Technical Note 1

Moon Base Mission Scenario Definition

&

Life Support System Requirements

MELISSA ADAPTATION FOR SPACE, PHASE II

ESTEC/Contract Nº 20104/06/NL/CP

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J. Duatis J. Mas	1draft	25/06/07	New Document
J. Duatis J. Mas	1.0	11/01/08	Includes comments after PM 1, [R 29].

CONTENTS

ACRONYMS LIST

ATP	Authorisation To Proceed
BLSS	Bioregenerative Life Support System
BVAD	Baseline Values Assumption Document ([R 10])
COTS	Commercial Off The Shelf
ECLSS	Environmental Control and Life Support System
EVA	Extra Vehicular Activity
FPU	Food Production Unit
GCR	Galactic Cosmic Rays
HPC	Higher Plants Compartment
ISPR	International Standard Payload Rack
ISRU	In Situ Ressources Utilisation
LSS	Life Support System
MELiSSA	Micro Ecological Life Support System Alternative
SMAC	Spacecraft Maximum Allowable Concentration
SPE	Solar Particles Events

0. SCOPE

This document covers the definition of a Moon Base Mission Scenario as well as the Life Support System Requirements that must be taken into account for a potential use of a MELiSSA-based life support system in a lunar base context.

1. APPLICABLE AND REFERENCE DOCUMENTS

1.1 Applicable Documents

[A 1] Request for Quotation RFQ/3-11481/05/NL/CP – MELISSA Adaptation for Space - Phase 2, ref.: RES-PTM/CP/cp/2005.915, dated 16/11/05

[A 2] Statement of Work MELiSSA Adaptation for Space – Phase 2, Ref. TEC/MCT/2005/3467/In.CL dated November 4th, 2005, Version 1 (Appendix 1 to RFQ/3-11481/05/NL/CP)

[A 3] Special Conditions of Tender, Appendix 3 to RFQ/3-11481/05/NL/CP

[A 4] ESA Fax Ref. RES-PTM/CP7cp/2006.226, dated 29/03/06

[A 5] Minutes of Meeting ESA-NTE Clarification meeting on MELiSSA Adaptation for Space – Phase 2; no reference, dated 20/04/06

1.2 Reference Documents

[R 1] "Dynamics and steady state operation of a nitrifying fixed bed biofilm reactor: mathematical model based description" Pérez, J., Poughon, L., Dussap, G., Montesinos, J., Gòdia, F. Process Biochemistry 40 (2005) 2359 – 2369.

[R 2] "A structured Model for Simulation of Cultures of the Cyanobacterium Spirulina Platensis in photobioreactors: I. Coupling between light transfer and growth kinetics" Cornet, J.F., Dussap, C.G., Dubertet, G. Biotechnology and Bioengineering, Vol. 40, Pp 817-825 (1992)

[R 3] MELiSSA Yearly Report for 2004 Activity. Memorandum of Understanding TOS-MCT/2002/3161/In/CL. Vieira da Silva, L., Lasseur, Ch. ESA-EWP 2287 (June 2005)

[R 4] Ordóñez et al. "MELiSSA Higher Plants Compartment modeling using EcosimPro" ICES 004-01-2351 (2004)

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[R 6] CDF Study Report. Human Spaceflight Vision. European Man-tended Moon Base. CDF-23(A). (2004)

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[R 10] Advanced Life Support Baseline Values and Assumptions Document. Hanford, A.J. et al. (2004). NASA JSC-47804

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[R 13] Fulgent N., Poughon L., Richalet J., Lasseur C. Melissa, global control strategy of the artificial ecosystem by using first principles models of the compartments. Advances in Space research (1999), 24(3), 397-405.

[R 14] MELiSSA Memorandum of Understanding, Contract No. 19071/05/NL/CP

[R 15] Mas, J. L. et al., "Design Approach of Closed Loop Food Systems in Space", ICES 2005-01-2920 (2005)

[R 16] Vanrobaeys, X. et al., "A Crop Selection Algorithm for Closed Loop Food Systems" ICES 2005-01-2817, (2005)

[R 17] Proposal in response to ESA RFQ/3-11481/05/NL/CP MELiSSA Adaptation for Space - Phase 2, Ref. NTE-MEL2-OF-001, issue 1, 25/01/05

[R 18] Albiol, J. et al. Preliminary Review of the Pilot plant Final Loop; MELiSSA Technical note 47.3, December 2000

[R 19] Lasseur, Ch. Et al. MELiSSA: Overview of the Project and Perspectives, ICES 2005-01-3066, (2005)

[R 20] Schrunk, D. et al. The Moon: Resources, Future Development and Colonization. John Wiley & Sons – Praxis Publishing Ltd. 1999

[R 21] Eckart, P., The Lunar Base Handbook, Chapter 16, The McGraw-Hill Companies, 1999

[R 22] ECSS-E-30 Part 4A: Environmental Control and Life Support, 5 August, 2005

[R 23] Advanced Life Support Requirements Document, NASA document CTSD-ADV-245C, February 2003

[R 24] ALS Baseline Values and Assumptions Document, JSC-47804, NASA CTSD-ADV-484A, August 2004

[R 25] Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies. Commission on Physical sciences, Mathematics and Applications. National Research Council. International Standard Book Number 0-309-06491-0. National Academy Press, 2000

[R 26] ECSS-E-10 Part 11: Human factors engineering (to be published)

[R 27] ST9-4000-TN-021-NTE, issue 1.1, 28/05/05, Technical Note 3: Model Simulation and Trade-off, Closed Loop Food Systems ST9.1.

[R 28] NASA-SRD-3000. Man-Systems Integration Standards. Revision B, July 1995

[R 29] PM 1 Minutes of Meeting, Ref.: NTE-MEL2-MN-010, dated 05/07/07

[R 30] International Space Station Medical Operations Requirement Document, ISS MORD, SSP 50260, Revision C Draft 6.1, August 2005

[R 31] ESA water quality standards in manned space vehicles, ESA-PSS-03-402, issue 1, October 1994

2. MOON BASE MISSION SCENARIO DEFINITION

A Moon Base Scenario is proposed in Appendix 1 of ESA's fax [A 4]. For clarity purposes the scenario description is reproduced hereafter.

2.1 Overall Objective

It is assumed that a Moon Base infrastructure and its associated support are already in place on the lunar surface. The objective is to progressively assemble an integrated closed-loop Life Support System in a dedicated European module of the Moon Base and to operate it with the metabolic products and needs of the crew for demonstration purposes. All the functions need to be fulfilled:

- Air revitalization,
- Food production,
- Waste management and
- Water recycling.

It is also assumed that a primary Life Support System (LSS) exists already within the Moon Base and that the crew's life does not totally depend on the functioning of the Life Support System demonstrator in the European module. However, its implementation shall have clear benefits to the overall mission cost and risk, improving the recycling efficiency and providing operational redundancy to the functions ensured by the primary Life Support System.

2.2 Scenario Description

A potential European participation to the NASA Moon exploration architecture could be envisaged. In this perspective, a crew of four is assumed. Their stay is longer than six months or a new crew of four will be rotated every six months. Such a long duration justifies the use of a closed-loop Life Support System.

