MELISSA

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Definition of the control requirements for the MELISSA Loop

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TABLE OF CONTENTS

1 SCOPE

This document is the definition of the global Control System Requirements of the MELISSA Loop, including associated technologies. The document starts with an introductory part in Chapter 3, providing a brief description of the MELISSA system and a review of the present status, addressing specifically the current Control System implementation. This chapter also presents the definition of the Control System as a subsystem of MELISSA.

Chapter 4 addresses the General Control System requirements, followed by a review of requirements for all the planned compartments of the MELISSA future plant in Chapter 5. Chapter 6 refers to System Requirements, stating a characterisation of the subsystems that are part of the Control System. Chapter 7 presents the non-functional requirements, and Chapter 8 and 9 cover the Internal and External interfaces respectively.

Each requirement stated in the document is associated to a unique identifier label with the format CS-XXX-NNN, where:
- CS: Stands for Control System Requirements.
- XXX: Stands for classification (GR, General Requirements, SFY, Safety Requirements, etc.).
- NNN: Identifies the Requirement number in the classification.

For clarity reasons, the requirement statement is complemented by textual explanations where necessary.

2 Reference documents

2.1 Applicable documents

[A1] **MELISSA. Adaptation for Space, Phase 1. Statement of Work**.TOS-MCT/2000/2977/ln/CL. Issue 5. April 2001.

[A2] **MELISSA. Adaptation for Space-Phase 1. Proposal issued by NTE**. MEL-0000-OF-001-NTE. Issue 2. October 2001.

2.2 Reference Documents

[R1] **Review of the Complete MELISSA Loop and Identification of the Critical Developments**. TN 72.001. Version 1. Issue 0. February 2002.

[R2] **Preparation of the Physical Realisation of the MELISSA Ecosystem.** ESA YCL/CHL 1609 November 1992

[R3] **Dependability Technical Analysis Specification.** TN 62.9. ADERSA, November 2001**.**

[R4] **Photoheterotrophic Compartment Set-up.** TN 37.6. UAB, February 1998.

[R5] **Nitrifying Compartment Studies.** TN 25.310. UAB, September 1996.

[R6] **Set-up of the Photosynthetic Pilot Reactor.** TN. 37.2. UAB, April 1998.

[R7] **MELISSA CONTROL SYSTEM: Software de control para la planta piloto del proyecto MELiSSA.** UAB**,** Javier Mengual Sánchez, Ramón Vilanova Arbós, February 2002.

[R8] **Preliminary Review of the MELISSA Pilot Plant Final Loop.** TN 47.3. UAB December 2000. Draft version, Issue 0.

3 INTRODUCTION

3.1 System description

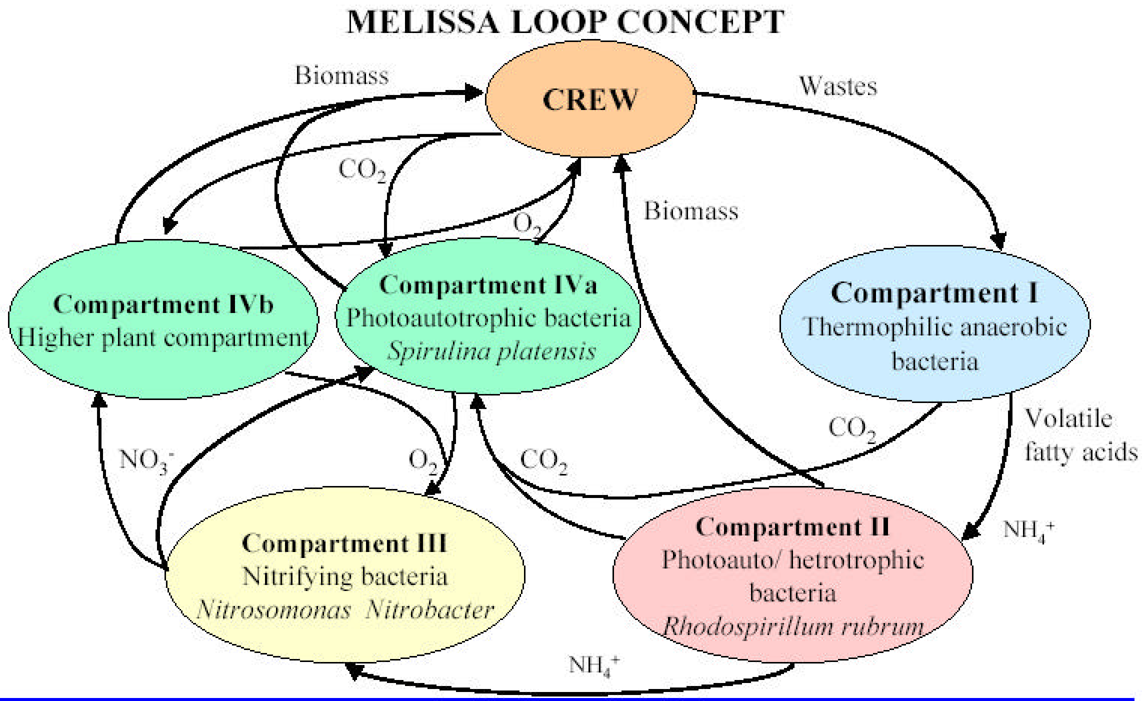


Figure 1. Melissa Loop Concept

MELISSA was developed as a model to study Closed Ecological Life Support Systems (CELSS) as a response to the demonstration that food supply is not feasible for long duration manned space missions such as a Mars Outpost. The driving element of the MELISSA model is the reprocessing of edible biomass from waste, CO2 and minerals with the direct use of sunlight as a source for biological photosynthesis energy. MELISSA is modelled as a four compartment ecosystem that allows the complete recycling of wastes generated by a crew, providing food, drink water and atmosphere regulation. This MELISSA loop is based on a series of strains that were selected at the beginning of the project. The main purpose of MELISSA is to have a research tool that will allow engineers to develop technology to be included in future Bio-regenerative Life Support Systems.

From the Control System perspective, MELISSA can be seen as a group of individual processes, one for each compartment, and a global process that include control laws for the complete loop regulation. Each compartment process, include strain conditioning, inputs and outputs from other processes or buffer tanks, and operations such as evacuation of overproduced biomass or separation systems.

Several factors have been taken into account when defining the Control System requirements:

- As a Life Support System, it shall be a continuous process, reliable and safe.
- As a biological process and due to its compartmentalised structure, it is an unstable process, because of the amount of factors that affect the development of a culture in this

enclosed environment, and difficult to control due to the non-linearity of the processes present in the system.

- As a research tool, proper data generation is relevant.
- In addition, because the system definition has not been completely stabilised yet, the system shall be designed to be flexible and adaptable to the change.

3.2 Present Status

3.2.1 Present status of MELISSA

The MELISSA project has reached a point where all the compartments are being studied separately and some of them are already well characterised. A Pilot Plant has been created to perform compartment connection experiments at pilot scale. Nowadays, the scientific research is in consolidation of compartments design and the integration of the Higher Plants Compartment (Compartment IVb). Preliminary studies on space experiments (BIORAT, FEMME, MASK, MESSAGE, etc.) are on going. A Dependability Analysis for the MELISSA system is under development.

3.2.2 Present status of the MELISSA Pilot Plant

Presently, the Pilot Plant is composed by three compartments at Pilot Scale, the Compartment II or the Photoauto/heterotrophic compartment, the Compartment III or Nitrifying compartment and the Compartment IVa or Photosynthetic compartment. For Compartment IVa the control rules have been already validated and for Compartment III are under development. During the past years, experiments interconnecting these compartments have been performed at Bench Scale and experiments interconnecting compartment II and III at Pilot Scale are expected by 2003.

For Compartment I, optimisation of technologies studies and preliminary closed loop experiments are in process. In addition, a Pilot Scale version is under development and it is planned to be placed at the Pilot Plant in 2004.

Compartment IVb or Higher Plants Compartment (HPC) is under study and is envisioned to start set-up operations by 2004 and achieve an operational version by 2006.

In conclusion, the connection of some of the different compartments at Pilot Scale as a main objective of the Pilot Plant is envisioned in the near term. This will allow demonstrate that an interconnected loop of all the foreseen compartments can be built, operated and maintained in stable operation conditions for reasonable long periods of time.

