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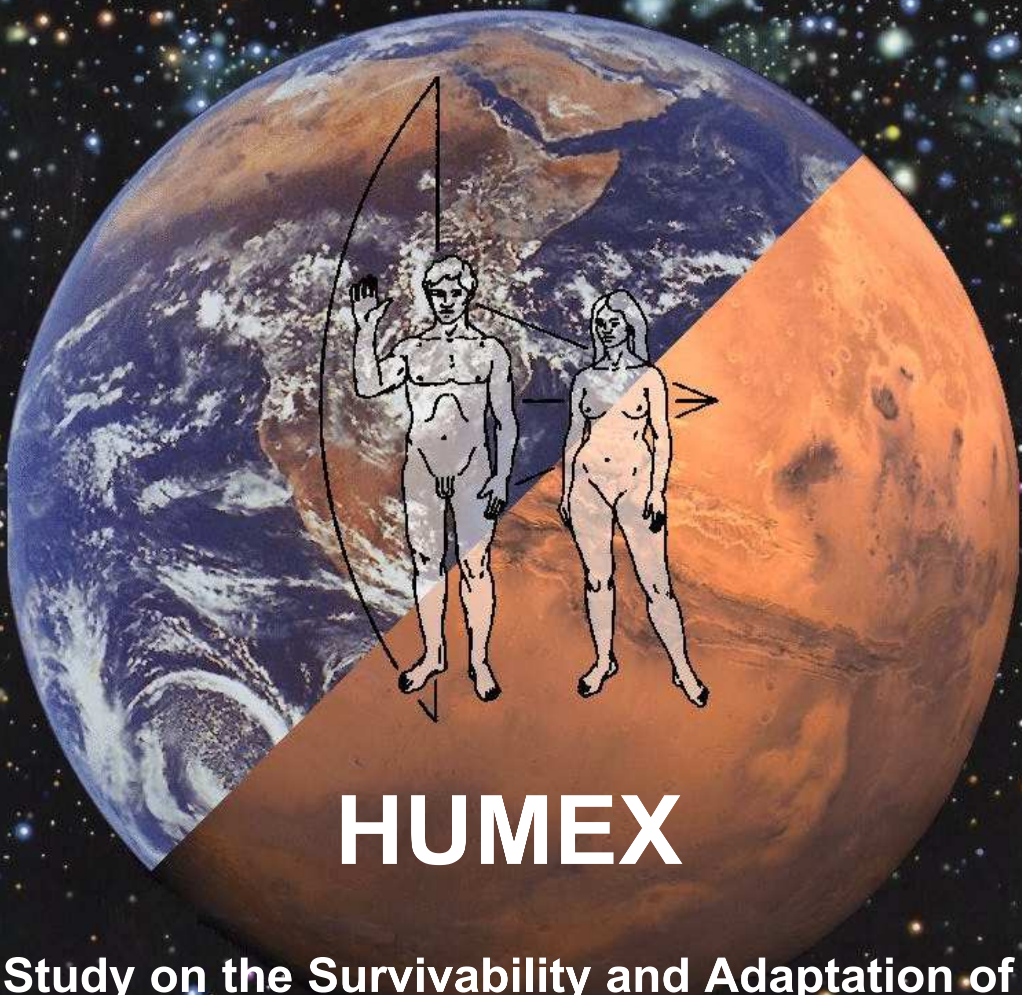

HUMEX

Study on the Survivability and Adaptation of Humans to Long-Duration Interplanetary and Planetary Environments

Technical Note 1

Definition of Reference Scenarios for a European Participation in Human Exploration and Estimation of the Life Sciences and Life Support Requirements

Issue: Draft

September, 2000

DERA MEDES DLR DaimlerChrysler Aerospace Dornier BLAISE PASCAL LGCB

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Technical Note 1

Definition of Reference Scenarios for a European Participation in Human Exploration and Estimation of the Life Sciences and Life Support Requirements

HUMEX-TN-001

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1. SCOPE

This document is part of the technical documentation produced in the frame of the "Study on the Survivability and Adaptation of Humans to Long-Duration Interplanetary and Planetary Environments". This study is carried out under ESA contract by a study team which comprises 5 partners from the European scientific and industrial community and which is led by DLR. The current document HUMEX-TN-001 describes the results of the study work package WP 2000.

The study is based on the results of the following activities dealing with a potential European participation in human missions to the Moon or to Mars initiated by ESA:

- An **Interdirectorate Group de Réflexion** of ESA has investigated the role Europe could play in an international cooperative initiative of a human mission to Mars. This resulted in a plan for activities and decisions, to be adopted by Europe in 4 phases, to enable European participation in an international Mars Human Exploration mission led by NASA [RD 1]. It was recommended that in the areas of human factor engineering, human physiology, radiation monitoring etc., which are already in the research plan for the ISS program, research aimed at supporting, or preparing, for the human mission to Mars, should be stressed. A special effort should be made to:
  - emphasize the use of the ISS and ground-based research in the fields of human adaptation to microgravity, the transition from microgravity to hypergravity and development of specific countermeasures;
  - develop very advanced technologies and procedures in preventive medicine, medical diagnostics and medical treatment, suitable for a very long duration space flight outside LEO, and for possible ground applications;
  - start immediately a ground research program looking especially into the key problems of psychological adaptation, confinement, and isolation, and into the effects of space radiation.

  Among other activities, Europe's potential participation in the definition of the mission scenarios was envisaged in the area of Life Sciences as a "cruise science package" including crew health monitoring/maintenance and radiation monitoring. Concerning Environmental Control and Life Support, a European potential participation was envisaged for biological systems at the experimental level.

- A **Lunar Study Steering Group** of ESA has investigated in 1992 Europe's priorities for the scientific exploration and utilization of the Moon [ESA SP-1150] which was followed by an International Lunar Workshop in 1994 [ESA SP-1170]. Within the overall scenario of lunar exploration, the life science needs were assessed as follows:
  - to establish the boundary conditions for human safety, health, well-being and working efficiency at a lunar base (e.g., human physiology under reduced gravity, radiation protection and life support systems) with due consideration of the scientific as well as the operational aspects;

- to establish an artificial ecosystem on the Moon, which could begin with a simple, remotely controlled system to be built up as the lunar base is developed.

The following environmental issues were identified:

- protection from lunar surface dust;
- protection from ionizing radiation;
- protection from ultraviolet radiation;
- protection from reduced gravity;
- protection from meteorite impacts;
- lack of essential prerequisites for supporting life, such as a significant atmosphere, water and moderate temperatures.

- An **Exobiology Study Team** of ESA has investigated the role a manned Mars station could play in exobiology research (ESA SP-1231). They concluded that trained professionals could be of considerable value in substantial activities on Mars, such as:
  - site identification of locations of high exobiological interest;
  - sample acquisition at these sites;
  - in-situ judgement and intuition;
  - in-situ analysis and pre-selection, if a laboratory is installed.

With the ISS a global cooperative program has started for the joint development, operation and utilization of a permanent space habitat in LEO. In conjunction with human missions in LEO, since Spacelab 1, Europe has gained a leading role in several fields of Life Sciences, such as human physiology and countermeasures, gravity biology, and radiation biology and dosimetry as well as in Life Support Technologies. Achievements can be claimed in:

- radiation dosimetry and protection;
- human adaptation to microgravity conditions;
- countermeasures;
- physico-chemical and biological Life Support Systems;

Within a strategy of human exploration of the solar system, the ISS has been identified as a mission benchmark, in particular in the areas of human factors research, technology demonstration, and on-orbit demonstration of precursor elements [RD 1].

Long-duration missions beyond LEO present tremendous human challenges. However, the proposed study will only address human related aspects: potential scenarios, Advanced Life Support Technologies, crew health, performance and survivability.

This study provides a critical assessment of the human responses, limits and needs with regard to the stress environments of interplanetary and planetary missions. Emphasis is laid on human health and performance care (radiation effects, microgravity and reduced gravity, psychology and health maintenance) and Advanced Life Support Developments.

The study results are described in 5 Technical Notes as follows:

- Definition of reference scenarios for a European participation in human exploration and estimation of the Life Sciences and Life Support requirements (HUMEX-TN-001)
- Critical assessments of the limiting factors for human health and performance and recommendation of countermeasures (HUMEX-TN-002)
- Critical assessment of the potential of advanced Life Support scenarios for human explorations and terrestrial applications (HUMEX-TN-003)
- Critical assessment of the feasibility of existing facilities and technologies as testbeds for human exploratory missions (HUMEX-TN-0004)
- Development of a roadmap for a future European strategy towards human exploratory missions and terrestrial applications and benefits (HUMEX-TN-0005)

In HUMEX-TN-001 the following set of three possible future reference scenarios is described and quantified for a potential European participation:

- Scenario 1: Lunar base at the south pole,
- Scenario 2: 1000 day Mars mission with long-term stay on Mars and in-situ resource utilization,
- Scenario 3: 500 day Mars mission with short-term stay on Mars

For each scenario, a timeline has been elaborated with regard to

- mission events
- radiation levels, and
- gravity levels,

and the optimal crew size and number and duration of EVAs has been estimated. This detailed characterization of the three candidate scenarios is used as baseline for all following tasks of the study.

Based on the definition of the set of candidate scenarios and using risk estimations as derived from individual risks of death and illness by natural or accidental events on Earth as well human space flight requirements, for each of the three scenarios the following needs have been assessed:

- minimum habitable volume
- quantity and quality of consumables, such as oxygen, water, food, beverages and individual kits including clothing

Furthermore, a quantitative estimate is given for human waste production and the probability of occurrence of diseases or fatal events. Alternative solutions are considered concerning gas losses from EVA, or body hygiene procedures.

Finally open issues are identified that would need special further consideration in order to optimize a specific mission scenario.

2. DOCUMENTS

2.1. Applicable Documents

AD1 Statement of Work "Study on the Survivability and Adaptation of Humans to long-Duration Interplanetary and Planetary Environments", (Appendix 1 of ESA AO/1-3622/99/NL/PA)

AD2 Work Packages Descriptions WP2100 and WP2200 of Contractors Proposal of November 19, 1999.

2.2. Reference Documents

RD1 ESA and the Mars Initiative, Final Report of the Interdirectorate Group de Réflexion. Sept. 15, 1998. D/MSM/98-248.

RD2 Human Exploration of Mars: the Reference Mission of the NASA Mars Exploration Study Team. NASA SP-6107, July 1997.

RD3 Advanced Technology for Human Support in Space, National Academy Press, 1997, No. 97-68305.

RD4 Physical Countermeasures for Long-Duration Manned Space Flights, ESA SP-1160, 1993.

RD5 Task force on Countermeasures, Final Report, NASA, 1997.

RD6 System Concepts, Architecture and Technologies for Space Exploration and Utilization (SE&U Study), ESA Co 12756/98/nl/JG(SC), Final Report.

RD7 A Strategy for Research in Space Biology and Medicine in the Next Century (http://www.nas.edu/ssb/csbmmenu.html).

RD8 Workshop in Advance Life Support, ESTEC, Noordwijk, The Netherlands, 13-14 April 1999, ESA WP-163.

Further reference documents, specifically related to this Technical Note, are given in the respective sections.

3. DEFINITION OF REFERENCE SCENARIOS FOR A EUROPEAN PARTICIPATION IN HUMAN EXPLORATION

3.1. Introduction

3.1.1. Background

In 1961, the age of manned space flight was initiated by the launch of Juri Gagarin on board a Russian Vostok rocket. Since that time, numerous manned missions to Earth orbit have been carried out by the Americans and Russians, lasting from a few days in capsules to several hundred days in space stations. A highlight in manned space flight was achieved in 1969, when the first humans landed on the Moon in the frame of the American Apollo program. After the Moon landings from 1969 to 1972, manned space activities were, however, exclusively limited to low Earth orbit. At the end of the eighties, a manned return to the Moon and a subsequent manned Mars Mission were again publically discussed. The stimulus for this discussion was the speech of former US-President Bush in 1989 on the occasion of the 20th anniversary of the first manned Moon landing, when he proclaimed a return to the Moon, the establishment of a permanently manned lunar base, and a following manned Mars mission. However, due to budgetary constraints, these ambitious plans had to be postponed. With the beginning of the nineties, manned missions beyond Earth orbit were again subject to extensive investigations. In 1994, in Europe, at a pioneering ESA conference in Beatenberg, Switzerland, a four-phase Moon program was proposed [ESA-SP-1170], the last phase of which consists of a manned return to the Moon, including the establishment of a lunar base. This Moon program may be regarded as a useful step for the preparation of a manned Mars mission because the Moon offers - like the international space station - unique environmental conditions as a testbed for the development and qualification of required technologies. In 1997, NASA published its first version of a feasibility study for manned missions to Mars, accompanied by ESA's activities in the "Groupe de Reflexion" and in the SE&U-study [RD1,RD2,RD6]. Also in the nineties, increasing attention has been given to the topic of space tourism due to its enormous economic (multi billion dollar) potential in the future. In 1998, NASA completed a space tourism feasibility study in co-operation with the Space Transportation Association, with encouraging results. In Japan, different space tourism scenarios have been investigated in the context of industrial research for about 10 years. Also in Germany [RD8] and Europe [RD6] the first space tourism studies have been initiated.

3.1.2. Study Approach for WP 2000

Taking into account this background, **WP2000** comprises the definition of a set of possible future reference scenarios for a potential European participation in order to:

- identify the influence of the reference scenarios on life sciences and life support systems;
- identify requirements for life sciences and life support systems for the different reference scenarios.

In a first approach a set of different reference scenarios (4 Mars scenarios, 3 Moon scenarios and 1 space tourism scenario) listed below was proposed to ESA/ESTEC as potential reference mission scenarios at the kick-off meeting:

Mars Scenarios (MAS)

- MAS 1: The 1000 day mission with long term stay on Mars and in-situ resource utilisation (e.g. NASA Ref. Mission)
- MAS 2: The 500 day mission with short term stay on Mars
- MAS 3: Reusable Interplanetary Bus spacecraft (up to 30 year lifetime)
- MAS 4: Mars Base (permanently manned)

Moon Scenarios (MOS)

- MOS 1: The 14 day mission (stay on the Moon only during the 14 days of sunlight)
- MOS 2: The 90/180 day mission (the crew in a lunar outpost will be substituted every 90/180 days and a lunar oxygen production plant could be assumed)
- MOS 3: Lunar outpost on the south pole (e.g. constant sunlight and potential water ice deposits could be assumed)

Space Tourism Scenarios (STS)

- STS 1: Earth orbit tourism in a rotating space hotel complex, with a life time of up to 30 years

In close accordance with ESA/ESTEC the following 3 scenarios, listed in tab. I-3.1.1 have been selected as reference scenarios during the kick-off meeting:

Table I-3.1.1: The 3 selected reference scenarios

Scenario 1 (Moon Scenario):	Lunar outpost on the south pole (e.g. constant sunlight and potential water ice deposits could be assumed)
Scenario 2: (Mars Scenario):	The 1000 day Mars mission with long term stay on Mars (Option: In-situ resource utilization)
Scenario 3: (Mars Scenario):	The 500 day Mars mission with short term stay on Mars

It is evident that each scenario, individually and differently drives the requirements for life sciences and life support systems, for example, the degree of closed LSS cycles, radiation protection, countermeasures to limit zero gravity effects, and psychological issues. Therefore, for each scenario, a timeline will be elaborated, which defines the duration of:

- Radiation (within Earth's magnetic field, in the interplanetary space, on Mars and Moon, solar flare danger,...);
- Gravity levels (zero gravity during the lunar or interplanetary transfer, reduced gravity on Moon and Mars, propulsive acceleration, deceleration during landing and aerocapture);
- IVAs and EVAs in orbits, during interplanetary transfer, on Moon and Mars (also Rover activities on planetary surfaces).

The detailed description and quantification of the scenarios, as well as the elaborated timelines, represent the fundamental issues which need to be taken in to account for the following Work packages 3000, 4000, 5000 and 6000 and which provide important input parameters for assessing the requirements for life sciences and life support systems and their corresponding design.

3.2. Definition of Reference Scenarios

Each of the selected 3 reference scenarios will be described on the following pages with respect to major mission events and sequences and the required space infrastructure. Furthermore, each scenario will be quantified with respect to relevant and characteristic parameters (e.g. minimum required crew size), infrastructure masses and total program costs.

