NASA/TP—2001–209371

# The Mars Surface Reference Mission: A Description of Human and Robotic Surface Activities

*Stephen J. Hoffman, Ph.D., editor*
*Science Applications International Corporation*

December 2001

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# FOREWORD

This document, originally published as Johnson Space Center document EX13-98-065, describes representative activities that will be carried out by humans and robots as they explore the surface of Mars.

The Mars Surface Reference Mission is a tool used by the Exploration Team and the exploration community to compare and evaluate approaches to surface activities. Intended to identify and clarify system drivers, or significant sources of cost, performance, risk, and schedule variation, it does not represent a final or recommended approach. The Exploration Team is currently studying alternative scenarios, including technical approaches to solving mission and technology challenges, and human exploration missions to the Moon, asteroids, or other targets beyond Earth orbit. Comparing alternative approaches in this way provides the basis for continual improvement to technology investment plans and a general understanding of future human exploration missions.

This document represents a “snapshot” of work in progress in support of planning through October 1998 for future human exploration of the Martian surface. Publication of revisions to this document is planned.

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BITE | built-in test equipment |
| CD | compact disk |
| $CH_4$ | (chemical formula for methane) |
| ECCV | Earth crew capture vehicle |
| EELV | evolved expendable launch vehicle |
| ERV | Earth return vehicle |
| ESA | European Space Agency |
| EVA | extravehicular activity |
| FRU | field replaceable unit |
| ISRU | in situ resource utilization |
| ISS | International Space Station |
| IVA | intravehicular activity |
| km | kilometer |
| kWe | kilo Watt, electric |
| LFBB | liquid flyback booster |
| LEO | low Earth orbit |
| LOX | liquid oxygen |
| LRU | line replaceable unit |
| LRV | lunar rover vehicle |
| MAV | Mars ascent vehicle |
| NASA | National Aeronautics and Space Administration |
| NDR | NERVA-derivative reactor |
| NERVA | Nuclear Engine for Rocket Vehicle Application |
| nmi | nautical mile |
| PLSS | portable life support system |
| RLV | reusable launch vehicle |
| ROV | remotely operated vehicle |
| RPV | remotely piloted vehicle |
| SRU | shop replaceable unit |
| TBD | to be determined |
| TEI | trans-Earth injection |
| TMI | trans-Mars injection |
| TWA | Trans World Airlines |
| UAV | unmanned aerial vehicle |
| UV | ultraviolet |

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# OVERVIEW AND EXECUTIVE SUMMARY

This document describes current expectations for the activities of human crews—and the activity of associated support equipment—that will occur as humans explore the surface of Mars. These descriptions are made at a functional level. The approach of discussing activities at a functional level was chosen for two reasons. First, it creates a starting point for continued discussion of necessary surface mission activities and functions. Second, it allows functionally equivalent designs or technologies to be proposed and then evaluated to find a best overall implementation for the exploration mission. Ongoing comparisons provide the basis for continual improvement to technology investment plans and a general understanding of future human exploration missions.

The Reference Mission and this response to it are intended to be used as tools by the Exploration Team and the exploration community to compare and evaluate approaches to mission and system concepts that could be used for human exploration missions. They are intended to identify and clarify system "drivers", or significant sources of cost, performance, risk, and schedule variation. This document is not intended to represent a final or recommended approach to human Mars missions.

Surface activities are defined as those crew activities that occur after landing and before departure for the return to Earth. Activities associated with launch from Earth, interplanetary travel, and landing or departing from Mars are discussed in other documents. In addition to crew activities, this document also describes the activities of automated systems that could arrive before the crew and keep operating on the surface while no crew is present.

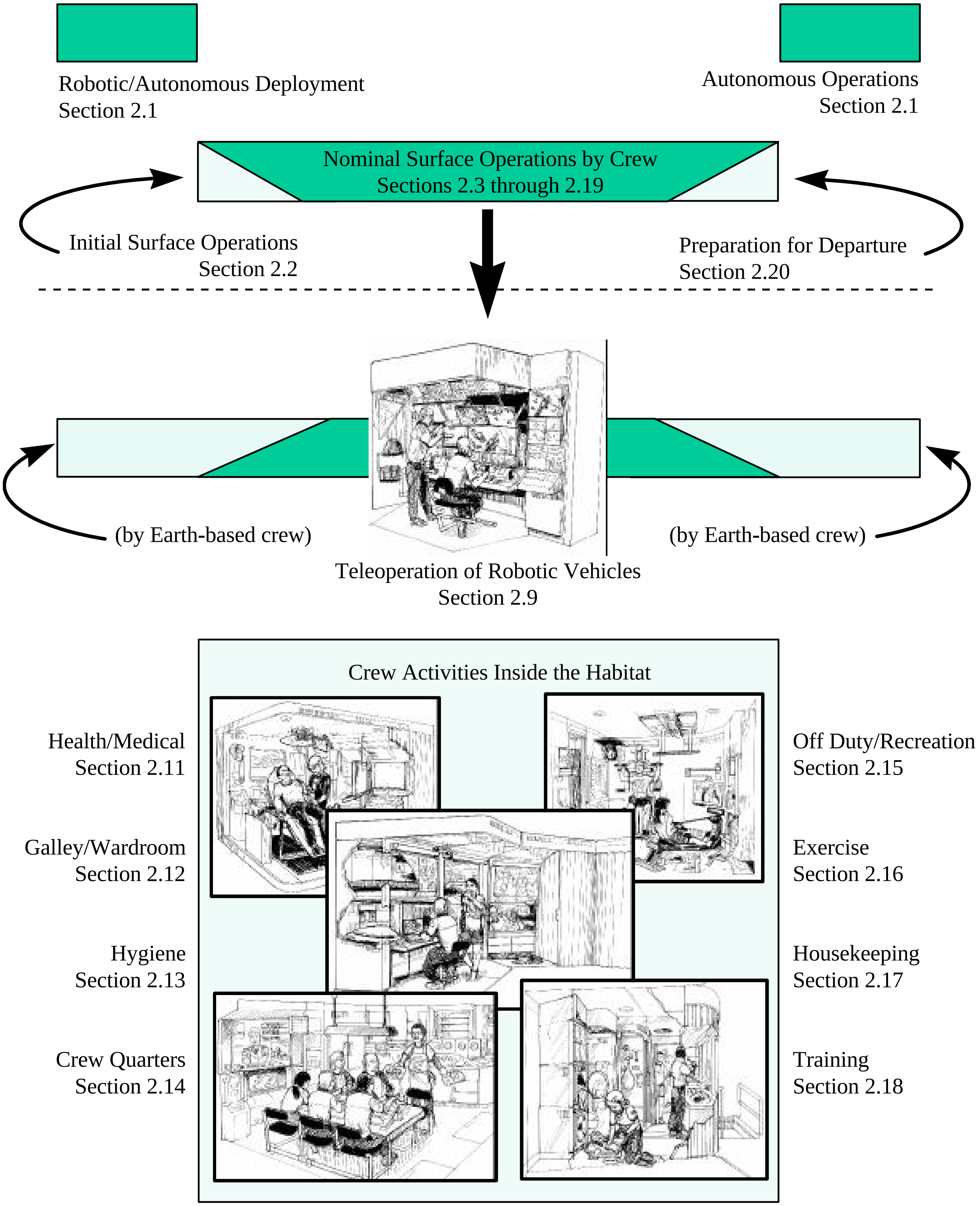
This document is divided into several major sections. The first of these sections provides an overview of the mission approach (to provide a framework for the surface mission) for the Mars mission. The remainder of this document is devoted to a series of vignettes describing key activities or functions that will be part of the surface mission. The figure on the following two pages lists these vignettes and the associated section numbers in this document, with the horizontal bars indicating the approximate level of activity during a typical surface mission.

The remainder of this executive summary briefly describes mission and science objectives as well as key points or findings from each of the vignette sections.

The human exploration of Mars will be based on two major goals:

- Explore Mars and discover how it is similar to and different from Earth. This includes diverse scientific investigations such as determining: whether life ever existed or still exists on Mars; and, if so, whether and how such life ever became extinct (because Mars is believed to have had characteristics consistent with the emergence of life, if no evidence of life is discovered then the discovery of clues to its absence will also be important); determining if Mars is still geologically active and how it evolved to its present state; and the climatological history of the planet including the fate of many of its volatile components (including water).