The crewmembers will find a man-tended base with dedicated modules, some of them provided by Europe. Such modules have a nuclear power source, which provides up to 40kW of electrical power. Nevertheless, the power usage shall be minimized.

The modules are completely fitted with structural, electrical, data & communications, thermal systems and interfaces. In particular, the European module dedicated to Life Support System has interfaces to other modules, which allow the reception and delivery of metabolic products and needs of the crew. Therefore, the Life Support System can be operated with the supplies of the neighbouring modules and deliver its products to them.

2.2.1 LSS envelope and volume

The volume envelope of the Life Support System without Food Production Unit (FPU) is potentially constraint to one module.

The LSS module shall be considered with semicircular cross section of diameter 8m and a length to be determined by the constraints on the volume, see Figure 2-1. The centre of this cross section shall be reserved for the crew and provide at least a free space of 2.5 x 2.5 m. The depth of this cross section is variable and can be freely chosen to accommodate necessary hardware and to meet any other considered requirements, such as NASA-STD-3000 requirements [R 28].

Volume usage shall be optimised by applying appropriate design and trade-off criteria.

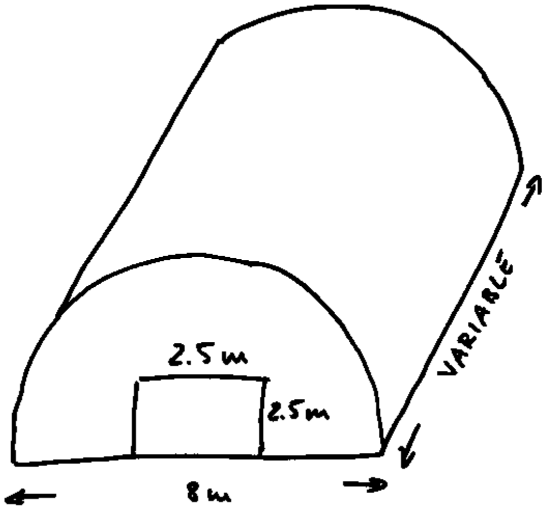

Figure 2-1: LSS module envelope sketch

Other accommodation options can be based on cylindrical geometry (as illustrated in the example of Figure 2-2). It offers certain advantages, like commonality with existing ISS designs, possibility of using International Standard Payload Rack-like (ISPR) support structures and also better compatibility during transport and surface operation phases.

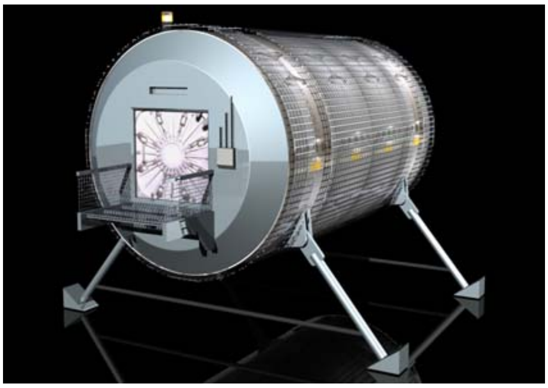

Figure 2-2: Planetary surface moule

2.2.2 Logistics and operational aspects

Logistics aspects shall cover consumables' needs and crew time for assembly, operation and maintenance of the system.

Operational aspects shall take into account a possible reduced power or less than four crew members, so that the system shows flexibility.

A staggered approach is envisaged, assembling and demonstrating progressively the entire closed-loop Life Support System unit by unit.

2.2.3 Performance

The following performance parameters shall be met for a four-member crew:

- The air shall be recycled to close to 100%
- The water shall be recycled to >90%
- Up to 5% of the food for the crew of four shall be produced in a first phase, then up to 40% as final performance.

The final performances must not be met within the first months but at the end of the second year. Instead, it is envisaged to assemble the Life Support System units in a suitable sequence to allow for closing all the life support system flows in an efficient manner. The units to be considered are the MELISSA compartments, the ARES subsystems, the Urine and Wastewater treatment units and associated European life support system hardware and technologies.

2.3 Moon Base Scenario: critical understanding

The Moon Base Scenario does not define some aspects that might have some impact on the design of the LSS. These will be further analysed in the course of the project and are advanced hereafter.

2.3.1 Lunar base location: thermal and illumination implications

The base location within the lunar surface may be relevant in the design of the LSS. Equatorial or Polar landing sites are likely locations for the base. However, they have very different features in terms of peak temperature excursion, illumination periodicity (due to the lunar day) and light intensity whose impact must be considered. For LSS concepts enclosed within the referred European module the base location on the lunar surface may not be relevant (assuming that such module provides sufficient thermal isolation and enough power supply). However for LSS with high food production units this issue may be relevant since likely greenhouse structures for the growth of higher plants will be necessary. And in this case, trades on illumination (natural versus artificial), consequences on power supply, thermal dissipation needs etc. will have to be considered against the deliveries and infrastructure provided by the European module.

2.3.2 Other environmental implications

The hostile lunar environment presents some features that need to be assessed in case some consequences may be derived for the design of the LSS. These are:

- Radiation: the LSS, being likely a combination of physico-chemical and biological devices, will host different forms of life (crew, microorganisms, higher plants) and electronic equipment that need to be protected from the wide radiation spectrum that reaches the lunar surface. Therefore radiation protection strategies (e.g. shielding) need to be dimensioned based on agreed below-lethal dose levels and proposed for the hosting modules.

- Reduced gravity: it may have an impact on the dynamics of the gas, liquid and solid loops and needs to be considered in the phase separation, notably gas/liquid

- Pressurised environment: the LSS will have to be located within a pressurised enclosure and the LSS elements will also have to maintain internally an equilibrium pressure. Therefore the entire system will have to feature pressure relieve valves /

venting where necessary to equalize pressure as well as the means to restore pressure in compensation for gas leakage.

Pressurised environment is particularly important for a food production unit as the gas loop is essential (carbon dioxide and oxygen) and higher plants need grow within certain pressure range for proper growth.

- Volume and envelope constraints: the available volume corresponding to the European module will be considered as in par. 2.2.1. Therefore, the study will determine the volume needs to attain up to 5% food production (assuming that it can be achieved with a combination of MELiSSA and other LSS technologies without the inclusion of a higher plans).

  To reach up to 40% food production capability a higher plants compartment seems necessary. In that case the cultivation surface for a crew size equal to four will be approximated and the volume needs derived.

3. LIFE SUPPORT SYSTEM REQUIREMENTS

3.1 Overview

This section contains the Life Support System (LSS) requirements that will define the scope of the system that will be evaluated in this study. They are not intended to define the implementation of such system and therefore can be designated as preliminary.

As a matter of structuring the requirements the ECSS-E-30 Part 4A Environmental Control and Life Support, [R 22], and the CTSD-ADV-245C Advanced Life Support Requirements Document, [R 23] have been taken as reference.