3.2.1. Scenario 1: Lunar outpost on the south pole

3.2.1.1. Rationale for the exploration of the Moon

The Moon's rich potential as a scientific outpost and a natural space station can be divided into three main areas [ESA-SP-1170, RD 6]:

- Science of the Moon (incl. geophysical, geochemical and geological research on the Moon, leading to a better understanding of the origin and evolution of the Earth-Moon system)
- Science from the Moon (taking advantage of e.g. the stable lunar surface, its atmosphere-free sky and its radio-quiet environment for study of the universe and potential applications for Earth observations)
- Science on the Moon (incl. exobiology and the development of artificial ecosystems beyond the Earth as well as studies of human physiology under reduced gravity, radiation protection and life-support systems)

This may include the use of the Moon as a testbed for technologies to be applied in further space exploration initiatives, such as a Mars mission. The Moon is only about three days away from Earth and frequent launch opportunities exist. The journey to other planets such as Mars are considerably longer and numerous aspects concerning the effects of the space environment on humans are not yet entirely understood. Even assuming a significant improvement in space technology during the next years, intermediate steps, such as a manned mission to the Moon, would be extremely useful for a journey to Mars. In addition, the Moon could be used for in-situ resources exploitation. There are indications that concentration and ore formation processes have occurred on the Moon in the context of magmatic processes or due to the vaporisation of volatile elements during volcanism or impacts. Remote sensing with high spectral and spatial resolution as well as in-situ analyses (incl. drilling) are required for a better characterisation of potential lunar resources. It would be extremely fortunate for life support and propellant production, if water could be found in permanently shaded craters as a relict of cometary impacts. Characterized by technologically challenging environments (e.g. extremely low temperatures), those craters are also interesting locations for placing science instruments which require cooling (e.g. for infrared-astronomy) or for propellant storage. In addition, nearby mountains that are nearly permanently illuminated by the sun could be ideal locations for establishing a permanent lunar infrastructure.

A distinct NASA interest in lunar exploration was documented by the partly successful Clementine mission in 1994 and the launch of Lunar Prospector in January 1998. According to results of bi-static radar experiments from Clementine, water might be present in permanently shaded craters near the poles. The Prospector results have confirmed an increased hydrogen content in the regolith of these regions, they did, however, not yet unequivocally prove the presence of water ice. For final clarification, in-situ analyses appear to be necessary.

An International Lunar Workshop was organised in 1994 in Beatenberg, Switzerland [ESA-SP-1170], which recommended a phased approach in four steps for an international initiative termed "Return to the Moon". Lunar robotic exploration including the optional long-term goal of a manned return to the Moon was addressed as a promising scenario (see fig. I-3.2.1). Japan has also established an ambitious four-step program for Moon exploration and colonization, which envisions the installation of a permanent lunar base after 2024.

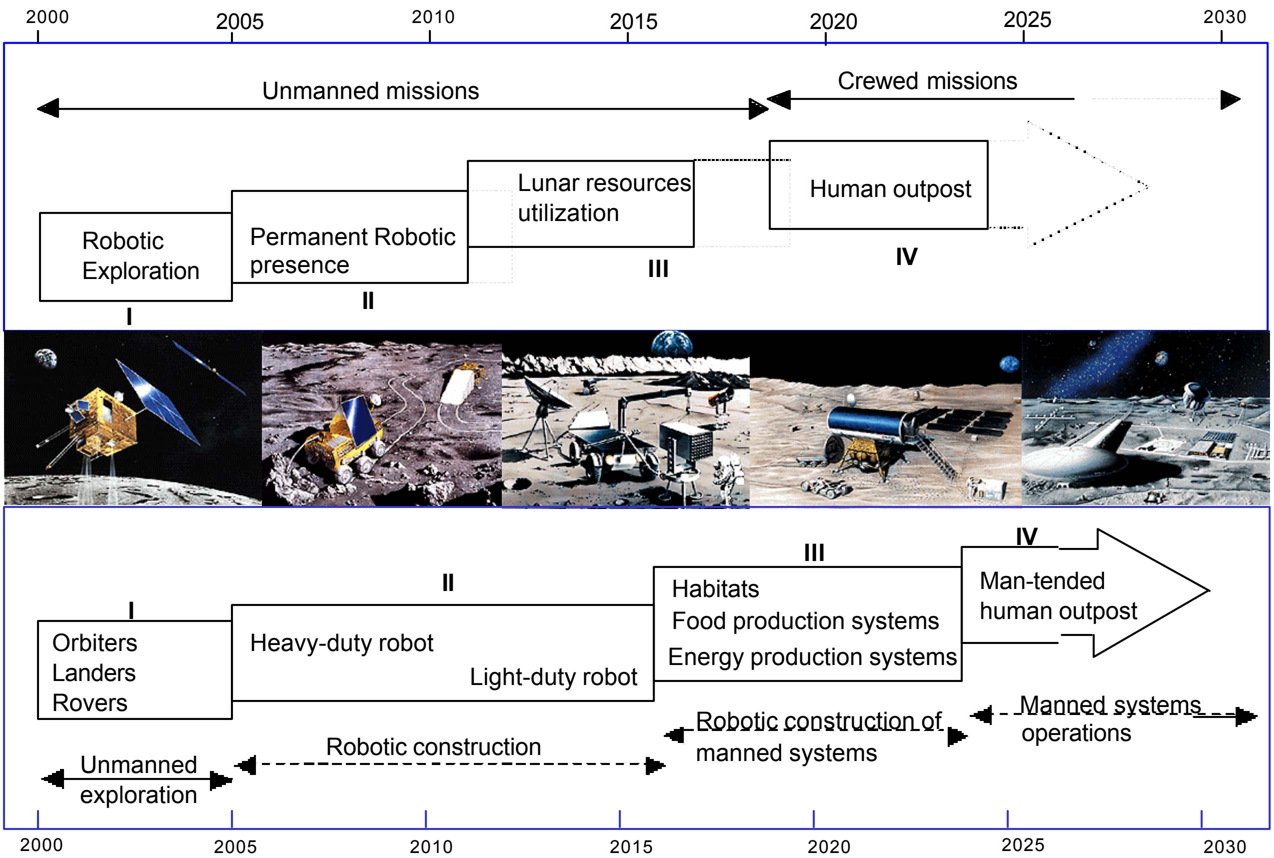

Figure I-3.2.1 International (top) and Japanese (bottom) four-step Moon exploration scenarios. [RD 6]

3.2.1.2. Lunar outpost on the south pole

In the beginning the Lunar base scenario consists of a small lunar base (1 habitation module and 1 laboratory module with corresponding scientific and operational infrastructure) which generally should be payload-compatible with an enhanced Ariane 5 launcher or Space Shuttle cargo bay. The Lunar base is located on the south pole in an area of eternal sunlight. The abundance of eternal sunlight in the south pole region significantly simplifies the design of the electrical power system (especially the power storage system) and leads to considerable mass and cost savings compared to e.g. equatorial bases who are characterized by 14 day lasting periods of sunlight and absolute darkness. The Lunar base should take advantage of an in-situ resource utilization plant (e.g. oxygen). Figure I-3.2.2 a shows an extended Lunar pole base which already consists of four modules (habitation and laboratory) and a crew rescue vehicle, which is docked to a connection node and would allow an emergency return back to Earth within 24 hours.

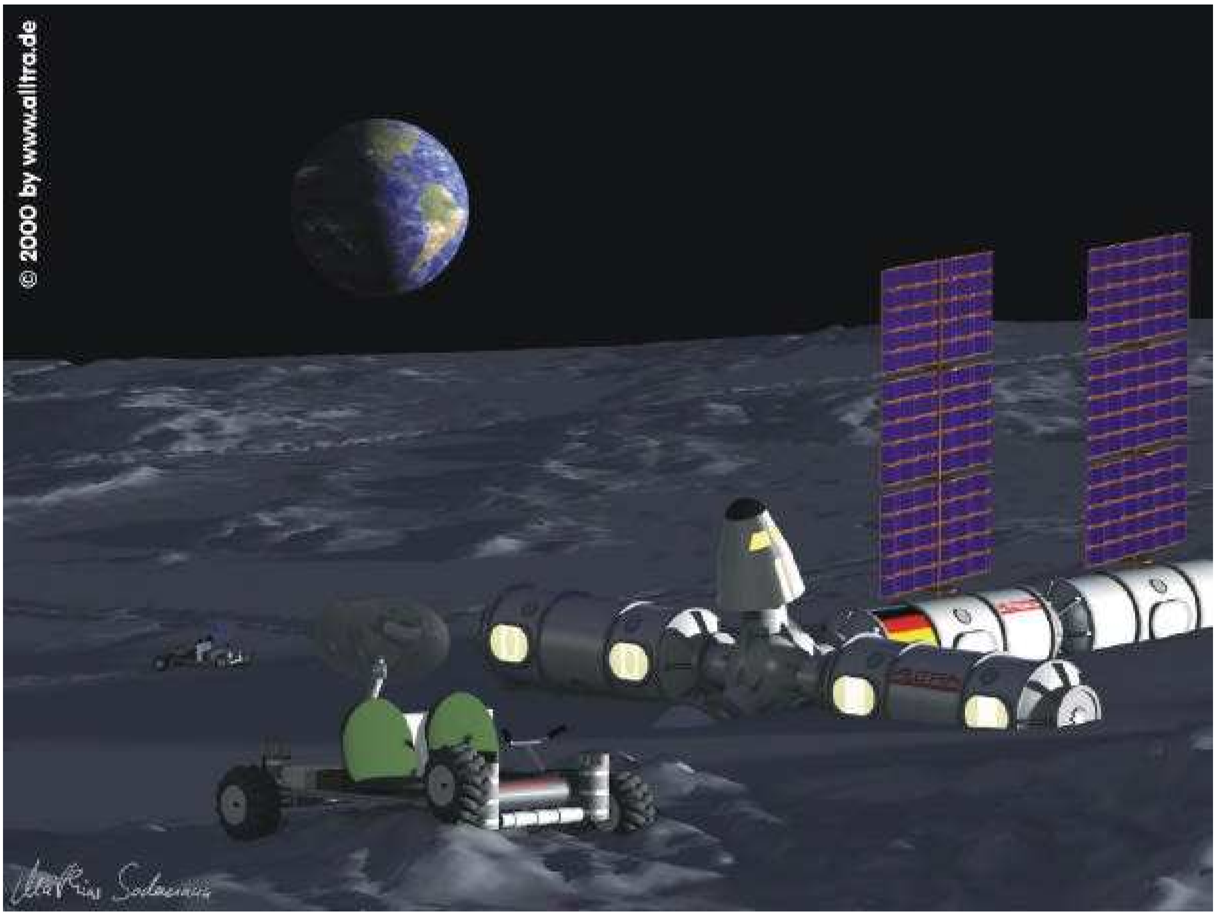

Figure I-3.2.2 Lunar Pole Base (artist view by www.alltra.de)

3.2.1.3. Crew size discussion

The selection of the lunar crew size represents an extensive trade off. On the one hand the crew size should be as high as possible to achieve a maximum mission safety and scientific and technological return. On the other hand, the crew size represents the most important driver for the complexity and therefore for the total mass and program cost of a manned lunar program. Positive experience has been gained during the Apollo program with a crew size of three. However, almost all Apollo Astronauts were educated and skilled in the military air force area. Due to the fact that the manned lunar program in this study aims mainly on scientific and technological objectives, the focus of the crew education should be more on scientific and technological issues. This should include skills in the scientific areas.

- Biology
- Medicine
- Geology
- Astronomy

Furthermore, the following technological skills of the crew members are essential and crucial for a safe and reliable operation of a Lunar program:

- Commander
- Spacecraft Engineering
- Manufacturing technology
- Software engineering

Assuming that each crew member is intensively educated in one scientific and one technological area, this leads to a crew size of 4 members. Compared to the crew of the Apollo program, this crew is increased by 25% and has more different skills so that a significant higher scientific and technological return can be achieved. Therefore, for the Lunar base scenario a permanent crew of 4 members has been selected, which will be substituted every 6 months (180 days) by supply flights from Earth. Depending on the specific objectives of future 180-day missions, the composition of the crew skills can be adapted on their individual requirements.

3.2.1.4. Lunar Trajectories

One transfer flight between Earth and Moon typically last between 3 to 5 days, depending on the selected launch window and propellant consumption. The departure Earth orbit should have an inclination of about 23.5°, which corresponds well to the plane on which the Moon orbits Earth. At Moon arrival a polar orbit has to be selected in order to minimize the Δv-requirement for the landing at a south pole base. Table I-3.2.1 quantifies the Δv-requirement for different mission events. Neglecting the Earth to LEO launch, the total Δv-requirement for a round-trip between LEO and Lunar surface amounts to about 9 km/s with an aerocapture maneuver for low Earth orbit insertion at Earth arrival. An aerocapture maneuver takes advantage of the upper layers of Earth's atmosphere in order to decelerate a spacecraft by atmospheric drag from its hyperbolic velocity down to orbital velocity of the LEO (in contrast to aerocapture, aerobraking decelerates a spacecraft which is already in the gravity field of a planet to achieve a lower orbit or landing like carried out in the Mars Global Surveyor and Pathfinder mission). Aerocapture and aerobraking represent therefore crucial technologies to significantly lower the Δv-requirement which leads to considerable mass and cost savings. However, these maneuvers are very risky (especially aerocapture has never done before) and increase the overall mission reliability. Taking into account that a Lunar roundtrip requires a Δv of about 9k/s and assuming that all spacecraft are equipped with a conventional chemical oxygen/hydrogen propulsion system, comprehensive spacecraft calculations indicate that a fleet of two spacecraft is sufficient to fulfill the transportation tasks.

Table I-3.2.1 Δv-requirement for different mission events

Mission Event	Δv-requirement [m/s]
1. Earth to LEO Launch (e.g. with Airane 5 or Space Shuttle)	9500
2. Departure from 400 km Low Earth Orbit (LEO)	3150
3. 100 km circular orbit insertion at Moon arrival	850
4. Descent and landing on Moon	2025
5. Ascent to 100 km circular Moon orbit	1984
6. Departure and return flight to Earth	850
7. 400 km orbit insertion at Earth Arrival without aerocapture	3150
with aerocapture	200
Total Δv-requirement (with aerocapture at Earth arrival)	**18559**

3.2.1.5. Lunar spacecraft fleet

Table I- 3.2.2 Mass Budget of the Lunar spacecraft fleet

MR			6
Isp [s]			475
AOTV	**LEO->LLO**		**LLO->LEO**
Δv-requirement [km/s]	4.0		1.1
Initial mass	188.7		34.0
ΣPayload	61.6		9.0
Mission payload	30.0		9.0
Return propellant	6.6		-
Propellant of LB + tank	25.0		-
Propellant (consumed)	108.7		6.6
Dry weight		18.4	
Lunar Bus (LB)	**LLO->LS**		**LS->LLO**
Δv-requirement [km/s]	2.0		2.0
Initial mass	54.1		13.5
ΣPayload	30.7		5.0
Mission payload	26.0		5.0
Ascent propellant	4.7		-
Propellant (consumed)	19.6		4.7
Dry weight		3.8	

All masses in [mt]

Therefore, the Lunar roundtrip flights (between LEO and Lunar surface) are accomplished by a reusable fleet of two spacecraft, consisting of a so called AOTV (Aeroassisted Orbital Transfer Vehicle) and LB (Lunar Bus) as shown in fig. I-3.2.3.

Figure I-3.2.3 The reusable lunar spacecraft fleet, consisting of an AOTV (above) and Lunar Bus (LB, below), artist view by Boeing/NASA

The reusable AOTV ensures the crew and payload transfer between LEO (400 km circular Low Earth Orbit) and LLO (100 km circular Low Lunar Orbit). The reusable LB provides the remaining transport between LLO and LS (Lunar Surface). Calculations indicate, that also the LB could serve as a crew rescue vehicle capable to transport the crew back to Earth within 24 hours if it is completely fueled on the Lunar surface and the crew cabin is equipped with a Thermal protection system. Generally, as far as possible, all required infrastructure elements should be payload compatible with an enhanced Ariane 5 launcher and Space Shuttle.

3.2.1.6. Build-up Scenario

Table I-3.2.2 shows the mass budget for the reusable Lunar spacecraft fleet consisting of an AOTV and LB. To build up the reusable spacecraft fleet, firstly all subsystem modules of both spacecraft (including payload and propellant) have to be launched into LEO where both spacecraft are integrated. It is worth to mention that the dry mass and different payload modules of both spacecraft do not exceed the payload capacity of existing launchers. However, due to the geometrical dimensions of several subsystems (e.g. thermal protection system, payload modules) the transport into LEO has to be divided up. For example, only the roundtrip propellant mass of the AOTV (about 115 mt) requires at least five build-up flights with an enhanced Ariane 5 and, furthermore, complex refueling activities in LEO. As soon as both spacecraft are completely built-up and refueled in LEO, the LB injects by its own propulsion system towards the Moon and inserts in a low circular 100 km Lunar orbit, where it is waiting for the AOTV in order to be again refueled and to transfer the payload to initiate the nominal operation. About 12 Earth to LEO flights are required for the build up of the spacecraft fleet and about 8 flights (only payload and propellant) are required for the operation of one nominal manned Lunar flight with a crew of four and 20 mt payload transported to the Lunar surface, if a the launcher has a LEO payload capacity of about 20 mt. Investigations in [REICHERT94] show, that the required initial LEO mass can be decreased by 50%, if a Lunar oxygen propellant production plant is operated on the Moon.