- Determine the challenges that must be met for a self-sustaining human presence on Mars. This will involve testing a variety of technologies and techniques important for any long-term human presence; initial activities to ensure no fundamental biological limitations to Martian habitability exist (e.g., reduced gravity, oxidizing soil, etc.); and discovering the availability of surface and subsurface resources essential for a sustained or expanding human presence.



Mars Surface Mission Activities

## Mars Surface Mission Activities (continued)

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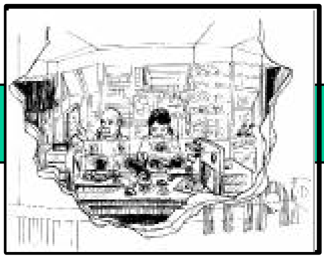

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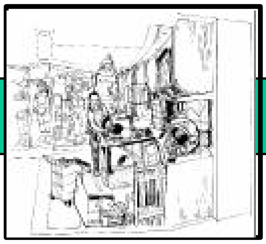

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For these scientific goals and the questions they give rise to, there is a basic assumption that a human crew will provide unique enhancements toward their achievement. The following paragraphs illustrate, by means of a series of short vignettes, some of these enhancements.

1. ***Perform field geology, field biology, and sample collection.***

   Humans' unique ability to observe and synoptically integrate their observations is exercised in the discipline called field work. Similar methods are used by geologists, biologists, and paleontologists. This ability comes from a combination of visual acuity and the ability to look at the surface from several perspectives, integrating observations made at different times and different angles to identify subtle differences between materials. A field scientist is able to conduct experiments as needed, such as deploying a field instrument, knocking a corner off of a rock, drilling a core, etc., which improve the ability to recognize rocks. Observations, experiments and decisions are done rapidly. Finally, humans can use on-the-spot judgment to obtain images of the surface and of materials they sample to document the mission and communicate contextual information.

2. ***Perform teleoperation of robotic sample collection systems such as rovers.***

   Humans on Mars can operate remote systems, extending field geology capabilities beyond their own range. This can be done effectively because of the short delay times that can exist during human missions. While telerobotic systems cannot replace the observational abilities of an astronaut in the field, such systems may be particularly effective at collecting samples under human supervision. These systems could be used to extend astronaut operating range, or could be used in advance of astronaut sorties to provide detailed information about a specific local area or rock type.

3. ***Conduct preliminary analysis of samples.***

   An on-site laboratory on Mars will be used to confirm field identification of rock type, texture, major mineral phases, and presence of physical indicators for life (fossils, structures). As more rocks are studied, it will become easier for the crews to recognize rocks of the same type in the field. It will also accelerate understanding by allowing sample data to be folded back into exploration sorties. Equally important will be the use of this laboratory to study volatile or transient characteristics of samples which could not otherwise be contained for the journey back to Earth-based facilities (e.g., water in its various states or atmospheric samples).

   While the purpose of on-site analysis will be primarily to support the field investigations, it will also be possible to help select the suite of samples to be returned at the end of the human mission, increasing the possibility of new discoveries.

4. ***Communicate findings to geology team on Earth.***

   The astronauts on Mars will be in daily communication with the Earth, allowing a wide range of scientists (biologists, geologists, climatologists) on Earth to be intimately involved in planning exploration sorties. A large amount of scientific information will be transmitted. The Earth-based scientists will have the opportunity to review and discuss the data being returned and can help in the construction of working hypotheses for the geological/biological problems being addressed (e.g., what is the geological environment in which lifeforms persisted?). Together, explorers on Mars and scientists on Earth will reevaluate exploration plans and strategies to more effectively pursue investigations and sample collection. These activities will include reevaluating sampling priorities and identifying new objectives, and potentially planning revisits to previously sampled terrain or visits to new and different sites.

5. ***Deploy geophysical/meteorological experiment packages.***

   It is likely that instrument stations will be established to assess interior physical properties and monitor meteorological phenomena, such as dust storms. The crew may also conduct active geophysical investigations (seismic, radar sounding) to explore the local subsurface, particularly with respect to location of water. The deployment of these stations may benefit from the capabilities of crew members to manipulate instruments and supporting systems to improve their sensitivity and reliability. Straightforward calibrations of the instruments by the crew may be available.

6. ***Conduct and monitor special sampling, such as deep-drilling.***

   Deep drilling will be used to access sites where liquid water is stable, to explore deep sections of sedimentary deposits to search for evidence of extinct or extant life, or to sample special features such as hydrothermal deposits. The characteristics of systems for deep subsurface sampling (>1000 meters) are likely to include substantial mass, mechanical complexity, and the need to operate over extended periods of time at power levels most compatible with human exploration.

7. ***Conduct active life science experiments.***

   Studies of the Martian environment and questions about the practical use of Mars by humans will naturally lead to active experiments in which Martian materials may be tested in new environments. For example, biological experiments associated with a biological regenerative life support system and experiments on the capability of Mars soil to support plant growth may be undertaken. Crew health and performance will be evaluated with respect to mission operations needs as well as the long term needs for Mars habitation. Astronauts may also launch balloons or sounding rockets to study the environment.

8. ***Prepare samples for return to Earth.***

   Subsamples may be prepared and packaged for return to Earth by the crews. Remainders will be left in a special area, protected from degradation, where these rocks may be stored in case there is a future requirement to obtain additional samples. It is probable that some samples of the subsurface will have to be obtained under aseptic conditions (i.e., the Martian environment is protected from human contamination and the humans are protected against the possibility of infectious Martian agents), and it is assumed that sampling can be carried out without contaminating the crews or their systems. Analysis conducted on Mars may be sufficient to demonstrate subsurface samples to be harmless. If that is not possible, however, samples from these environments will be packaged on Mars to prevent them from contaminating the space habitats or crews and to protect them from inadvertent release to the Earth's biosphere—a process that could require complex crew activities.

While these descriptions illustrate a few of the activities likely to be carried out by a Mars surface crew, others will be identified or may be added as data from robotic missions improve our knowledge of the surface.

The decision on where it is best to establish a human outpost on Mars is a complicated one and must consider crew safety, scientific potential, access to resources, and where the highest public interest potential is located. A focused program of site selection has yet to be developed. It is appropriate to begin the site selection process now, however, to make optimum use of the capabilities of the robotic missions.

The main portion of this document has taken the activities described in these vignettes and has either expanded or augmented them into functional descriptions of specific crew activities. These functional descriptions are intended to cover the entire range of activities a crew could expect to participate in or rely upon for the successful completion of the surface mission. Each of these functional descriptions concludes with a summary of key points or a list of areas requiring additional research and development. These summaries have been collected here to highlight areas of future work needed to support human missions; the material supporting these summaries can be found in the body of the report.

## Robotic/Autonomous Deployment Summary

This section discusses a number of activities that could occur before the arrival of the first human crew on Mars.

- Several surface systems may be deployed and operated for significant periods of time before the crew arrives. These include the power plant, the ISRU plant, and associated systems (e.g., a thermal control system).
- A high degree of automation is associated with these activities, including selection and preparation of surface sites, deployment of potentially large and complex systems, inspection of these systems as they are operated, and performance of routine maintenance and repair as required.

## Initial Surface Operations Summary

This section discusses the sequence of activities the crew will perform during the first several days on the surface of Mars. These activities are focused on reaching a “ground operational” state which allows extensive exploration activities to commence. Key points made in this section include:

- The crew habitat must be connected to surface power, thermal control, high volume communication, and the ISRU-produced life support system cache within the first several days (typically on the first day) after landing.
- Extended exposure to a zero-gravity environment has caused deconditioning of the human body. Depending on the extent of their exposure to this environment on the outbound portion of this mission, the crew should not be expected to be available for critical tasks during the first several days after landing due to the need for adaptation to a Mars gravity environment.
- Most, if not all, of the tasks that occur during the first several days may be automated because of the crew’s physical condition and the restrictions this places on the tasks that can be performed.