Based on the mission scenario described in the precedent session a LSS associated to the Moon Base will assume the primary life support functionalities and will be referred to as primary LSS. The European LSS to be accommodated in the European module will be a supplementary LSS for demonstration purposes and is referred to as secondary LSS or simply, LSS.

3.2 Mission and system

3.2.1 General

The European LSS module shall be designed to fulfil to the mission scenario definition and the mission objectives proposed in Chapter 2.

3.2.2 Mission

Mission characteristics are detailed in par. 2.1 to 2.3.

Req. 3-1: Mission duration
In steady state conditions the LSS will operate in continuous mode serving to a rotating crew, with a minimum stay equal to six months.

The mission is considered continuous once established although it can exhibit inactivity periods (system in stand-by conditions).

The operational lifetime of the system shall consider six-month periods without cargo re-supply (TBD 1). Therefore, system operations must follow a proper maintenance plan, defining accurately maintenance activities, list of spares and consumables, replacement periods and overall logistics.

Req. 3-2: Crew size and composition
The system shall serve to a four-members crew (mixed or non-mixed genders)

3.2.2.1 Mission phases

As a primary LSS is assumed to be operative in the Moon Base, the target LSS does not necessarily be fully operative at the mission onset.

The proposed LSS does not need to be operational during launch and transit phases. Therefore it can be transported disassembled and stowed (according to the logistics approach) and assembled and deployed in the reserved Moon Base's modules. As the secondary LSS will operate in parallel to an existing, already operative primary LSS, a staggered assembly can be planned through several assembly phases.

Once deployed a transient time of (TBD 2) duration can be expected until the LSS will be fully operational (i.e. able to recycle close to 100% air, more than 90% water and 5% food).

The system shall be designed with flexibility to support evolution of the technologies. As the experience generated by its real operation can cause improvements and could derive into changes of the initial design.

Req. 3-3: Transient time
The transient time until the LSS becomes operative shall be minimised.

Req. 3-4: Applicable conditions for mission phases
The applicable conditions for the LSS during the different mission phases shall be defined. Mission phases shall include:

- Ground and pre-launch operations
  - Storage, transport
  - Functional check out
  - Waiting on launch pad
- Launch and ascent
  - Launch time
  - External environment
  - Specific requirements during multi-g phases
  - Impact of depressurization and re-pressurization (IVA)
  - Launch abort situation
- Planetary orbital phase
- Transfer phase;
- Docking, docked and separation phases, rendezvous and parking;
- Planetary phase;
  - Landing, mission on planet;
  - Assembly
  - Commissioning and start of operations

The storage and transport conditions for supplies shall be specified.

External environmental conditions, both on ground and in space shall be taken into account.

3.2.3 System

3.2.3.1 Multi-ECLSS phases

The European LSS module will run in parallel with a main LSS. For the purpose of this study it is assumed that both LSS share the same accessible pressurised volume[1]. Therefore, specific interfaces for the exchange of gas, liquid and solid products amongst the two LSS systems shall be defined.

[1] Accessible pressurised volume corresponds to the Moon Base pressurised volume where crew can freely enter on a routine basis (e.g. crew quarter, planetary laboratories, etc.) plus the pressurised volume accessed by the crew only during maintenance operations (e.g. removable ceilings or floors, racks internal volume, etc.).

It is considered that the primary LSS will cope with life support needs arising from the performance of EVA, arrival of new planetary surface elements, etc. (e.g. it is assumed that space suits for EVA or planetary vehicles will feature their own LSS and will interface with the main LSS for replenishment, discharge of wastes etc.)

Req. 3-5: LSS in a Multi-ECLSS operation
The secondary LSS shall operate jointly with the primary LSS, sharing the same accessible pressurised volume and appropriate interface points.

Req. 3-6: LSS operational stability
The secondary LSS, being a demonstration LSS, may exhibit the possibility of working at a reduced performance, remaining in stand-by conditions or even being shut down. To prevent potential safety hazards or undesired operational conditions the LSS shall have the means to isolate from the primary LSS.

3.3 General

3.3.1 Forms of life

Req. 3-7: Forms of life - human
The proposed LSS shall be designed for any combination of male and female crew composition.

Human factors and metabolic characteristics are detailed in [R 23] and [R 24].

Req. 3-8: Other forms of life
The LSS shall ensure the compliance with the metabolic and environmental conditions required to sustain any other forms of life that may be associated to the system (e.g. higher plants, microorganisms, etc.)

3.4 Functional Requirements

3.4.1 Overview

The ESA's LSS under study is planned to be in a separated module docked to the Moon Base. See conceptual views in Figure 3-1 and Figure 3-2. A primary LSS associated to the Moon Base will be running in parallel and will be responsible for the overall base's environmental control and life support functions. The ESA's LSS, or secondary LSS, may thus be deployed progressively.

The main goal of the ESA's LSS is technological and functional demonstrations. In addition its implementation shall have clear benefits to the overall mission cost and risk, improving the recycling efficiency and providing operational redundancy in case of environmental contingencies to the functions ensured by the primary LSS.

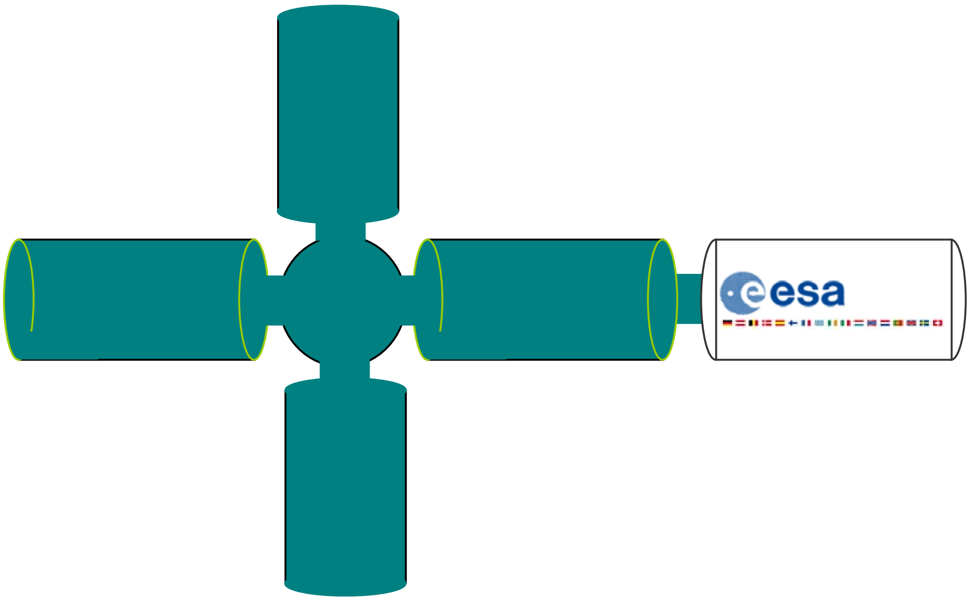

Figure 3-1: European LSS module attached to the Moon Base structure (top view).

