



REGLISSE

Review of European ground Laboratories and Infrastructures for
Sciences and Support Exploration

ESA Internal study

TECHNICAL NOTE 1

Definition of the Ideal Facility for Medical Issues

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ACRONYMS LIST

AC	Altitude Chamber
BR	Bed Rest simulations
EHA	Extra Habitat Activity
EVA	Extra Vehicular Activity
IC	Isolation – confinement simulations
LSB	Life Support Breadboards
PF	Parabolic Flight
PI	Patient immobilisation
SR	Sounding Rocket
WI	Water Immersion
WDI	Water “Dry” Immersion

REFERENCE DOCUMENTS

RD 1: ESA and the Mars Initiative, Final Report of the Interdirectorate Groupe de Reflexion. Sept. 15, 1998. D/MSM/98-248.

RD 2: HUMEX, Study on the Survivability and Adaptation of Humans to Long- Duration Interplanetary and Planetary Environments, TN-002- Issue Draft of Part 1, September 2000.

RD 3: ESA WPPP –163, Workshop on Advanced Life Support ESTEC, Noordwijk, The Netherlands, 13-14 April 1999.

RD 4 : Catalogue of Ground based facilities in Life Sciences Draft Version 00/11/20.

RD 5 : MELISSA Dossier for further development , Version 1, issue2.1, march 2000.

RD 6 : NASA astrobiology webpage

RD 7: Astrobiology book, Lecture Notes in Physics (C. Baumstark-Khan ed.) in press

(Ehrenfreund et al) eds. Astrophysics space science library, Vol 236

1. INTRODUCTION

Over the last 20 years European countries have developed their national facilities to study specific problems of extreme environments : space radiation, bed-rest, submarines, Antarctic environment, nuclear accident, bio-safety (i.e. viruses/bacteria). Unfortunately, the needs for future space explorations has not been taken into account and there are currently no overall synergies or collaborations between these centres.

It must be pointed out that these facilities exist for some of our international partners (i.e. Bioplex for US and CEEF in Japan).

Additionally, it is expected that such a facility will have a very strong terrestrial interest in line with the last EC programme plan.

As recognised by the Inter-directorate “Groupe de Reflexion” in their final Report on “ESA and the Mars there “is a definite interest and potential for the European participation to a human mission to Mars” RD1. In the field of space life sciences it is noted, that “a human mission to Mars will not be possible unless some critical aspects of human physiology and psychology” are not solved before the mission (RD 2). The International Space Station is seen as a testbed for many of those issues. The spaceflight environment and specifically microgravity, alters several physiological parameters in the long run. These changes, analogous to the physiological deconditioning observed in elderly people, can be life threatening, especially in emergency situations or when considering that extravehicular activities on a planetary surface are physically intense. Currently, there is insufficient information on spaceflight-induced changes and their consequences on performance and health during prolonged missions, either in zero-G or reduced gravity. Because of this lack of data, all physiological systems carry risks for exploration missions. Critical issues have been identified in the areas of neurosensory, musculoskeletal, cardiovascular and regulatory physiology. Some of these areas may be even amplified by the necessary transition from zero-G to hypergravity (de-orbit) and reduced gravity implied by interplanetary missions. An additional important aspect is radiation. Space radiation is different from the radiation on the Earth surface, both from a qualitative and quantitative point of view. There is currently no legal limit on radiation exposure for interplanetary missions. There is also great uncertainty on the biological effects of energetic charged particles on astronauts. The unpredictability of the occurrence and magnitude of Solar flare events, which can potentially deliver lethal doses in a matter of hours is also a problem to be considered in the preparation of future exploration missions.

Especially the HUMEX study (final presentation in May 2001) further elaborates on critical medical issues for long duration space missions (Technical note 2, RD 2). For all relevant medical fields (Control of infectious disease, metabolic disorders, mental disorders, eye and ENT disorders, cardiovascular disorders, injuries, radiation risks, 0-g induced musculoskeletal disorders etc.) the study lists:

- Life science knowledge acquisition needs,
- Space related countermeasure needs,
- Space related biomedical technology needs,
- Potential space/ ground synergy

The issues identified in the HUMEX study represent the topics, that preparatory ground based research will have to cover. For this research various different, in some cases very complex facilities are needed. This study should examine to which degree existing facilities, for example for bed rest studies, can be

improved to provide better synergy with facilities that study related medical issues.

The radiation related issues are not included in the present document, because the ethical constraints do not allow to expose human subjects in the anticipated radiation environment of an exploratory mission for research purposes .

1.1 PURPOSE AND SCOPE OF THE DOCUMENT

In the field of medical issues, this document proposes to make a review of the existing infrastructures in Europe. Then, by comparison with the medical needs to prepare exploratory missions, it identifies pros and cons .

1.2 EXISTING EUROPEAN INFRASTRUCTURES

Terrestrial analogues for undertaking the research needed to prepare interplanetary and planetary exploratory missions are as follows:

Isolation - Confined environment simulation (IC): specially created within confinement chambers, or “naturally” existing confinement as during Antarctica base missions (ANT), submarine missions, or working on off-shore platforms. These analogues can be used for long duration studies.