3.2.1.7. Radiation Level

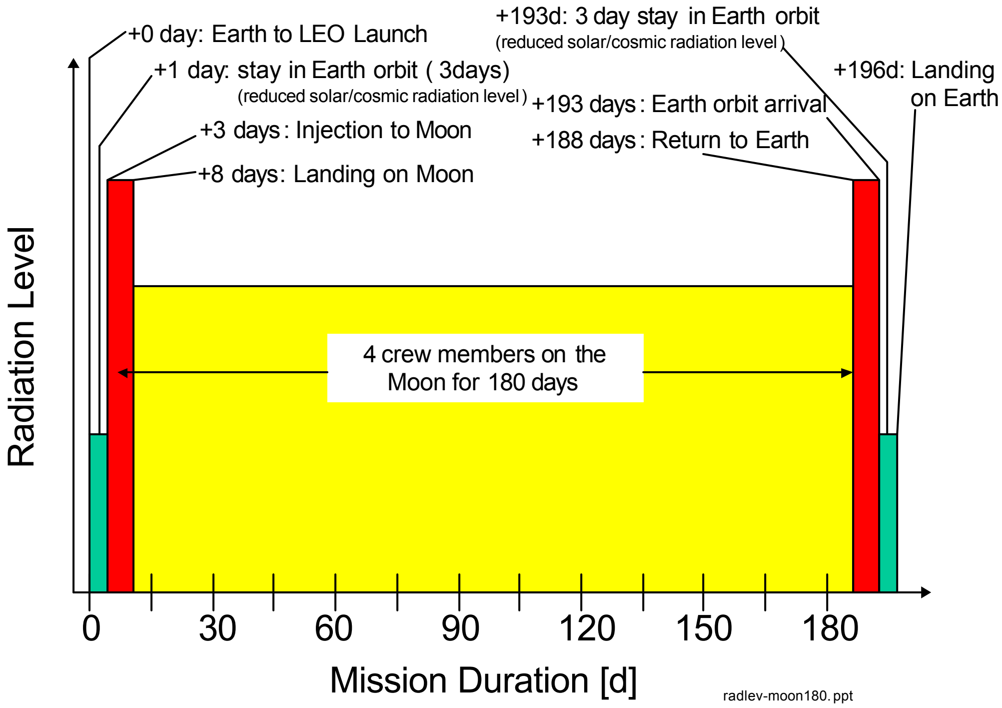

Figure I-3.2.4 Timeline of radiation levels for one Lunar roundtrip (detailed quantification in WP 3100)

Figure. I-3.2.4 shows the timeline of radiation level for one lunar roundtrip. Before the injection towards Moon, the crew stays for 3 days in Earth orbit under reduced solar/comic radiation levels to get prepared for the flight. High standard solar/cosmic radiation levels occur during the Earth-Moon roundtrip (each flight about 3-5 days) and slightly reduced radiation levels occur during the 180 day stay on the lunar surface due to the partly protection of the Moon. Radiation by dangerous solar particle events is in detail analyzed and quantified in WP 3100.

3.2.1.8. Gravity levels

Figure I-3.2.5 shows the timeline of gravity levels for one Lunar roundtrip. The launch from Earth, Injection maneuvers from LEO or LLO and the ascent from Moon are characterized by maximum G-loads of 3 G, which last for about 10 minutes. The gravity level during the aerocapture maneuver at Earth arrival can reach a maximum G-load of up to 6 G due to the atmospheric drag and uncertainties due to a changing density of the upper layers of Earth's atmosphere. The descend from LEO to Earth with a Space shuttle type spacecraft ranges between 1-2 G. The Earth-Moon roundtrip is carried out a zero gravity level. On the Moon the gravity level is 1/6 G. Especially the aerocapture maneuver at Earth Arrival with a potential maximum 6 G-load may burden the crew.

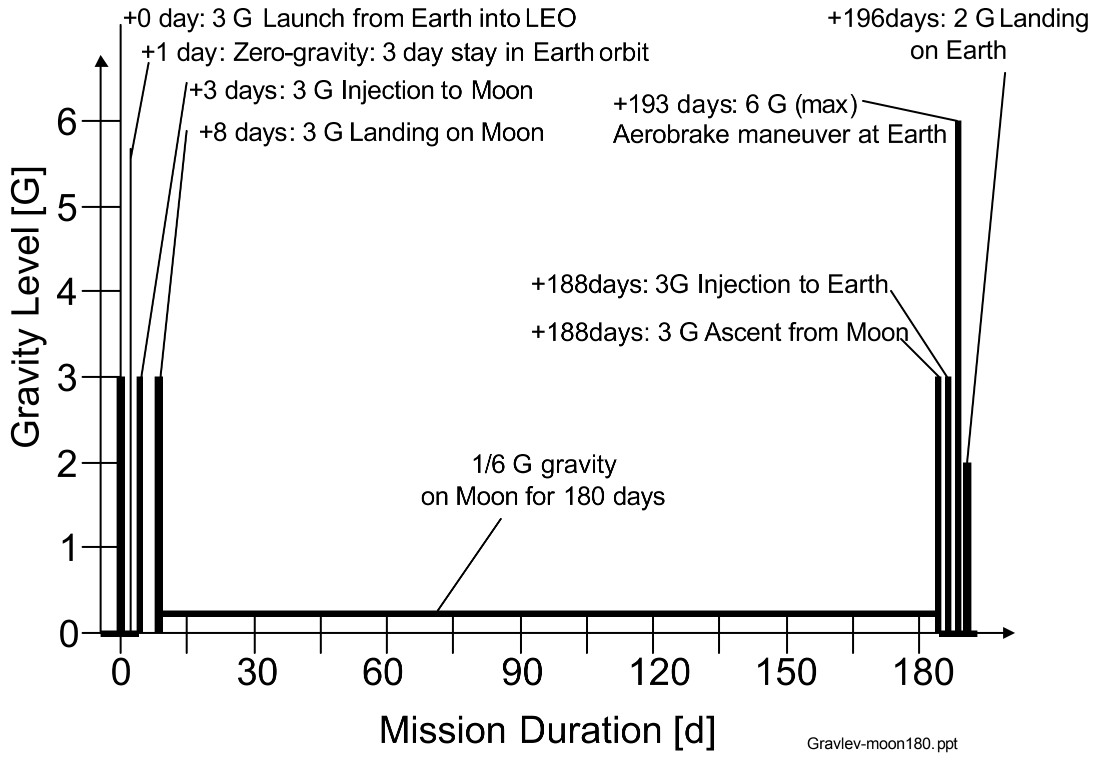

Figure I-3.2.5 Timeline of gravity levels for one Lunar roundtrip

3.2.1.9. Extra Vehicular Activities (EVA)

Due to the fact that EVA's are crucial for an essential and efficient research work on the Moon, the numbers of EVA's should be maximized. However, the LSS of an EVA-spacesuit requires considerable masses of resources (e.g. water for cooling) which can't be recycled and are lost. Therefore a compromise between the number of EVAs and the required LSS-resource mass has to be identified. Within the HUMEX study we assume an EVA of 2 astronauts every 3 days. Because the capacity of the portable EVA-LSS is limited, the maximum duration of one EVA is 8 hours. Furthermore, airlock losses (volume 2 m^3) have to be considered, when the crew leaves the base for an EVA. The number of possible EVAs could profit from a lunar oxygen production plant.

3.2.1.10. Program planning and total costs

The first phase of the Lunar base scenario is assumed to be carried out within a longstanding 20 year program, consisting of a 10 year development and production phase and a following 10 year operational phase in which a crew with supplies is transported to the Lunar surface every 6 month. This leads to 20 manned Lunar flights during the 10 year operational phase. The consideration of a 10 year operational phase allows, for example, trade-offs and the identification of break even points for advanced life support systems using in-situ resources versus conventional life support systems. The first manned flights to the Moon are envisaged between 2015 and 2020 with a cost efficient Earth to LEO launcher (specific payload transportation cost are assumed to be 1000 $/kg).

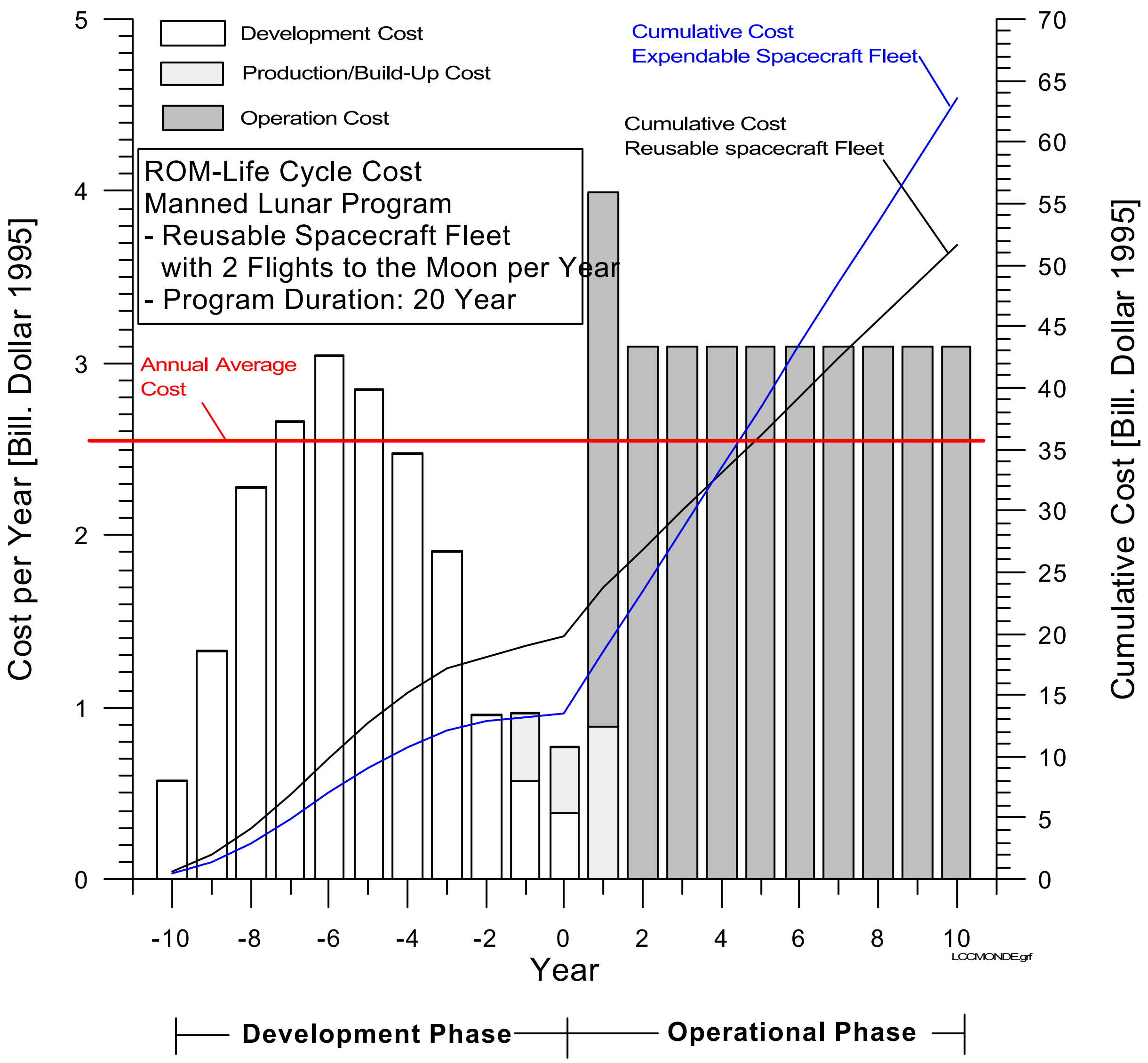

Figure I-3.2.6 Life cycle costs for a manned Moon program, consisting of 20 manned missions to the Moon

Fig. I-3.2.6 shows the yearly distribution for development, production and operation cost, the cumulative cost and the average cost per year for a 20 year manned Return to the Moon program, consisting of 20 manned flights to the Moon during the considered 10 year operational phase, which will be continued afterwards. Figure I-3.2.6 also shows the cumulative costs for an expendable space transportation system. The break even between the reusable transportation system and the expendable transportation system is achieved already in the fourth operational year. The cumulative costs for the Return to the Moon scenario amount for the reusable transportation system to about $52 billion. This corresponds to an average cost per year of $2.6 billion. This is about the budget, which the USA spent every year just for the operation of its Space Shuttle fleet. Therefore the discussed manned Lunar program appears to be affordable, especially if it is carried out with international cost- and task-distribution following the built-up phase of the International Space Station, when corresponding budgets might be again available.

3.2.2. Scenario 2: The 1000 day Mars mission with long term stay on Mars

In 1953, Wernher von Braun first proved the technical feasibility of a manned Mars mission [Braun 53]. In the following decades further investigations concerning the general feasibility of such a mission were mainly performed in the USA [NASA 89, NASA 97, Boeing 91] as well as in Europe [ESA 92] especially with regard to a continuation of manned space exploration after the Apollo Program.

3.2.2.1. Rationale for exploration of Mars

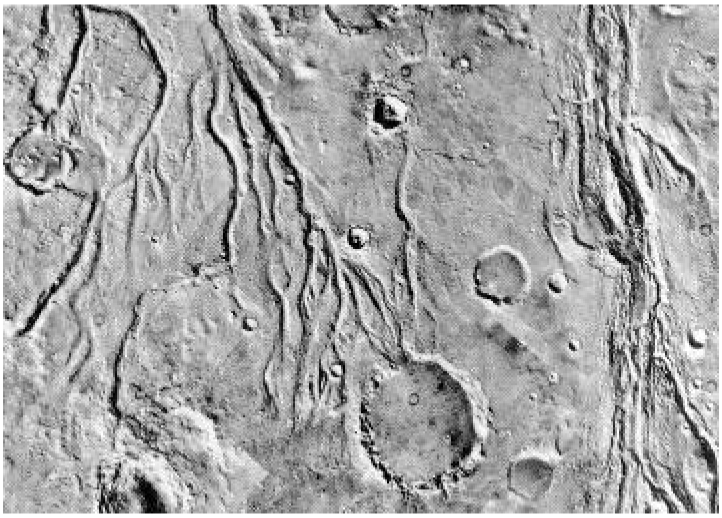

Figure I- 3.2.7 Promising landing site: Maja Vallis (right) and Vedra Vallis (left) [NN86]

The exploration of Mars is mainly driven by scientific and technological objectives, while commercial aspects (utilization/exploitation of local resources etc.) could arise in the future [RD 6]. The disciplines geology, mineralogy, atmospheric research as well as exobiology, i.e. the search for extraterrestrial life forms and the investigation of life outside our biosphere, play a central role in this scientific exploration. The general goal is to understand planetary formation and evolution processes including, if possible, the evolution of life. Mars is the planet most similar to Earth, and the question of climatic changes, especially the loss of water and atmospheric gases, is fascinating and relevant for understanding the Earth. Dry river beds (fig. I-3.2.7) indicate that huge amounts of water and a denser atmosphere were present about 2-3 billion years ago. There is some speculation that during this warmer and wetter period simple life forms have existed on Mars and may even exist today in special "oases or refuges" (e.g. geological formations below the surface with favorable conditions). The published, but controversially discussed, discoveries of possible fossil life forms in Martian meteorites may warrant optimism. Therefore the search for morphological or chemical indicators of life is one of the primary and most exciting goals of Mars exploration.

After the completion of the International Space Station (ISS) assembly around the beginning of the new millennium, it is expected that attention will be directed towards manned activities beyond the Earth's orbit. Inteligent sample selection and collection (e.g. by drilling), field studies via geologic traverses and in-situ experiments (e.g. chemical and mineralogical analyses) are essential for a successful exploration and the complex search for life on Mars. The unknown terrain and the limited possibilities to predict events together with the long travel times of signals between Earth and Mars (10 to 45 minutes bi-directional) require great flexibility and a talent for improvisation. Presently, this can only be provided by humans with their cognitive, explorative, combinatory and manipulative capabilities.

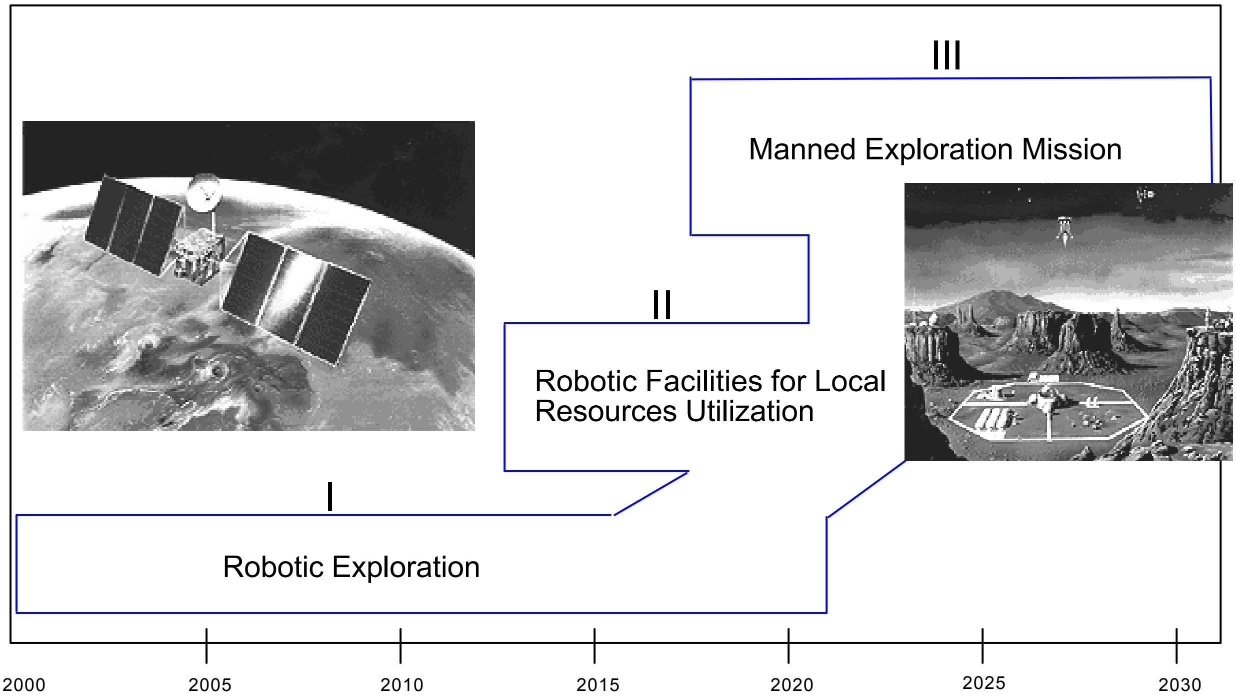

Figure I-3.2.8 The three phases of a Mars exploration scenario *[RD 6]*

A significant benefit is also expected from a manned Mars Mission as a technology driver from which other space programs could profit, e.g. by the development of a heavy lift vehicle, the improvement of propulsion systems, the use of extraterrestrial resources, advances in electrical power supply and closed life support systems as well as in automation and robotics. As in the ISS program, the political objectives of manned missions to Mars would focus on large scale international co-operation. Only co-operation in the realization of such a multi-billion dollar program with a corresponding distribution of tasks and costs appears to be a viable option. A manned Mars mission can also be regarded as an important cultural task for mankind with the objective to globalize the view of our home planet Earth, thereby contributing to the solution of local conflicts. In any case, a manned Mars mission would meet the natural human need to explore and expand to new regions.