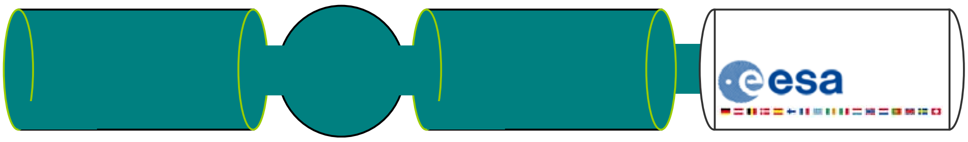

Figure 3-2. European LSS module attached to the Moon Base structure (lateral view).

3.4.2 Maintain environment

Based on the mission concept primary and secondary (ESA's) LSS will operate in parallel and therefore it is likely to have some interaction between both systems. A regulation of flows to / from both systems should be planned and controlled to optimize their joint operations.

For controlling these flows a simple configuration is proposed. In this case, the primary LSS module performs the flows control to/from the accessible pressurized volume within the Moon Base and the secondary LSS module becomes in fact a subsystem of the primary LSS. Therefore, the ESA LSS module delivers processed air, water and food to the main LSS and obtains waste water, solid wastes and air from the main LSS (Figure 3-3)

The exchange between the primary and secondary LSS should be dimensioned so that it is equivalent to the flows generated by a crew of four members.

The following requirements address the conditions in which the secondary European LSS shall operate. Some of these requirements apply to the LSS itself. However some requirements apply to the Moon Base existing infrastructure and therefore, are included herein for completion.

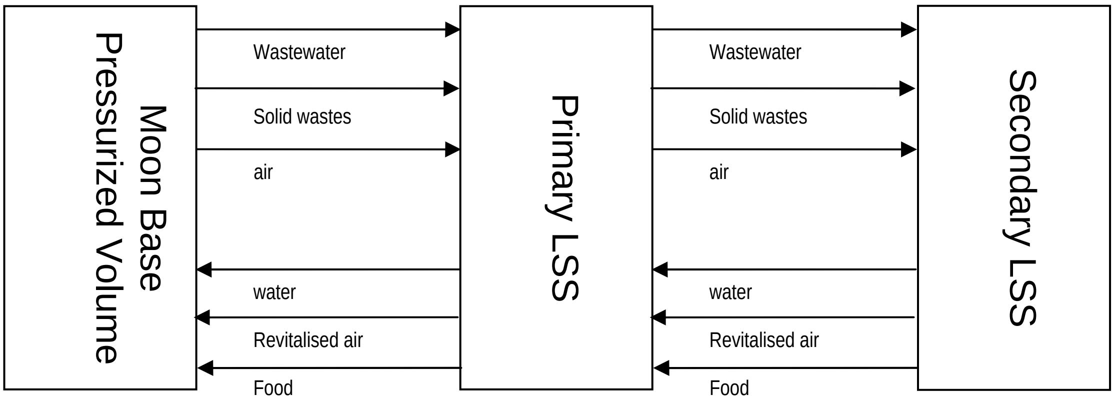

Figure 3-3: Primary and Secondary LSS joint operation

Req. 3-9: Control atmosphere total pressure
The existing Moon Base infrastructure that houses the LSS shall provide the means to control the total atmosphere pressure so that the LSS module's accessible pressurised volume remains within the limits defined in Req. 3-41.

Pressure control infrastructure at least shall account for:

- Total pressure monitoring
- Over-pressurization prevention
- Means for pressure equalization with adjacent pressurised volumes
- Means for pressure adjustment (e.g. addition of nitrogen)

Req. 3-10: Control oxygen partial pressure
The LSS shall control the oxygen partial pressure in order to meet the required value so that the air eventually delivered to the pressurised volume maintains the appropriate oxygen partial pressure.

Req. 3-11: Control trace gases and odour
The LSS shall monitor and control trace gases and odour so that the contribution to the total trace gases and odour contents in the accessible pressurised volume remains within the SMAC limits.

Note: as the contribution of the primary LSS is unknown the contribution due to the secondary LSS shall meet the SMAC requirements. The compounds of interest are (TBD 4).

Req. 3-12: Control airborne particles
The LSS shall include the means to monitor and maintain the airborne particles at such level so that the concentration in the accessible pressurised volume remains within the (TBD 5) threshold.

Req. 3-13: Control thermal nominal condition
The existing Moon Base infrastructure that houses the LSS shall provide the means to control the thermal nominal conditions in the module's pressurised volume in order to safeguard the operations of the LSS. Thermal nominal conditions shall be as per the thermal environment defined in Req. 3-43.

The thermal control infrastructure shall include, at least:

- Maintenance of the temperature within the acceptable limits (heating or heat removal capability)

- Monitor and maintenance of the relative humidity within the acceptable limits defined in Req. 3-44.
- Air recirculation for ventilation purposes

Req. 3-14: Control of microorganisms
The LSS shall monitor and control the presence of microorganisms when delivering air, water and food to the main LSS.

Req. 3-15: Support ionizing radiation control
The existing Moon Base infrastructure that houses the LSS shall provide the means to protect against the ionising radiation by including appropriate shielding to maintain this radiation below the allowable limits. Consensus dose limits can be found in [R 22], annex B.2.4.

This infrastructure should also provide the capability to monitor the radiation levels inside the LSS accessible pressurised volume where other forms of life like microorganisms or plants reside.

Req. 3-16: Support non-ionizing radiation control
Non ionizing radiation shall be maintained below the standard limits [R 22],

3.4.3 Respond to environmental contingencies

3.4.3.1 Respond to uncontrolled depressurization

It is assumed that the module that will house the secondary LSS features the required infrastructure to detect and recover from uncontrolled depressurization events, either because the depressurization rate is higher than a (TBD 7)value or because the total pressure in the accessible (habitable) volume decreases below a threshold (TBD 8) limit value.

Req. 3-17: Withstand depressurization
The secondary LSS shall be designed to withstand the module's uncontrolled depressurization while maintaining safe conditions. The maximum depressurization rate is (TBD 7).

3.4.3.2 Respond to uncontrolled pressurization

It is assumed that the module that will house the secondary LSS features the required infrastructure to detect and recover from uncontrolled pressurization event that takes place when the pressurization rate is higher than a specified value and shall be detected before the accessible (habitable) volume total pressure exceeds a threshold limit value.

Req. 3-18: Withstand pressurization
The secondary LSS shall withstand the module's uncontrolled pressurization while maintaining safe conditions. The pressure threshold is (TBD 9).

3.4.3.3 Respond to fire

It is assumed that the module that will house the secondary LSS includes the appropriate safety elements for fire detection, suppression and recovery

Req. 3-19: Fire prevention
The secondary LSS shall be constructed with fire resistant materials. Fire hazards shall be identified and hazard suppression methods shall be implemented.

3.4.3.4 Respond to hazardous radiation exposure

The Moon Base infrastructure is assumed to include the means for detecting and protecting from exposure to hazardous radiation. It implies the infrastructure for real-time measurement of radiation levels (hazardous or normal), alarm system in case of hazard occurrence and shelter or safe-heaven for protection from hazardous radiation. This infrastructure is specially oriented for protection of human life.