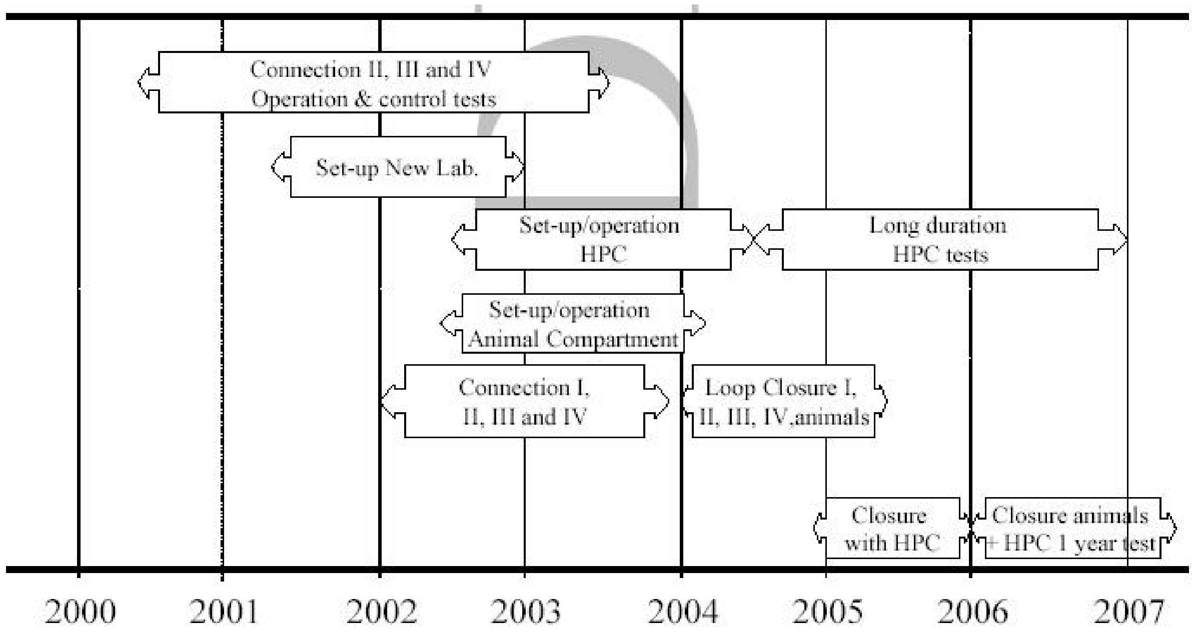


Figure 2. Melissa Pilot Plant development plan [R8].

In the following years (end 2003), the Pilot Plant will be moved to a new location and the rest of the compartments (Compartment I, Compartment IVb (HPC) and the Crew Compartment) will be placed and interconnected to perform complete loop verification tests (see Figure 3). A Preliminary Review of the Pilot Plant Final Loop is already available [R8]. Tests of the complete loop are expected to start by 2006.

Status of MELISSA compartments modelling and control rules is going to be maintained by the MELISSA partners in a table as specified in ANNEX A.

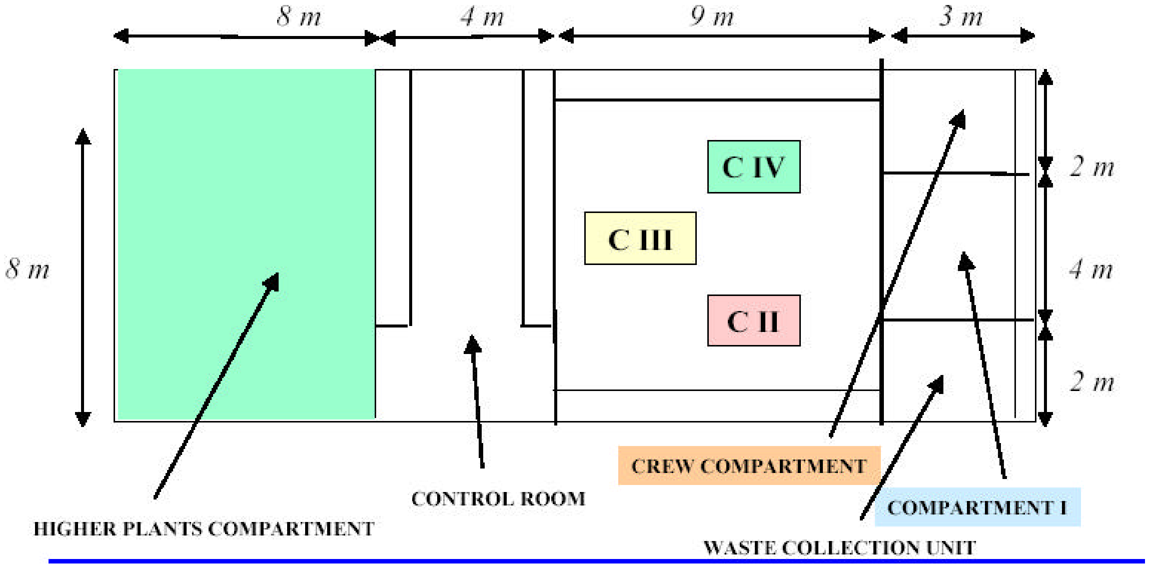


Figure 3: Preliminary design of the new Melissa Pilot Plant Laboratory at UAB

3.2.3 Present status of the Control System

Due to the compartmentalised structure of MELISSA, each compartment has its own model and control laws. Nowadays, only the control laws for the Photoauto-heterotrophic compartment (Compartment IVa) have been validated. Efforts are devoted to achieve a validated control law for the Nitrifying compartment in the near term, following with the rest of the compartments. Additionally, control laws for the global loop optimisation need to be implemented. At this time, a preliminary model of the global loop is being developed.

3.2.3.1 Present control system implementation

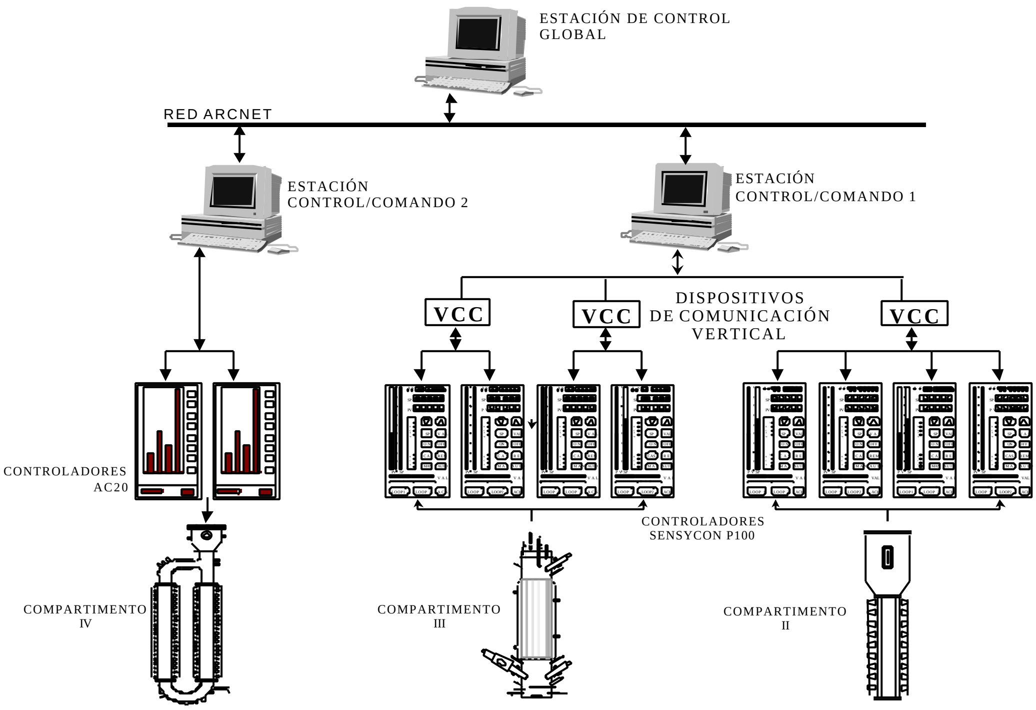


Figure 4: Present Control System implementation (from [R6])

A control system is currently in place to control the Pilot Plant operation (see Figure 4). This control system has been used to perform functional tests and to validate the Photosynthetic compartment control law.

The present control system is based in the well-known multi-tiered structure for complex control systems:

Level 0	Process
Level 1	Sensors and actuators. Present status estimation.
Level 2	Regulators and Automatons. Flow estimations, optimisation of steady states, simple alarm control.
Level 3	Computers. Long term prediction, global optimisation, long term error detection.

3.2.3.2 Identification of system parts

Level 0, consisting of the biological processes taking place in the compartments currently placed in the Pilot Plant.

Level 1, sensors and actuators to maintain the cultures in the compartments in their optimal conditions. Some sensor measure examples are pH, Biomass, Oxygen, Nitrogen, Temperature and Pressure. Some actuators examples are light regulators, flow (liquid/gas) regulators, Temperature regulators and pH regulators.

Level 2, regulators and automatons are grouped per compartments. Compartment II comprises 4 controllers of type SENSYCON P100 connected to a Vertical Communication Controller (VCC). Compartment III features 4 controllers SENSYCON P100 connected to two VCC. Compartment IVa has 2 controllers of type ASCON A20 that communicate directly to the command station through the protocol JBUS. At his level some basic alarm control is performed, so it is possible to program alarm control in the controllers and alarms are visualised through controllers displays.