## Exploration Field Work Summary

Examples described in this section point out several guidelines for surface operations, development of surface extravehicular activity (EVA) suits, and the equipment used by the crews while in these suits:

- “[F]irst is [the] ability for suited crew members to observe the environment around them. First and foremost, geologic field work is an exercise in seeing rocks and structures. The accommodations that allow observation must allow as wide a field of view as possible. …. Further, the visibility provided must be as free of optical distortion [as possible] and preferably without degradation of color vision. In particular, seeing colors allows discrimination between otherwise similar rock units.” (Eppler, 1997)
- “The second major implication is that EVA suits and other exploration accommodations must allow as much mobility as possible, both in terms of suit mobility and the ability to see as much countryside as possible. …. Where suit mobility is difficult or disallowed by the mechanics of inflated suits (e.g., bending and squatting down), an easily used suite of tools should compensate for the lack of mobility, so rock samples and dropped tools can be picked up with as little effort as possible.” (Eppler, 1997)
- Tools and equipment must be maintainable in the field and the EVA suit/tool interface must accommodate the environmental conditions under which this maintenance will take place. The level of maintenance that must be accomplished in the field versus maintenance at the outpost has yet to be determined.
- Communication between the EVA team in the field and the outpost, as well as navigational aid for the EVA team while in the field, are two capabilities that apply to all of the field activities envisioned for the surface crew.

## Surface Transportation Summary

This section discusses the types of surface transportation that will be available to the crew and the variety of missions on which the equipment can be deployed. Important points include:

- Both pressurized and unpressurized rovers should be available to the crew.
- The two types of rovers complement one another in the field activities that can be accomplished.
- Crew safety and the number of rovers deployed will determine the maximum range and duration that can be attained.
- Field maintenance will be a necessity.
- The unpressurized rover can be viewed as an extension of the EVA suit; allocation of functionality between the two systems needs further research.
- Dual pressurized rovers will allow distant sites to be visited or extended operations to be accomplished at selected sites.

## The Field Camp Summary

This section discusses the key mission objectives satisfied by, and functional capabilities of, a remote field camp. These include:

- Improved use of the crew by providing the capability to remain in the field for many days or weeks, with resupply, at sites of significant interest.
- The ability to perform daily EVAs.
- The ability to support a diversity of experiments ranging from walking traverses to operating large and/or complex machinery.
- The ability to accommodate a nominal crew of three.
- The ability to periodically resupply consumables from the central base, nominally once per week.
- The ability to relocate the field camp, once activities at a given site are complete.

System definition and trade studies remain to be performed on the habitation and supporting systems needed to implement this capability.

## Toxin and Biohazard Hazard Assessment Summary

There will be an ongoing need for crews to evaluate the level of toxicity or potential for biological activity throughout all phases of the surface mission. The active search for evidence of past or present life will inevitably lead these crews to environments where such assessments will be necessary to assure their own health and safety and to protect Earth’s biosphere from contamination. Such assessments will be derived from equipment and procedures that exhibit the following characteristics and capabilities:

- Control of the potential toxic effects of Mars’ dust on humans, through separation of humans from the environment, cleaning, and deactivating toxic materials.
- Special precautions to protect crews from samples taken from isolated environments that may harbor Martian organisms.
- Capability to analyze the characteristics of samples taken from these isolated environments without exposing the astronauts to potential Martian organisms.
- Special aseptic sampling and packaging procedures for samples with possible Martian organisms.
- Quarantine procedures for samples and crews to be used whenever new environments are sampled that may contain Martian life.
- Capability to prevent contamination or disruption by human activities of isolated Martian environments that may contain organisms.

## Sample Curation Summary

The following curatorial activities will be conducted by astronaut crews on the Martian surface:

- Sample documentation—to record the geologic and physical setting of the sample before collection, and to describe everything done to that sample during examinations.
- Splitting of selected samples—to provide subsamples for preliminary examinations and "minimally contaminated" subsamples for remote storage and possible shipment to Earth.
- Sample storage—to maintain readily accessible samples in as pristine and secure a condition as possible.
- Sample tracking—a database of current information pertaining to the location and condition of all samples and subsamples.
- Preliminary examination—to identify and characterize each sample and subsample.
- Contamination control—to maintain samples in as pristine a condition as possible.

## Sample Analysis Summary

This section discusses the sample examination and analytical capabilities likely to be used on the Martian surface. These capabilities are a key, distinguishing feature of these Mars missions. Two general categories of examination and analysis will take place: those focused on geological investigations, and those focused on biological investigations. Having these capabilities available will allow the crew to better understand the environment being explored and adapt to the findings made, allow for collaboration with colleagues on Earth, and "high-grade" the collected samples to determine which should be returned to Earth.

There are several key areas that require additional research and definition:

- Where to divide the analytical capability needed on Mars from that which will be brought to bear on those samples and data returned with the crew.
- How rock and soil samples are handled and examined inside a habitat laboratory.
- Protocols for handling samples that may be biologically active.

## Teleoperation of Robotic Vehicles Summary

This section describes the use of mobile robots to support science and exploration activities on the surface of Mars. Several key points can be derived from this section:

- Mobile robots will be an integral part of the tools available for leveraging crew time and accomplishing scientific and exploration objectives.
- These robots will be active in many phases of surface exploration: reconnaissance in advance of EVA traverses, EVA assistance, follow-up investigation or data gathering, and independent science and exploration traverses. Simulation of these various activities will help to refine the appropriate division between robotic and crew activities.
- Teleoperation is currently assumed to be an enhancing feature to speed up the activity of the robot, thus improving the effectiveness of both the crew and the robot. However, this conjecture needs to be tested through appropriate tests and simulations.

## Life Sciences Experiments Summary

The life sciences research activities to be conducted on the surface of Mars will be shaped by several complementary requirements:

- Support monitoring for medical assurance of crew member health and fitness for strenuous surface exploration activities.
- Reveal the effects of a novel gravitational environment on the major organ systems.

- Support planning for design of future missions and spacecraft, especially those with the capability for artificial gravity.
- Document the presence, currently or in the past, of Martian life forms, and to compare them to corresponding Earth forms for insights into the truly fundamental biological processes which may develop independently of planet of origin.

Research and development to ensure that these requirements are met will be required in the areas of:

- Identification of the critical questions to be answered in preparation for these expeditions.
- Minimally invasive, highly accurate physiological monitoring techniques.
- Development of appropriate biomarkers indicative of life on Mars.

## Crew Health/Medical Operations Summary

This section discusses the general approach planned for medical operations while on Mars. More specific discussions highlight the medical activities likely to occur both inside of the pressurized habitat and while the crew is away from the habitat, as well as crew training and areas of necessary technology development. Key points pertinent to developing an effective medical support infrastructure for future Mars surface crews include:

- Develop the medical knowledge and technologies needed to maintain human health and performance on the Martian surface.
- Develop systems and procedures to prevent, diagnose, and treat illness and injury on the Martian surface.
- Develop a group of physician astronauts with the appropriate clinical skills and training in space medicine to support a Martian surface mission.

## Wardroom and Food Preparation Summary

This section focuses on the proposed wardroom and galley area of a surface habitat and the activities that will take place there. Important items regarding the time and facilities necessary include:

- Adequate space and equipment in the wardroom for the whole crew to simultaneously perform various activities associated with eating, briefing, or entertainment.
- Temperature-controlled food storage and food heating units.
- Further research into developing foods or food storage systems to meet a 5+-year shelf life storage requirement.
- Better information regarding nutritional requirements for long-duration spaceflight.
- Cyclic menu planning involving both crew members and dietitians.
- Plans for a group dinner at least once a day.
- Short meal preparation and cleanup times.

## Personal Hygiene Summary

This section discusses crew members’ requirements for personal hygiene. Important issues regarding the time and facilities necessary include providing:

- Hygiene facilities to accommodate multiple personal hygiene activities.
- A full-body cleansing system.
- A clothes cleaning system to eliminate the need for disposable clothes.
- Personal hygiene kits.
- Standard personal hygiene times at the beginning and end of every day, after exercise periods, and before and after an EVA.