In addition, it is also assumed that the module that will house the secondary LSS will include the radiation shielding infrastructure for nominal surface radiation protection. In view of the other forms of life present in the LSS protection in case of hazardous, non-nominal radiation must be guaranteed.

Req. 3-20: Hazardous radiation
Protection of other forms of life (e.g. microorganisms, plants) under hazardous radiation levels (e.g. during solar flares events) shall be guaranteed.

Note: The Moon-Base should feature a safe heaven to protect the crew in case of solar flares. Safe heaven implementation should take into account the presence of other life forms in the LSS and the fixed, not easily transportable habitat where these forms leave.

The radiation dose acceptable thresholds of the other forms of life present in the LSS are (TBD 3).

3.4.3.5 Respond to hazardous atmosphere

It is assumed that the Moon Base has the functionality for detecting and recovering from a hazardous atmosphere composition in the accessible pressurized volume. This functionality includes:

- Detect hazardous atmosphere
- Provide human protection
- Restore an acceptable atmosphere

Req. 3-21: Hazardous atmosphere
The LSS shall feature the means for detecting, protecting and restoring from a hazardous atmosphere, by:

- Inclusion of proper sensors or detection equipment able to distinguish the hazardous atmosphere condition
- Inclusion of provisions (e.g. air locks, venting, etc.) to avoid harm for humans

Note: hazardous atmosphere may be due to the presence of airborne contaminants (particles, micro-organisms, dust, off-gassing materials, etc.) or due to a non-nominal gas composition.

3.4.4 Provide Resources

3.4.4.1 Provide inert diluent gas

Inert diluent gas, typically nitrogen mainly used for pressure control, is assumed to be supplied to the LSS and its associated pressurised volume by the corresponding storage facilities belonging to the Moon Base infrastructure.

No specific requirements concerning diluent gas are levied on the LSS.

3.4.4.2 Provide oxygen

The LSS shall supply oxygen to support the metabolic activities of a crew of four members.

Req. 3-22: Oxygen production
The mission scenario defines air-recycling efficiency near the 100%. That means that oxygen production shall be near to 100% oxygen consumption.

	Standard value ($Kg\ p^{-1}\ d^{-1}$)	Range ($Kg\ p^{-1}\ d^{-1}$)
Crew O2 consumption	0.84	0.49 – 1.25

The total production for the crew of four shall be thus 3.36 Kg d^{-1}. Values and ranges can vary depending on the crew activity, composition and other oxygen consumer elements, as for example specific experiments [R 23].

Req. 3-23: Oxygen storage
The LSS shall be able to store excess oxygen produced, if any, in order to allow the regulation of oxygen delivery to the pressurized volume.

Req. 3-24: Oxygen supply
The LSS shall be able to regulate oxygen supply in order to maintain the nominal partial pressure (P_{O2}). The nominal oxygen partial pressure in the accessible pressurised volume shall be maintained within the range 180 to 231 hPa [R 23].

3.4.4.3 Provide water

Req. 3-25: Water production
The mission scenario defines water recycling over the 90%. That means that the system shall be able to provide at least the 90% of the crew's water needs.

	Standard value ($Kg\ p^{-1}\ d^{-1}$)	Range ($Kg\ p^{-1}\ d^{-1}$)
Crew water consumption	2.8	Up to 5.15
Crew hygiene water usage	6.8	Up to 7.3
Total water needs	9.6	Up to 12.45

Therefore the total water production to cover at least 90% of the 4-members crew needs shall be at least 34.5 Kg d^{-1}.

Req. 3-26: Water storage

The LSS shall be able to store excess water produced in order to allow the regulation of water delivery.

Req. 3-27: Water supply
The LSS shall be able to regulate water supply in order to maintain a regular flow.

Req. 3-28: Output water quality standard
The system shall recover the yellow, grey and condensate input water into drinkable and / or hygiene quality water.

For that purpose the reference quality standard shall be the *ESA water quality standards in manned space vehicles*, ESA-PSS-03-402, issue 1, October 1994, [R 31], which identifies in its Part II the quality criteria applicable to potable and hygiene water relative to:

- Organoleptic parameters
- Physical-chemical parameters
- Substances undesirables in excess amounts
- Toxic substances
- Microbiological parameters
- Minimal required concentration of softened water intended for human consumption
- Radiological requirements

The Medical Operations Requirements Document [R 30] shall also be considered for this requirment.

Req. 3-29: Output water quality determination
The LSS shall include on-line and / or off-line water quality determination equipment.

3.4.4.4 Provide food

The LSS shall include the means for producing food in two consecutive steps. Firstly the LSS shall provide 5% of the dietary contents for the crew of 4. In a second step, the LSS shall deliver up to 40% of the dietary needs for this crew of 4.

The LSS will deliver food in raw form. Food processing function is considered part of the Moon Base facilities and therefore is not included in the ESA LSS module.

Metabolic energy requirements are actually depending on several factors like gender, age, body mass, level of activity, etc. and eventually should be determined on an individual basis. Thus, for a 70 kg weight person, the metabolic energy intake needs may lay between 2,300 and 2,975 kcal d^{-1} [R 23]. For the purpose of this study an average value of 2,830 kcal d^{-1} (or 11.82 MJ d^{-1}) is considered.

Req. 3-30: Food production
According to the two consecutive cases defined in the mission scenario the LSS shall be able to deliver the following metabolic energy to the crew of four:

	Standard value (kcal d^{-1})	Range (kcal d^{-1})
5% metabolic requirement	566	-
40% metabolic requirement	4,528	-

Req. 3-31: Nutrient requirements
The distribution of nutrients on the Recommended Dietary Allowance (RDA) is as follows:

- The energy provided by the proteins intake present in the RDA shall generate 12-15 % of the total metabolic energy consumed.
- The energy provided by the carbohydrates intake present in the RDA shall generate 50-55 % of the total metabolic energy consumed.
- The energy provided by the lipids intake present in the RDA shall generate 30-35 % of the total metabolic energy consumed.

Table 3-1 provides an example of nutritional composition of four representative crops in 100 g of fresh, raw edible material, which can be used as reference for the computation of the food production needs defined in Req. 3-30.

Note: micronutrients (vitamins, minerals and trace elements) are not considered for the purpose of this study.

	*for 100 g of edible part (fresh and raw)						
	g H_2O	g protein	g lipid	g carbohydrate	g carbohydrate available (carbohydrate - fiber)	g fiber	Kcal
French beans	11,0	21,6	1,4	62,4	47,2	15,2	341,0
Lettuce	94,6	1,2	0,3	3,3	1,2	2,1	17,0
Soybean	8,5	36,5	19,9	30,2	20,9	9,3	416,0
Wheat	12,8	15,4	1,9	68,0	55,8	12,2	329,0

Table 3-1: Contents (in grams) of water, proteins, lipids, carbohydrates, fibre and kilocalories per 100 g of fresh, raw vegetable [R 27]

The mass – energy conversion factors for the various type of macronutrients that can be used for food mass computations are the following:

Macronutrient	Kcal g^{-1}	kJ/g^{-1}
Protein	4	16.7
Fat	9	37.7
Carbohydrate	4	16.7

Req. 3-32: Food storage
The infrastructure for food storage in proper preservation conditions is considered to be part of the main LSS. Food surplus, if any, shall be dimensioned.