Obviously, for a cost-effective Mars exploration an appropriate combination of unmanned and manned activities supplementing each other in a logical way must be developed (e.g. selection of landing site by unmanned precursor missions). In this context the development and test of technologies for in-situ resources utilization (e.g. propellant from the CO_2 of the Mars atmosphere or from the water ice) should be also taken into account which would allow even more cost-effective missions in the future. Therefore, as illustrated in fig. I-3.2.8, a consistent Mars exploration scenario over the 2000-2030 period could, in principle, be divided into three main phases. It is worth noting that each phase should not be considered strictly limited to defined temporal limits: Robotic activities will presumably continue after first manned missions in order to support human life and operations on Mars.

3.2.2.2. Spacecraft Concepts for a manned Mars mission

According to older conventional spacecraft configurations which have mainly been designed until 1995, the total departure mass of a manned spacecraft in low Earth orbit is around 1000 mt, if the mission is carried out in one “shot” with a 4-staged expendable vehicle on a low energy transfer, using oxygen/hydrogen propellant for the main propulsion systems. Newer spacecraft designs (like the NASA reference mission V3.0 from 1997, which is mainly based on Zubrins 'Mars Direct' Concept from 1990) lead to lower total masses of about 400 mt, if a split mission design is selected and a propellant production plant is operated on the Martian surface for the production of the ascent propellant [RD 2]. ESA's SE&U-study [RD 6] under the lead of DLR indicated that a spacecraft with solar electric propulsion can offer mass and cost advantages. A further important output of this study was, that the use of a conventional propulsion system (instead of a nuclear thermal propulsion as in NASA's design) leads to a manned Mars program with the lowest total program costs [RD 6]. However, in the context of the HUMEX study, the detailed selection of a spacecraft design is not so important due to the fact that mainly the selected trajectory and mission profile (which both define the mission duration of the interplanetary transfer, Mars orbit and surface stay) drive mainly the requirements for life science and life support systems.

Therefore, a conventional spacecraft design (I-3.2.9 shows the entire spacecraft with a crew of six just before departure to Mars, an international co-operation is exemplary illustrated) is foreseen for the HUMEX study. The spacecraft consists of 4 stages: An injection stage, an interplanetary parent ship (for the two interplanetary flights to and from Mars), a lander stage and an ascent stage (to return to the parent ship, waiting in Mars orbit). All spacecraft elements have during all mission sequences a manned control and access. In an emergency case during the flight towards Mars, the crew can brake off the flight an finds a backup habitat in the lander habitat module, which is designed for an accommodation of the crew for several 100 days (as the Lunar Modul spacecraft ensured the survival of the Apollo 13 crew). After Mars arrival, 4 crew members descend to the Martian surface and 2 crew members remain for 525 days in Mars orbit (comparable to the Apollo program where 1 astronaut stayed in Lunar orbit while 2 astronauts descended to the Lunar surface). With respect to the long term stay of 2 astronauts in Mars orbit, the past and future experience of the MIR/ISS program will be very useful. The main reason of the two in the Mars orbit remaining astronauts are safety reason. During the 553 day stay of four crew members on the Martian surface, the two remaining astronauts have to monitor and control the parent ship to ensure, that the whole crew can return back to Earth. With respect to accidents at the MIR space station and technological problems with the first ISS modules, it is not expected that the parent ship can be kept in a good workable condition for more than 500 days without human presence and support. However, these two astronauts will be subject of considerable strain (e.g. bone loss) and stress, because they spend almost 1000 days in a 0-gravity environment within the limited volume of the habitation module. Artificial gravity might be a useful solution to lower the strain of the entire crew but leads to higher spacecraft masses and costs by about 10 percent [Boeing91]. The following work packages will address these issues in more detail. Nevertheless, the two astronauts can provide significant support to their colleagues on the Martian surface by e.g. remote sensing activities and communication services.

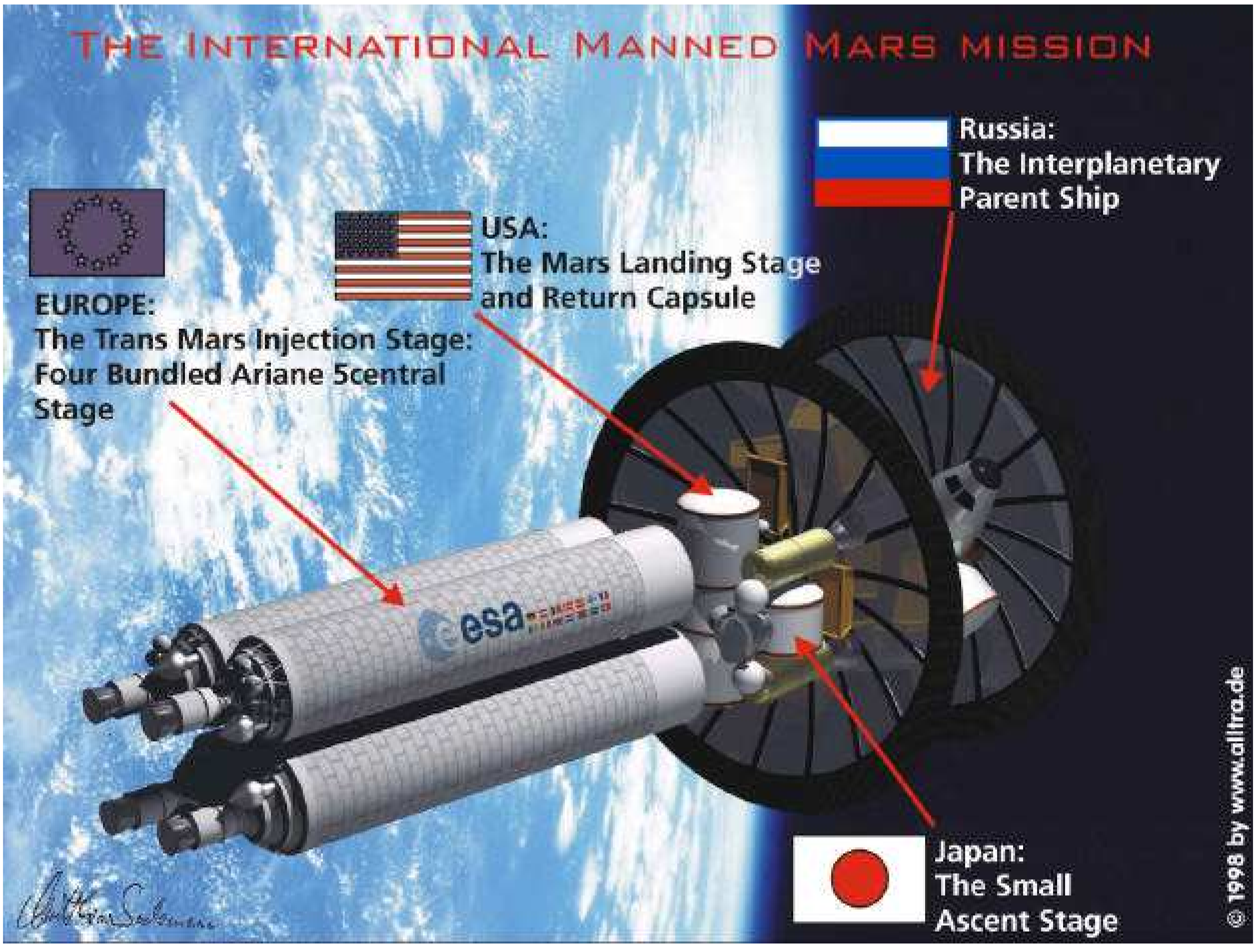

Figure I-3.2.9 An international manned Mars space transportation system in LEO before departure, using four Ariane 5 core stages as injection-stage (former proposal by DLR) [RD 8, artist view by www.alltra.de]

3.2.2.3. Trajectories for a manned Mars mission

In contrast to the lunar flights during the Apollo program, each manned Mars Mission represents a long lasting undertaking. Depending on the selected interplanetary transfer trajectory the total mission duration ranges between 500 days (fast high energy transfer) and 1000 days (slow minimum energy transfer). A suitable launch window opens only about every 26 month for several weeks.

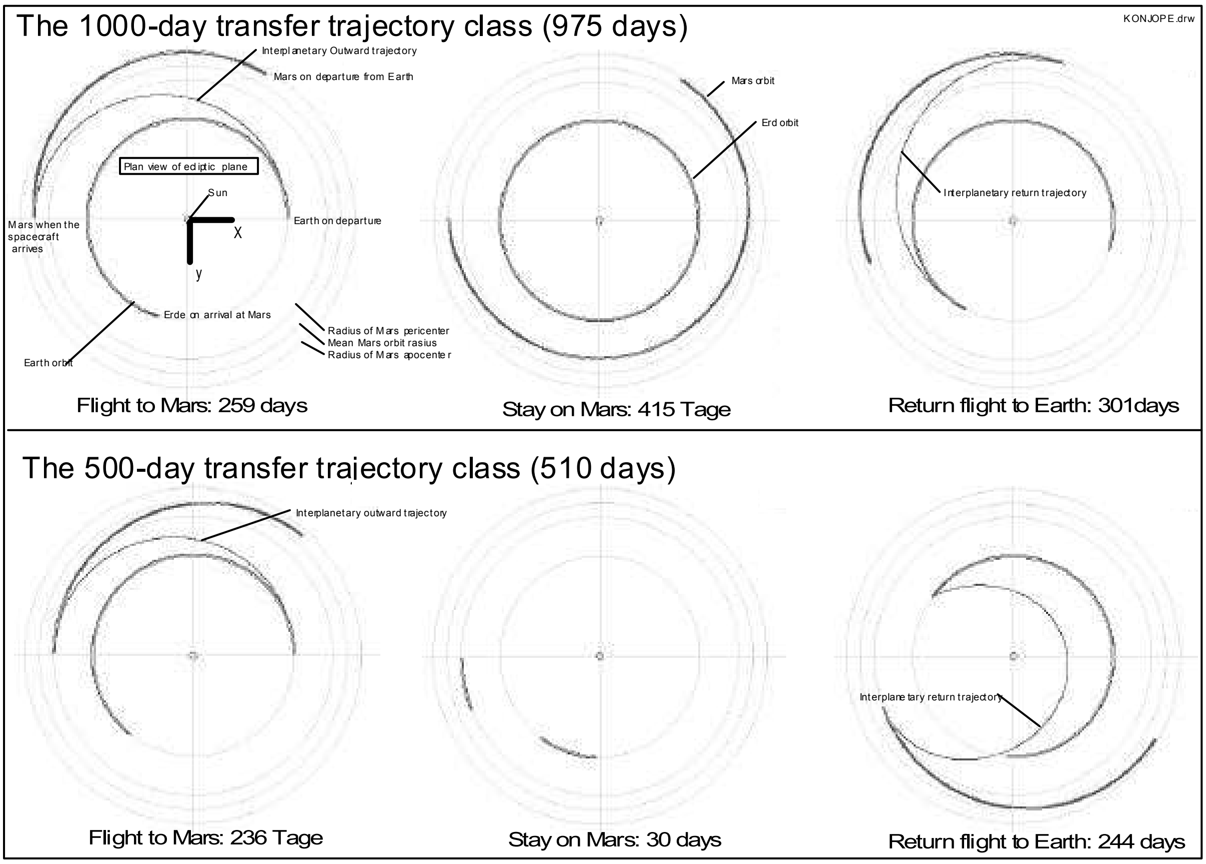

Figure I-3.2.10 Earth-Mars transfer trajectories of the 1000 day and 500 day class [REICHERT 97]

Figure I-3.2.10 shows the general characteristic of a 1000 day mission profile according to [REICHERT97]. The flight to Mars typically lasts 200-300 days. After the crew is landed on Mars, the crew has to stay on Mars for 400 to 500 days, because then for the first time, a low energy launch window opens again to return to Earth. The use of a low energy transfer trajectory is essential to significantly reduce the spacecraft's mass and therefore the total program costs. The return flight again lasts 200 to 300 days, depending on the selected launch date.

Table I-3.2.3 lists energetic requirements for a typical 1000 day mission profile. The energetic requirement is expressed by the velocity requirement (Δv) in meters per second (m/s). The Δv-requirement mainly drives the propellant consumption and therefore the total mass of the spacecraft as well as the total life cycle costs. For this reason it is very important to design a mission architecture, which is characterized by minimized Δv-requirements. Table I-3.2.3 already considers Δv-losses by gravity, midcourse maneuvers, hovering maneuvers and inclination changes. The total Δv-requirement amounts to about 11000 m/s (without Earth to LEO launch) which leads to the design of a 4-staged spacecraft (for comparison: the 9500 m/s requirement from Earth to LEO requires 3 stages, e.g. Ariane 4)

Table I-3.2.3 Typical Δv-requirement for different mission events of a manned Mars mission

Mission Event	Δv-requirement [m/s]
1. Earth to LEO Launch	9500
1. Departure from 400 km Low Earth Orbit (LEO)	3606
2. High elliptical orbit insertion at Mars arrival without aerocapture	1316
with aerocapture	200
3. Descent and landing on Mars	1105
4. Ascent to high elliptical Mars orbit	5452
5. Departure and return flight to Earth	653
Total Δv-requirement (with aerocapture at Mars arrival)	**20516**

For the HUMEX study, the low energy launch window in 2018 will be taken as the reference. The first manned Mars Mission takes advantage of the low energy launch window on 11. May 2018 which is characterized by the the following mission sequences:

0. day:	Launch of the Crew into LEO
1st day	7 day stay in Earth orbit
7th day:	Injection from LEO towards Mars (transfer time: 204 days)
211th day	Mars arrival
211th day	Mars orbit (for 14 days)
225th day	Landing on Mars (stay time on Mars: 525 days)
750th day	Ascending from Martian surface (stay time in Mars orbit: 14 days)
764th day	Injection from Mars orbit towards Earth (transfer time: 190 days)
954th day	Earth arrival and landing on Earth

3.2.2.4. Crew Size Selection

As for the Moon the selection of the crew size for a first manned Mars mission represents an extensive trade off. On the one hand the crew size should be as high as possible to achieve a maximum mission safety and scientific and technological return. On the other hand, the crew size represents the most important driver for the complexity and therefore for the total mass and program cost. Because a manned Mars mission is a more cost-intensive undertaking compared to a manned Lunar mission, each additional crew member increase the initial program costs by several billion dollars. This means that the crew size should be limited to the absolutely necessary minimum. However, in comparison with the Moon, Mars offers more scientific opportunities (e.g. Mars has an Atmosphere and a climate) which requires more crew members with different skills. Furthermore, a manned Mars mission last for up to 1000 days which again is an argument for an increased crew size to establish a certain level of mission safety.

Due to the fact that a manned Mars mission aims mainly at scientific and technological objectives, the composition of the crew education should focus on the following scientific and technological issues:

a) scientific education

- Biology
- Medicine
- Psychology
- Geology
- Atmosphere and Climate research
- Astronomy

b) technological education

- Commander
- Spacecraft Engineering
- Manufacturing technology
- Navigation
- Communication
- Software engineering

Assuming that each crew member is intensively educated in one scientific and one technological area, this leads to a crew size of 6 members. For a Lunar mission, the illness of one crew member does not directly jeopardize the mission safety thanks to short transportation and communication opportunities. For a mars missions, however, a serious illness of one crew member (e.g. the doctor) can jeopardize the mission due to very long communication links (up to 45 minutes bi-directional) and transportation of several 100 million kilometers. Therefore, it appears important for the mission success, that some crew members have a third back-up education in crucial skills like medicine, software and spacecraft engineering. This means that some or all crew members have be educated in up to three different scientific and technological areas. More research in this area is recommended to trade off the optimized crew size versus the program costs.