## Crew Quarters Summary

This section discusses functions and related equipment associated with crew quarters in a Mars surface habitat. Important items regarding the time and facilities available include:

- Providing a reconfigurable bed, noise reduction, and time cues to allow crew members to obtain satisfying sleep.
- Respecting signals from crew members regarding their need for privacy and personal time.
- Placing two crew members in one room with sides separated by a removable partition to allow for both private space and extra volume depending on the configuration.
- Providing storage space for personal belongings, a desk and workstation, and ample space for personal decorations within each crew chamber.
- Providing similar crew quarters for all crew members.

## Off-Duty and Recreation Summary

This section discusses the need for free time and entertainment activities on a long-duration mission. Important issues regarding the time and facilities available include providing:

- Equipment and facilities for both group and individual off-duty entertainment.
- Variety in all entertainment supplies.
- A small area to allow groups of two or three crew members to socialize privately.
- Personal workstations in crew quarters.
- Adequate communication time with friends and family back home.
- External viewing time to prevent eye problems and help maintain psychological stability.
- A regular yet loose schedule which balances work and off-duty time to keep crew members organized and on task.

## Exercise Summary

This section addresses the need for exercise on long-duration space missions, as well as the time and equipment required to accomplish it. Important items regarding the time and facilities necessary include:

- Conducting further research on the long-term effects of partial gravity and microgravity on the human body.
- Providing a variety of exercise equipment.
- Developing the entertainment side of exercise to encourage crew members to take advantage of available time and equipment.
- Providing a dedicated gym area with good circulation and removed from high traffic areas.

## General Housekeeping Summary

This section focuses on the need for general housekeeping and trash storage within a surface habitat. Important issues regarding the time and facilities necessary include:

- Further investigation of the effects and expected quantities of Mars dust inside the habitat.
- Further investigation of the time expected for these activities.
- Better estimations of trash volumes expected.
- Further investigation of eliminating the source(s) of trash, not just storage after it has been created.
- The inclusion of supplies to allow each crew member to clean his or her own personal areas, as well as share in the cleaning of public areas.

## Training Summary

This section focuses on training methods for a mission to Mars as well as several potential training subject areas. Important items regarding the time and facilities necessary include:

- Further investigation into preferred training techniques and easy ways to store associated materials within the habitat.
- The importance of providing training on both sociological and technical issues.
- Further investigation into the amount of time required during the flight for training to take place.

## Inspection, Maintenance, and Repair Summary

This section addresses the maintenance philosophies for repairs required in and around a Mars surface habitat. Important issues regarding the time and facilities necessary include:

- Further investigation into this topic as a whole.
- The inclusion of a dedicated shop area and portable workbench with proper restraints for equipment, spare parts, and tools.
- Better management of tools and spare parts to reduce expected mass and volume of these items.
- The development of equipment and systems that do not require constant human intervention or periodic part replacement and that are easier to interpret.
- Further investigation into the type of equipment and training necessary for fabrication of spare parts from raw materials.
- The acquisition of better mean time between failure data for actual hardware proposed for use.

## Preparation for Departure Summary

This section describes the activities the Mars surface crew performs when preparing to depart. Key activities include:

- Selecting, in collaboration with Earth-based colleagues, those samples and data that will be returned to Earth.
- Performing, in conjunction with Earth-based support teams, a thorough checkout of the ascent vehicle and the Earth return vehicle.
- Placing all surface systems in an appropriate mode of operation for when no surface crew is present.

## Conclusion

The information presented in all of these sections represents a “snapshot” of work completed through October 1998 and is intended to serve as design guidelines consistent with the Mars mission architectures. These guidelines are intended to be used in future concept definitions and trade studies. It is anticipated that as these studies are completed, appropriate functional requirements and system specifications will be developed and documented in future revisions of this or other reports. It is also anticipated that the lessons learned from these concept definitions and trade studies will be incorporated into future versions of this document.

****

# 1.0 INTRODUCTION

Throughout human history explorers have ventured into the unknown and challenged harsh environments. Columbus, Cook, Lewis and Clark, Nansen, Amundsen, and Scott are but a few of the more prominent members of this intrepid class of individuals. Many of these explorers spent months, if not years, actively and successfully investigating these regions without any contact with their home base or source of support.

Humans are poised once again for an era of exploration missions that rival these earlier journeys in terms of scope, duration, isolation from sources of supply and assistance, and potential for exciting new discoveries. Spaceflight opened a new realm of exploration for human crews with its first tentative steps in the early sixties. In the intervening years capabilities have been gradually built for a long-term, sustained presence in this realm. These capabilities are now reaching the level of sophistication and durability necessary for human crews to explore, first hand, the surfaces of the Moon, Mars, and many of the small bodies of the inner solar system.

The purpose of this document is to describe current expectations for the activities of human crews, and the associated support equipment that will occur as they explore the surface of Mars. Surface activities are defined as those crew activities that occur after landing and before departure for the return to Earth. Activities associated with launch from Earth, interplanetary travel, and landing or departing from a planetary surface are discussed in other documents. However, in addition to crew activities, this document will also describe the activities of automated systems that arrive before the crew and keep operating on the surface while no crew is present.

These descriptions are generally made at a functional level. Some descriptions, however, will be more detailed or explicit. In some cases, constraints—imposed by the laws of physics or choices made regarding the exploration scenario—require that activities be carried out in a certain way or equipment be designed in a certain fashion. In these cases, more detail is needed in the descriptions.

The approach of discussing activities at a functional level was chosen for two reasons. First, it creates a starting point for continued discussion regarding the activities and functions that are appropriate and necessary for these human exploration crews to carry out. Second, it allows functionally equivalent designs or technologies to be proposed as implementations for these activities and then evaluated to find a best overall implementation for the exploration mission.

## 1.1 Background

Almost from its inception NASA has sponsored numerous studies that examined various means of sending human explorers to Mars, with varying degrees of public interest and acceptance.* The most recent of these efforts began with the publication of an approach for exploring the Moon and Mars prepared by the Synthesis Group, led by former astronaut and Air Force General Thomas Stafford (Synthesis Group, 1991). Additional detail and interesting alternatives were investigated from 1992 through 1994 by personnel representing several NASA field centers (NASA, 1997). Work continues at several NASA field centers to improve mission approaches, including solar electric propulsion to high Earth orbit (e.g., NASA, 1998c). These studies have been undertaken in an effort to identify viable means to reduce risk, lower cost, and provide a better technical approach to the mission. Information related to these studies can be found at the following Internet site:

http://exploration.jsc.nasa.gov/EXPLORE/explore.htm

However, studies of surface activities and related systems have not always been carried out to the same breadth or depth as those focused on the space transportation and entry or ascent systems needed for a Mars mission. A subset of the Exploration team began to evaluate these issues and the technologies needed for surface operations during the 1992 - 1994 time period (Briggs and Lemke, 1993). A subsequent workshop was held in 1997 to address the types of activities expected to be associated with science and resource utilization as well as with facilities operations (Duke, 1997). Participants in this workshop identified a number of activities that were grouped into two broad

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* An annotated collection of abstracts for many of these studies can be found at the following Internet site: http://members.aol.com/dsfportree/explore.htm

categories: “science and resources” and “living and working on Mars.” A number of vignettes were assembled from these lists of activities. The work presented in this document builds upon these earlier efforts and expands the scope into new areas as mission goals and objectives are further refined, and as architecture studies clarify the scope of activities that can be attained during a surface mission.

## 1.2 Document Organization

The remainder of this section describes architecture-level information to set the stage for a series of surface mission vignettes. The first of these sections describes the overarching goals and objectives of the surface mission. The second discusses those aspects of the overall mission architecture pertinent to the surface mission, with the remainder of the document devoted to the series of vignettes describing key activities or functions that will make up the surface mission.

The information presented in all of these sections is intended to serve as design guidelines consistent with current Mars mission architecture studies. These guidelines are intended to be used in future concept definitions and trade studies. It is anticipated that as these studies are completed, appropriate functional requirements and system specifications will be developed and documented in future revisions of this or other reports.