3.4.5 Manage waste

3.4.5.1 Manage carbon dioxide

The carbon dioxide to be processed is that found in the accessible pressurised volume. It is assumed that the Moon Base infrastructure includes the appropriate equipment for CO_2 separation as well as the appropriate interface with the LSS that allows the collection of this gas for its processing by the LSS.
The CO_2 monitoring functionality is assumed to be part of the Moon Base infrastructure as this function is particularly relevant for the monitoring of the CO_2 partial pressure within the crew habitat.

It is also assumed that the Moon Base has the appropriate air circulation infrastructure to ensure a homogeneous atmosphere composition within the accessible pressurised volume.
Note: it is assumed that the nominal Moon Base air circulation speed for ventilation purposes is within 0.076 to 0.203 m s^{-1} [R 23].

Req. 3-33: CO_2 management
The LSS shall be sized to allow the processing (i.e. mainly conversion into oxygen) of the metabolically produced CO_2 by the crewmembers. The standard daily rate equals 1 Kg p^{-1} d^{-1}. Taking into account that the mission scenario defines air-recycling efficiency near the 100% then the LSS shall be able to process near the totality of carbon dioxide produced by the four-members crew (4 kg d^{-1}).

	Standard value ($Kg\ p^{-1}\ d^{-1}$)	Range ($Kg\ d^{-1}$)
Crew CO_2 generation rate	1,00	0,52 – 1,50

The CO_2 to be processed is thus 4,00 Kg d^{-1}. CO_2 potentially generated by LSS internal processes is not considered here. Waste combustion, as another potential carbon dioxide source, is neither considered.

Req. 3-34: Carbon dioxide regulation
The LSS shall include the means for regulation of CO_2 processing. For that purpose the LSS shall feature the required elements for flow control and storage.

Note: a Food Production Unit based on the cultivation of higher plants, as part of the LSS, may have its own CO_2 regulation loop in order to optimise the productivity in terms of fresh food and / or oxygen.

3.4.5.2 Manage wastewater

Req. 3-35: Wastewater sources
The system shall be able to manage the following wastewater sources for resource recovery and / or storage:

- Yellow water, YW:
  - Urine
  - Urinal flush
- Grey water, GW:
  - Shower water
  - Hand wash
  - Oral hygiene
  - Laundry
  - Dish washing
  - Food processing water
- Crew Latent Humidity Condensate

In addition to these recyclable wastewater sources plant transpiration water shall be considered for recycling in the context of the Food Production Unit.

Req. 3-36: Wastewater processing

The system shall be able to process the daily amounts of wastewater per each incoming source as indicated in the following table (source [R 24], for a mature planetary base) to recover potable or hygiene water and produce a concentrated waste:

	Daily amounts ($kg\ p^{-1}\ d^{-1}$)	Remark
Urine	1,5	[R 24]
Urinal flush	0,5	[R 24]
Oral hygiene	0,37	[R 24]
Hand wash	4,08	[R 24]
Shower	2,72	[R 24]
Laundry		Primary LSS
Dish washing		Primary LSS
Food preparation		Primary LSS
Crew Humidity Condensate	2,27	[R 24]
Plant Humidity Condensate	(TBD 10)	Crop dependant
Total daily amount	11,44	

For the 4-member crew served by the LSS the total amount of wastewater to be processed equals to 45,76 kg d^{-1}.

Req. 3-37: Wastewater collection, transport and storage
The LSS shall provide means for collecting, transporting and storing wastewater:

- Wastewater collection shall be performed through specific interface collection points.
- The LSS shall include the means for transporting wastewater from the collection points to the processing equipment and storage facilities
- Wastewater storage facilities shall account from peak demands and contingency situations, mainly temporary loss of downstream processing capability

Req. 3-38: Contaminants rejection
The LSS shall reject water contaminants within the limits established in *ESA water quality standards in manned space vehicles*, ESA-PSS-03-402, issue 1, October 1994:

- Soap
- Chemical contaminants of condensate water
- Chemical and microbial characteristics of biologically treated urine

3.4.5.3 Manage solid and concentrated liquid wastes

Req. 3-39: Solid and concentrated liquid sources
The system shall be able to manage the following solid and concentrated liquid wastes for resource recovery, storage and / or disposal:

- Human faeces (black water, BW)
- Inedible portion of plants

Note: other solid or concentrated liquid wastes exist (e.g. food packaging, trash, medical wastes, etc.) but are assumed to be managed in the primary LSS context and therefore not considered in this study.

Req. 3-40: Solid and concentrated liquid processing

The system shall be able to process the daily amounts of wastes indicated in the next table. It is assumed that these wastes are directly processed by a bioreactor holding a fermentation type of process.

	Daily amounts ($g\ p^{-1}\ d^{-1}$)	Remark
Faeces (solid part)	32	[R 24]
Faeces (water part)	91	[R 24]
Flush water	500	Assumption
Inedible parts of plants	(TBD 11)	Highly crop selection dependant
Total daily amount	623	

The LSS shall be able to process a total black water amount for a 4-members crew equal to 2,5 kg d^{-1}, most of which corresponds to flush water.

The amount of inedible part of plants is largely dependant on the selected crops. E.g.: the cultivation plan proposed in Table 3-1 generates about 6,7 kg d^{-1} of fresh, non edible biomass.

3.4.6 Environmental conditions

3.4.6.1 Pressure environment

It is assumed that the LSS, once assembled inside the European module, will operate in a pressurised environment with pressure levels equal to the overall Moon Base accessible pressurised volume. Nominal operational pressure is within the range 1000 to 1027 hPa [R 23].

Req. 3-41: Pressure environment
The proposed LSS shall be designed to operate in a pressurised environment, with nominal operational pressure levels within the range 1000 to 1027 hPa [R 23].

Req. 3-42: Pressure equalization
The interface between the (secondary) LSS module and the rest of the Moon Base shall permit to equalize the pressure differential to less than a difference of 70 Pa within 180 s.

Note: specification extracted from ISS

3.4.6.2 Thermal environment

The lunar surface temperature is depending on the latitude and the time of the lunar day (equivalent to ca. 28 terrestrial days). The hottest temperature is achieved at equatorial latitude and at noon, reaching 380 K. The coldest temperatures are attained during the lunar night and can descend down to 120 K. It is supposed that the thermal environment is regulated by the thermal control infrastructure existing in the module that houses the LSS so that ambient temperature is around 20ºC.

Req. 3-43: Thermal environment
The proposed LSS shall operate in a thermal environment within the range 18.5 to 26.8 ºC [R 23].

Req. 3-44: Humidity environment
The environmental humidity shall be within the range 25 to 70% [R 23].