Level 3, performing the optimisation functions are the Control/Command Stations. These stations are two computers (COMPAQ-386 and COMPAQ-286 running MS-DOS) which have interface cards and software to communicate to Level 2 controllers. The following functions are identified: on-line visualisation of process variables, change variable values for the controllers at Level 2 and Data Management.
In addition, at Level 3, an additional computer known as the Global Purpose Station (GPS) is in charge of global system optimisation by means of a custom-developed software . This software records data coming from all compartments communicating to the Control/Command Stations through ARCNET, and computes the set-point values implementing the control algorithms for each compartment and global optimisation.

3.2.3.3 Current Control System drawbacks

- Development tool for the control algorithms has the Y2K effect.
- Operative system of stations is not multitasking (MS-DOS).
- It cannot provide a Relational Database based Data Management.
- Limited performance of the General Purpose Station and Control Command Stations.
- The user interface is difficult to operate. Changes are cumbersome.
- The out-of-date technologies prevent the system from evolving. .
- Some sensors cannot be calibrated on-line.
- Unable to use full features of complex analysers.

3.3 Definition of the control system, functionality and interfaces.

This section will provide a definition of the Control System for the complete MELISSA Pilot Plant (i.e. comprising all the foreseen compartments). The definition will include the control system boundaries analysis (external interfaces) and a breakdown in various subsystem (internal interfaces and subsystems). External interfaces define the scope of the control system, each interaction with it is done using these interfaces. The breakdown is generated from a functional division, each subsystem has a specific functionality in the Control System and communicates with other subsystems by means of a internal interface.

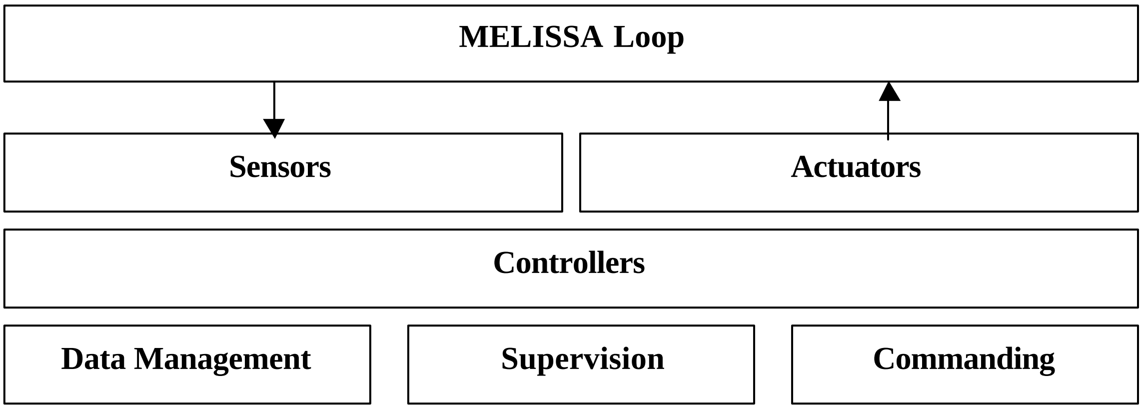
3.3.1 External Interfaces

- Mechanical Interface: defines the allocation and housing of the sensors and actuators within the system.
- Electrical Interface: defines the requirements and characteristics of MELISSA´s power supply.
- Man Machine Interface (MMI): defines how the user interacts with the system.
- Data Handling Interface: defines the data input/output to the system.
- Communications Interface: defines how MELISSA connects to external systems.

3.3.2 Internal Interfaces

- Electrical Interfaces: Interface between sensors/actuators and controllers.
- Communication Interfaces: Interfaces between controllers and between controllers and Data Management, Supervision and Commanding.

3.3.3 Subsystems breakdown



In contact with the process there are the Sensors and Actuator subsystems. Sensors translate the physicochemical measures into values which can be handled by the Controllers. Actuators translate changes calculated by the controllers into specific actions over the process. Receiving the information of the sensors and manipulating the actuators there is the Controller Subsystem. The Controller Subsystem main function is to perform the calculations programmed in the control algorithms and handle and notify alarm situations. Interacting with the controllers there are the Data Management, Supervision and Commanding Subsystems. Data Management Subsystem store data generated during the process running and provide permanent access to this data. Supervision allow the interaction with the system, displaying the information needed to follow system behaviour. The Commanding subsystem allow the modification of the system behaviour.

4 GENERAL REQUIREMENTS

The Control System must respond to three main requirements:

- To maintain the controlled variables in the optimal ranges to maximise MELISSA function, that is, to balance atmosphere regulation and biomass production, with the maximum closure factor.
- To prevent errors or malfunctions, detecting deviations and warning monitoring,
- To provide a way to respond to system deviations in order to minimise effects, starting counter-measures or adapting the MELISSA function to the new conditions.

Maintaining the controlled variables in the optimal conditions implies system stability. Because the processes involved are highly non-lineal, traditional control algorithms cannot be used, but advanced algorithms as Model Predictive Control algorithms are a must. Stability is also affected by traditional factors as system performance, range of measurement (saturation) and the capability of the system to fix deviations (counter-measures). In addition, technology of sensors and actuators, control algorithms, response times and backup functions are factors that must be taken into account.

Preventing system errors and malfunctions implies system reliability. The information coming from the system shall allow the detection of problems that could derive in safety hazards or impact MELISSA's function. Self-tests, redundancy, automatic calibration, long term prediction algorithms and alarm management address this requirement.

Capability of responding to malfunctions or deviations implies safety. Counter-measures shall be provided to avoid safety hazards and to minimise effects in the MELISSA function. As closely related to stability and reliability, factors coming from both characteristics affect safety.

Other requirements originate from the fact that MELISSA is also a research tool. The Control System shall provide means of recording data obtained after the experimentation with MELISSA function as to perform data analysis and trending. Because MELISSA is still a system under development, this research information is a valuable resource and it should be considered as an output of the MELISSA system. Therefore, the Data Management function shall be strengthened through the requirements.

CS-GR-100
The control system shall maintain the controlled variables in their optimal range in order to achieve the optimal conditions for the MELISSA system function.

CS-GR-110
When the system cannot technically maintain optimal conditions, it shall be possible to program counter-measures in order to avoid safety hazards and in a secondary term scientific knowledge loss.

CS-GR-120
The control system shall detect and register deviations, errors and malfunctions, notifying MELISSA operators adequately to the warning category.

CS-GR-130
The control system shall provide the data generated by the MELISSA operation as well as means for data storage. .

5 COMPARTMENT CONTROL REQUIREMENTS

This section defines the control requirements for each compartment. The compartments are characterised through the variables that need to be measured and controlled from the functional point of view. This approach allows to:

- quantify the system capacity (number of digital/analogue input/outputs and complex analyser ports)
- provide a guide for sensors and actuators selection (accuracy, range of the measures) and the controllers performance (number of loops, response time).

Variables are divided in five groups:

- measured variables in compartment,
- measured variables at liquid input
- measured variables at gas input
- measured variables at liquid output
- measured variables at gas output

The first group contains the variables related to the compartment´s behaviour itself, whereas the latter two groups allow the regulation of the input and output composition in each loop phase (gas, liquid and solid). Each variable is characterised by:

- accuracy,
- nominal range (range in which the measure is stable according to the MELISSA function),
- measure range (range that cover nominal and non-nominal operations such as sterilisation),
- physical units,
- sampling rate (to provide guidance over performance in the controllers),
- importance (mandatory, when it covers a basic system or safety function and Useful if it helps on auxiliary functions but it is not critical for the main process).

The characterisation of the variables is stated in tables. White cells in the tables mean that no information was available at the time of the edition of this technical note.

Although most likely output variables in one compartment coincide with input variables to the next one, and therefore do not represent an extra measurement, input or storage space, they are counted separately due to the possibility of inclusion of extra buffers or feedback when the complete loop would be closed.

5.1 Compartment I

The inputs to this compartment are organic components coming from three sources: human wastes (dirty water, faeces and urine), overproduced microbial biomass and higher plants components from the Compartment IVb (Greenhouse). Its function is to biodegrade these components producing Volatile Fatty Acids and Ammonia in the liquid phase, CO_2, H_2, NH_3 and Volatile Fatty Acids in the gas phase, and dry weight excess in the solid phase.

5.1.1 Measured variables

CS-CI-100
In this compartment following variables shall be measured

5.1.1.1 Measured variables in compartment

Measurement	Description	Accuracy	Nom. Range	Measure Range	Units	SR	Importance
CI-MV-SC	Measure of salts in the media			0-8	mS	1 min	useful
CI-MV-pH	pH			1-14	pH	1 min	mandatory
CI-MV-Eh	Oxidation-reduction potential			-600-0	mV	1 min	mandatory
CI-MV-T	Temperature			0-150	°C	1 min	mandatory
CI-MV-Cx	Biomass concentration					1 min	useful
CI-MV-L	Level of the liquid in the compartment					1 min	mandatory
CI-MV-Phos	Phosphorus content					1 min	useful
CI-MV-SS	Suspended solids in the media						useful
CI-MV-St	Stirring				rpm		mandatory

In addition to the variables specified in this table, complex analysers for protein content of the media and genetic analysers are expected to be needed.