## 1.3 Surface Mission Goals and Objectives

The human exploration of Mars will be based on two major goals:

- Explore Mars and learn how it is similar to and different from Earth. This includes investigations in a number of diverse scientific disciplines like: determining whether life ever existed (or still exists) on Mars and, if so, whether and how such life ever became extinct (because Mars is believed to have had characteristics consistent with the emergence of life, if no evidence of life is discovered, then the discovery of clues to its absence will also be important); determining if Mars is still geologically active and how it evolved to its present state; and determining the climatological history of the planet, including the fate of many of its volatile components like water.
- Determine the challenges that must be met for a self-sustaining human presence to exist on Mars. This will involve a variety of technologies and techniques that will be important for any long-term human presence. But some of the initial activities must assure there are no fundamental biological limitations to Martian habitability (e.g., reduced gravity, oxidizing soil, etc.) and must determine, through exploration and prospecting, the availability of surface and subsurface resources essential for a sustained or expanding human presence.

These goals will be accomplished through a combination of human and robotic missions, both of which are considered essential and complementary.

In the context of these goals, the principal role of humans in exploration is related to human characteristics that will allow higher fidelity exploration activities operating at much accelerated rates than if robots alone are sent. These human characteristics include observational skills, the manipulation skills needed to prepare and analyze samples in a Mars laboratory, the capability to interpret data and translate information and objectives into action. Humans also provide the capability to learn as they go, based on observations, analyses, and guidance received from colleagues on Earth.

However, not all activities envisioned for Mars surface exploration require the presence of humans and, in some cases, crew safety and forward- or back-contamination issues favor the use of robot explorers. Humans will be sent to Mars when the risk to crews is deemed acceptable, when it has been demonstrated that the surface materials they encounter will pose little or no risk, and when the expected scientific and exploration accomplishments of the mission are compelling. The data that will be used as the basis for making these determinations will be gathered by robotic explorers sent in advance of human crews.

By the time humans are sent to Mars, a rich history of data from robotic missions will exist. These missions will have explored the surface, transmitted large quantities of data about what they have found, and returned one or more samples of Mars regolith and rock materials for study on Earth. The detailed study of samples in Earth laboratories is considered essential for two important reasons: (1) to attain a more thorough scientific understanding of the geological, climatological and biological history of the samples, and (2) to ensure that there are no harmful or toxic effects of Martian materials on humans or to the Earth's biosphere. Although the possibility of biological activity in Martian *surface* material is believed to be very low, based on the results of the Viking missions, astronauts will inevitably come into secondary contact with the Martian surface. Under these circumstances, the means of breaking the chain of contamination on return to Earth would be exceedingly difficult to implement and certify. Back contamination protocols and strategies have not yet been developed or approved. However, it is likely that analysis of a *surface* sample and demonstration that it is sterile will be required for any site to which humans are sent.

But a negative answer on the existence of present or past life at a few locations on the Martian surface says nothing about what might be found in layers beneath the surface or at unique but sporadic locations on the surface. The search for past or extant life on Mars has been adopted as the principal objective of the robotic exploration program for the next decade. It is unlikely that the robotic missions will satisfactorily resolve the major issues in this search within a decade, so this objective is likely to carry over into the human mission phase of Mars exploration. If the results of the robotic missions are positive, the human missions will be charged with expanding and deepening our understanding. If the results of the robotic missions prove negative, it may be that human missions are required to definitively answer the important questions. In either case, much of the search for evidence of life will be addressed by geological studies aimed at understanding the environments in which life could have existed, in particular charting the history of liquid water on Mars. Therefore, understanding the geological and climatological history are inextricably intertwined with the study of possible life.

For these scientific goals and the questions they give rise to, there is a basic assumption that a human crew will provide unique enhancements towards their achievement. The following paragraphs illustrate, by means of a series of short vignettes, some of these enhancements.

### ***1. Perform field geology, field biology, and sample collection.***

Humans’ unique ability to make observations and synoptically integrate those observations is employed in the discipline called field work. Several professions employ the methods of field work, including geologists, biologists, and paleontologists. A combination of visual acuity and the ability to look at the surface from several perspectives allows humans to integrate observations made at different times and different angles and identify subtle differences between materials. These differences may be related to composition, texture, or structure. A field scientist is also able to determine when experiments, like deploying a field instrument, knocking a corner off of a rock, drilling a core, etc., are necessary to improve the ability to recognize rocks. Observations, experiments, and decisions are done rapidly. A conservative estimate for the time required for an astronaut on Mars to be able to identify and sample three rocks within a few meters of one another is 30 minutes, compared with several days for a robotic sample collection mission. Human explorers will also collect samples using tools, such as a hammer, coring tool, and rake, and will rapidly and accurately document the sample with respect to location, orientation, and relationship to bedrock and geologic structure. Finally, humans will use on-the-spot judgment to obtain images of the surface and the materials they sample to document the mission and communicate contextual information.

These activities, by analogy with terrestrial experience, will produce three dimensional reconstruction of the surface relationships, identification of principal rock types, and collection of representative rocks for later analysis. And since field explorers are continually searching for possible explanations for their observations, they can refine and focus their attention on the most critical observations.

### *2. Perform teleoperation of robotic sample collection systems such as rovers.*

Humans on Mars can operate remote systems that extend their field geology capabilities beyond a human's range. This can be done effectively because of the short delay times that can exist on the surface during human missions. While telerobotic systems can not replace the observational abilities of an astronaut in the field, such systems may be particularly effective at collecting samples under human supervision. These systems could be used to extend astronaut operating range, or could be used in advance of astronaut sorties to provide detailed information about a specific local area or rock type. They can be used to collect caches of samples previously collected and left by astronauts.

### *3. Conduct preliminary analysis of samples.*

An on-site laboratory on Mars can be used to confirm field identification of rock type, texture, major mineral phases, and presence of physical indicators for life (fossils, structures). As more rocks are studied, it will become easier for the crews to recognize rocks of the same type in the field. It will also accelerate understanding by allowing sample data to be folded back into exploration sorties. Equally important will be the use of this laboratory to study volatile or transient characteristics of samples which could not otherwise be contained for the journey back to Earth-based facilities (e.g., water in its various states or atmospheric samples).

The purpose of on-site analysis will be primarily to support the field investigations. But it will also be possible to help select the suite of samples to be returned at the end of the human mission, maximizing the possibility of new discoveries. For example, crews could select the widest range of rock types and relate these to the places they were collected. If large rocks were sampled in the field, the amount of material to be returned can be determined after analysis, leaving the remainder of the sample in a curatorial facility on Mars. A number of sophisticated analytical tools and instruments for microscopic, mineralogical, and chemical analysis can be compatible with a small laboratory. The skills of a human in sample selection and preparation are often key to obtaining the desired result.

### *4. Communicate findings to geology team on Earth.*

The astronauts on Mars will be in daily communication with the Earth, allowing a wide range of scientists (biologists, geologists, climatologists) on Earth to be intimately involved in planning exploration sorties. There will be a large amount of scientific information transmitted. The Earth-based scientists will have the opportunity to review and discuss the data being returned and can help in the construction of working hypotheses for the geological or biological problems being addressed (e.g. what is the geological environment in which lifeforms persisted?). Together, explorers on Mars and scientists on Earth will reevaluate exploration plans and strategies to more effectively pursue investigations and sample collection. They will reevaluate sampling priorities and identification of new objectives, and potentially plan revisits to previously sampled terrain or visits to new and different sites.

### *5. Deploy geophysical, meteorological, or other experiment packages.*

It is likely that instrument stations will be established to assess interior physical properties and monitor meteorological phenomena, such as dust storms. The crew may also conduct active geophysical investigations (seismic, radar sounding) to explore the local subsurface, particularly with respect to location of water to address scientific questions and potentiality for practical use. The deployment of these stations may benefit from the capabilities of crew members to manipulate instruments and supporting systems to improve their sensitivity and reliability. Straightforward calibrations of the instruments by the crew may be available.

### *6. Conduct and monitor special sampling, such as deep-drilling.*

Deep drilling will be used to access sites where liquid water is stable, to explore deep sections of sedimentary deposits, or to sample special features such as hydrothermal deposits. The characteristics of systems for deep subsurface sampling (>1000 meters) are likely to include substantial mass, mechanical complexity, and the need to operate over extended periods of time at power levels most compatible with human exploration.

