). If a multi-year mission life proves possible this could become a contribution to a future lunar geophysics network.
- Heat Flow – to better characterize lunar thermal evolution; needs to measure temperature and thermal conductivity as a function of depth.
- Dust, radiation and charging package – to determine dust particle size and electrostatic charging; should also include radiation monitor.
- Sample imager – to image samples analysed by others to provide colour and context (may have microscope capability).
- Low-frequency (LF) radio-astronomy investigation package – to investigate the practicality of LF radio-astronomy from the Moon (interference environment, etc); possible radio-frequency beacon to aid future missions.
- Proof of concept Magnetosphere Imager.

The above list is not exclusive and other instruments may be possible. This will be reviewed and consolidated as the project develops.

APPENDIX C. STRAWMAN ARCHIVE PAYLOAD

The following model payload is indicative of the archive currently anticipated. It will be refined as a result of future studies. In particular, the total length of capsules could be reduced in anticipation of a reduced expected minimum drilling depth.

- Mass: 10 kg.
- Volume: 10 litres.
- Dimensions: 10 metres of cylinders of 3.5 cm diameter and 33 cm length.
- Environmental requirements: TBD.