5.1.1.2 Measured variables at Input

Measurement	Description	Accuracy	Nom. Range	Measure Range	Units	SR	Importance
CI-MI-CH	Composition of the material at the input – carbohydrate				g/L		useful
CI-MI-Lip	Composition of the material at the input – lipids				g/L		useful
CI-MI-Prot	Composition of the material at the input – Proteins				g/L		useful

5.1.1.3 Measured variables at Liquid Output

Measurement	Description	Accuracy	Nom. Range	Measure Range	Units	SR	Importance
CI-MLO-Fl	Liquid flow						
CI-MLO-Hac	VFA Acetic			0-500	mmol/L	10 m	mandatory
CI-MLO-HBut	VFA Butyric			0-500	mmol/L	10 m	mandatory
CI-MLO-Hpr	VFA Propionic			0-500	mmol/L	10 m	mandatory
CI-MLO-Hisobut	VFA Isobutyric			0-100	mmol/L	10 m	mandatory
CI-MLO-Hisoval	VFA isovaleric			0-100	mmol/L	10 m	mandatory
CI-MLO-Hcap	VFA caproic			0-100	mmol/L	10 m	mandatory
CI-MLO-Hisocap	VFA isocaproic			0-100	mmol/L	10 m	mandatory
CI-MLO-NH4	Ammonium				$N\text{-}NH_4^+$ppm	60 s	mandatory

5.1.1.4 Measured variables at Gas Output

Measurement	Description	Accuracy	Nom. Range	Measure Range	Units	SR	Importance
CI-MGO-Fg	Gas Flow				nL/min	60 s	mandatory
CI-MGO-Hac	VFA Acetic			0-500	mmol/L	10 m	useful
CI-MGO-Hbut	VFA Butyric			0-500	mmol/L	10 m	useful

CI-MGO-Hpr	VFA Propionic			0-500	mmol/L	10 m	useful
CI-MGO-Hisobut	VFA Isobutyric			0-100	mmol/L	10 m	useful
CI-MGO-Hisoval	VFA isovaleric			0-100	mmol/L	10 m	useful
CI-MGO-Hcap	VFA caproic			0-100	mmol/L	10 m	useful
CI-MGO-Hisocap	VFA isocaproic			0-100	mmol/L	10 m	useful
CI-MGO-NH4	Ammonium				N-NH_4^+ppm	60 s	mandatory
CI-MGO-NH3	Ammonia				mmol/L	60 s	useful
CI-MGO-CO2	CO_2 at gas output				mmol/L	60 s	mandatory
CI-MGO-H2	H_2 at gas output				mmol/L	60 s	useful
CI-MGO-H2S	H_2S at gas output				mmol/L	60 s	useful
CI-MGO-CH4	CH_4 at gas output				mmol/L	60 s	useful

5.1.2 Control loops

CS-CI-200
The following local control loops shall be implemented in this compartment, maintaining the controlled variable in the appropriate range (see tables below) with the given deviation.

Loop	Description	Deviation	Importance
CI-CL-pH	pH control		mandatory
CI-CL-P	Pressure control		mandatory
CI-CL-Fq	Flow control-liquid		mandatory
CI-CL-Fg	Flow control-gas		mandatory
CI-CL-T	Temperature control		mandatory
CI-CL-St	Stirring		mandatory

5.2 Compartment II

This compartment is based on a photoheterotrophic reactor. The inputs are the gas and liquid outputs from Compartment I. Its main function is to consume Volatile Fatty Acids producing Ammonia in the liquid phase, CO2 in the gas phase and dry weight excess in the solid phase. A light source is mandatory for this process because it is based in a photoheterotroph culture.

5.2.1 Measured variables

CS-CII-100
In this compartment following variables shall be measured:

5.2.1.1 Measured variables in compartment

Measurement	Description	Accuracy	Nom. Range	Measure Range	Units	SR	Importance
CII-MV-SC	Measure of salts in the media (conductivity)	±0.1		0-10	mS	60s	useful
CII-MV-pH	pH	±0.01	6.85-6.95	0-14	pH unit	1s	mandatory
CII-MV-Eh	Oxidation-reduction potential	±5		-600-0	mV		useful
CII-MV-T	Temperature	+/-1	30	0-150	Cº	1s	mandatory
CII-MV-Cx	Biomass concentration	±0.1	1.5	0-5	g/L	60s	mandatory
CII-MV-L	Liquid volume in the compartment	±0.2	70	65-75	L	1s	mandatory
CII-MV-P	Pressure	±1	1100±5	0-3000	hPa	1s	mandatory
CII-MV-Fx	Light	±10	0-400	0-1000	$W \cdot m^{-2}$	60s	mandatory

5.2.1.2 Measured variables at Liquid Input

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
CII-MLI-Fl	Liquid flow	±0.01	3	0-15	L/h	1s	mandatory
CII-MLI-NH3	Ammonia	±0.5		0-100	mmol/L	1h	useful
CII-MLI-Hac	VFA Acetic	±0.5		0-500	mmol/L	10 m	mandatory
CII-MLI-Hbut	VFA Butyric	±0.5		0-500	mmol/L	10 m	mandatory
CII-MLI-Hpr	VFA Propionic	±0.5		0-500	mmol/L	10 m	mandatory
CII-MLI-Hisobut	VFA Isobutyric	±0.5		0-100	mmol/L	10 m	mandatory
CII-MLI-Hisoval	VFA isovaleric	±0.5		0-100	mmol/L	10 m	mandatory
CII-MLI-Hcap	VFA caproic	±0.5		0-100	mmol/L	10 m	mandatory
CII-MLI-Hisocap	VFA isocaproic	±0.5		0-100	mmol/L	10 m	mandatory

5.2.1.3 Measured variables at Gas Input

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
CII-MGI-Fg	Gas flow	±0.01			nL/h	1s	mandatory
CII-MGI-H2S	H_2S gas					60s	useful
CII-MGI-CG	Contaminant gases					60s	useful

5.2.1.4 Measured variables at Liquid Output

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
CII-MLO-Fl	Liquid flow	±0.01	3	0-15	L/h	1s	mandatory
CII-MLO-Hac	VFA Acetic (1)	±0.001	0-1	0-100	mmol/l	10 m	mandatory
CII-MLO-Hbut	VFA Butiric	±0.001	0-1	0-100	mmol/l	10 m	mandatory
CII-MLO-Hpr	VFA Propionic	±0.001	0-1	0-100	mmol/l	10 m	mandatory
CII-MLO-Hisobut	VFA Isobutiric	±0.001	0-1	0-100	mmol/l	10 m	mandatory
CII-MLO-Hisoval	VFA isovaleric	±0.001	0-1	0-100	mmol/l	10 m	mandatory
CII-MLO-NH4	Ammonium at liquid output (2)	±0.001	0-1	0-100	N-NH_4^+ppm	15m	mandatory

5.2.1.5 Measured variables at Gas Output

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
CII-MGO-Fg	Gas flow	±0.01			nL/h	1s	mandatory
CII-MGO-HS2	Sulfuric gas				mmol/l		useful
CII-MGO-CG	Contaminant gases				mmol/l		useful
CII-MGO-NH4	Ammonium	±0.001	0-1	0-100	mmol/l		useful
CII-MGO-CO2	CO_2	±0.1	0-1	0-100	mmol/l		mandatory

(1) For VFA a high level of accuracy is needed then measures are below 1.
(2) VFA and Ammonium need to be measured with complex analysers

5.2.2 Control Loops

CS-CII-200
In this compartment following loops shall be implemented

Loop	Description	Deviation	Importance
CII-CL-P	Maintain the pressure of the gas phase		mandatory
CII-CL-pH	Maintain the pH in culture medium		mandatory
CII-CL-Fx	Maintain light intensity at bio-reactor surface		mandatory
CII-CL-T	Maintain temperature of the culture		mandatory
CII-CL-L	Maintain liquid level		mandatory
CII-CL-NH3	Maintain Ammonia concentration (1)		
CII-CL-Fl	Regulate input/output liquid flow		mandatory
CII-CL-Fg	Regulate input/output gas flow		mandatory

(1) Ammonia concentration is maintained adding additional Ammonia from a buffer filled from CI.
(2) Probably, biomass concentration will be regulated by regulating light and VFA concentration.

5.3 Compartment III

This compartment is based on a Nitrifying reactor. The inputs are the liquid output of the compartment II and gas outputs from other compartments via a Buffer Tank. Its main function is to transform Ammonia to Nitrates producing Nitrate in the liquid phase and CO2 in the gas phase.