***7. Conduct active experiments.***

Studies of the Martian environment and questions about the practical use of Mars by humans will naturally lead to active experiments in which Martian materials may be tested in new environments. For example, biological experiments associated with a biological regenerative life support system and experiments on the capability of Mars soil to support plant growth may be undertaken. Crew health and performance will be evaluated with respect to mission operations as well as the long-term needs for Mars habitation. Astronauts may also launch small airplanes, balloons, or sounding rockets to study the environment.

***8. Prepare samples for return to Earth.***

Subsamples may be prepared and packaged for return to Earth by the crews. Remainders will be left in a special area, protected from degradation, where rocks may be stored in case there is a future requirement to obtain additional samples. It is probable that some samples of the subsurface will have to be obtained under aseptic conditions (i.e., the Martian environment will be protected from human contamination, and the humans are protected against the possibility of infectious Martian agents). Analysis conducted on Mars may be sufficient to demonstrate subsurface samples to be harmless. If that is not possible, however, samples from these environments will be packaged on Mars to prevent them from contaminating the space habitats or crews and to protect them from inadvertent release to the Earth's biosphere—a process that could require complex crew activities.

While these descriptions illustrate a few of the activities likely to be carried out by a Mars surface crew, others will be identified or may be added as data from robotic missions improves our knowledge of the surface.

The decision on where best to establish a human outpost on Mars to address these primary goals will include considerations of crew safety, scientific potential, spectacular scenery (for public relations purposes), and access to resources. A focused program of site selection for human landing sites has yet to be developed. This program should include identification of promising areas, based on results from robotic missions and Earth-based simulations of the surface exploration capabilities to determine whether the capabilities of the human missions are consistent with advancing scientific knowledge of the area chosen. These simulations will include evaluation of the accessibility of key features in the vicinity of the outpost site to astronauts on foot and in vehicles, evaluation of the degree to which resources can be accessed, and the capabilities of field and laboratory systems to obtain data in the context of available crew time. It is appropriate to begin the site selection process now in order to make optimum use of the capabilities of the robotic missions.

## 1.4 Mars Mission Overview

This section will discuss aspects of the entire mission architecture that provides the framework for the surface mission and influences both what activities can be done or how activities are done. These topics include:

- The choice of the outbound and return trajectory and the implication this has on the crew’s time on the surface.
- A split-mission strategy that deploys some of the mission assets at Mars before the launch of the crew.
- Science instruments and equipment the crew will use.
- Infrastructure assets available to the crew while on the surface.
- Assumptions regarding the crew complement.

### *1.4.1 Trajectory Selection and Surface Stay Time*

Numerous trajectory options exist for moving people and equipment between the Earth and Mars (see, for example, Niehoff and Hoffman, 1996), each with certain benefits and detriments. Recent Mars mission studies have tended to emphasize several considerations when choosing from among these options, chief among these being:

- Reducing the amount of propellant needed to move hardware and people from one planet to another (propellant mass typically being the single largest element of these missions), and thus reducing the ETO launch requirement.
- Extending the amount of time the crew spends conducting useful investigations on the surface of Mars.

These considerations have resulted in a focus on trajectories with relatively short interplanetary transit times and relatively long stay times at Mars. The implication this has for the surface mission is that each crew can spend as much as 500 to 600 days exploring the surface of Mars before returning to Earth. Table 1.4-1 illustrates specific dates and net amounts of time spent on the surface by three crews, assuming this endeavor is started at a time that allows the first crews to be sent to Mars early in the second decade of the next century. It should be noted that the time it takes for Mars to rotate on its axis is 24 hours and 36 minutes long. This period of time, referred to as a “sol” to distinguish it from an Earth “day,” will be the standard workday for the crew. Table 1.4-1 also indicates how many of these workdays each crew will have on the surface.

**Table 1.4-1 Arrival Dates, Departure Dates, and Net Amount of Time on the Surface for Possible Surface Missions***

| Crew | Arrival at Mars | Departure from Mars | Earth Days on Mars | Earth Months on Mars | Mars Sols on Mars |
|---|---|---|---|---|---|
| 1 | 7/22/14 | 1/10/16 | 537 | 17.9 | 523.9 |
| 2 | 8/23/16 | 3/27/18 | 581 | 19.4 | 566.8 |
| 3 | 11/17/18 | 6/14/20 | 575 | 19.2 | 561.0 |

* (NASA, 1998c)

### *1.4.2 Split-Mission Strategy*

This deployment strategy for Mars missions has received a significant amount of study. This strategy breaks mission elements into pieces that can be launched directly from Earth using reasonable extrapolations of current launch vehicles. Another attribute of this split-mission approach is that it allows the option of sending cargo to Mars without a crew, using the same launch opportunity or even one or more opportunities before the crew's departure. This creates a situation where cargo can be transferred on low energy, longer transit time trajectories, while the crew can be sent on a higher energy, shorter transit time trajectory. Breaking the mission into two launch windows allows much of the infrastructure to be in place and checked out before committing crews to their mission. It also allows for a robust capability, with duplicate launches on subsequent missions providing backup for the earlier launches, or growth of initial capability (Figure 1.4-1).

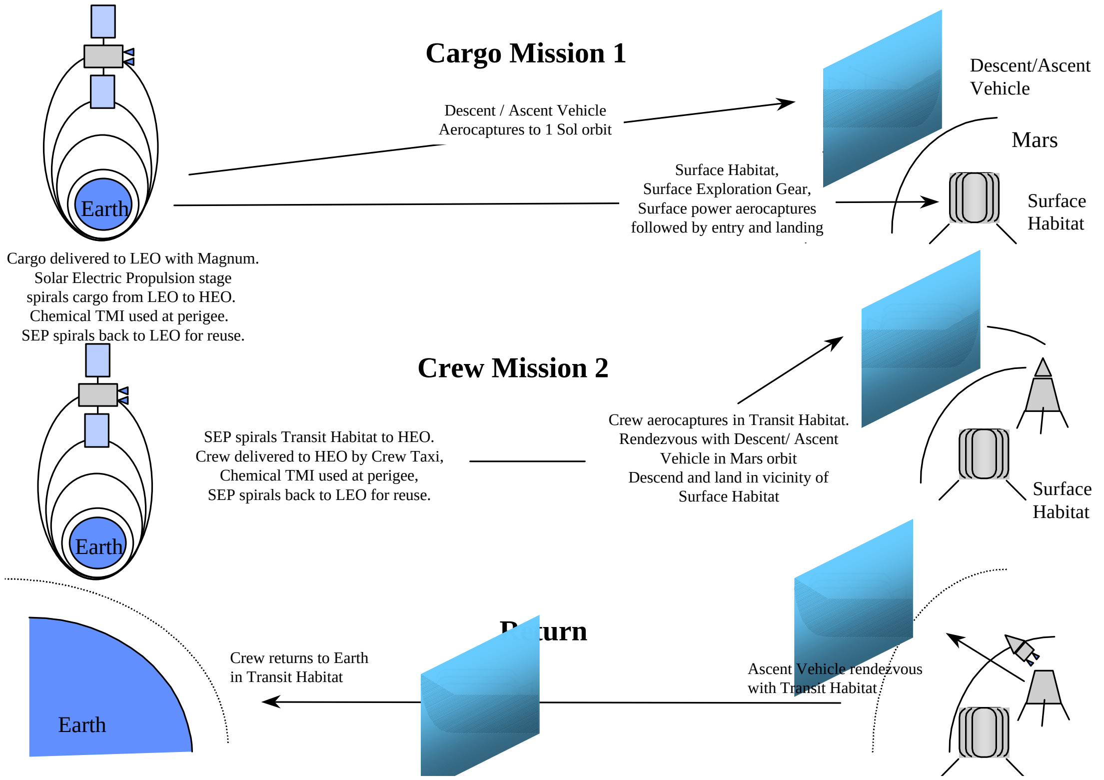

Figure 1.4-1 This figure illustrates how a split-mission strategy can be used to divide major elements needed for a Mars mission into independent segments. With such a strategy, all elements could be deployed during a single opportunity (i.e., Opportunity 1 is the same as Opportunity 2) or some element could be deployed before sending the crew to Mars (i.e., Opportunity 1 occurs 26 months before Opportunity 2). Such a strategy can be used to provide operational flexibility while keeping any one payload small enough to be launched by reasonable extrapolations of current launch vehicles.