3.4.6.3 Radiation environment

The lunar surface is exposed to two major natural radiation sources: solar particles events (SPE), which include solar wind and solar flares, and galactic cosmic rays (GCR). This ionizing radiation is a potential thread for both, biological systems present in the lunar base, including crew, and also electronic equipment.

The deleterious effects of ionizing radiation on biological systems are a function of the dosage and the exposure time. Over the lunar surface GCR deliver a relatively constant radiation of approximately 30 rem/year. High-energy protons produced during solar flare events can deliver hundreds of rem[2] in few hours.

In terrestrial conditions the maximum permissible whole-body radiation dose rate for an individual is determined at 5 rem/year [R 21].

The microbiological species involved in the biological treatment processes within the LSS tolerate radiation doses below (TBD 3) rem/year.

Req. 3-45: Radiation environment
It is assumed that the module that will house the LSS provides the required structural means to protect from the radiations present at the lunar surface.

See also Req. 3-20 for protection against hazardous radiation levels

3.4.6.4 Lunar dust

The lunar surface is covered by a fine talc-like powder, which is abrasive and tends to adhere to the objects with which it comes into contact.

Req. 3-46: Lunar dust protection
The LSS operation shall not be degraded due to the effects of the lunar dust.

3.4.6.5 Lunar gravity

The gravity of the moon is one sixth of that on Earth. Phase management (liquid, solid and possibly gaseo) in a reduced gravity environment needs to be considered in the LSS design.

Flow in porous media (which in the LSS case can be exemplified by the liquid flow through filtration devices) depends on primary driving forces like gravity, pressure gradients and capillarity. However the behaviour of flow in conditions of reduced gravity is poorly understood [R 25]. Impact of reduced gravity in liquid flow control elements like bioreactors, filters, etc., which will be likely present in the LSS, shall be determined.

Req. 3-47: Operations under reduced gravity
The operation of the LSS systems and subsystems shall not be impaired by the reduced gravity conditions (1/6g) on the lunar surface.

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[2] Rem: radiation equivalent man, unit for the Biologically Effective Dose. This is the radiation dose in rads multiplied by a relative biological effectiveness (rbe) factor, which is an assessment of the effectiveness of that particular type and energy of radiation. For alpha particles the rbe may be as high as 20, so that one rad is equivalent to 20 rems. However, for gamma rays, the rbe is taken as one so that the rad and rem are equivalent for those radiation sources. Biologically Effective Dose can also be measured in sieverts (Sv). One sievert is equal to 100 rems.

3.4.6.6 Environmental protection

Environmental protection is an important measure that shall be taken in lunar exploration missions, specially those involving human presence. Environmental protection requirements can be levied on the LSS assembly and operation.

Req. 3-48: Compatibility with environemental protection procedures
The LSS systems, subsystems and materials shall permit the application of environmental protection measures, also taking into consideration the human presence on the planetary surface (e.g. sterilization, chemical decontamination, etc.).

Req. 3-49: Waste handling
Waste materials resulting from the LSS operations must be stored, deactivated or, if possible, reintroduced in waste treatment assemblies and their dispersion to the planetary surface shall be avoided.

4. DESIGN REQUIREMENTS

4.1 General

The LSS is considered as a stand-alone module to be docked to an existing Moon Base. The design requirements shall cover the housing of the LSS, i.e. the module design, as well as the internal components consisting on the different LSS components, which can be considered pressurized payloads.

4.2 Structural and mechanical

Structural and mechanical applicable requirements can be derived considering the LSS module with the same baseline cylindrical structure as that of standard ISS-like modules (e.g. Columbus, ATV). Additional factors that can affect are:

- Landing on lunar surface
- Regolith, dust
- Radiation
- Temperature gradients

LSS elements can be accommodated using ISPR-like rack structures.

Req. 4-1: Module mechanical structure
The LSS without the FPU shall be initially constraint to one module, as suggested in Figure 2-1, with a half-cylinder cross section and dimensions there in indicated.

Note: structural and mechanical characteristics of this module are not in the scope of this document, as the module itself is assumed to be already deployed on the lunar base.

4.3 Thermal

It is assumed that the LSS is thermally protected by its shelter module. It features a thermal control system able to maintain the internal temperatures within the nominal range appropriate for the operation of the LSS components given in Req. 3-43.

Req. 4-2: Thermal radiation
The LSS shall feature a thermal radiation system to evacuate excess heat.

Req. 4-3: Thermal control system
The LSS shall provide thermal control system that will maintain the temperature inside the allowable margins for proper LSS operation.

Req. 4-4: Thermal interface regulation
The LSS shall provide thermal regulation especially with the interface with the rest of the Moon Base.

4.4 Operations and logistics

The LSS shall be maintainable, i.e. it shall be possible to retain in, or restore to, the LSS into a state in which it performs its required functionalities after maintenance actions are completed.

Req. 4-5: Operational modes
The LSS, depending on its status, shall have at least three operational modes:

- Nominal: the LSS maintains all the operational parameters (production rates, settings, etc.) within the nominal ranges.
- Degraded: The operational parameters' threshold limit values corresponding to the degraded mode are TBD 12.
- Emergency: The operational parameters' threshold limit values corresponding to the emergency mode are TBD 13.
- Autonomous mode: the LSS is able to maintain operations autonomously, without crew intervention (e.g. in case of temprary moon base evacuation).

Note: In case of emergency mode, the crew shall have the capability to restore (at least) the state of degraded mode without external resources.

Req. 4-6: Nominal mode
Nominal mode shall be defined with flexibility with respect to crew size since reduced crew than four shall be supported. In this case, the system shall reconfigure itself according to the new demand.

Req. 4-7: Accessibility
The LSS elements shall be accessible for inspection, repair or exchange. For this purpose standard tools shall be privileged. Non-standard tools, if any, shall be clearly identified.

Req. 4-8: Maintenance plan
The LSS concept shall have associated a maintenance plan where preventive and corrective maintenance actions are identified.

Req. 4-9: Preventive maintenance
The LSS items subject to preventive maintenance (i.e. all actions taken while the item is in an operational state in order to eliminate the causes for potential failures), the maintenance schedule or frequency, the maintenance time and the required tools and consumables shall be identified.

Note: items subject to preventive maintenance shall include, at least, elements requiring purging, cleaning or calibration.

Req. 4-10: Corrective maintenance
LSS elements whose life expectancy is below (TBD 6) year(s) shall be subject to corrective maintenance (i.e. the unscheduled repair or replacement of an item after failure).

Req. 4-11: Crew time
The LSS design shall minimise the crew time needs for performing the scheduled preventive maintenance tasks addressed in Req. 4-9 or the corrective maintenance tasks addressed in Req. 4-10.

Req. 4-12: Spare plan
A spare plan shall be defined in order to identify the LSS items that will need repair or replacement within next six month.

Note: it is assumed that the re-supply period is 6 month.

Req. 4-13: Recovery actions

Failure of the function of the LSS can degrade human capability to implement the recovery actions to return the system to the nominal condition. Automatic recovery actions shall be planned in case of emergency.