Simulation of microgravity using Bed-Rest (BR) (on healthy subjects, with or without head-down tilt / head-up tilt for reduced gravity) to study cardiovascular deconditioning, exercise capacity impairment, and musculo-skeletal disorders. This analogue can be used for long duration studies.

Some particular situations such as long term patient immobilisation (PI) (with spine trauma for example) can also be used to study cardiovascular deconditioning, exercise capacity impairment, and musculo-skeletal disorders.

Simulation of microgravity using Water Immersion (WI) to study rapid and transitory fluid and hormonal regulation. The normal duration of WI is limited to a maximum of 12-24h.

So-called water “dry” immersion (WDI) is mainly used to study cardiovascular deconditioning and body fluid and mineral changes over longer periods of time than is possible with “wet” immersion.

Parabolic flight (PF) allows short exposure to 0-g (maximum 25-30 sec.). These simulations are suitable for studies of acute phenomena - cardio-vascular and neuro-sensory, and also for technical demonstrations of the utilisation of equipment under 0-g. This type of analogue can be used for human but also for animals, tissue or cells studies.

Breadboards are widely used for studies related to advanced life support systems (LSB = Life Support Breadboards). Large scale breadboards (Habitable Closed Chamber or HCC) can be used with man-in-the-loop for long duration simulations. This type of analogue can be used for human but also for animals, tissue or cells studies.

Altitude Chambers (ACs) can be used to optimise EVA / EHA exercise scheduling.

Mathematical modelling and computer simulations can also be used.

A short list of the existing European facilities is :

CRF - MEDES (FR) : Facility Capabilities : Human factors, Confinement, Isolation, Simulated weightlessness, Metabolic Ward, Human Physiology, Circadian Rhythm, Human performance, Sleep, Noise

Short Description : The Clinical Research Facility is a 1000 m² multipurpose facility located within the Toulouse Rangueil hospital. It has been designed to host most of the ground based clinical or human factors experimental research needed to conduct space research, as for instance:

- Simulation of the effects of weightlessness by bed rest,
- Simulation of the effects of other factors of space environment (confinement, circadian rhythms),
- Ground based control experiments,
- Testing of equipment's and procedures,
- Medical screening and check-up of healthy volunteers

AMSAN DLR Cologne (D) : Facility's Capabilities : Human factors, Confinement, Isolation, Simulated weightlessness, Metabolic Ward, Human Physiology, Circadian Rhythm, Jet Lag, Shift Work, Irregular duty hours, Human performance, Sleep, Noise.

Short Description : The multi purpose research facility is designed for investigation in the area of aviation and space medicine and human factors. The facility is capable of housing up to 8 subjects at a time and providing for environmental control (artificial light, climate, sound proofing). It can be operated as a closed system and run in complete isolation from the outside for days or weeks. The facility consists of an area within the simulation facility for occupational medical research (AMSAN). It has a close relation to the biochemical laboratories and software and equipment to plan and prepare the diet and all related aspects of electronic recording and biosamples.

Antartic Stations : Facility's capabilities : Human factors, Human / Animal Physiology

Short description : The Antarctic scientific stations are dedicated to scientific research in several domains using specific aiming of Polar region: Human Biology and Medicine Psychology, Other topics : Technology, including Life Support systems, Glaciology & Paleo-climatology, Astronomy and astrophysics (Concordia), Internal & External geophysics: terrestrial magnetism, seismology, geology, volcanism & study of magnetosphere & ionosphere, Physics & Chemistry of the lower layers of the atmosphere: meteorology, low radioactivity, pollution, green house gases, ozone layer.

DESC (NL) (1) : Facility's capabilities : Human physiology, Animal physiology, Fluid Physics, Combustion Sciences, Material Sciences

Short description : The human rated centrifuge is mainly used for aircrew training, physiological and medical research, equipment testing and evaluation. It has also been used for studies investigating the Space Adaptation Syndrome.

Clim. Chambers, TNO (NL) : Facility's Capabilities : Human factors, Human physiology

Short Description : The climate chambers and microclimate conditioning suits can create environmental conditions from -20°C to $+50^{\circ}\text{C}$. Together with wind, humidity level, solar radiation and rain, it can be used to produce an environment in which the human performance can be studied.

COMEX (F) : Facility's Capabilities : Human factors, Human/animal physiology

Short description : Equipment : The H.E.C has two different facilities, two simulation chambers for human research three simulation chambers for biological models.

Vestib. Lab. TNO, Soesterberg (NL) : Facility's Capabilities : Human Factors, Human/Animal Physiology

Short Description : The research group Equilibrium & Orientation at TNO-HF employs the vestibular laboratory to expand their knowledge on the effects of angular and linear acceleration on human spatial orientation, postural stability, and motion sickness. For research on hypergravity, the group uses the human centrifuge at the Aeromedical Institute next-door. The vestibular laboratory combines several devices in which subjects can be to various motion stimuli: 3-D rotating chair, Linear Track (the ESA, Space Sled), Tilting Room, and Ship Motion Simulator. For presentation of computer generated visual motion stimuli a Helmet Mounted Display is available. The laboratory is also fully equipped to measure psychophysiological responses, such as eye movements, subjective vertical, stabilometry, Vitaport, etc.