### *1.4.3 Science Instruments and Surface Equipment*

The primary technical objective for crews on Mars will be to carry out scientific and exploration investigations. A number of study groups examined these investigations in sufficient detail to prepare a manifest of the tools and equipment that will be needed by the crews to complete these objectives (NASA, 1997 and NASA, 1998c). The manifest of tools and equipment that will be used by the first of several crews is listed in Table 1.4-2. Cruise science includes those investigations carried out by the crew while in transit both to and from Mars and from orbiting vehicle(s) while the crew is on the surface. The surface science instruments are typically carried on a cargo vehicle and are intended to be used exclusively on the surface.

**Table 1.4-2. Science Equipment Manifested on the First Cargo Flight and the First Habitat Flight***

| | |
|---|---|
| **Cruise Science Equipment** | |
| Particles and Fields Science | 100 kg |
| Astronomy Instruments | 200 kg |
| Small Solar Telescope | 100 kg |
| Biomedical Instruments | 200 kg |
| Total | 600 kg |
| **Surface Science Equipment** | |
| Field Geology Package | 300 kg |
| Geoscience Laboratory Equipment | 110 kg |
| Exobiology Laboratory | 50 kg |
| Traverse Geophysical Instruments | 275 kg |
| Geophysical/Meteorological Packages | 75 kg |
| 10 Meter Drill | 260 kg |
| Meteorological Balloons | 200 kg |
| Biomedical/Bioscience Laboratory | 500 kg |
| Discretionary Science | TBD kg |
| Total | 1770 kg |

* mass estimate derived from Budden, 1994

Subsequent cargo and piloted flights in a Mars exploration architecture carry similar science payloads with similar mass values. The cargo flights will also carry other surface systems to be used in a variety of activities by the crew. Teleoperated rovers, small unpressurized rovers, and larger pressurized rovers that will arrive incrementally over the course of the launch opportunities will be used to support the crew in exploration activities away from the outpost site and in routine tasks at the outpost. Larger and more complex science payloads will also be delivered on later flights. As an example, the 10-meter drill cited above is planned to be augmented with a device that can drill to depths of approximately one to three kilometers, sufficient to reach potential sources of liquid water (Clifford, 2000). For each of these devices, as well as for other surface infrastructure elements, replacement parts and additional spare parts will be manifested as needed on each cargo and piloted flight. All of these examples of science instruments and exploration support systems are a reflection of the general philosophy of incrementally expanding, with each succeeding crew and cargo flight, the scope and scale of the activities carried out at a surface site.

### *1.4.4 Surface Infrastructure*

In addition to dedicated surface exploration equipment, elements of the surface infrastructure that are on the surface primarily for other reasons will be available for crew use. Examples of these infrastructure elements include in situ resource utilization (ISRU) plants, a surface power system, and communication and navigation systems.

A current area of significant study for Mars missions is the capability to make useful products (oxygen, water, propellants) from local resources, typically referred to as ISRU. Nominally, these products are used to augment the mission (e.g., reduce mass by producing breathing oxygen) or to reduce risk (e.g., provide redundancy and alternate functional paths, caches of consumables, etc.).

Another significant element of the surface infrastructure will be a power system and the associated thermal control system. Two options for this system are currently under study: a solar array/fuel cell combination and a nuclear system. The size of each of either of these systems will be driven by not only the direct usage requirements of the crew (e.g., life support systems, habitat lighting and heating) but also the final complement of other surface infrastructure elements. A significant user of power could be the ISRU plant if it is used to generate not only breathing gases and water, but also propellants for surface transportation systems or crew ascent vehicles. Both of these systems will require a nontrivial deployment procedure as well as maintenance concept to ensure that power is provided on a reliable basis for the crew.

Finally, a significant communication stream will connect the Earth and Mars while a crew is on the surface. Because of the relatively close horizon on Mars, an over-the-horizon communication system connecting the main surface habitat and EVA crews will be needed. And because real-time communication between Earth and Mars will not be feasible, this system may not be continuously pointed at Earth or operating at the high power level likely to be used for communication with Earth. This opens the possibility for these communication resources to be used to move larger amounts of data between different points on Mars, be they EVA crews or teleoperated rovers. During those periods when a crew is not present on the surface, this communication system could also be used to support more significant interaction between robotic rovers on Mars and operators on Earth, allowing continuous exploration of the surface site.

### *1.4.5 Crew Complement*

Past studies examined the size and make-up of the crew needed to meet both operational needs and mission objectives (Briggs and Lemke, 1993). The results of these studies arrived at the following general conclusions:

- Skill mix requirements indicate the need for a crew of at least five.
- Peak workload indicates the need for a crew of six (three at the base and three in the field).
- A requirement for margin suggests the need for a crew of seven or eight.

While no conclusion has been reached regarding the required number of crew members, recent studies have tended to assume a crew of six. Specifically, a crew of four is considered “operationally sufficient” (Griffith, 1999), meaning that all skill areas can be covered by four appropriately selected individuals. However, this same study acknowledges that there are operational situations, such as a statistical probability of illness or injury or concurrent EVAs for local and remote tasks, which will require more than four people to accomplish. No specific set of crew skills has been officially established. However, the following are representative skills for which there will be a crew member assigned as primarily responsible and other crew members will be trained to back up the primary crew member:

- Command
- Medical sciences and practice
- Geological sciences
- Biological sciences
- Mechanical systems operations
- Electrical/electronic systems operations

## 1.5 Summary

The mission architecture ultimately chosen for Mars exploration will impact the surface exploration mission. It will affect it directly in terms of the scope and scale of activities that can be supported, and indirectly in terms of the secondary use of resources at the landing site. The vignettes described in the following section have sought to identify these impacts and the possible resulting response(s).

## 1.6 References

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## 2.0 SURFACE MISSION ACTIVITIES

This section describes key activities or functions that will be part of the Mars surface mission. These activities include:

- Robotic/Autonomous Deployment
- Initial Surface Operations
- Exploration Field Work
- Surface Transportation
- Field Camp
- Toxin and Biohazard Assessment
- Sample Curation
- Sample Analysis
- Teleoperation of Robotic Vehicles in Support of Science and Exploration
- Life Sciences Experiments
- Crew Health/Medical Operations: Routine and Emergency
- Wardroom and Food Preparation
- Personal Hygiene
- Crew Quarters
- Off-Duty and Recreation
- Exercise
- General Housekeeping
- Training
- Inspection, Maintenance, and Repair
- Preparation for Departure

Each of these vignettes follows (approximately) the following outline:

I. A description of what mission need (s) is (are) being fulfilled or what mission objective (s) is (are) being satisfied.

II. A discussion of the importance of satisfying this need or objective.

III. A description of the functions to be carried out.

IV. A description of how the capability will be used in an operational sense.

V. A summary of system functionality and identification of research and development areas that need work.

References are listed at the end of each vignette. These references have also been consolidated for user convenience in a Reference section at the end of this document.

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## 2.1 Autonomous Deployment of Surface System Elements

One option of the split-mission strategy is the deployment of significant portions of surface infrastructure before the human crew arrives. This strategy also implies that technology will exist so that portions of these infrastructure elements can be unloaded, moved significant distances, connected to each other, and operated for significant periods of time without humans present. In fact the successful completion of these various activities will be part of the decision criteria for launch of the first crew from Earth.

The mission architecture described in Section 1.4 assumes that two vehicles, an ascent vehicle and a surface habitat, will be launched and sent to Mars independently of the crew (NASA, 1997). Each of the vehicles will arrive with its own descent/landing stage to place them at the desired surface site. Delivered to the surface with these vehicles are the following surface systems:

- An ascent vehicle that the crew will use to reach the Earth Return Vehicle.
- An ISRU plant that will, at a minimum, make breathing gases and water for use by the crew. This same processing technology could also be used to make propellants for use by surface transportation vehicles or by the ascent vehicle. In either of the latter two cases, there is a potential savings in launch mass at Earth by making these propellants on Mars as opposed to bringing them from Earth.
- A power plant to provide the energy needed to operate other surface systems.
- A thermal control system to support the heat-rejection needs of various surface systems.
- Other supporting infrastructure that is either needed to support the landing of the crew or that is not needed until after the crew reaches the surface.