4.5 Human factors

The design of all the LSS hardware and their mounting inside the pressurized volume cannot be done without taking into consideration that hardware is functioning with, for and under the control of humans. That implies the complete apprehension and application of ergonomics, psychological and cognitive factors and constraints. Some basic human factor requirements can be outlined.

Req. 4-14: Labelling
LSS elements shall be properly labelled so that the can be readily and univocally identifiable.

Req. 4-15: Sharp edges
The design shall avoid the presence of sharp edges, protrusions, etc., that could cause harm to the crew, in all operational cases.

Source: NSTS 1700.7B ISS ADDENDUM, Safety Policy and Requirements for Payloads Using the International Space Station, paragraph 222.1.

Req. 4-16: Accessibility
The LSS system and subsystems shall guarantee an easy accessibility to the crew for maintenance purposes, down to the level of exchangeable components.

Req. 4-17: Man machine interaction
The LSS man machine interface (hardware and software) shall be designed according to standards for ergonomics, psychological and cognitive factors and constraints. Requirements on human factors can be found in ECSS-E-10 Part 11 and are not detailed here.

4.6 Data management and control

The LSS shall have a control system (either specific for this system or integrated within the overall base's life support control system). The purpose of this control system shall be:

- To maintain the controlled variables in the optimal ranges to maximise the LSS operation in terms of efficiency and system stability
- To prevent errors or malfunctions, detecting deviations from nominal conditions and implementing alarms in order to have a reliable operation
- To provide a way to respond to system deviations in order guarantee a safe system operation.

Req. 4-18: Sensors and actuators
The LSS control system shall include the proper set of sensors and actuators required for the monitoring and automatic control of the LSS system.

Req. 4-19: Supervision
The LSS control system shall implement a supervisory function, which shall provide

- An efficient way for detecting malfunctions or performance deviation
- On-line information about system processes

- A proper man-machine interface to interact with the system for deviation or malfunction correction

Req. 4-20: Alarms
The LSS control system shall generate alarms when detecting that any measured and/or controlled variable is out of the nominal range and shall permit the management of these alarms. The response to the alarms shall correspond to their severity, in accordance to the safety / risk analysis of the system.

Req. 4-21: Data management
The LSS control system shall feature a data management function, which at least shall include on-line data display of all the monitored variables in the system and data storage for off-line analysis.

Req. 4-22: Failure isolation and recovery
The LSS control system shall provide for failure isolation, informing about the component of the system that caused the failure. It shall also provide means for failure recovery either using hardware or analytical redundancy to allow graceful degradation of the performance until major corrective actions are taken.

Req. 4-23: Automation
The Control System shall implement the highest automation degree allowable.

Req. 4-24: Interface
The Control System shall interface with other on-base data management systems and with on-ground support.

Req. 4-25: Manual override
The Control System shall provide means for the manual override of its control function.

5. INTERFACE REQUIREMENTS

The LSS will be run in parallel with a main support system. The interface between the two systems shall be taken into account at design level.

5.1 General

The ESA LSS module will have mechanical, electrical, data communications and thermal interfaces with other Moon Base modules.

5.2 Mission Interfaces

Req. 5-1: Software and data systems interface
The LSS Software and data systems interface shall be consistent with the main Software and data handling systems on the Moon Base. Furthermore, it shall be conformant to the main on-ground data handling system.

Req. 5-2: Thermal interface
The LSS shall feature its internal thermal control and be consistent with the thermal control system at Moon Base level.

Req. 5-3: Biological interface
The LSS shall isolate biologically all the interfaces to / from the rest of the base modules.

Req. 5-4: Mechanical and structural interface
The module will have external mechanical interfaces with at least another Moon Base module. These mechanical interfaces shall cover:

- Metabolic product flows to / from the module to enable the LSS function (air, water, food and wastes).
- Crew access to the module.
- Electrical and data communication connection.

Req. 5-5: Electric power
The LSS shall minimize power usage. Expected available power for the Moon Base is 40 Kw (nuclear plant).

6. SAFETY AND RELIABILITY REQUIREMENTS

The LSS can be classified as a critical system in manned missions, since it is mandatory for crew survival.

6.1 Safety

Req. 6-1: Crew survival
The inclusion of the LSS into the Moon Base shall not impair the safety levels that guarantee the crew survivability throughout the mission.

Req. 6-2: Hazards
All hazardous elements within the LSS design shall be identified, associated risks assessed and risk reduction options identified. Special care shall be taken concerning the use of hazardous materials, as part of the LSS itself or as consumables and appropriate levels of containment shall be ensured.

Req. 6-3: Biosafety
LSS shall include the means for control biosafety in order to prevent and to avoid the spreading of biological contamination from the LSS to the rest of the Moon Base through the gas, liquid and / or solid system's loop.

6.2 Reliability

Req. 6-4: Fault Tolerance
LSS shall be two-fault tolerant and when this is not feasible systems shall be designed so that no single failure can cause loss of the crew. As the envisaged European LSS module will be at the beginning redundant to the main ECLSS this requirement may be initially relaxed. However, as a demonstration technology, the system shall be designed to plan the full coverage of the requirement progressively.

Mission duration is expected to be continuous non-stop, rotating four crew members every six months. That means that multiple failures can be expected. The system shall consider fault tolerance as a combination of reliable hardware design, redundancy and logistic capabilities to support preventive and corrective maintenance. In addition, the system shall be designed to degrade gracefully, that is, failures may affect the performance of the system but do not stop its main function. Expected time of spares re-supply can vary from weeks to months, therefore maintenance of the system components shall be programmed accordingly.

Req. 6-5: Failure detection, diagnosis and recovery
Failure detection, diagnosis and recovery procedures shall be implemented. Recovery procedures can imply hardware redundancy, analytical redundancy or maintenance depending on the criticality of the failure.

Req. 6-6: Lifetime
The LSS lifetime shall be (TBD 14). The LSS components shall have the appropriate life expectancy in order to permit a reliable operation according to the maintenance plan. Limited life items and their repair or exchange needs shall be identified. Lifetime shall be assessed by means of:

- Mean Time Between Failures (MTBF): the average time between two consecutive failures of a repairable item.
- Mean Time To Failure (MTTF): the average lifetime of a non-repairable item.
- The life cycle expectancy of the other forms of life potentially present in the LSS.

ANNEX 1: TBD LIST

TBD 1: A re-ssuply period equal to six months is assumed for the LSS design. To be confirmed if this is the minimum time

TBD 2: The initial transit time on the Moon Base is unknown

TBD 3: Radiation levels on microbiological species used in MELiSSA

TBD 4: Compounds of interest that must be the SMAC criteria should be defined

TBD 5: Characteristics and threshold concentration of unacceptable airborne particles

TBD 6: Life expectancy of LSS items

TBD 7: Depressurization rate

TBD 8: Accessible volume lower pressure threshold

TBD 9: Accessible volume higher pressure threshold

TBD 10: Plant humidity condensate values (crop dependant)

TBD 11: Plant inedible fraction (crop dependant)

TBD 12: Degraded mode parameters limits

TBD 13: Emergency mode parameters limits

TBD 14: LSS System lifetime