VVIS, Medes (F) : Facility Capabilities : Human Factors, Human Physiology

Short Description : This ESA-developed human centrifuge for the NEUROLAB mission, known as the VVIS (Visual and Vestibular Investigation System) is used as a way of investigating the role of the inner ear in detecting changes in motion and orientation. Centripetal acceleration ranging from 0.5g-1.0g can be applied along the subject's interaural ($\pm\text{Gy}$) or longitudinal (-Gz) axis. This facility can be used for studies in human vestibular physiology, testing labyrinthine defective patients, or studies on the effectiveness of centrifugation as a countermeasure for deconditioning due to spaceflight.

CAR Barcelona (E) : Facility Capabilities : Human factors, Human/Animal Physiology

Short description : The CAR center has been specifically designed to support the improvement of performances of top athletes and to characterize the physiological and general training conditions contributing to such improvement. The Olympic Training Center is providing all necessary equipment and know-how that is necessary for the improvement of performances of top athletes, from the characterization of physiological cardiorespiratory and musculoskeletal systems,

movement analysis including kinematics modelisation and simulation, resistance-endurance-nutrition aspects, stress prevention, -management and recovery, functional characterization, training programmes, up to personal skills and psychological aspects.

Other testbeds are covering the simulation means not yet existing but that are to be imagined to assess the human survivability for the interplanetary and planetary exploratory missions.

1.3 PREPARATION OF EXPLORATORY MISSIONS : CREW HEALTH CONTROL NEEDS

NB: all the requirements related to health / psychological issues and health / life support issues are treated separately in TN 2 and TN 3.

Life Sciences knowledge improvement needs

Fundamental research:

- Determine the nature, time course, and severity of immune function changes induced by long duration spaceflight, and identify which factors are responsible.
- Determine the effects of long duration spaceflight on endocrine and homeostatic systems, and relate the consequences to other systems.
- Determine sensory inputs and co-ordination processes of muscular function before, during and after flight. Determine whether the decrease in afferent inputs (vestibular, proprioceptive, somatosensory) that are associated with long duration space flight results in a permanent reflex deficits.
- Determine the mechanisms of muscle metabolism regulation during normal activity and exercise, in acute and chronic unloaded states, and during recovery from unloading. Determine the endocrine, nutritional and mechanical requirements for maintaining bone, muscle and connective tissue and so reduce space-induced impairments. Determine whether the space- induced bone loss is reversible in terms of mass, and ultra and microstructural organisation. Identify bone and muscle metabolism markers (if any) convenient for monitoring the space- induced muscle and bone impairments.
- Determine the effects of prolonged exposure in a confined environment in terms of factors such as atmosphere, food, and water.: conduct necessary microbiology and toxicology studies.
- Investigate how neoplasms common to chronological ageing relate to limitations of cell lifespan, and susceptibility to abnormal growth regulation, under space environmental conditions (0-g and radiation).
- Provide answers to the following questions relating to disorders induced by exposure to reduced gravity (0.16 and 0.38 g) :
- What is the level of bone demineralisation induced in a 0.16 and in a 0.38 g environment ?

- What are neuro-sensory disorders induced in a 0.16 and in a 0.38 g environment ?
- What are muscular disorders induced in a 0.16 and in a 0.38 g environment ?
- What are cardiovascular disorders (orthostatic intolerance and exercise capacity impairment) induced in a 0.16 and in a 0.38 g environment ?

Applied research:

- Establish a international astronauts / cosmonauts medical database to allow a longitudinal epidemiological study of the effects of long space flight on humans
- Determine how adaptive responses to long duration space flight affect absorption efficiency, toxicity, and side effects of medications (including pharmacokinetics studies).
- Determine if the space environment (0-g + radiation) will increase the mutation rate of micro-organisms and what the therapeutic consequences are.
- Determine how adaptive responses to long duration space flight affect nutritional requirements and gastrointestinal functions.
- Investigate long term space flight alterations in blood pressure and blood flows, and the functional consequences for tissues and organs. Determine whether the extent of cardiovascular adaptation to space flight affects the post flight orthostatic intolerance.
- Determine how adaptive responses to long duration space flight (0-g + radiation) affect reproductive functions. Are these effects reversible ?
- Determine how adaptive responses to long duration space flight affect kidney functions (filtration, reabsorption, secretion, excretion) and the consequences in terms of fluid and electrolytes losses and kidney stone risks.
- Determine how well injured skin, muscle, connective tissue or fractured bone repair in spaceflight environment.
- Determine the factors responsible for 0-g induced back pain.
- Determine whether space flights, EVA, or EHA increase cardiac arrhythmia, and identify mechanisms.