3.2.2.5. Radiation level

Figure. I-3.2.11 shows the timeline of radiation level for the 2018 launch window. Before the injection towards Mars, the crew stays for 7 days in Earth orbit under reduced solar/comic radiation levels to get prepared for the flight. The highest solar/cosmic radiation levels occur during the interplanetary flight to and from Mars. On Mars, slightly reduced solar/cosmic radiation levels can be assumed. Radiation by dangerous solar flares is in detail analyzed and quantified in WP 3100.

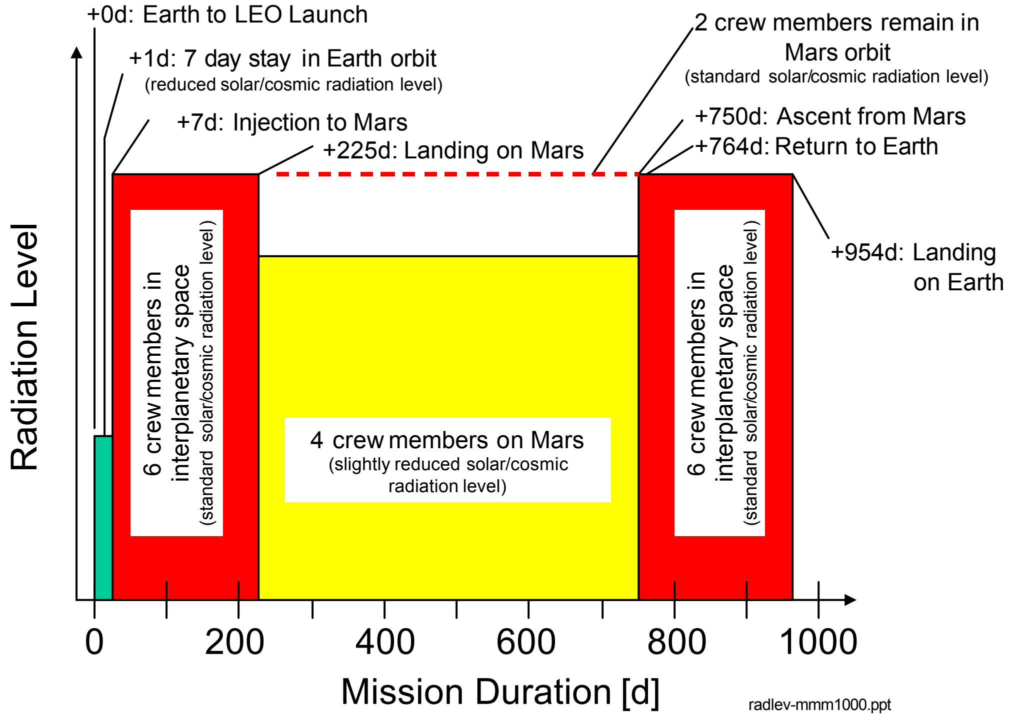

Figure I-3.2.11 *Timeline of radiation levels for the 2018 launch window (detailed quantification in WP 3100)*

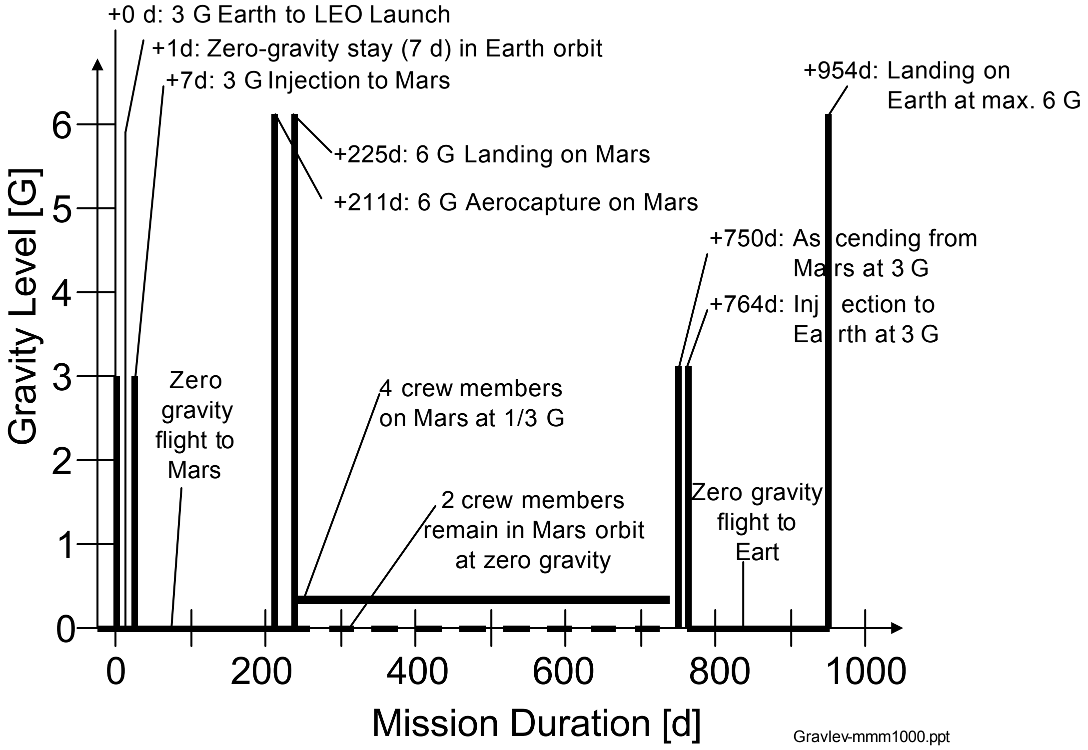

Figure I-3.2.12 Timeline of gravity levels for the 2018 launch window

3.2.2.6. Gravity levels

Figure I-3.2.12 shows the timeline of gravity levels for the 2018 launch window. Injection maneuvers from Earth or Mars and the ascent from Mars are characterized by maximum G-loads of 3 G, which last for about 10 minutes. Landing maneuvers on

Mars and Earth are characterized by maximum G-loads of up to 6 G due to the atmospheric drag. The interplanetary cruise is carried out a zero gravity level. Due to the fact that 2 crew members stay in Mars orbit, they have a cumulative zero gravity period of 947 days, only interrupted by orbit insertion at Mars (6 G) and injection towards Earth (3G). On Mars the gravity level is 1/3 G. Especially the high gravity levels of 6 G at Mars arrival (aerocapture) and landing on Earth (with a capsule) appear critical for the health of the crew and have to be investigated in the following work packages.

3.2.2.7. Extra Vehicular Activities (EVA)

Due to the fact that EVA's are crucial for an essential and efficient research work on Mars, the numbers of EVA's should be maximized. However, the LSS of an EVA-spacesuit requires considerable masses of resources (e.g. water for cooling) which can't be recycled and are lost. Therefore a compromise between the number of EVAs and the required LSS-resource mass has to be identified. Within the HUMEX study we assume an EVA of 2 astronauts every 3 days. Because the capacity of the portable EVA-LSS is limited, the maximum duration of one EVA is 8 hours. Furthermore, airlock losses (volume 2 m^3) have to be considered, when the crew leaves the base for an EVA. The number of possible EVAs could profit from a Martian oxygen and water production plant.

3.2.2.8. Program planning and total costs

Table I-3.2.4 Life Cycle Cost for a modified NASA reference mission v3.0 with chemical TMI-stages [RD 6, REICHERT98]

Life Cycle Cost Estimation for NASA´s Reference Mission V 3.0 with Chemical LOX/LH2 TMI-Stage			
LCC_Nasa Reference Mission V3_chem_TMI.xls	**[Bill.$ (95)]**	**%**	**Sum %**
Development Costs	**28.56**		**74.61**
TMI-Stage	1.053	2.75	
ERV-Stage	10.293	26.89	
Cargo Lander	7.124	18.61	
Manned Lander	10.090	26.36	
Production Costs	**5.227**		**13.66**
TMI-Stage (6 TMI stages required)	1.122	2.93	
ERV-Stage	1.365	3.57	
Cargo Lander	1.344	3.51	
Manned Lander	1.396	3.65	
Operation Costs	**4.492**		**11.73**
Development of Magnum Launcher	2.500	6.53	
Launch Preparation	0.229	0.60	
Cargo Transport (544.9 mt) into LEO (2000 $/kg)	1.089	2.84	
Crew Transport into LEO	0.120	0.31	
Mission Control (1.5 MY/day for 5 years)	0.548	1.43	
Capsule Sea Recovery	0.006	0.02	
Total Costs	**38.279**	**100.00**	**100.00**

Assuming present cost-levels, the total program costs are estimated to be around $60 billion for the first manned Mars mission [REICHERT 97a] with a conventional design. Each follow-on mission can be carried out at considerable lower costs of about $20 billion (for production and operation) because then the development costs (~$40 billion) don't have to be invested again. Therefore, manned Missions to Mars should be carried out in the frame of a long-term program which consists of several flights to Mars. A considerable cost saving potential of about $10 billion does exist, if existing modified subsystems (especially propulsion systems from existing launchers and habitat modules from the ISS program) can be implemented. A further cost reduction of about $10 billion could be achieved, if the future specific Earth to LEO transportation costs can be reduced down to $1000 per kilogram payload.

A more optimized Manned Mars mission concept has been elaborated in ESA's SE&U study in 1999 [RD 6]. For this split mission concept with in situ propellant production on the Martian surface the total costs for the first manned Mars mission amount to $38.3 billion (tab. I-3.2.4) which is even below the costs for NASA's reference mission. Table I-3.2.4 indicates that the development costs dominate with total costs of approximately $31 billion (including the development of the *Magnum* launcher) which represent more than 80 percent of the total cost. This means, that a manned Mars mission program should be carried out in the framework of a long lasting program consisting of several flights to Mars. Already the second manned Mars mission, for which only the operation and production costs have to be taken into account, is feasible at low total costs of about $7.2 billion.

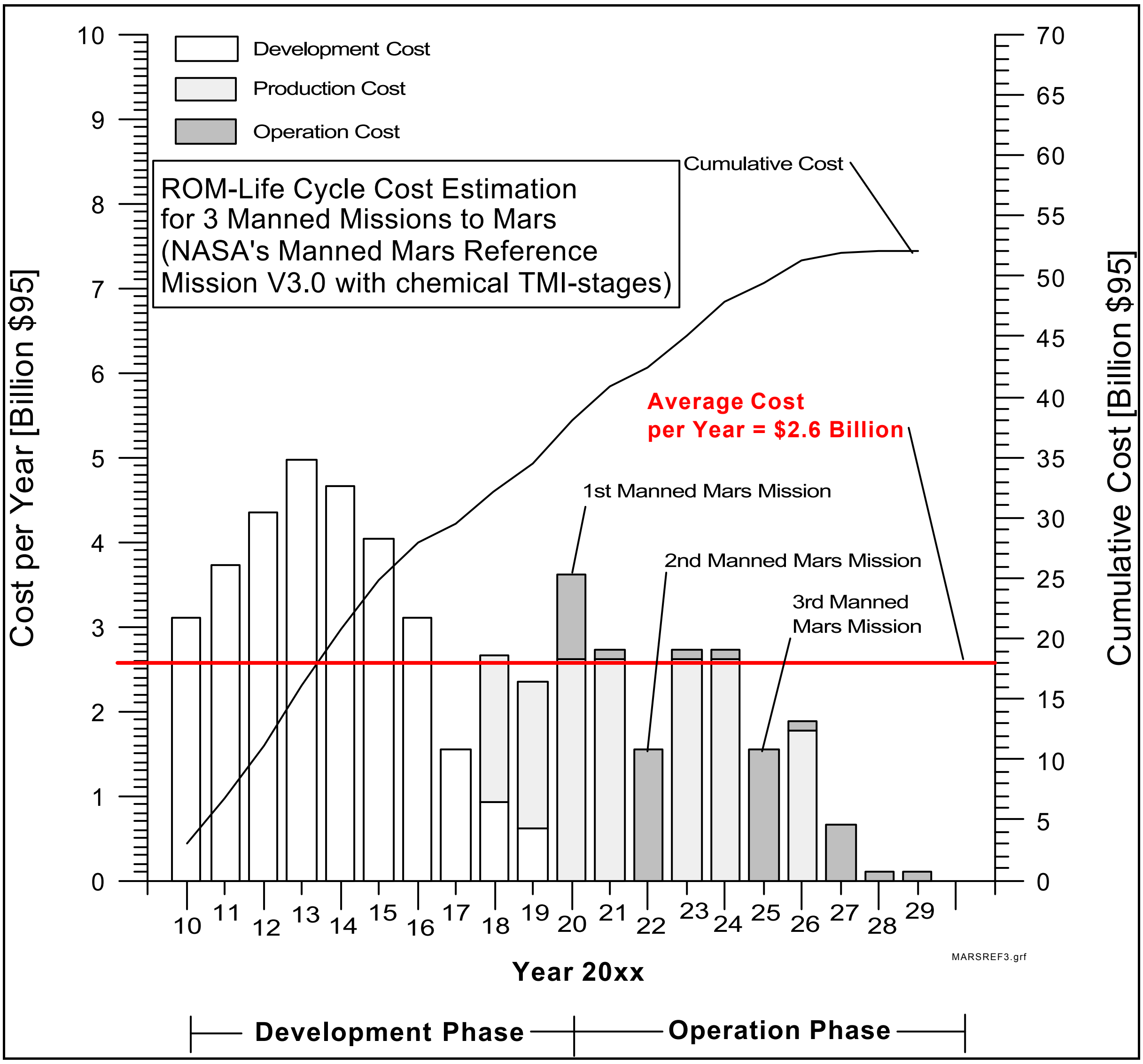

Figure I-3.2.13 Life cycle costs for a Mars program, consisting of 3 manned missions to Mars [RD 6, REICHERT98]

Fig. I-3.2.13 shows the yearly distribution for development, production and operation cost, the cumulative cost and the average cost per year for a 20 year manned Mars program, consisting of 3 manned Mars missions and lasting from 2010 to 2029. A cost peak of up to $5 billion occurs during the 10 year development phase in 2013. In this example from ESA's SE&U study, the first manned Mars mission takes place in 2020 and the last crew of the third mission returns to Earth in 2029. The cumulative costs for the three manned Mars missions amount to about $52 billion which corresponds to an average cost per year of $2.6 billion. This is about the budget, which the USA spent every year just for the operation of its Space Shuttle fleet. Therefore the discussed manned Mars mission appears to be affordable, especially if it is carried out with international cost- and task-distribution following the built-up phase of the International Space Station, when corresponding budgets might be again available.

3.2.3. Scenario 3: The 500 day Mars mission with short term stay on Mars

3.2.3.1. The 500 day Mission

This manned Mars Mission scenario comprises manned flights to Mars with a crew of six on fast high energy 500 day trajectories. Figure I-3.2.10 shows the general characteristic of a 500 day mission profile according to [REICHERT97]. The flight to Mars typically lasts 160-250 days. After the crew is landed, it only stays on Mars for 10 to 60 days. If the flight to Mars is carried out on a Hohmann trajectory (as figure I-3.2.7 shows), the return flight to Earth has to be carried out on a fast trajectory with a high Δv-requirement which consumes a lot of propellant and leads to high spacecraft masses of at least 2000 tons for chemical LOX/LH2 propulsion and therefore high total life cycle costs of about $100 billion). The high energy return trajectory intersects Earth orbit and can even reach the orbit of Venus. At Earth arrival, the hyperbolic velocity of the spacecraft can reach an extent, which requires an additional deceleration maneuver, in order not to burn up the capsule during its entry in the atmosphere of Earth. A further disadvantage of the 500 day trajectory is, that the Δv-requirement differs significantly for different launch windows. The Δv-requirement ranges typically between 14 km/s to 26 km/s only for the interplanetary roundtrip (without aerocapture and landing on and ascending from Mars). For comparison: the 1000 day trajectory requires less than 8 km/s for the roundtrip to a 250 km circular Mars orbit without aerocapture. The significant varying Δv-requirements of the 500 day mission make it difficult, to carry out several missions to Mars with one spacecraft design, because the size and performance parameters of the spacecraft differs significantly from one launch window to another according to significant different propellant mass fractions. However, an advantage is the low total mission duration of only about 500 days which causes lower strains and stresses for the crew. For this reason, the 500 day mission to Mars has been selected as the second reference scenario in the HUMEX study and also in order to have a comparison reference to the 1000 day mission.

The mission profile is assumed to be conventional, where the entire spacecraft is injected towards Mars. All spacecraft elements have during all mission sequences a manned control and access. After Mars arrival, 4 crew members descend to the Martian surface and 2 crew members remain for 40 days in Mars orbit. This Manned Mars Scenario is again assumed to be carried out within a longstanding program of about 15-20 years, consisting of a 10 year development and production phase and a operational phase with 3 manned Mars missions in 2018, around 2020 and around 2022.