5.3.1 Measured variables

CS-CIII-100

In this compartment following variables shall be measured

5.3.1.1 Measured variables in compartment

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIII-MV-SC	Measure of salts in the media	±0.1		0-10	mS	60s	useful
CIII-MV-Cx	Biomass concentration					1s	useful
CIII-MV-L	Level of the liquid in the compartment	0.01		3.75-4.22	L	1s	mandatory
CIII-MV-P	Pressure	10		0-3000	hPa	1s	mandatory
CIII-MV-DO	DO-average	±0.5		0-100%	%	1s	mandatory
CIII-MV-DOTop	DO Top	±0.5		0-100%	%	1s	mandatory
CIII-MV-DOBot	DO Bottom	±0.5		0-100%	%	1s	mandatory
CIII-MV-pH	Ph-average	±0.1		0-14	pH	1s	mandatory
CIII-MV-pHt	Ph Top	±0.1		0-14	pH	1s	mandatory
CIII-MV-pHb	Ph Bottom	±0.1		0-14	pH	1s	mandatory
CIII-MV-T	Temperature average	±0.1		20-35	Cº	1s	mandatory
CIII-MV-Tt	Temperature Top	±0.1		20-35	Cº	1s	mandatory
CIII-MV-Tb	Temperature Bottom	±0.1		20-35	Cº	1s	mandatory
CIII-MV-St	Stirring				rpm		mandatory

5.3.1.2 Measured variables at Liquid Input

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIII-MLI-Fl	Liquid flow				l/h		mandatory
CIII-MLI-NH4	Ammonium	±1		0-1000	N-NH_4^+ppm	15 m	mandatory
CIII-MLI-NH3	Ammonia	±10%				1h	mandatory
CIII-MLI-CO2	Carbon dioxide						mandatory
CIII-MLI-NO3	Nitrite						mandatory
CIII-MLI-SO4	Sulphate (1)						useful
CIII-MLI-PO4	Phosphate (1)						useful

(1) The SO_4 and PO_4 concentrations are theoretically necessary for the model based control of NO_2. Nevertheless, if they are never limiting, their values in the model could be a function of the salt concentration of the media whose measurement is foreseen. In that case, the measurements of SO_4 and PO_4 could be spared in order to minimise the number of sensors.

5.3.1.3 Measured variables at Gas Input

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIII-MGI-Fg	Gas flow				l/h		mandatory
CIII-MGI-O2	Oxygen concentration in gas				mmol/L	60s	mandatory
CIII-MGI-CO2	Carbon dioxide						mandatory

5.3.1.4 Measured variables at Liquid Output

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIII-MLO-Fl	Liquid flow						mandatory
CIII-MLO-NO3	Nitrate						mandatory
CIII-MLO-NO2	Nitrite						mandatory
CIII-MLO-SO4	Sulphate						useful
CIII-MLO-PO4	Phosphate						useful

5.3.1.5 Measured variables at Gas Output

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIII-MGO-Fg	Gas flow						mandatory
CIII-MGO-CO2	Carbon dioxide						mandatory

5.3.2 Control Loops

CS-CIII-200
In this compartment following loops shall be implemented

Loop	Description	Deviation	Importance
CIII-CL-P	Maintain the pressure of the gas phase		mandatory
CIII-CL-pH	Maintain the pH in culture medium		mandatory
CIII-CL-T	Maintain temperature of the culture		mandatory
CIII-CL-Fl	Regulate input/output liquid flow		mandatory
CIII-CL-NH4	Maintain Ammonium concentration (1)		mandatory
CIII-CL-O2	Oxygen concentration		mandatory
CIII-CL-St	Stirring		mandatory

5.4 Compartment IVa

This compartment is based on a Photosynthetic reactor. Its inputs are the liquid phase of the compartment II and the gas outputs of other compartments via a Buffer Tank. The main function of this compartment is to convert Nitrates into edible biomass and CO2 into O2. Therefore the outputs are O2 in the gas phase and edible biomass in the solid phase.

5.4.1 Measured variables

CS-CIV-100
In this compartment following variables shall be measured

5.4.1.1 Measured variables in compartment

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIV-MV-T	Temperature	±0.1		20-35	Cº	1s	Mandatory
CIV-MV-P	Pressure	±10		0-3000	hPa	1s	Mandatory
CIV-MV-pH	pH	±0.1		0-14	pH	1s	Mandatory
CIV-MV-SC	Measure of salts in the media	±0.1		0-10	mS	60s	Useful
CIV-MV-DO	Oxygen dissolved	±1		0-100	%	1s	Mandatory
CIV-MV-Cx	Biomass concentration	±0.001		0-5	g/L		Mandatory
CIV-MV-L	Level of the liquid in the compartment	±0.2		74-80	L	1s	Mandatory
CIV-MV-Fr	Radiant Flux	±0.1		10-300	W/m^2	1s	Mandatory
CIV-MV-NO3	Nitrate concentration	±1		0-1000	N-NO_3^-ppm		Mandatory

5.4.1.2 Measured variables at Liquid Input

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIV-MLI-Fl	Liquid flow				l/h	1s	
CIV-MLI-NO3	Concentration of Nitrite	±1		0-1000	N-NO_3^-ppm	1h	Mandatory
CIV-MLI-NO2	Concentration of Nitrate	±1		0-1000	N-NO_2^-ppm	1h	Mandatory
CIV-MLI-NH4	Concentration of Ammonium	±1		0-1000	N-NH_4^+ppm	1h	Mandatory

5.4.1.3 Measured variables at Gas Input

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIV-MGI-Fg	Gas flow				l/h		
CIV-MGI-CO2	CO_2 at gas input	±0.1		0-100%			mandatory

5.4.1.4 Measured variables at Liquid Output

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIV-MLO-Fl	Liquid flow				l/h		

5.4.1.5 Measured variables at Gas Output

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIV-MGO-Fg	Gas flow				l/h		
CIV-MGO-O2	O_2 at gas output	±0.1		0-100	mmol/l		Mandatory
CIV-MGO-CO2	CO_2 at gas output	±0.1		0-100	mmol/l		Mandatory

5.4.2 Control Loops

CS-CIV-200
In this compartment following loops shall be implemented

Loop	Description	Deviation	Importance
CIV-CL-P	Maintain the pressure of the gas phase		mandatory
CIV-CL-pH	Maintain the pH in culture medium		mandatory
CIV-CL-T	Maintain temperature of the culture		mandatory
CIV-CL-Cx	Maintain biomass concentration		mandatory
CIV-CL-Fr	Maintain light intensity inside the bio-reactor		mandatory
CIV-CL-L	Maintain liquid level		mandatory

5.5 Compartment IVb

This compartment is based in a Greenhouse with hydroponic culture. Its inputs are TBD. The main function of this compartment is to convert Nitrates into edible biomass and CO2 into O2. The outputs are O2 in the gas phase, water in the liquid phase and edible and excess biomass in the solid phase.

For this compartment only an indicative set of variables and control loops are specified. Due to it is a complex compartment, it needs to be further studied and the expected number of measured and controlled variables is expected to be greater.

5.5.1 Measured variables

CS-CIVb-100
In this compartment following variables shall be measured

5.5.1.1 Measured variables in compartment

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
CIVb-MV-T	Temperature	±0.1		10-35	Cº	1s	Mandatory
CIVb-MV-pH	pH	±0.1		0-14	pH	1s	Mandatory
CIVb-MV-P	Pressure	±10		0-3000	hPa	1s	Mandatory
CIVb-MV-Fr	Radiant Flux	±0.1			W/m^2	1s	Mandatory
CIVb-MV-O2	Oxygen	±1		0-100	%	1s	Mandatory
CIVb-MV-CO2	Carbon dioxide					1s	Mandatory
CIVb-MV-Hum	Humidity						Mandatory
CIVb-MV-CH	Trace of hydrocarbons						Mandatory
CIVb-MV-VOC	Volatile organic compounds						Mandatory

5.5.1.2 Measured variables at Liquid Input

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
CIVb-MLI-Fl	Liquid flow				l/h		Mandatory
CIVb-MLI-NH4	Ammonium						Mandatory
CIVb-MLI-NO3	Nitrate						Mandatory

5.5.1.3 Measured variables at Gas Input

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
CIVb-MGI-Fg	Gas flow				l/h		Mandatory
CIVb-MGI-O2	Oxigen						Mandatory
CIVb-MGI-CO2	Carbon dioxide						Mandatory

5.5.1.4 Measured variables at Liquid Output

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
CIVb-MLO-Fl	Liquid flow						mandatory

5.5.1.5 Measured variables at Gas Output

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
CIVb-MGO-Fg	Gas flow				l/h		mandatory
CIVb-MGO-O2	Oxygen						mandatory
CIVb-MGO-CO2	Carbon dioxide						mandatory

5.5.2 Control Loops

CS-CIVb-200
In this compartment following loops shall be implemented

Loop	Description	Deviation	Importance
CIVb-CL-P	Maintain the pressure of the gas phase		mandatory
CIVb-CL-O2	Maintain O2 concentration		mandatory
CIVb-CL-CO2	Maintain CO2 concentration		mandatory
CIVb-CL-Hum	Maintain humidity		mandatory
CIVb-CL-T	Maintain Temperature		mandatory
CIVb-CL-Fl	Regulate liquid flow		mandatory
CIVb-CL-pH	Regulate pH		mandatory
CIVb-CL-Fr	Regulate light		mandatory

5.6 Crew compartment

This compartment is where a biological being will receive Live Support assistance from the MELISSA system, consuming its outputs (O2, water, and edible biomass) and under the conditioned atmosphere. The inputs of this compartment are the produced O2, water and edible biomass and the outputs are CO2 in the gas phase, solid wastes in the solid phase and urine and dirty water in the liquid phase.