Needs for a better control of crew health issues (countermeasures)

At the level of crew selection (to be completed by psychological issues)

- A medical and surgical capability must be onboard the Mars transit vehicle (1000 and 500 day missions) and the Mars habitat (1000 day mission).
- Define an astronaut selection process for a better risk assessment of mental disorders, dental disorders, digestive and genitourinary disorders etc

In flight safety and countermeasures

- Define the human health and safety limits for quality of water, food and atmosphere (adapted Spacecraft Maximum Allowable Concentration values) for long duration human space exploration mission.
- Design an optimised dietary regimen for long duration space flight.
- Define criteria for designing and operating a countermeasure system (physical exercise, dietary, pharmacological, mechanical) for long duration 0-g exposure to minimise :
 - musculoskeletal impairments (muscle atrophy, bone demineralisation, back pain).
 - neuro-sensory disorders and their consequences.
 - the flight-induced exercise capacity impairment.
 - the post flight orthostatic intolerance.
- Assess the whether periodical exposure to artificial gravity (using a short arm centrifuge as a potential 0-g countermeasure) is acceptable in terms of :
 - The neuro-sensory induced discomfort .
 - Benefits on the bone loss .
 - Benefits on exercise capacities .
- Determine the best exercise/denitrogenation decompression schedule for EVA and EHA .
- Design appropriately modified prescriptions (dose, use frequency,) for medications used during long duration spaceflight.
- Define the criteria for designing and operating a countermeasure programme before, during and after flight to prevent crew infectious diseases and dental disorders.
- Define and develop a skill maintenance programme (i.e. medical and surgical skills) by using teletraining capabilities.

Space related biomedical technology (diagnostic and therapeutic)

NB: only non existing equipment (or equipment that needs serious adaptation or full development for space utilisation) is listed here.

For monitoring :

- Design a real time monitoring system (microbiological and toxicological) to control the atmosphere, water, food and surface quality during long duration space exploration.
- Design bubble formation monitoring equipment to prevent decompression sickness events.

- Design a telemedicine system to support:
- The management of all potential disorders (for diagnostic and care purposes).
- A medical and surgical skill maintenance programme.

For medical diagnostic :

- Design equipment to measure bone ultra and microstructural organisation, and local mechanical bone properties, in order to monitor space-induced impairments of bone.
- Design compact equipment adapted for long term space flight allowing:
- The identification of pathogen micro-organisms
- The determination of the in vitro Minimum Concentration of Inhibition of antibacterial, antibiotic, antifungal, antiparasitic agents
- Blood cell counting and analysis
- Blood and urine chemical analysis
- Blood or urine biomarker identification and quantification of potential endocrine, nutritional, and metabolic disorders, and measurement of the bone and muscle metabolism markers.
- Compact abdominal ultrasound, endoscopy and X-ray equipment will be available onboard a Mars transit vehicle (for the 500 and 1000 day Mars missions) and Mars habitat (for the 1000 day Mars mission).

For medical care:

- Design optimised exercise equipment for long duration space flight.
- Design a medical kit for long term space flight.
- These onboard medical kits will include the instruments (diagnostic and therapeutic) necessary to treat the most common dental, eye and ENT diseases.
- Design medical equipment to allow the following:
- pulmonary life support (with hyperbaric capability) to be used in case of a decompression sickness event, resuscitation or anaesthesia.
- Anaesthesia
- Resuscitation
- Endoscopic surgery
- Surgery under 0-g conditions

- Immobilisation
- Medical facilities to manage adverse effects of reduced temperature, heat and light exposure should be available onboard Mars transit vehicle (for the 500 and 1000 day Mars missions) and Mars habitat (for the 1000 day Mars mission).

Terrestrial analogues as test beds for addressing medical and physiological crew health control issues to prepare exploratory missions.

In table I the issues identified here before are listed, terrestrial analogues as tests beds for facilitating their resolution (++ = mandatory, + = useful, +/- = can be used but uncertainties about space applicability will remain for the results, - = not relevant). The research studies in the field of the health risk assessment may concern human but also animals.

<u>Medical Physiological issues / simulation means</u>	BR	PI	WI /WDI	PF	IC /ANT	HCC LSB	AC
Determine nature, time course, and severity of immune function changes induced by long duration space flight, and which factors are responsible.	+	-	-	-	+	+	+
Determine effects of long duration space flight on endocrine and homeostatic functions and related physiological systems.	+	-	-	-	+	+/-	-
Determine sensory inputs and co-ordination of muscular function for locomotion before, during and after flight. Determine whether the decreases in afferent inputs (vestibular, proprioceptive, somatosensory) that are associated with long duration space flight exposure, result in a permanent reflex deficits.	+/-	-	-	+	-	-	-
Determine effects of long duration space flight on individual human performance, and on group behaviour and dynamics Determine effects of long duration space flight on sleep cycle and circadian rhythms and their impact on physiological adaptation, responses to stress, and human performance. Identify criteria for evaluating individual and crew performance / productivity.	+/-	-	-	-	++	+	-
Identify factors concerned with the regulation of muscle metabolism during normal activity and exercise, in acute and chronic unloaded states, and during recovery from unloading. Determine the endocrine, nutritional and mechanical requirements for maintaining bone, muscle and connective tissue integrity in microgravity-. Determine whether the space- induced bone loss is reversible in terms of mass, ultra, and microstructural organisation. Identify bone and muscle metabolism markers (if any) convenient for monitoring the space-induced muscle and bone impairments.	++	+	-	-	+/-	+	-
Determine the effects of living in a confined environment during long duration exploratory space missions (atmosphere, food, water) by conducting microbiology and toxicological studies.	-	-	-	-	++	++	+/-
Determine how neoplasms common to chronological ageing relate to limitations of cell lifespan and susceptibility to abnormal growth regulation under space environmental conditions (0-g and radiation).	-	-	-	-	-	-	-