For the HUMEX study, the launch window in 2018 will be taken as the reference. The first manned Mars Mission takes place on 7. April 2018. The following mission sequence for the first manned mars Mission can be defined:

0. day:	Launch of the Crew into LEO
1st day:	7-day stay in Earth orbit
7th day:	Injection from LEO towards Mars (transfer time: 165 days)
172nd day	Mars arrival
172nd day	Mars orbit (for 7 days)
179th day	Landing on Mars (stay time on Mars: 30 days)
209th day	Ascending form Martian surface (stay time in Mars orbit: 3 days)
212th day	Injection from Mars orbit towards Earth (transfer time: 245 days)
457th day	Earth arrival and landing on Earth

3.2.3.2. Radiation levels

Figure. I-3.2.13 shows the timeline of radiation level for the 2018 launch window. Before the injection towards Mars, the crew stays for 7 days in Earth orbit under reduced solar/comic radiation levels to get prepared for the flight. The highest solar/cosmic radiation levels occur during the interplanetary flight to and from Mars. On Mars, slightly reduced solar/cosmic radiation levels can be assumed. Radiation by dangerous solar flares is in detail analyzed and quantified in WP 3100.

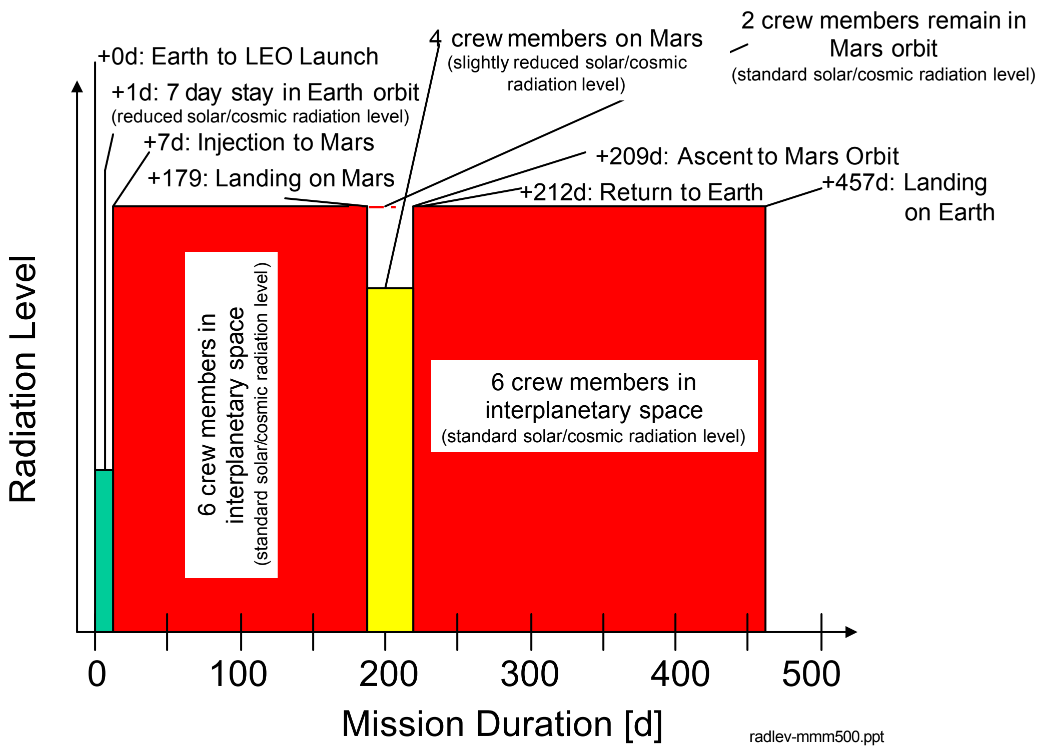

Figure I-3.2.14 Timeline of radiation levels for the 2018 launch window (detailed quantification in WP 3100)

3.2.3.3. Gravity levels

Figure I-3.2.15 shows the timeline of gravity levels for the 2018 launch window. Injection maneuvers from Earth or Mars and the ascent from Mars are characterized by maximum G-loads of 3 G, which last for about 10 minutes. Landing maneuvers on Mars and Earth are characterized by maximum G-loads of up to 6 G due to the atmospheric drag. The interplanetary cruise is carried out a zero gravity level. Due to the fact that 2 crew members stay in Mars orbit, they have a cumulative zero gravity period of 450 days, only interrupted by orbit insertion at Mars (6 G) and injection towards Earth (3G) Especially the high gravity levels of 6 G at Mars arrival (aerocapture) and landing on Earth (with a capsule) appear critical for the health of the crew and have to be investigated in the following work packages.

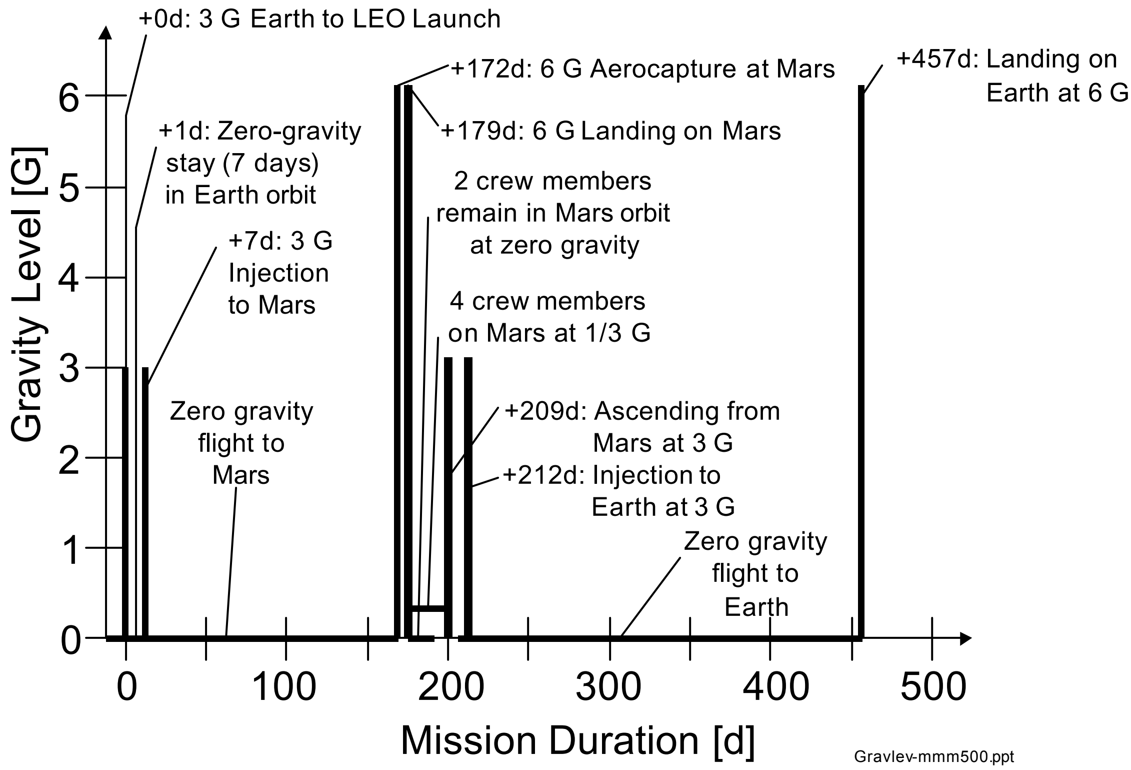

Figure I-3.2.15 Timeline of gravity levels for the 2018 launch window

3.2.3.4. Extra Vehicular Activities (EVA)

Due to the fact that EVA's are crucial for an essential and efficient research work on Mars, the numbers of EVA's should be maximized. However, the LSS of an EVA-spacesuit requires considerable masses of resources (e.g. water for cooling) which can't be recycled and are lost. Therefore a compromise between the number of EVAs and the required LSS-resource mass has to be identified. Within the HUMEX study we assume more frequent EVAs for the 500 day mission, compared to the 1000 day mission, because the stay time on Mars is only limited to 30 days. Therefore we define an EVA of 2 astronauts every day. Because the capacity of the portable EVA-LSS is limited, the maximum duration of one EVA is 8 hours. This could also mean, that all astronauts can undertake an EVA for four hours every day (neglecting increased airlock losses). Furthermore, airlock losses (volume 2 m^3) have to be considered, when the crew leaves the base for an EVA.

3.2.4. Summary and Conclusions

Both, the Moon and Mars represent a promising destination for human long-term exploration in scientific and technological areas.

The defined 20 year manned Lunar scenario comprises the build-up of a lunar south pole base with a permanent crew of four astronauts, which are substituted every 6 month during the 10 year lasting operational phase. The transportation task for the roundtrip between Earth orbit and Lunar surface is accomplished by a reusable spacecraft fleet, consisting of an orbital spacecraft (for the roundtrip transfer between Earth and Lunar orbit) and a Lunar Bus (for the roundtrip between Lunar surface and Lunar orbit). The requirements on the crew and on life support systems with respect to the mission duration, radiation and gravity levels indicates no general showstoppers and correspond mainly to the requirements of past and future space station programs in Earth orbit. However, the solar particle event danger during the transfer to and the stay on the Moon requires a more detailed investigation, which will be carried out in WP 3100. Furthermore, the implementation of in-situ resource utilization production plants (e.g. Lunar oxygen) offer operational, mass and cost advantages and will be investigated in more detail in WP 4400.

The two defined 20 year manned Mars mission scenarios consist of a relatively fast 500 day and a long lasting 1000 day mission. Each scenario comprises 3 manned Mars missions with a four staged spacecraft during the 10 year operational phase. In contrast to lunar flights, manned Mars missions represent a long lasting undertaking with significant delays in the communication and almost no mission abort and fast return capability in an emergency case. The solar particle event danger (investigated in more detail in WP 3100) represents a serious danger for the crew especially during the interplanetary transfers. The high gravity levels at Mars arrival (caused by aerocapture and landing) represent a further strain for the crew after more than 200 days of an interplanetary 0-gravity flight (investigated in more detail in WP 3200). Because the lack of quick return possibility and the delay in communication the medical care concepts might have to completely different than those used in LEO and on the Moon. This might require the development of highly sophisticated automated medical competence centers in addition to a medical doctor on board. As for the Moon, in-situ resource utilization production plants (e.g. Martian oxygen) offer operational, mass and cost advantages and will be investigated in more detail in WP 4400.

A detailed investigations and trade off for the crew size optimization versus the resource requirements and the required crew skills is strongly recommended.

Both, the manned Moon and Mars Scenario require average cost per year of about \$2.5 billion. This is about the budget, which the USA spent every year just for the operation of its Space Shuttle fleet. Therefore, the discussed manned Moon and Mars missions appear to be affordable, especially if they are carried out with international cost- and task-distribution following the build-up phase of the International Space Station, when corresponding budgets might be again available

3.2.5. References

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4. LIFE SCIENCES AND LIFE SUPPORT REQUIREMENTS

4.1. Introduction

The purpose of this technical note is to define, within the framework of the "Study on the Survivability and Adaptation of Humans to Long-Duration Interplanetary and Planetary Environments" (the HUMEX study), the Life Support and Crew Health Control requirements during the 3 referenced missions.

The logic of this WP 2200 achievement can be drawn as following :

INPUTS coming from WP 2100 for each of the 3 scenarios :

- Mission Safety objectives
- Crew size and profile
- Mission duration (phase by phase)
- Induced identified risks

INPUTS coming from the state of the art:

- $3\ 10^{-2}$> Individual acceptable risk > $2.4\ 10^{-3}$/ year **
- Manned space flight human requirements
- the medical risk (probability of disease occurrence)

WP 2200 ACHIEVEMENTS

OUTPUTS coming from WP 2200 for each of the 3 scenarios :

- Minimum habitable volume needs
- Consumables needs (quantity, quality); O_2, water (hygienic and potable), foods, beverage, individual kits (clothing etc.…) will be given
- Human waste production (quantity, quality); gas, liquid and solid will be given
- The probability of diseases occurrence will be given

Figure I-4.1.1 Logic of the HUMEX study WP 2200

** The individual risk (on Earth) of death by illness, so called "natural death", for a person 30-60 years old is quoted at : $2\ 10^{-3}$/ year (extracted from human death statistical tables used by insurance companies)
** The individual risk (on Earth) of death by injury, so called "accidental death", for a person 30-60 years old is quoted at : $4\ 10^{-4}$/ year (extracted from human death statistical tables used by insurance companies)
(so, the baseline terrestrial risk of mortality by illness or injury is 0.002+ 0.0004 = 0.0024 / man-year for a person aged between 30 and 60 years)
** The maximum individual risk of death by injury for the most exposed professions (Fighters' pilot, Helicopters' pilot, astronauts) is quoted at : $3\ 10^{-2}$/ year (extracted from human death statistical tables used by insurance companies)

In the frame of the HUMEX study we have chosen the following safety objectives :

- **that the individual risk of death by illness shall be maintained during the mission ≤ 2 10^{-3}/ year**
- **that the individual risk of death by injury (excluding spacecraft failure) shall be maintained during the mission ≤ 4 10^{-4}/ year.**
- **That the individual risk of death (all caused mixed, including spacecraft failure) shall be maintained during the mission ≤ 3 10^{-2}/ year.**

4.2. Inputs

See the reference documents list used for WP 2200 here after in the paragraph 4.0. The three referenced scenario are (inputs from the WP :2100):

- **Scenario 1: Lunar Base on the south pole**

The Lunar base is characterized by a permanent crew of 4 members, which will be substituted every 6 months (180 days) by supply flights from Earth. One transfer flight between Earth and Moon will typically last between 3 to 5 days, depending on the selected launch wi ndow.

All the crew members will transfer to the Lunar surface, with no stay on Lunar orbit, 30 EVA are planned on Lunar surface every six months (each EVA achieved by 2 astronauts with a duration of 8 hours maxi).

It must be pointed out that an emergency return to Earth in less of 2 days (using a specific Crew Rescue Vehicle or by using the "nominal" transfer vehicle with appropriate acceleration / deceleration profiles) is always possible to consider.

This scenario can be summarized in the following table :

Table I- 4.2.1 Main parameters of the Lunar base mission

Mission phase / Duration Crew involved	Earth-Moon transfer	Moon stay	Moon-Earth transfer	TOTAL Mission duration
Duration	3-5 days	180 days	3-5 days	186-190 days
Crew	4	4	4	
EVA (each EVA=2 astro and 8 hours maxi))		30		

The mission safety objectives:

Based on the classical reliability requirements for manned space missions (see ref. REF 13 and REF 14) we can propose the following reliability objectives.

Table I- 4.2.2 Estimated reliability objectives for the Lunar base mission

Mission phase / Element reliability requirements	Earth Launch	Earth-Moon transfer 3-5 days	Moon landing	Moon stay	Moon Launch	Moon Earth transfer	Earth aerocapture phase	Earth landing	Reliability goals
Earth launcher	0.99 *(with crew escape system)*								0.99
Spacecraft (without launchers) or Moon habitacle	0.99712*	0.99712*	0.99712*	0.99712*	0.99*(with no crew escape system)*	0.99712*	0.99	0.99712*	0.9633
Crew survivability with regard to death by illness or injury (spacecraft failure excluded)	#1	**0.9999**	#1	**0.9953**	#1	**0.9999**	#1	#1	**0.9951**
Ground segment with communication system	0.999987*	0.999987*	0.999987*	0.999987*	0.999987*	0.999987*	0.999987*	0.999987*	0.9999
Overwhole Mission reliability requirement									**0.949**

* = the mission phase reliability requirements have been arbitrary and equally shared between the mission phases when reliability requirement was unknown.

So, with this above figure of reliability objectives for the 180 days Lunar base mission:

- The over whole mission reliability objective is quoted at : **0.949** *(that meets the objective of an individual probability of death (all caused mixed, including spacecraft failure) < 3 10^{-2}/ year that could authorized an over whole 180 days Lunar base mission reliability (4 crewmembers) of 0.94 = $(1-(0.03/2))^4$.)*

- The over whole mission crew survivability probability with regard to death by illness or injury (spacecraft failure excluded) is quoted at : **0.9951** (a survivability objective of **0.9998** during the 3-5 days Moon – Earth transfers and of **0.9953** during the 180 days Moon stay) *(that meets the objective of an individual risk of death by illness or injury < 2.4 10^{-3}/ year that could authorized for the over whole 180 days Lunar base mission (4 crewmembers) an accepted probability of death by illness or injury of 0.995 = $(1-(0.0024/2))^4$.).*

So to design and size the crew health control system for the 180 days Lunar base mission the objectives of a probability of death by illness or injury (excluding spacecraft failure) for the whole crew are:

- ***< 2 10^{-4}/ onboard the Earth-Moon transfer vehicle***
- ***< 4.7 10^{-3}/ onboard the Moon lander and habitable vehicle***

are compatible with the figure of the mission safety objectives presented here before and will be taken as an input for the rest of the HUMEX study.

- **Scenario 2: 1000-Day Manned Mars Mission**

The manned Mars Mission scenario comprises manned flights to Mars with a crew of six and required infrastructure systems such as an in-situ resource utilization plant. The following mission sequence for the first manned Mars Mission can be identified:

1st day: Injection from LEO towards Mars (transfer time: 204 days)

204th day Mars orbit arrival

204th day Mars orbit (for 14 days)

218th day Landing on Mars (stay time on Mars: 525 days) , 90 EVA are planned (each EVA achieved by 2 astronauts with a duration of 8 hours maxi).