5.6.1 Measured variables

CS-C0-100
In this compartment following variables shall be measured

5.6.1.1 Measured variables in compartment

Measurement	Description	Accuracy	Nom.Range	Range	Units	SR	Importance
C0-MV-O2	Oxygen						Mandatory
C0-MV-CO2	Carbon dioxide						Mandatory
C0-MV-T	Temperature	±0.1		10-35	Cº	1s	Mandatory
C0-MV-P	Pressure						Mandatory

5.6.1.2 Measured variables at Gas Input

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
C0-MGI-Fg	Gas flow				l/h		Mandatory
C0-MGI-O2	Oxigen						Mandatory
C0-MGI-CO2	Carbon dioxide						Mandatory

5.6.1.3 Measured variables at Gas Output

Measurement	Description	Accuracy	Nom. Range	Range	Units	SR	Importance
C0-MGO-Fg	Gas flow				l/h		mandatory
C0-MGO-O2	Oxygen						mandatory
C0-MGO-CO2	Carbon dioxide						mandatory

5.6.2 Control Loops

CS-C0-200
In this compartment following loops shall be implemented

Loop	Description	Deviation	Importance
C0-CL-P	Maintain the pressure of the gas phase		mandatory
C0-CL-T	Maintain temperature		mandatory
C0-CL-O2	Maintain O2 concentration		Mandatory

5.7 Compartment connections

This section is intended to take into account the variables that need to be measured and controlled in devices located in the compartments' interconnections. These will include separation techniques, filtration, centrifugation, sterilisation, storage and buffer tanks, etc. The complete list of these variables is not yet fully defined. However, for Control System budget purposes an estimation has been performed according to the information available in [R8], see section 6.4.1.

6 SYSTEM REQUIREMENTS

6.1 Sensors

Two types of sensors can be differentiated

- simple sensors, that is, sensors that take the measurement on-line and have a standard electrical interface (4-20mA, 0-20mA, etc.)
- complex analysers, which are sensors that have a more complex interface, based in a protocol over RS-232 or similar. Complex analysers have normally more capacities than a simple sensor, allowing to capture more than one measure at a time, or to change measurement parameters on-line.

CS-SEN-100
For both types a common group of characteristics that shall be taken into account when selecting the sensors:

Characteristic	Description
Range	Range of measurement. This is of special importance because MELISSA is subject of perturbance tests. In addition, sterilisation operations impose a wide range of operating conditions.
Accuracy	Range of deviation from the sensor given value.
Calibration	Sensor can be calibrated on-line (without losing anexenic condition) or must be calibrated off-line (which implies a dismounting operation and sensor sterilisation when is assembled again if it is in contact with the medium).
On-line utilisation	Sensor takes measurements in a continuous form, instead of a by sample basis.
Electrical requirements	Power consumption, AC, DC
Need of consumables	If the sensor needs consumables to operate (filters, chemical products, etc.) a provision must be defined.
Alarm management	Capacity of the sensor to detect malfunctions or errors in the measurement.
Commercial or adaptation	State of the technology associated to the sensor. It might need adaptation to MELISSA utilisation.
Communication Protocol	Electrical (24V, 0-20mA) or digital protocol (RS-232, RS-485, etc.)
General conditions	Conditions that impose constraints on the utilisation of the sensor (temperature, humidity, noise)
Sterilisable	Anexenic condition is mandatory for sensors that need to be in contact with the media.
MTTR	Mean time to repair
MTBF	Mean time between failures
MUP	Mean up time

6.1.1 Complex analysers

CS-SEN-110
In addition, for complex analysers, specific characteristics shall be taken into account:

Characteristic	Description
Hardware support	Level of complexity of the hardware that is part of the analyser.
Level of automation	Operation can be manual or completely automatic.
Software interface	Standard (OPC) or custom Possibility to modify measurement options Possibility to store configurations Data storage
Reliability	Situation after power break-down

CS-SEN-120
For complex analysers a specific software compatible with the Control System shall be provided in order to use its full features.

6.1.2 Image acquisition devices

It is expected, in principle for the compartment IVb or the Higher Plants compartment, to use an image acquisition system to provide light spectrum control and a fast diagnose for potential plants diseases by means of image processing techniques. Therefore the interface to connect this type of devices should be provided.

CS-SEN-200
The control system shall allow interfacing with image acquisition devices by means of standard protocols.

6.2 Actuators

Actuators cover a wide range of functions: from pumps or valves to air-cooling systems.

CS-ACT-100
Similar to sensors, a common group of characteristics that shall be taken into account when selecting actuators can be defined:

Characteristic	Description
Range	Range of actuation. This is of special importance because MELISSA is subject of perturbance tests. In addition, sterilisation operations impose a wide range of operating conditions.
Accuracy	Range of deviation from the actuator setting point.
Calibration	Actuator can be calibrated on-line (without losing anexenic condition) or must be dismounted and calibrated off-line (which implies to sterilise it before assembly if it is in contact with the medium).

Response Time	Time in which the setting point is reached.
Electrical requirements	Power consumption, AC, DC.
Necessity of consumables	If the actuator needs consumables to operate (filters, chemical products, etc.) a provision must be defined.
Alarm management	Capacity of the actuator to detect malfunctions or errors in the measurement.
Commercial or adaptation	State of the technology associated to the actuator. It might need adaptation to MELISSA utilisation.
Communication Protocol	Electrical (24V, 0-20mA) or digital protocol (RS-232, RS-485, etc.)
General conditions	Conditions that impose constraints on the utilisation of the actuator (temperature, humidity, noise etc.)
Sterilisable	Anexenic condition is mandatory for actuators that need to be in contact with the media.

6.3 Supervision

Supervision main functions:
- To provide a fast way for malfunction or deviation detection.
- To provide on-line information about system processes.
- To provide a way to interact with the system for deviation or malfunction correction.

Supervision functionality in control systems is commonly provided by Supervisory Control and Data Acquisition (SCADA) software packages.

In addition, the following features are recommended:
- Support for Internet platform.
- Access control
- Operations Auditing

CS-SUP-100
A Development environment shall be provided to generate Plant displays where to associate measurements and actuators status. These displays shall provide a schematic representation of the real process in the Plant, with an easy identification of the parts and including trends and reports of configured variables.

CS-SUP-110
Supervision shall allow the creation or modification of Plant displays on-line.

CS-SUP-120
Supervision shall provide a user interface to display developed Plant screens and allow the possibility of on-line modification of process variables configured to do so.

CS-SUP-130
Supervision shall allow multiple clients interacting with the system simultaneously, using a client/server architecture.

CS-SUP-140
Supervision shall provide connectivity with Database Management Systems through ODBC (or similar) to allow historical data storage.

CS-SUP-150
Supervision shall allow connectivity with field bus standards.

CS-SUP-160
Supervision shall provide OPC client and server connectivity.

CS-SUP-170
Supervision shall provide Alarm management.

6.3.1 Alarms

CS-SUP-200
Supervision shall generate alarms when detecting that any measured and/or controlled variable is out of the nominal range.

CS-SUP-210
Supervision shall allow the display, log and print of the alarms.

CS-SUP-220
Supervision shall allow inhibiting an alarm depending on the operational mode (see Operational modes in section 7.1.1).

CS-SUP-230
Supervision shall provide at least three levels of Alarm: Critical, Warning and Information.

6.3.1.1 Critical

Critical Alarms have to be notified through a permanent communication system. This type of Alarms should be acknowledged by an authorised user. Common methods are Alarm Centre notification through a digital communications protocol or notification through a telephonic line.

6.3.1.2 Warning

Warning Alarms need to be registered and require acknowledgement by a supervisor. Usually a supervisor is a person with user rights over the supervision software.

6.3.1.3 Information

Information Alarms are recorded for information purposes only, and do not require acknowledgement.

6.3.2 Data monitoring

All control processes and measured variables need to be monitored. The common way of monitoring variables is through the supervision screens for on-line monitoring, and reports for off-line monitoring.

CS-SUP-310
All controlled and/or measured variables shall be monitored.

CS-SUP-320
Supervision shall allow data archiving through a connection to a DBMS.

CS-SUP-330
Supervision shall allow displaying current values of measured/controlled variables.

CS-SUP-340
Supervision shall display a fast variable change (variable acquired at less than 1 second) with a maximum delay of 1 second.

CS-SUP-350
Supervision shall allow the generation of historical data reports.