<u>Medical Physiological issues / simulation means</u>	BR	PI	WI /WDI	PF	IC /ANT	HCC LSB	AC
Determine the disorders induced by exposure to reduced gravity (0.16 and 0.38 g) in terms of the following issues: What is the level of bone demineralisation induced by 0.16 and 0.38 g environments ? What are neuro-sensory disorders induced by 0.16 and 0.38 g environments ? What are the muscular disorders induced by 0.16 and 0.38 g environments ? What are the cardiovascular disorders (orthostatic intolerance and exercise capacity impairment) induced by 0.16 and 0.38 g environments ?	+/-	+/-	-	+/-	-	-	-
Determine how adaptive responses to long duration space flight affect absorption efficiency, toxicity, and side effects of medications (including pharmacokinetics).	+	+/-	+/-	+/-	-	-	-
Determine if the space environment (0-g + radiation) will increase mutations of micro-organisms, and establish the therapeutic consequences.	-	-	-	-	-	-	-
Determine how adaptive responses to long duration space flight affect nutritional requirements and gastrointestinal functions.	+	+/-	-	-	+/-	+	-
Determine the effects of long term space flight on blood pressure and blood flow, and identify the functional consequences for tissues and organs. Determine whether the extent of cardiovascular adaptation to space flight affects post flight orthostatic intolerance.	+	+/-	+/-	-	-	-	-
Determine how adaptive responses to long duration space flight (0-g + radiation) affect reproductive function. Establish whether these responses are reversible.	-	-	-	-	-	-	-
Determine how adaptive responses to long duration space flight affect kidney function (filtration, reabsorption, secretion, excretion), and the consequences in terms of fluid and electrolytes losses, and kidney stone risk.	++	+/-	+	-	-	-	-
Determine how effectively injured skin, muscle, connective tissue or fractured bone repair in a space flight - environment.	-	+/-	-	-	-	-	-
Determine factors responsible for 0-g induced back pain.	+	+/-	+/-	-	-	-	-
Determine whether space flights, EVA and EHA increase cardiac arrhythmia, and identify mechanisms.	+/-	+/-	+/-	+/-	-	-	+
Determine the medical and surgical capability requirements for the Mars habitat (1000 days mission).	-	-	-	-	+	-	-
Define an astronaut selection process for better risk assessment of mental disorders, dental disorders, digestive and genitourinary disorders etc	+/-	+/-	-	-	++	-	-
Define the human health and safety limits for quality of water, food and atmosphere (adapted Spacecraft Maximum Allowable Concentration values) for long duration human space exploration mission.	-	-	-	-	++	++	-
Define and develop a pre-flight training programme (for crew and ground support staff) to enhance the crew and ground support effectiveness for communication, interpersonal dynamics, and problem solving.	-	-	-	-	++	-	-

<u>Medical Physiological issues / simulation means</u>	BR	PI	WI /WDI	PF	IC /ANT	HCC LSB	AC
Develop counter measures to minimise the risk of human performance impairment induced by sleep cycle and circadian rhythm perturbances, and to maintain human performance throughout the missions.	+/-	+/-	-	-	++	-	-
Design an optimised dietary regimen for long duration space flight.	+	+/-	-	-	++	-	-
Define the criteria necessary to design and operate a countermeasure system (physical exercise, dietary, pharmacological, mechanical) for long duration 0-g human exposure to minimise : musculoskeletal impairments (muscle atrophy, bone demineralisation, back pain). neurosensory disorders. flight- exercise capacity impairment. post flight orthostatic intolerance.	++	+/-	+/-	+/-	+	-	-
Assess the possible benefits of periodic exposure to artificial gravity (using a short arm centrifuge as a potential countermeasure) on the following: neuro-sensory discomfort bone calcium loss exercise capacity	++	+/-	-	+/-	-	-	-
Determine the best exercise/denitrogenation schedule before EVA or EHA decompression process (altitude chamber)	+/-	-	-	-	-	-	++
Design a prescription (dose, use frequency, ...) of medications for long duration space flight.	++	-	-	-	+/-	-	-
Define the criteria necessary to design and operate a countermeasure programme before, during and after flight, to prevent crew infectious diseases, dental disorders, etc.	-	-	-	-	+	-	+/-
Define and develop a skill maintenance programme (i.e. medical and surgical skills) by using teletraining capabilities.	+/-	-	-	-	++	-	-
Design a real time monitoring system (microbiological and toxicological) to control atmosphere, water, food and surface quality during long duration human space missions.	-	-	-	-	+	-	-
Design bubble formation monitoring equipment to prevent decompression sickness.	-	-	-	+/-	-	-	+
Design a telemedicine system to support the management of all potential disorders (for diagnostic and care purposes) likely to be encountered, together with a medical and surgical skill maintenance programme.	-	-	-	-	++	-	-
Design equipment to measure bone ultra and microstructural organisation, and local mechanical bone properties, and to monitor space induced impairments of bone during flight.	++	+	-	-	-	-	-
Ensure that compact abdominal ultrasound, endoscopy and X-ray equipment will be available onboard the Mars transit vehicle (for the 500 and 1000 day Mars missions), and the Mars habitat (for the 1000 day Mars mission).	-	-	-	+/-	+	-	-
Design optimised exerciser regimens for long duration space flight.	++	+	-	+	+/-	-	-

confinement simulations, ANT = Antarctica/underwater/off-shore situations, HCC= Habitable Closed Chamber / LSB= Life Support Breadboards, AC =
Altitude Chamber)