743rd day Ascending from Martian surface (sta y time in Mars orbit: 14 days)

757th day Injection from Mars orbit towards Earth (transfer time: 190 days)

947th day Earth arrival and landing on Earth

This scenario can be summarized in the following table :

Table I- 4.2.3 Main parameters of the 1000 days Mars mission

Mission phase / Duration Crew involved	Earth-Mars transfer +14 days on Mars Orbit	Mars Orbit stay onboard the transfer vehicle	Mars surface stay	Mars-Earth transfer +14 days on Mars Orbit	TOTAL Mission duration
Duration	218 days	525 days	525 days	204 days	947 days
Crew	6	2	4	6	
EVA (each EVA=2 astro and 8 hours maxi))			90		

The mission safety objectives:

Based on the classical reliability requirements for manned space missions (see ref. REF 13 and REF 14) we can propose the following reliability objectives.

Table I- 4.2.4 Estimated reliability objectives for the 1000 days Mars mission

Mission phase / Element reliability requirements	Earth Launch	Earth-Mars transfer 218 days	Mars aerocapt ure phase	Mars landing	Mars stay 525 days	Mars Launch	Mars-Earth transfer 204 days	Earth aerocapt ure phase	Earth - landing	Reliability goals
Launcher	0.99 *(with crew escape system)*									0.99
Spacecraft (w ithout launchers) –tranfer vehicule + Mars lander/habitat	0.99712*	0.99712*	0.99	0.99712*	0.99712*	0.99 *(without crew escape system)*	0.99712*	0.99	0.99712*	0.963
Crew 'death by illness or injury (spacecraft failure excluded)	#1	**0.9914**	#1	#1	**0.98**	#1	**0.992**	#1	#1	**0.964**
Ground segment with communication system	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.9999
Overwhole Mission reliability requirement										**0.919**

* = the mission phase reliability requirements have been arbitrary and equally shared between the mission phases when reliability requirement was unknown.

<u>So, with this above figure of reliability objectives for the 1000 days Mars mission:</u>

- The over whole mission reliability objective is quoted at : **0.919** *<u>(that greatly meets the objective of an individual probability of death (all caused mixed, including spacecraft failure) < 3 10^{-2}/ year that could authorized an over whole 1000 days Mars mission reliability (6 crewmembers) of 0.599 = $(1 – (0.03*1000/365))^6$.).</u>*

- The over whole mission crew survivability probability with regard to death by illness or injury (spacecraft failure excluded) is quoted at : **0.964** (a survivability objective of **0.9834** (= 0.9914*0.992) during the 204 + 218 days Mars – Earth transfers and of **0.98** during the 525 days Mars stay) *<u>(that meets the objective of an individual risk of death by illness or injury < 2.4 10^{-3}/ year that could authorized for the over whole 1000 days Mars mission (6 crewmembers) an accepted probability of death by illness or injury of 0.96 = $(1 – (0.0024*1000/365))^6$.).</u>*

So to design and size the crew health control system for the 1000 days Mars mission the objectives of a probability of death by illness or injury (excluding spacecraft failure) for the whole crew are:

- ***< 1,66 10^{-2}/ onboard the Earth-Mars transfer and Mars orbiting vehicle***
- ***< 2 10^{-2}/ onboard the Mars lander habitable vehicle***

are compatible with the figure of the mission safety objectives presented here before and will be taken as an input for the rest of the HUMEX study.

- **<u>Scenario 3: 500-Day Manned Mars Mission</u>**

This manned Mars Mission scenario comprises manned flights to Mars with a crew of six on fast high energy trajectories. The following mission sequence for the first manned Mars Mission can be identified:

1st day:	Injection from LEO towards Mars (transfer time: 165 days)
165th day	Mars orbit arrival
165th day	Mars orbit (for 7 days)
172th day	Landing on Mars (stay time on Mars: 30 days) , 15 EVA are planned (each EVA achieved by 2 astronauts with a duration of 8 hours maxi).
202nd day	Ascending from Martian surface (stay time in Mars orbit: 3 days)
205th day	Injection from Mars orbit towards Earth (transfer time: 245 days)
450th day	Earth arrival and landing on Earth

The mission profile is assumed to be conventional – ie, the entire spacecraft is injected towards Mars. All spacecraft elements have manned control and access during all mission sequences. After Mars arrival, 4 crew members descend to the Martian surface and 2 crew members remain for 30 days in Mars orbit.

This scenario can be summarized in the following table :

Table I- 4.2.5 Main parameters of the 500 days Mars mission

Mission phase / Duration Crew involved	Earth-Mars transfer + 7 days on Mars Orbit	Mars Orbit stay onboard the transfer vehicle	Mars surface stay	Mars-Earth transfer + 3 days on Mars Orbit	TOTAL Mission duration
Duration	172 days	30 days	30 days	248 days	450 days
Crew	6	2	4	6	
EVA (each EVA=2 astro and 8 hours maxi))			15		

The mission safety objectives:

Based on the classical reliability requirements for manned space missions (see ref. REF 13 and REF 14) we can propose the following reliability objectives.

Table I- 4.2.6 Estimated reliability objectives for the 500 days Mars mission

Mission phase / Element reliability requirements	Earth Launch	Earth-Mars transfer 172 days	Mars aerocapture phase	Mars landing	Mars stay 30 days	Mars Launch	Mars-Earth transfer 248 days	Earth aerocapture phase	Earth - landing	Reliability goals
Launcher	0.99 *(with crew escape system)*									0.99
Spacecraft (without launchers) –tranfer vehicule + Mars lander/habitat	0.99712*	0.99712*	0.99	0.99712*	0.99712*	0.99 *(without crew escape system)*	0.99712*	0.99	0.99712*	0.963
Crew 'death by illness or injury (spacecraft failure excluded)	#1	<u>**0.993**</u>	#1	#1	<u>**0.9988**</u>	#1	<u>**0.9902**</u>	#1	#1	<u>**0.982**</u>
Ground segment with communication system	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.999988*	0.9999
Overwhole Mission reliability requirement										<u>**0.936**</u>

* = the mission phase reliability requirements have been arbitrary and equally shared between the mission phases when reliability requirement was unknown.

<u>So, with this above figure of reliability objectives for the 500 days Mars mission:</u>

- The over whole mission reliability objective is quoted at : **0.936** <u>*(that greatly meets the objective of an individual probability of death (all caused mixed, including spacecraft failure) < 3 10^{-2}/ year that could authorized an over whole 500 days Mars mission reliability (6 crewmembers) of 0.78 = $(1 – (0.03*500/365))^6$.).*</u>

- The over whole mission crew survivability probability with regard to death by illness or injury (spacecraft failure excluded) is quoted at : **0.982** (a survivability objective of **0.983** (=0.993*0.9902) during the 172 + 248 days Mars – Earth transfers and of **0.9988** during the 30 days Mars stay) <u>*(that meets the objective of an individual risk of death by illness or injury < 2.4 10^{-3}/ year that could authorized for the over whole 500 days Mars mission (6 crewmembers) an accepted probability of death by illness or injury of 0.98 = $(1 – (0.0024*500/365))^6$.).*</u>

So to design and size the crew health control system for the 500 days Mars mission, the objectives of a probability of death by illness or injury (excluding spacecraft failure) for the whole crew are :

- ***< 1,7 10^{-2}/ onboard the Earth-Mars transfer and Mars orbiting vehicle***
- ***< 1,2 10^{-3}/ onboard the Mars lander habitable vehicle***

are compatible with the figure of the mission safety objectives presented here before and will be taken as an input for the rest of the HUMEX study.

4.3. LIFE SUPPORT and CREW HEALTH CONTROL needs:

Based on the techniques used to-day onboard existing spacecraft, we have taken the most demanding following hypothesis (coming from the references REF 1, REF 2, REF 3, REF 4, REF 8 and REF 9 (see also tables of the annex 1, 2nd column) :

- All the items and consumables to satisfy the human needs are carried from Earth
- No recycling of the human wastes
- Oxygen consumption average value : 1020 g / man.day (taking into account that the astronauts have to perform intensive physical training 2 hours per day)
- Body hygiene hypothesis:
  - Body hygiene hypothesis 1: during the Earth – Moon transfer (lunar base mission) and during the 30 days stay on the Mars surface (500 days Mars mission), the body hygiene are based on the do-day used techniques **(no shower)**: soap impregnated towels, wet and dry towels, dry shampoo, teeth paste and gums (see the quantity in the tables, 2nd column of the annex 1), water need 1800 g / man.day.
  - Body hygiene hypothesis 2: during the 180 days Moon stay (lunar base mission), onboard the Earth – Mars transfer vehicle (for the 1000 days and 500 days Mars missions), and during the 525 days stay on Mars surface (1000 days Mars mission), **the body hygiene are based on 1 shower/ man.day** or a water need of 23000 g / man.day
- Water delivery : 4600 g / man.day (hypothesis 1) and 25 800 g / man.day (hypothesis 2)
  - drinking water: 2100 g / man.day
  - water for food hydration : 700 g / man.day
  - water for hygiene purpose: 1800 g / man.day (hypothesis 1)
  - 23 000 g /man.day (hypothesis 2)
- Water for EVA suit evaporator : 5 000 g / suit * EVA (8 hours duration)
- Foods delivery are based on a mixed of freeze, dried, dehydrated foods (450+800 g / man day or 47% of the needs), canned foods (1350 g / man day or 53% of the needs)
- Air for airlock maneuver : 4 800 g / EVA (airlock volume # 4 m^3).
- The man wastes production have been rated on the following way :
  - Vomits : 4 vomits / man.day or (during 3 days after planet launch and during 2 days after planet landing)
  - Defecation : 1 defecation / man.day or 300 g / man.day
  - Urination : 5 urination / man.day or 1500 g / man.day
- The weight of the personal kits are extrapolated from the to-day flying personal kits by increasing the weight with regard to the mission duration.

- The cloths exchange : 3 underwear / person week + 1 complete set of cloths (excluding underwear) / person week + 1 sleeping bag/person for 2 weeks.

4.3.1. Life support needs

- **<u>Scenario 1: Lunar Base on the south pole</u>**

Details of the needs and waste disposal requirements of the Life Support system are listed in annex 1, and are summarized below:

Table I- 4.3.1 Human needs and wastes production for the Lunar base mission

Needs and wastes	Total amount for Earth-Moon-Earth transfers	Total amount for Moon –180 day Stay
O_2	32.64 Kg	734.4 Kg
Air for EVA airlock maneuvers		144.0 Kg
Water (total needs):	147.2 Kg	18 876.0 Kg
For Hygienic purpose	57.6 Kg	16 560.0 Kg
Drinking water	89.6 Kg	2 016.0 Kg
For EVA suits		300.0 Kg
Foods	85.44 Kg	1922.4 Kg
Unique Items	62.272 Kg	541.12 Kg
Human metabolic wastes		
CO_2	39.68 Kg	892.8 Kg
Water Vapor	94.4 Kg	2124.0 Kg
Energy	462 080 KJ	10 396 800 KJ
Other Human Wastes		
Solid (Faeces, packaging, towels, cloths)	67.072 Kg	1 509.12 Kg
Liquid (Urine, Vomits, Hygienic water)	92.4 Kg	17 209.6 Kg

<u>The requirements for the Earth-Moon-Earth transfers</u> can be met by existing manned spacecraft (STS and Soyuz).

- **Needs # 327.55 Kg**
- **Wastes # 293.6 Kg + Energy (at a mean rate 670 Watt)**

NB: the difference of weight between the needs and wastes is explained by the weight of the personal kits (40 kg) counted in the needs and not counted in the wastes.

<u>The requirements for the 180 days Moon are:</u>

- **Needs # 22 217.92 Kg**
- **Wastes # 21 736.55 Kg + Energy (at a mean rate 670 Watt)**

NB: the difference of weight between the needs and wastes is explained by the weight of the personal kits (40 kg) + air lost during airlock maneuvers (144 Kg) + water lost by EVA suits evaporators (300 Kg) counted in the needs and not counted in the wastes.

On first analysis, the potential areas where mass savings might be achieved are:

- An O_2 / CO_2 recycling system
- An H_2O recycling system (from water vapor and liquid wastes)
- A "towels + cloths" washing-drying system
- A recycling packaging system for foods and unique items
- An "on site" food production system

A detailed analysis of these potential mass saving actions will be undertaken under WPs 4100, 4200, 4300 and 4400.

- **<u>Scenario 2: 1000-Days Manned Mars Mission</u>**

Details of the needs and waste disposal requirements of the Life Support system are listed in annex 1, and are summarized below:

Table I- 4.3.2 Human needs and wastes production for the 1000 days Mars mission

Needs and wastes	Total amount for Earth-Mars Earth transfers	Total amount for Mars 525 day stay
O_2	3 654 Kg	2 142 Kg
Air for EVA airlock maneuvers		432.0 Kg
Water (total needs):	92 415.6 Kg	55 080 Kg
For Hygienic purpose	82 386 Kg	48 300 Kg
Drinking water	10 029.6 Kg	5 880.0 Kg
For EVA suits		900.0 Kg
Foods	9 563.94 Kg	5 607.0 Kg
Unique Items	2 673.0 Kg	1 581.0 Kg
Human metabolic wastes		
CO_2	4 441.68 Kg	2 604.0 Kg
Water Vapor	10 566.9 Kg	6 195 Kg
Energy	51 724 080 KJ	30 324 000 KJ
Other Human Wastes		
Solid (Feces, packaging, towels, cloths)	7 507.9 Kg	4 401.0 Kg
Liquid (Urine, Vomits, Hygienic water)	85 615.8 Kg	50 191.6Kg

<u>The requirements for the Earth-Mars-Earth transfers</u> greatly exceed the capacities of current manned spacecraft (eg, STS and Soyuz):.

- **Needs # 108 306.25 Kg**
- **Wastes # 108 137.36 Kg + Energy (at the mean rate # 1005 Watt)**

NB: the difference of weight between the needs and wastes is explained by the weight of the personal kits (180 kg) counted in the needs and not counted in the wastes

On first analysis, the potential areas where mass savings might be achieved are:

- An O_2 / CO_2 recycling system
- An H_2O recycling system (from Water vapors and liquid wastes)
- A "towels + cloths" washing drying system
- A recycling packaging system for foods and unique items
- An "onboard" food production system

The needs for the 525 day Mars stay are also substantial: :

- **Needs # 64 842.6 Kg**
- **Wastes # 63 395.19 Kg + Energy (at the mean rate # 670 Watt)**

NB: the difference of weight between the needs and wastes is explained by the weight of the personal kits (120 kg) + air lost during airlock maneuvers (432 Kg) + water lost by EVA suits evaporators (900 Kg) counted in the needs and not counted in the wastes.

On first analysis, the potential areas where mass savings might be achieved are:

- An O_2 / CO_2 recycling system
- An H_2O recycling system (from Water vapors and liquid wastes)
- A "towels + cloths" washing drying system
- A recycling packaging system for foods and unique items
- An "on site" food production system

A detailed analysis of these potential mass saving actions will be undertaken under WPs 4100, 4200, 4300 and 4400.

- **Scenario 3: 500-Days Manned Mars Mission**

Details of the needs and waste disposal requirements of the Life Support system are listed in annex 1, and are summarized below:

Table I- 4.3.3 Human needs and wastes production for the 500 days Mars mission

Needs and wastes	Total amount for Earth-Mars- Earth transfers	Total amount for Mars – 30 day Stay
O_2	2 631.6 Kg	122.4 Kg
Air for EVA airlock maneuvers		72.0 Kg
Water (total needs):	66 564 Kg	702 Kg
For Hygienic purpose	59 340 Kg	216 Kg
Drinking water	7 224 Kg	336 Kg
For EVA suits		150.0 Kg
Foods	6888.6 Kg	320.4 Kg
Unique Items	1 915.68 Kg	173.52 Kg
Human metabolic wastes		
CO_2	3 199.2 Kg	148.8 Kg
Water Vapor	7 611 Kg	354.0 Kg
Energy	37 255 200 KJ	1 732 800 KJ
Other Human Wastes		
Solid (Feces, packaging, towels, cloths)	5 407.68 Kg	251.52 Kg
Liquid (Urine, Vomits, Hygienic water)	61 668 Kg	325.6 Kg

The requirements for the Earth-Mars-Earth transfers greatly exceed the capacities of current manned spacecraft (eg, STS and Soyuz):

- **Needs # 77 999.88 Kg**
- **Wastes # 77 889.56 Kg + Energy (at the mean rate # 1005 Watt)**

NB: the difference of weight between the needs and wastes is explained by the weight of the personal kits (120 kg) counted in the needs and not counted in the wastes

On first analysis, the potential areas where mass savings might be achieved are:

- An O_2 / CO_2 recycling system
- An H_2O recycling system (from Water vapors and liquid wastes)
- A “towels + cloths” washing drying system
- A recycling packaging system for foods and unique items
- An “onboard” food production system

The requirements for the 30 days Mars stay are similar to those which are being/will be met by current/planned manned space stations (MIR and ISS) , but only if the Mars surface spacecraft is designed just for a 30 day manned exploration mission, and not as a first step to a permanent manned Mars base.