CS-SUP-360
Supervision shall provide trending capabilities for monitored data.

CS-SUP-370
Supervision shall store running time and start/stop time parameters for any sensor, analyser and actuator.

6.4 Controllers

Controllers are the devices that execute the control loops. Controllers consist of a hardware platform and software that implements the control algorithm. The control algorithms range from conventional (Simple or advanced PID) to advanced control techniques, depending on the process dynamics, linearity, stability or other constrains. When a physical or behavioural model is available, techniques such as Model Predictive Based Control are used. If an empirical model based on logical rules is available only, then the technologies used are Expert systems. Therefore, controllers should support this range of technologies.

It is now accepted that a breakdown in levels of the controller subsystem allows a better characterisation. The following levels can be identified in a Control System such as MELISSA Control System:

Level 0 - Sensors, actuators and ancillary controllers.
Level 1 – Dynamic Control (Model Based Predictive Control)
Level 2 – Static or Dynamic optimisation
Level 3 – Planning Scheduling
CS-CON-100
Controllers shall allow a breakdown of their functions in levels according to the type of control that is performed.

CS-CON-110
Controllers shall support basic control operations such as PID loops and more sophisticated control algorithms such as Model Predictive Based Control.

6.4.1 Hardware

Stemming from requirements defined in Chapter 5, Controllers needs in terms of analogue and digital input and outputs have been estimated and presented in the following table:

	Comp. An.	AI	AO	DI	DO	Control loop
Compartment 0	TBD	TBD	TBD	TBD	TBD	TBD
Compartment I	4	35	6	140	70	6
Compartment II	2	32	8	128	64	8
Compartment III	2	31	7	124	62	7
Compartment IVa	2	19	6	76	38	6
Compartment IVb	TBD	TBD	TBD	TBD	TBD	TBD
Comp. Connect.[1]	0	148	37	592	296	37
Total	10	117	27	468	234	27
Risk factor[2]	13	344	83	1378	689	83
Incremented Total[3]	**16**	**384**	**128**	**1408**	**768**	**128**

6.4.2 Software

CS-CON-110
Control laws are integrated into controllers through software programs. A Development Tool to implement these programs shall be provided.

In order to maintain interoperability between platforms and facilitate communication between participants, the use of a standard is mandatory. The IEC supports the IEC-6-1131-3 standard, which defines a set of programming languages oriented to controllers, which are widely used. In addition general programming languages such as C, C++ will also provide portability and common understanding.

CS-CON-120
The control programmes Development Tool shall maximise interoperability between different hardware platforms and minimise proprietary architecture dependencies.

6.5 Commanding

Commanding functions allow configuring and changing the system behaviour. Part of the commanding functions are usually delivered by the supervision software, providing displays to set-up and modify system parameters restricted by Access Control. In addition, commanding allows the modification of control algorithms to adapt control system to changes in the scientific requirements and to perform perturbation tests. Usually this functionality is provided by the controllers' Software Development Tool.

CS-CMD-100

[1] Estimation of the input/outputs for inter-compartment connection has been done taking into account the number of buffer tanks, storage tanks, separation and filtration devices from [R8].
[2] Applied a risk factor of 30%.
[3] Rounded to next 64 multiple.

Commanding shall provide capabilities to change set-up parameters of a process, modify process parameters (start, stop, change of setting points, watermarks, etc.) and modify process control algorithms on-line and off-line.

CS-CMD-110
Commanding shall allow the modification of any parameter of the process from any display configured to do so, using a client/server approach.

CS-CMD-120
Commanding shall allow updating a variable with a maximum delay of 1 second for fast variables (variables that intervene in a loop with a time cycle less than 1 second).

CS-CMD-130
Manual commanding or automatic backup shall be provided for critical operations, especially to stop processes that can result in safety hazard situations.

6.6 Data Management

Data generated by the MELISSA process is a valuable resource. MELISSA is developed as a research tool, and its function is to allow performing experiments to test scientific research and related technologies. Therefore, Data Management should include the capability to store, recover and export all data generated during tests. Nowadays, it is widely accepted that Database Management Systems are suitable to store control systems data at a reasonable performance. The use of this type of systems allow the use of standard languages to manage data (SQL language) and a wide variety of tools can be used to export data and generate reports through common APIs (ODBC, JDBC, etc.). Other well-known characteristics of DBMS are security and reliability.

The principal source of data in MELISSA is the process itself. Process Data are generated by sensors and normally pre-processed before storage. Other data are generated by the operation of the Control System. These data can be classified in:

- Measurement Data: Data generated by the controllers that are used to monitor the process behaviour. These data should include setting points, processed measures and alarms.
- Configuration Data: Data from the configuration parameters used to set-up processes.
- Log Data: Data generated by the devices operating in the system that are used to check devices operation and diagnose error causes.
- Audit Data: Data generated when a user makes changes in the processes.

CS-DM-100
Data Management shall be dimensioned to store all data generated during the MELISSA operation of a TBD duration.

CS-DM-110
Data Management shall provide capabilities to store, recover and export all data generated during MELISSA operation.

7 NON FUNCTIONAL REQUIREMENTS

7.1 Operational

7.1.1 Operational modes

Depending on the system status, several operational modes can be identified:

Status	Description
On-Line	System is operational. All alarms are notified, all automatic control loops are enabled, supervision is active and all generated data is archived.
In-Maintenance	Some parts of the system are being repaired, modified or changed. In this mode, Supervision filters the alarms generated by the parts intervened and disables their automatic control. Maintenance mode includes sterilisation, calibration, repairing and other maintenance tasks.
Stopped	The system is stopped and no alarms should be taken into account nor registered. Also Supervision is stopped and data generated is not stored in the system database.

CS-OP-100
The Control System shall allow disabling alarms and automatic control in parts when in Maintenance Mode, to permit manual operations and minimise interference with other parts in MELISSA. .

CS-OP-110
The Control System shall allow a soft transition between modes.

7.1.2 Reliability

Although the MELISSA Pilot Plant has not the same reliability constraints than a Life Support System, the fact that long term experiments (more than a year of continuous operation) are planned to be performed in the near term, impose requirements on the reliability issue. An analysis on single point failures should be performed before starting this type of tests to prevent from time and budget loss.

Redundancy should be provided where a failure could cause the stop of the experiment. This includes controllers that regulate mandatory processes, sensors that provide essential measures for the process and for the experiment itself, and the same for actuators. In addition, backup functions should be provided in order to allow changing the source of mandatory fungible media supply without affecting the experiment. A Reliability/Dependability analysis should provide the list of mandatory functions where redundancy should be assured.

CS-REL-100
On mandatory functions, the Control System shall allow the first failure transparency, providing redundancy permanently.

CS-REL-110
Mandatory sensors shall provide on-line calibration and error detection.

7.2 Maintainability

Since the MELISSA process design is not completely closed, the Control System should be prepared to the change. That is, a change in the scientific requirements should not imply a dramatic change in the Control System, resulting in a change on the technologies or the overall architecture. In addition, the MELISSA project is expected to take a long life cycle, so technology providers should be well established in order to assure supply and maintenance over the parts.
Other aspects are the characteristics of the development of the parts of the MELISSA process. Because it is developed in a distributed manner, the Control System should allow the integration of different technologies, which goes on support of using well-known standards at all levels.
In addition, maintainability requirements shall enhance the capability for the system to cope with the replacement of damaged or broken parts, to be adapted to requirement changes or to absorb technology evolution.

CS-MAN-100
The Control System shall be designed taking into account that the system can evolve, change or expand, in order to minimise the impact.

CS-MAN-110
The selection of technologies for the Control System shall take into account the maintenance and support for the purchased elements for a long period (>5 years).

CS-MAN-120
The Control System shall allow the fixing or replacement of broken or damaged parts without affecting the MELISSA function.

7.3 Security

The MELISSA system is very vulnerable because any small change or perturbation can cause the complete system to stop and provoke scientific knowledge losses or even safety hazards. Security protocols should prevent unauthorised modifications of the process parameters.

CS-SEC-100
The Control System shall provide security in the operations performed.

7.3.1 Auditing

CS-SEC-110
The Control System shall log any actions that modify its behaviour, identifying the action, the time stamp and the author.

7.3.2 Identification control

CS-SEC-120
The Control System shall provide identification authentication to its users.

7.3.3 Access control

CS-SEC-130
The Control System shall allow the resource access restriction (data, applications, devices) in a per user basis.

7.4 Safety

A specific study should determine the potential safety hazard functions. For these identified functions, specific redundancies should be provided in order to prevent human injuries or material damages. In this paragraph, only generic requirements are stated to reinforce safety and to reduce the criticality on software controlled functions.

CS-SFY-100
For functions identified as potential safety hazards, specific backups shall be provided.

CS-SFY-110
All critical functions controlled by software and identified as potential safety hazards shall feature a hardware backup.