If we limit the previous table for the mandatory and useful opportunities to use the terrestrial analogues to progress in the solving of crew health issues in preparation of space manned exploratory missions, the resulting table is more limited, see table 2 :

<u>Medical Physiological issues / simulation means</u>	BR	IC /ANT	HCC LSB	AC
Determine nature, time course, and severity of immune function changes induced by long duration space flight, and which factors are responsible.	+	+	+	+
Determine effects of long duration space flight on endocrine and homeostatic functions and related physiological systems.	+	+		
Determine effects of long duration space flight on individual human performance, and on group behaviour and dynamics Determine effects of long duration space flight on sleep cycle and circadian rhythms and their impact on physiological adaptation, responses to stress, and human performance. Identify criteria for evaluating individual and crew performance / productivity.		++	+	
Identify factors concerned with the regulation of muscle metabolism during normal activity and exercise, in acute and chronic unloaded states, and during recovery from unloading. Determine the endocrine, nutritional and mechanical requirements for maintaining bone, muscle and connective tissue integrity in microgravity-. Determine whether the space- induced bone loss is reversible in terms of mass, ultra, and microstructural organisation. Identify bone and muscle metabolism markers (if any) convenient for monitoring the space-induced muscle and bone impairments.	++		+	
Determine the effects of living in a confined environment during long duration exploratory space missions (atmosphere, food, water) by conducting microbiology and toxicological studies.		++	++	
Determine how adaptive responses to long duration space flight affect absorption efficiency, toxicity, and side effects of medications (including pharmacokinetics).	+			
Determine how adaptive responses to long duration space flight affect nutritional requirements and gastrointestinal functions.	+		+	
Determine the effects of long term space flight on blood pressure and blood flow, and identify the functional consequences for tissues and organs. Determine whether the extent of cardiovascular adaptation to space flight affects post flight orthostatic intolerance.	+			
Determine how adaptive responses to long duration space flight affect kidney function (filtration, reabsorption, secretion, excretion), and the consequences in terms of fluid and electrolytes losses, and kidney stone risk.	++			
Determine factors responsible for 0-g induced back pain.	+			
Determine whether space flights, EVA and EHA increase cardiac arrhythmia, and identify mechanisms.				+
Determine the medical and surgical capability requirements for the Mars habitat (1000 days mission).		+		
Define an astronaut selection process for better risk assessment of mental disorders, dental disorders, digestive and genitourinary disorders etc		++		

<u>Medical Physiological issues / simulation means</u>	BR	IC /ANT	HCC LSB	AC
Define the human health and safety limits for quality of water, food and atmosphere (adapted Spacecraft Maximum Allowable Concentration values) for long duration human space exploration mission.		++	++	
Define and develop a pre-flight training programme (for crew and ground support staff) to enhance the crew and ground support effectiveness for communication, interpersonal dynamics, and problem solving.		++		
Develop counter measures to minimise the risk of human performance impairment induced by sleep cycle and circadian rhythm perturbances, and to maintain human performance throughout the missions.		++		
Design an optimised dietary regimen for long duration space flight.	+	++		
Define the criteria necessary to design and operate a countermeasure system (physical exercise, dietary, pharmacological, mechanical) for long duration 0-g human exposure to minimise : musculoskeletal impairments (muscle atrophy, bone demineralisation, back pain). neurosensory disorders. flight- exercise capacity impairment. post flight orthostatic intolerance.	++	+		
Assess the possible benefits of periodic exposure to artificial gravity (using a short arm centrifuge as a potential countermeasure) on the following: neuro-sensory discomfort bone calcium loss exercise capacity	++			
Determine the best exercise/denitrogenation schedule before EVA or EHA decompression process (altitude chamber)				++
Design a prescription (dose, use frequency, ...) of medications for long duration space flight.	++			
Define the criteria necessary to design and operate a countermeasure programme before, during and after flight, to prevent crew infectious diseases, dental disorders, etc.		+		
Define and develop a skill maintenance programme (i.e. medical and surgical skills) by using teletraining capabilities.		++		
Design a real time monitoring system (microbiological and toxicological) to control atmosphere, water, food and surface quality during long duration human space missions.		+		
Design bubble formation monitoring equipment to prevent decompression sickness.				+
Design a telemedicine system to support the management of all potential disorders (for diagnostic and care purposes) likely to be encountered, together with a medical and surgical skill maintenance programme.		++		