- **Needs # 1390.32 Kg**
- **Wastes # 1080.09 Kg + Energy (at a mean rate 670 Watt)**

NB: the difference of weight between the needs and wastes is explained by the weight of the personal kits (90 kg) + air lost during airlock maneuvers (72 Kg) + water lost by EVA suits evaporators (150 Kg) counted in the needs and not counted in the wastes.

Detailed information concerning atmosphere quality, potable and hygienic water quality, and human waste management is provided in 4 the ESA standards (see REF 3, REF 15, REF 16 and REF 17).

A detailed analysis of these potential mass saving actions will be undertaken under WPs 4100, 4200, 4300 and 4400.

4.3.2. Crew Health Control Needs

- **Scenario 1: Lunar Base on the south pole**

Details of crew health control needs are listed in annex 2 and have been established by using the figures of the diseases’ estimated probabilities of occurrences during space flights given in REF 7.

In that reference the risks of occurrence of illness or injury were estimated from a weighted compilation of epidemiological data derived from analogous hazardous situations (the incidence rates are treated with 95% confidence limits):

*Antarctic Winterers (male- 4590 man*year)*

*Previous Space Flight data (male- 2.27 man*year)*

*Polaris Submarines (male- 21000 man*year)*

*US Navy (male- 760000 man*year)*

*Offshore (mixed - 24300 man*year)*

*McHurdo Antartic (mixed – 4760 man*year)*

*Op Deep Freeze (male- 14800 man*year)*

and from other ground situations:

*GP National study (52% female – 86400 man*year)*

*British Forces (5% female- 3530000 man*year)*

Grampian RHA (UK) (general population 49% female – 2680000)

*US Military 85 Hosp.(mixed - 1360000 man*year)*

*US military MIL 80-85 OPD (mixed- 1080000 man*year)*

The following key points regarding medical treatments should be noted:

- There is a significant probability of diseases and injuries occurring during the 180 day Moon stay, with a lower risk during Earth-Moon Earth transfers.
- The onboard and «on site or onboard Moon lander or Moon habitat» medical equipment must allow both the diagnosis and treatment of infectious and inflammatory diseases (eg, respiratory, dental, skin, digestive, genito-urinary, arthropathies).
- The «on site or onboard Moon lander or Moon habitat» medical medications and communications system must allow treatment of psychological and mental problems. All crewmembers shall be trained to manage psychological issues.
- The «on site or onboard Moon lander or Moon habitat» medical diagnostic equipment and medications must allow the treatment of hypertensive disease, heart ischaemia, hemorrhoids, urinary calculus, peptic ulcer. .
- The «on site or onboard Moon lander or Moon habitat» medical equipment must include ENT, eyes and dental kits and related external medications.
- The crewmember with appendectomy will be preferred.
- The «on site or onboard Moon lander or Moon habitat» medical diagnostic equipment, mini-surgery kit, immobilization splits and medications must allow the treatment and management of minor injuries (sprains, strains, superficial injuries, local burns, contusions).
- In case of medical emergency situations (cardiac or cerebral stroke), serious injury (fractures, crushing, extended burns, open wounds) and poisoning, the on board and «on site or onboard Moon lander or Moon habitat» medical equipment must allow the stabilization of the patient(s) and **emergency return to Earth within some days**.

The following key points regarding **space related disorders should also be noted:**

- Radiation exposure <u>should be an accepted risk.</u>
- Bone demineralization during the Lunar stay (1/6 g of Earth gravity) is not documented, but should be less than for equivalent 0 g exposure (less than the 15% threshold considered as the level of significant increase of bone fracture risk); therefore <u>bone demineralization needs further investigations for the 180</u>

days Lunar stay. (Note that 6 months in 0 g results in loss of bone mass of # 11% mean value, but 23% in one case, at the worst body location, the pelvis (*see REF 10, REF 11 and REF 12)).*

- Space adaptation syndrome + Moon and Earth sickness (after Moon and Earth landing) will be treated for 3 days after Earth launch, and on Moon landing and Moon launch. Operational activities must be reduced during these periods, and the EVA must be avoided. The necessary medications will be available on board the transfer spacecraft and in the Lunar base.
- Orthostatic Intolerance occurring after Moon and Earth landing will be monitored, and treated if necessary during 2-3 days after Moon and Earth landing. The operational activities should be reduced during these periods, and the EVA avoided. The necessary equipment and medications must be available onboard the transfer spacecraft and in the Lunar base.
- Exercise capacity will decrease during the Lunar stay, but its magnitude is presently not documented. It should, however, be less than for an equivalent duration 0 g exposure (i.e. less than 20%). To minimize the reduction of physical work capacity a physical training facility (gymnasium) is mandatory in the Lunar base. The exercise type and duration will need further investigation.

All the questions addressed here above are in agreement with the previous analysis concerning the long duration space flights (see REF 5 and REF 6)

- **Scenario 2: 1000 day Mars Mission**

Details of crew health control needs are listed in annex 2 and have been established by using the figures of the diseases' estimated probabilities of occurrences during space flights given in REF 7. The following key points regarding medical treatments should be noted:

- There is a significant probability of diseases and injuries occurring during the 525 day Mars stay and during Earth-Mars-Earth transfers.
- The onboard and «on site or onboard Mars lander or Mars habitat» medical equipment must allow both the diagnosis and treatment of infectious and inflammatory diseases (eg, respiratory, dental, skin, digestive, genito-urinary, arthropathies).
- The «on site or onboard Mars lander or Mars habitat» medical medications must allow treatment of psychological problems. All crewmembers shall be trained to manage psychological issues.
- The «on site or onboard Mars lander or Mars habitat» medical diagnostic equipment and medications must allow the control of hypertensive disease, heart ischaemia, hemorrhoids, urinary calculus, peptic ulcer. .
- The «on site or onboard Mars lander or Mars habitat» medical equipment must include ENT, eyes and dental kits and related external medications.
- The crewmember with appendectomy will be preferred.
- All crew members will possess the necessary medical and surgical skills.
- The surgical and medical diagnostic equipment, surgery equipment, surgery consumables (adapted surgical fields, plaster, splits, suture, wound dressing

etc…) and medications available “on site” must allow the treatment and management of serious and slight injuries (fractures, crushing, extended burns, open wounds, sprains, strains, superficial injuries, local burns, contusions), and serious medical emergency situations (heart or cerebral stroke).

- **In case of medical emergency situations an emergency return to Earth is impossible.**

The following key points regarding **space related disorders should also be noted:**

- The radiation exposure likely to be experienced **<u>during a Mars mission is not fully documented. Permanent dose rate monitoring and an available radiation shelter are probably mandatory both on board</u> the transfer vehicle and in the Mars base <u>(see WP 3100).</u>**
- Bone demineralization during the Mars stay (0.39 g of Earth gravity) is unknown, but should be less than for an equivalent 0 g exposure.
- During the transfers (and specially for the 2 astronauts additionally orbiting during the 525 days Mars stay so 947 days under 0g) the level of demineralization could reached 50% at the pelvis, and it will certainly be more than the 15% threshold (considered as the level of significant increase of bone fracture risk). **Bone demineralization is therefore <u>an unacceptable risk, and must be controlled</u>**. (Note that 6 months in 0 g results in loss of bone mass of # 11% mean value, but 23% in one case, at the worst body location, the <u>pelvis level</u> (*see REF 10, REF 11 and REF 12)*). For that aspect a temporary artificial gravity system (centrifuge on board the transfer vehicle) or a permanent artificial gravity system (permanent rotation of the habitable transfer vehicle) could be considered but need further investigations and studies to verify the efficiency on man and the technical realism onboard the transfer vehicle.
- Space adaptation syndrome + Mars and Earth sickness (after Mars and Earth landing) will be treated during 3 days after Earth launch, Mars landing and Mars launch. The operational activities should be reduced during these periods, and the EVA avoided. The necessary medications must be available on board the transfer spacecraft and in the Mars base. For that aspect a temporary artificial gravity system (centrifuge on board the transfer vehicle) by repeating the adaptation periods will probably increase the problem of the space adaptation syndrome, only a permanent artificial gravity system (permanent rotation of the habitable transfer vehicle) could bring some benefits but needs further investigations and studies to verify the efficiency on man and the technical realism onboard the transfer vehicle.
- Orthostatic Intolerance (after Mars and Earth landing) will be monitored and treated if necessary. The operational activities will be reduced during these periods, and EVA should be avoided. The necessary equipment and medications must be available on board the transfer spacecraft and in the Mars descent spacecraft. For that aspect a temporary artificial gravity system (centrifuge on board the transfer vehicle) or a permanent artificial gravity system (permanent rotation of the habitable transfer vehicle) could be considered but need further investigations and studies to verify the efficiency on man and the technical realism onboard the transfer vehicle.
- Exercise capacity will decrease during Mars stay , but the magnitude of the decrease is unknown. However, it should be less than for an equivalent 0 g

exposure. To reduce the loss of physical work capacity physical exercise devices should be provided in the Mars base.

- During the transfers the decrease in exercise capacity will be serious (947 days under 0 g for 2 astronauts). To minimize the deleterious effects on muscle and work capacity of 0 g, a physical training program will be mandatory. Physical exercise devices must be provided onboard the transfer and Mars orbit vehicle. The type and duration of physical training must be defined and optimized. For that aspect a temporary artificial gravity system (centrifuge on board the transfer vehicle) or a permanent artificial gravity system (permanent rotation of the habitable transfer vehicle) could be considered but need further investigations and studies to verify the efficiency on man and the technical realism onboard the transfer vehicle.

All the questions addressed here above are in agreement with the previous analysis concerning the long duration space flights (see REF 5 and REF 6)

- **Scenario : 500 days Mars Mission**

Details of crew health control needs are listed in annex 2 and have been established by using the figures of the diseases' estimated probabilities of occurrences during space flights given in REF 7. The following key points regarding medical treatments should be noted:

- There is a significant probability of diseases and injuries occurring during the 450 days of Earth-Mars-Earth transfers.
- The onboard and «on site or onboard Mars lander or Mars habitat» medical equipment must allow both the diagnosis and treatment of infectious and inflammatory diseases (eg, respiratory, dental, skin, digestive, genito-urinary, arthropathies).
- The on-board transfer vehicle medical medications must allow treatment of psychological problems. All crewmembers shall be trained to manage psychological issues.
- The on board transfer vehicle medical diagnostic equipment and medications must allow the control of hypertensive disease, heart ischaemia, hemorrhoids, urinary calculus, peptic ulcer.
- The on-board transfer vehicle medical equipment must include ENT, eyes and dental kits and related external medications.
- The crewmember with appendectomy will be preferred.
- The surgical and medical diagnostic equipment, surgery equipment, surgery consumables (adapted surgical fields, plaster, splits, suture, wound dressing etc) and medications aboard the transfer vehicle will allow the control of both serious and minor injuries (fractures, crushing, extended burns, open wounds, sprains, strains, superficial injuries, local burns, contusions), and serious medical emergency situations (heart or cerebral stroke).
- All crew members will possess the necessary medical and surgical skills.

- **In case of medical emergency situations on the Mars surface an emergency return to the transfer vehicle must be possible.**

The following key points regarding **space related disorders should also be noted:**

- The radiation exposure likely to be experienced **during a Mars mission is not fully documented. Permanent dose rate monitoring and an available radiation shelter are probably mandatory both on board the transfer vehicle and in the Mars base (see WP 3100).**
- The bone demineralization likely to occur during a 30-day Mars stay (0.39 g of gravity) is unknown, but should be regarded as an acceptable risk.
- During the transfers, (and specially for the 2 astronauts additionally orbiting during the 30 days Mars stay, so 450 days under 0g), the level of demineralization could reached 25% at the pelvis, and will certainly exceed the 15% threshold (considered as the level of significant increase of bone fracture risk) , **so this disorder is as an unacceptable risk and must be controlled**. (Note that 6 months in 0 g results in loss of bone mass of # 11% mean value, but 23% in one case, at the worst body location, the pelvis level (*see REF 10, REF 11 and REF 12))*. For that aspect a temporary artificial gravity system (centrifuge on board the transfer vehicle) or a permanent artificial gravity system (permanent rotation of the habitable transfer vehicle) could be considered but need further investigations and studies to verify the efficiency on man and the technical realism onboard the transfer vehicle.
- Space adaptation syndrome + Mars and Earth sickness (after Mars and Earth landing) will be treated during 3 days after Earth launch, Mars landing and Mars launch. The operational activities must be reduced during these periods, and the EVA must be avoided. The necessary medications will be available on board the transfer spacecraft and in the Mars base. For that aspect a temporary artificial gravity system (centrifuge on board the transfer vehicle) by repeating the adaptations period will probably increase the problem of the space adaptation syndrome, only a permanent artificial gravity system (permanent rotation of the habitable transfer vehicle) could bring some benefits but needs further investigations and studies to verify the efficiency on man and the technical realism onboard the transfer vehicle.
- Orthostatic Intolerance (after Mars and Earth landing) will be monitored and treated if necessary. The operational activities will be reduced during these periods, and the EVA should be avoided. The necessary equipment and medications must be available on board the transfer spacecraft and in the Mars base. For that aspect a temporary artificial gravity system (centrifuge on board the transfer vehicle) or a permanent artificial gravity system (permanent rotation of the habitable transfer vehicle) could be considered need further investigations and studies to verify the efficiency on man and the technical realism onboard the transfer vehicle.
- Exercise capacity will decrease during Mars stay, but the magnitude of the decrease is unknown. For a stay of 30 days this risk can be accepted, and so the implementation of a physical training program is not necessary in the Mars base .
- During the transfers the decrease in exercise capacity will be serious (420 days under 0 g; 450 days for the 2 crewmembers staying on Mars orbit). To minimize the deleterious effects on muscle and work capacity of 0 g a physical training program will be mandatory. Physical exercise devices must be provided onboard

the transfer and Mars orbit vehicle. The type and duration of physical training must be defined and optimized. For that aspect a temporary artificial gravity system (centrifuge on board the transfer vehicle) or a permanent artificial gravity system (permanent rotation of the habitable transfer vehicle) could be considered but need further investigations and studies to verify the efficiency on man and the technical realism onboard the transfer vehicle.

All the questions addressed here above are in agreement with the previous analysis concerning the long duration space flights (see REF 5 and REF 6)

4.4. Conclusions

The consequences of the Life Support and Crew Health Control requirements and needs will be analyzed in WPs 3000 and 4000. (TN 2 and TN 3)

4.5. Reference documents (used for WP 2200)

The documents referred in the list here after have been used for the achievement of the WP 2200.

- REF 1 – Man-System Integration Standards – NASA STD-3000 – 3 Volumes
- REF 2 – Human Factors – ESA PSS-03-70 - 2 volumes
- REF 3 – Atmosphere quality standards in manned space vehicles – ESA PSS-03-401
- REF 4 – Requirements for extravehicular activities on the Lunar and Martian surfaces – SAE Technical Paper Series – 901427 – July 1990
- REF 5 – Human Physiological adaptation to extended space flights and its implications for Space Station – SAE Technical Paper Series – 851311 – July 1985
- REF 6 – Life Sciences : on the critical path for missions of exploration – SAE Technical Paper Series – 881012 – July 1988
- REF 7 – Quantification of medical risks during Space flight – RGIT – Hermes Programme Support Contract – 1994.
- REF 8 – Crew Transportation System – Man Integration Requirements Document (MIRD) – ESA – CTV/CRV project – HV-GS-1-1-HPD dated July 30, 1994.
- REF 9 - Living Aloft – NASA SP 483
- REF 10 - Oganov, V.S., Grigoriev, A.I., Voronine, L.I., Rakhmanov, A.S, Bakulin, A.B., Schneider, V and LeBlanc, A, « Mineral density of bone tissue in cosmonauts after 4.5 – 6 month missions on MIR », Kosmicheskaya Biologiya I Aviakosmischeskaya Meditsina, Vol. 26, No. 5, 1992, pp. 20-24 (in Russian).
- REF 11 - Oganov, V.S.and Schneider, V, « Skeletal system », Space Biology and Medicine, Vol. No. 3, 1996, pp. 247-266)).
- REF 12 – M.M. Daphtary, J.R Shapiro, J.N. Caminis, J.T. Toerge, K. Burman, V. Schneider, L. Schulteis : " Tetraplegic patient as a model of microgravity-related bone loss" – Abstract of the 13th HUMANS IN SPACE SYMPOSIUM – Santorini 20-26 May 2000.
- REF 13 – Probabilistic Risk Assessment of the Space Shuttle – Final Report – NASA document referenced : SAICNY95-02-25 dated February 25, 1995

- REF 14 – Hermes System Requirements Document - ESA document referenced : H-REQ-0-10-ESA dated January 29, 1990
- REF 15 - ESA-PSS-03-401 – Atmosphere Quality Standard
- REF 16 - ESA-PSS-03-402 – Water Quality Standard
- REF 17 - ESA-PSS-03-403 – Hygiene and Solid Waste Management and Control Standard

4.6. Annex 1

Detailed Life Support Requirements for :

Scenario 1: Lunar Base on the south pole

Scenario 2: 1000-Day Manned Mars Mission

Scenario 3: 500-Day Manned Mars Mission

4.7. Annex 2

Estimated probabilities of occurrence of diseases and injuries during :

- Scenario 1: Lunar Base on the south pole
- Scenario 2: 1000-Day Manned Mars Mission
- Scenario 3: 500-Day Manned Mars Mission