7.5 Performance

The MELISSA Control System cannot be considered a hard-real time system, i.e. a system where changes in the behaviour of the processes can take place in microseconds, but it is a system with a high level of inertia. For instance, culture growth could take hours to be perceptible. Contrarily, other variables exist in MELISSA that should be controlled every second, such as pressure or temperature. A characterisation of the response times between the levels of the Controller Subsystem can be given:

- Level 0 loops - ancillary control systems - cycle time < 15 seconds
- Level 1 loops - dynamic control - cycle time from 15 seconds to 5 hours
- Level 2 loops - optimisation - cycle time about one day
- Level 3 loops - planning - cycle time about a season

Therefore, and taking as inputs the characterisation of the compartments done in Chapter 5, a table giving an order of the number of loops and a cycle time can be estimated:

Fast Loops (<1 second cycle time)	100
Slow Loops (>1 second cycle time)	1000

Existing computer systems should provide desired processing capacity. A special attention should be given to data processing because a wide throughput could be generated. Data pre-processing could also be a significant processor-consuming factor. In addition, model based control algorithms are also very time consuming, so the model calculus can be based on data collected for one month. Therefore, a well-tiered structure should be designed to minimise the impact of this processing to the control loops according to their response time requirements.

CS-PER-100
Control Subsystem shall be dimensioned to grant the continuous execution of the given number of fast and slow loops.

CS-PER-200
The Control Subsystem shall provide the performance required by the Compartment Requirements stated in Chapter 5 in measurements sampling rates and response times refreshing set point values in actuators.

8 INTERNAL INTERFACE REQUIREMENTS

8.1 Electrical Interface

Electrical interfaces are used to communicate sensors, actuators, and controllers. Whenever possible, Standard 0-20 mA or 4-20 mA should be used. Where needed, specific drivers should be developed to adapt other types of electrical connections depending on the sensor or actuator requirements.

CS-IEI-100
Electrical interfaces shall be compliant to the local regulation rules for low voltage devices (EC directive 73/23/EEC on low voltage equipment or equivalent).

CS-IEI-120
Electrical devices shall be compliant to the local regulation rules for Electro-magnetic compatibility (EC directive (EMC)-89/336/EEC or equivalent).

8.2 Communications Interface

Presently, a large variety of industrial buses can be used in the control discipline. However, the use of standardised protocols such as Ethernet and TCP/IP provide several benefits, such as the possibility to select devices from wide range of suppliers, and the interconnection of heterogeneous systems, including smart sensors. Several network architectures implementing these protocols are available, which provide flexibility to grow and change. In addition, the number of protocols to use is reduced, resulting in a reduction of the system complexity. Therefore, standard protocols such as Ethernet/TCP-IP should be used whenever possible.

At the application layer (OSI level 7), recently (1998) a standard has been defined to allow communications between industrial devices (sensors, PLC, I/O devices). The OLE for process control standard provides a framework for connecting devices and software. Consequently, hardware and software selection should consider the compatibility with this standard.

CS-ICI-100
The communication services at any level shall allow the use of open standardised protocols.

9 EXTERNAL INTERFACE REQUIREMENTS

9.1 Mechanical Interface

For the Mechanical Interface, special attention shall be given to sensors and actuators that must be removed for calibration or for replacement in anexenic compartment parts. In principle, these devices should be avoided, but in any case, a mechanism for maintaining anexenic conditions should be provided.

CS-EMI-100
Mechanical interface shall provide the allocation of the sensors and actuators to the system.

9.2 Electrical Interface

Since MELISSA is a continuous process, the power supply shall be guarantied. Also, an estimation of the power consumption should be calculated from Control System devices specification and the power supply should be dimensioned according to estimated power consumption. Special attention shall be given to high power consumption actuators such as light providers, pumps and other high power electrical devices.

The Control System should be provided with a continuous, non-stop, power supply adequately to the estimated power consumption of TBD to assure its function.

CS-EEI-100
The Control System shall assure independent source power wiring for redundant functions.

CS-EEI-110
Electrical interfaces shall be compliant to the local regulation rules for low voltage devices (EC directive 73/23/EEC on low voltage equipment or equivalent).

CS-EEI-120
Electrical devices shall be compliant to the local regulation rules for Electro-magnetic compatibility (EC directive (EMC)-89/336/EEC or equivalent).

9.3 User Interface

A guide for the displays development of the user interface should be provided in order to minimise learning time and maximise common understanding. For example, the Display Graphics Commonality Standards (DGCS) from NASA, for ISS payloads.

9.4 Data Handling Interface

Data from system exploitation should be archived in log files and a Relational Database System. Archive files should be accessible through standard protocols such as FTP and stored data in the Database should be accessible through standard APIs such as ODBC. Use of standard protocols will facilitate data access from the Internet platform.

CS-EDH-100
Data Handling interfaces shall allow sharing data from with external systems through standard protocols.

CS-EDH-110
Data Handling interface shall allow the integration of data from external systems by means of standard APIs such as ODBC or JDBC.

9.5 Communications Interface

The Control System shall provide standard protocols for communicating with external systems such as Ethernet-TCP/IP. The use of standard protocols will allow communicating with the system through the Internet Platform. In this case, additional security measures shall be taken, such as firewalls, to avoid unauthorised access to the system.

CS-COM-100
Communications interface shall allow connection external systems by means of standard protocols.

10 ANNEX A. MELISSA Status Board

STATE of WORKS	Modelling					Control rules				
Updating 2002 june	Bench Scale		Pilot Scale			Bench Scale		Pilot Scale		
Compartment	In Process	Validated	Installed	Valdated	Connected	In Process	Validated	Installed	Valdated	Connected
C0 - Crew					2003					
CI -					2003			2004		
CII - Rhodo					CIII					
CIII - Nitri					CII - CIVa					
CIVa - Spiru					CIIII					
CIVb - H. Plant					2003				2006	

Source ADERSA

Table where progress of each compartment about modelling and control rules will be maintained. The green coloured cells determine the state of the compartment at the time of updating, non coloured cells contains expected date.

11 ANNEX B. Dictionary

11.1 Requirements mnemonics description

Mnemonic	Description
CS	Control System Requirement
GR	General Requirements
CI	Compartment I Specific Requirement
CII	Compartment II Specific Requirement
CIII	Compartment III Specific Requirement
CIV	Compartment IV Specific Requirement
CIVb	Compartment Ivb Specific Requirement
SEN	Sensors Subsystem Requirement
ACT	Actuators Subsystem Requirement
SUP	Supervision Subsystem Requirement
CON	Controller Subsystem Requirement
CMD	Commanding Subsystem Requirement
DM	Data Management Subsystem Requirement
REL	Reliability Requirement
MAN	Mantainability Requirement
SEC	Security Requirement
SFY	Safety Requirement
PER	Performance Requirement
IEI	Internal Electrical Interface Requirement

ICI	Internal Communications Interface Requirement
EMI	External Mechanical Interface Requirement
EEI	External Electrical Interface Requirement
EDH	External Data Handling Interface Requirement
COM	External Communications Interface Requirement

11.2 Variables mnemonics

Variables measured in compartment, at input and at output follow the following mnemonic rule:

AA-BBB-CCCC

where:

AA: Stands for the compartment number:

Name	Description
CI	Compartment I
CII	Compartment II
CIII	Compartment III
CIV	Compartment IVa
CIVb	Compartment IVb (HPC)
C0	Compartment 0 or Crew Compartment

BBB: Stands for the type of variable:

Name	Description
MV	Compartment measured variable
MI	Variable measured at input (no different phases)
MGI	Variable measured at gas input
MLI	Variable measured at liquid input
MGO	Variable measured at gas output
MLO	Variable measured at liquid output
CL	Control Loop

CCCC: Stands for the variable identifier

Name	Description
CG	Contaminant gases
CH	Carbohydrates
CO2	Carbon-dioxide
Cx	Biomass concentration
DO	Dissolved Oxygen
DOb	Dissolved Oxygen at bottom of the compartment
DOt	Dissolved Oxygen at top of the compartment
Eh	Oxidation-Reduction potential
Fg	Gas flow
Fl	Liquid flow

Fr	Light
Hac	VFA Acetic
Hbut	VFA Butiric
Hcap	VFA Caproic
Hisobut	VFA Hisobutiric
Hisocap	VFA Hisocaproic
Hisoval	VFA Hisovaleric
Hpr	VFA Propionic
Hum	Humidity
L	Level of liquid
Lip	Lipids
NH3	Ammonia
NH4	Ammonium
NO2	Nitrite concentration
NO3	Nitrate concentration
O2	Oxygen
P	Pressure
pH	pH
pHb	pH at bottom of the compartment
Phos	Phosphorus content
pHt	pH at top of the compartment
PO4	Phosphate
Prot	Proteins
H2S	Hydrogen Sulphide Gas
SO4	Sulfate
SC	Salts concentration
SS	Susended solids
St	Stirring
T	Temperature
Tb	Temperature at bottom of the compartment
Tt	Temperature at top of the compartment
VOC	Volatile Organic Compounds