<u>Medical Physiological issues / simulation means</u>	BR	IC /ANT	HCC LSB	AC
Design equipment to measure bone ultra and microstructural organisation, and local mechanical bone properties, and to monitor space induced impairments of bone during flight.	++			
Ensure that compact abdominal ultrasound, endoscopy and X-ray equipment will be available onboard the Mars transit vehicle (for the 500 and 1000 day Mars missions), and the Mars habitat (for the 1000 day Mars mission).		+		
Design optimised exerciser regimens for long duration space flight.	++			
Design compact equipment for long term space flight allowing: <ul style="list-style-type: none"> ▪ The identification of pathogenic micro-organisms ▪ The determination of the <i>in vitro</i> Minimum Concentration of Inhibition of antibacterial, antibiotic, antifungal, and antiparasitic agents ▪ Blood cell counting and analysis ▪ Blood and urine chemical analysis ▪ Blood or urine biomarkers for identification and quantification of potential endocrine, nutritional, and metabolic disorders, and to monitor bone and muscle metabolism. 		+		
Design a medical kit for long term space flight. The onboard equipment (diagnostic and therapeutic) should be sufficient to treat common dental, eye and ENT diseases.		+		
Design medical equipment for exploratory long term space flight, to include: <ul style="list-style-type: none"> pulmonary life support equipment (with hyperbaric capability) to be used in case of decompression sickness Anaesthesia Resuscitation Endoscopical surgery Surgical sets adapted for 0-g use Immobilisation 		+		
Medical equipment to manage adverse effects of reduced temperature, heat and light exposure should be available onboard the Mars transit vehicle (for the 500 and 1000 day Mars missions), and Mars habitat (for the 1000 day Mars mission).				+

Table II: crew health control issues for exploratory planetary missions, and possible utilisation of terrestrial analogues as test beds. limited at mandatory “++” and useful “+” opportunities (BR = Bed Rest simulations, IC = Isolation confinement simulations, ANT = Antartica/underwater/off-shore situations, HCC= Habitable Closed Chamber / LSB= Life Support Breadboards, AC = Altitude Chamber).

2 IDENTIFICATION OF PROS AND CONS

To summarize the previous Table II, to improve the crew health issues to prepare future manned interplanetary missions :

Bedrest simulations are mandatory for :

- 0-g induced muscle impairment studies
- 0-g induced bone impairment studies
- 0-g induced kidney function changes studies
- to design and validate the best countermeasures for bone and muscle 0-g impairments (exerciser, pharmacological mean and artificial gravity exposure)
- to conduct pharmacological studies under simulated 0-g
- to evaluate the 0-g bone impairment monitoring methods and equipment

Bedrest simulations are useful for :

- 0-g induced immune functions impairment studies
- 0-g induced endocrine and homeostatic functions impairment studies
- 0-g induced cardiovascular functions changes studies
- 0-g induced nutritional functions changes studies
- 0-g induced back pain studies
- to design and validate the best countermeasures for bone and muscle 0-g impairments (exerciser, pharmacological mean and artificial gravity exposure)
- to conduct pharmacological studies under simulated 0-g
- to evaluate the 0-g bone impairment monitoring methods and equipment

Isolation – confinement simulations, (Antartica + underwater + off-shore situations) are mandatory for :

- confinement and human performance and group behavior studies
- confinement sleep perturbances studies
- toxicological studies in confinement (atmosphere, water, foods)
- to validate and improve the crew medical and psychological selection process
- confinement induced nutritional functions changes studies
- to evaluate and improve tele-medicine and tele-training systems

Isolation – confinement simulations are useful for :

- confinement induced immune functions impairment studies
- confinement induced endocrine and homeostatic functions impairment studies
- to define the medical and surgical needs of long term isolated small groups
- to evaluate compact medical and surgical equipment
- to evaluate a real time atmosphere / water / food quality monitoring system

Habitable Closed Chamber with attached Life Support Breadboards simulations are mandatory for :

- toxicological studies in confinement (atmosphere, water, foods)
- to evaluate a real time atmosphere / water / food quality monitoring system

Habitable Closed Chamber with attached Life Support Breadboards simulations are useful for:

- confinement and human performance and group behavior studies
- confinement sleep perturbances studies
- to validate and improve the crew medical and psychological selection process
- confinement induced nutritional functions changes studies
- to evaluate and improve tele-medicine and tele-training systems

- confinement induced immune functions impairment studies
- confinement induced endocrine and homeostatic functions impairment studies

Altitude Chamber simulations are mandatory for :

- to support the denitrogenation (exercise / scheduling) studies for Extra Vehicular and Extra Habitat Activities (EVA and EHA), including the monitoring equipment.

Altitude Chamber simulations are useful for :

- to clarify the cardiac arrhythmia induced by EVA and EHA in space
- decompression induced immune functions impairment studies
- to validate the equipment necessary to manage adverse effects of reduced temperature, heat and light exposure during EVA and EHA.

3 IDEAL FACILITY REQUIREMENTS FOR MEDICAL ISSUES

To be an ideal facility to support the medical issues research, studies and development activities with the objectives to prepare the future exploratory missions, these facilities shall satisfy the following requirements :

Architectural Rqts. : To support realistic simulations, the facility shall offer an architectural lay out similar with a spacecraft arrangement for exploratory missions :

To host a crew of 6 crewmembers

Working zones (laboratory, telecommunications console (delay of 20 min. in teletransmission) ECLS control, airlock maneuver console, maintenance console etc.....

Meeting zone

Recreational zone

Privacy zones, (particularly the sleeping zone shall be in the center of the facility to simulate a spacecraft part offering the best shielding against radiation of the habitable volume).

Medical zone (including health maintenance and countermeasures equipment)

Food storage and preparation zone

Hygienic zone

Health Maintenance Rqts : To support realistic simulations, the facility shall offer the possibility of a **maximum autonomy** of the test subjects for the day to day life, for the experimental and health maintenance purposes, for exemple the facility shall offer the possibility of a full autonomy of the test subjects for the medical intercurrent problems (not serious diseases) :

- A MD shall be among the test subjects

- The necessary medical equipment shall be inside the facility.
- The exchange of materials with exterior shall be limited and done through an airlock,
- The external teletransmission with 20 min. delay, no visit of external staff etc.....

For autonomous health management the following equipment shall be inside the facility :

- A medical (and surgical to be discussed) capability must be inside the facility (MD + necessary equipment).
- A Telemedicine capacity (with delays of transmissions)
- A medical and surgical skill maintenance programme.
- A real time monitoring system (microbiological and toxicological) to control the atmosphere, water, food and surface quality during long duration staying in the facility.
- Equipment to measure and to monitor simulated 0-g (if the 0-g simulation is implemented) induced impairments of bone.
- Equipment to measure and to monitor simulated 0-g (if the 0-g simulation is implemented) induced impairments of muscle and physical capacity.
- Equipment to counter-measure the simulated 0-g (if the 0-g simulation is implemented) induced impairments of bone and muscle (exerciser, Short arm centrifuge others TBD).
- Compact equipment adapted for the utilisation inside the facility allowing :
 - The identification of pathogen micro-organisms
 - The determination of the in vitro Minimum Concentration of Inhibition of antibacterial, antibiotic, antifungal, antiparasitic agents
 - Blood cell counting and analysis
 - Blood and urine chemical analysis
 - Blood or urine biomarker identification and quantification of potential endocrine, nutritional, and metabolic disorders, and measurement of the bone and muscle metabolism markers.
- Compact adapted for the utilisation inside the facility allowing :
 - abdominal ultrasound,
 - endoscopy (to be discussed)
 - X-ray
- A medical kit adapted for autonomous long staying inside the facility. Medical kits will include the instruments (diagnostic and therapeutic) necessary to treat the most common dental, eye and ENT diseases.
- Medical – Surgical equipment to allow the following, to be discussed for ethical issues :

- pulmonary life support (with hyperbaric capability if decompression operations are involved in the simulation) to be used in case of a decompression sickness event, resuscitation or anaesthesia (to be discussed).
- Anaesthesia, Resuscitation, Endoscopic surgery (to be discussed).
- Immobilisation (to be discussed)

Ethical Rqts. : The facility shall satisfy the local and international ethical and safety rules.

Health Research Rqts. : The facility shall offer the possibility of a full coverage of the health research issues, i.e. the environmental parameters shall be controlled, the adequate data collection shall be possible in satisfactory conditions. The detailed requirements are fully dependant of the scientific objectives.

If 0-g is simulated, the facility shall allow a long-term and permanent (uninterrupted) unloading of the human musculo skeletal and cardiovascular system. (i.e. a mobility system allowing to maintain the unloaded situation for each test subjects and the facility shall be sized to allow use of such system).

The facility shall allow to apply and evaluate specific countermeasures on the human subject, like ;

physical (mechanical) exercise,

human short arm centrifuge

dietary, (food, beverages)

pharmacological,

others

Functional Rqts. : To make the simulations as realistic as possible, the facility shall offer a complete confinement similar with exploratory mission : isolation, 20 min. delay for external teletransmission, no visit of external staff etc.....

EVA/EHA Rqts. : To support realistic simulations, the facility shall offer an airlock system, with depressurization capability for simulation of EVA/EHA, physical exercise inside the airlock shall be possible keeping the unloaded position. (NB the airlock shall be usable for materials exchange with exterior).

4 COMPATIBILITY OF THE REQUIREMENTS

Regarding the health research requirements issues when the O-g simulations (bedrest / head down tilt) are mandatory and useful (see paragraph 2 before), these requirements are not compatible with the architectural requirements and not easily compatible with the health maintenance, ethical functional and EVA/EHA requirements.

For that reasons, we recommend to consider separately the health research issues when the O-g simulations (i.e. bedrest / head down tilt) are mandatory and useful.

Regarding the health maintenance, ethical and EVA/EHA requirements, they can be fully compatible with the architectural and functional requirements of facilities able to support Isolation – confinement realistic simulations, or facilities like Habitable Closed Chamber with attached Life Support Breadboards.

For that reasons, we recommend to consider compatible the health maintenance and EVA/EHA research and development activities when using Isolation – confinement facilities, or Habitable Closed Chamber that satisfy the architectural and functional requirements.

5 TN 1 CONCLUSION

A compilation and a compatibility analysis of the requirements for health issues (TN1), psychological (TN2), life support (TN3) and exobiological (TN4) issues shall be done to design what could be the ideal simulation European facilities and their utilization for preparation of space exploratory missions. This will be the subject of the TN 5