The mission architecture described in Section 1.4 also assumes that these systems will be autonomously deployed and operated in roughly the following scenario:

> After landing, a power plant will be unloaded, moved to its operating site, and made operational. The power plant is connected to a power distribution system that will deliver power to an ISRU plant (if used), the habitat, and any other surface system requiring electrical power. A thermal control system is also deployed. This system is separate from the power plant, with the primary responsibility of supporting the other systems needing a means of rejecting waste heat; a decision has not been made regarding this requirement. The ISRU plant is then placed into operation and begins producing commodities for use by the crew. All of these systems must operate successfully for approximately two years, with maintenance and repair accomplished remotely as necessary.
>
> At some time before the launch of the first crew, at least two other surface infrastructure elements will be autonomously deployed: a navigation system to guide the descent vehicle carrying the first human crew to an appropriate location on the surface relative to the other deployed surface elements, and a high-volume communication system. Failure of either of these systems to be deployed or to be operational before the launch of the crew will be an element in the decision process for the launch of this crew, but by themselves are not considered to be of the same level of importance as the power plant, ISRU plant, and the thermal control system.

The successful deployment and operation, including maintenance and repair, of these systems places a significant burden on autonomous or supervised systems that will accompany the first cargo mission. The design of these various surface systems and the robots that will support deployment, operation, maintenance, and repair must proceed concurrently and should allow for the eventual interaction by EVA crew members.

The following sections discuss additional details regarding the deployment and operation of these systems before the arrival of the first crew. Each of these sections assumes that robotic systems will be carrying out the activities described either in an autonomous mode or under the supervision of support teams on Earth.

### *2.1.1 Power*

As briefly mentioned above, the mission architecture described in Section 1.4 assumes that one of two options will be used to provide power for surface infrastructure: a solar array/fuel cell system or a nuclear system. In either case, a certain amount of autonomous or supervised activity will be required to deploy these systems and place them into operation.

For the solar array option, the deployment is likely to occur in two phases. In the first phase, which will occur shortly after landing, a portion of the complete system—solar arrays and thermal radiators—will be deployed by automated/robotic systems. The exact amount of the total system that will be deployed will be determined by the amount of power needed to keep the crew and critical systems at a minimal operational level. Once the crew is able to conduct EVA activities, the remainder of the system will be deployed either using the same automated devices or by an EVA crew.

Studies carried out to estimate the total amount of power that must be delivered by this solar array system, particularly in an off-nominal situation (e.g., dust storms), indicate that a large surface area will be needed, potentially covering thousands of square meters. The selected landing site cannot be guaranteed to satisfy all of the deployment constraints needed by this system (these constraints vary depending on the specific type of solar collection system, deployment procedure, and final configuration selected). This implies that a robot should also be prepared to do some amount of site preparation. This could include clearing debris or leveling surfaces.

If the nuclear power plant option is selected, it is assumed that the power plant must be unloaded and moved approximately one kilometer away from both the lander that delivered it and from the eventual landing site of the human crew. The separation distance requirement results from the need to minimize the radiation exposure to the crew and other vulnerable systems. In addition to the distance requirement, it also may be necessary to place additional shielding material between the reactor and the crew. This will depend on the reactor design and site-specific conditions. If needed, this material could come from naturally occurring terrain such as low hills or ridges, or the siting of the reactor in the bottom of a small crater. If this additional shielding cannot be provided naturally, then it must be provided by another means. As an example, a robotic vehicle could be used to dig a small hole or build small berms or both, in order to create a shield between the reactor and the crew.

With this requirement in mind, a number of events must occur prior to the reactor’s deployment. First, a robotic vehicle will be needed to locate the most suitable site within the distance and siting constraints of the reactor. This site cannot be guaranteed to meet all of the previously stated constraints, particularly the shielding requirement, implying that a robot must also be prepared to do some amount of site preparation. This could include clearing debris, leveling a surface, digging a depression, or constructing berms.

Once a suitable site has been located and prepared, the reactor will be off-loaded from its lander and moved to the site. The reactor will then be placed in its operating position and any necessary appendages (e.g., thermal radiators) will be deployed.

Once in operation the reactor may need periodic inspection, maintenance, or repair. These tasks could be scheduled or unscheduled and will be highly dependent on the reactor design. Components known to require some sort of inspection, maintenance, or replacement (or those components for which a random failure could disable the reactor), such as valves, pumps, or control electronics, should be designed for easy accessibility and robotic compatibility. It is assumed that these inspection, maintenance, or repair activities will be accomplished through automated or teleoperated robotic devices. Because of the radiation environment involved and the type of tasks to be accomplished, it may be necessary to dedicate one robotic vehicle to operations within close proximity of the active reactor, especially as a contingency against an extensive, high-radiation-exposure repair.

The final activity associated with the power system (this applies to either the solar or nuclear option) prior to its activation is the deployment of a power transmission and distribution system. This will be a system of power cables of appropriate capacity for the distributed users of electrical power on the surface. Such a cable will connect the power system to the ISRU plant (potentially the largest single user if large-scale commodities production is planned), to the surface habitat, and to the ascent vehicle. Finally, a secondary distribution handling system will be used to meet the needs of other surface systems. Little specificity was made regarding this distribution system in recent studies (NASA, 1997 and NASA, 1998) and additional study is needed to refine the concept.

### *2.1.2 ISRU and Thermal Control*

No requirement has been identified in recent studies (NASA, 1997 and NASA, 1998c) for the ISRU plant or the thermal control system to be located away from the cargo lander in order for them to carry out their function. However, their key role in the launch decision process for the first crew implies that these systems must be accessible for inspection, maintenance, and repair by robotic systems. These robots will operate in both automated and teleoperated modes, depending on the activity they are performing.

### *2.1.3 Summary*

This section has discussed a number of activities, each key to the success of the split mission strategy, that occur before the arrival of the first human crew on Mars.

- Several surface systems may be deployed and operated for significant periods of time before the crew arrive. These include the power plant, the ISRU plant, and associated systems (e.g., a thermal control system).
- A high degree of automation is associated with these activities, including selection and preparation of surface sites, deployment of potentially large and complex systems, inspection of these systems as they are operated, and performance of routine maintenance and repair as required.

A significant amount of technology development and demonstration will be required in several areas of automated systems if the strategy described in this section and Section 1.2 is to be successful.

### *2.1.4 References*

NASA (1997) Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, NASA SP-6107, NASA Lyndon B. Johnson Space Center, Houston, TX.

NASA (1998c) Reference Mission Version 3.0; Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Team, SP-6107-ADD (also EX13-98-036), NASA Lyndon B. Johnson Space Center, Houston, TX.

Smith, T.H. (1998) “An Operational Evaluation of the Mars Reference Mission,” paper written with the personnel of the Exploration Office, NASA Lyndon B. Johnson Space Center, Houston, TX, April 1998.

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## 2.2 Initial Surface Operations

During the period of time immediately following a successful landing on the Mars surface, several key events must occur to allow the crew to transition from an in-space mode to a ground safe mode and finally to a ground operational mode. Interspersed with these key events will be a number of other non-time-critical activities that the crew must perform before normal operations can occur. This section discusses these various events and their implication for crew operations and safety.

### *2.2.1 Initial Priority Events*

The very first event that will occur after touchdown is to safe the landing vehicle. This will include purging the engines, shutting down the landing systems, and securing the various other systems involved with flight. This process will be carried out by automated systems on the vehicle with status information displayed to the crew and sent to Earth-based support teams. The Mars surface crew will have an override/manual backup capability for this safing process that may be used in contingency situations. Direct crew involvement in activities other than contingency situations is not anticipated due to the uncertain nature of their functional capabilities after the flight to Mars in microgravity conditions.

Figure 2.2-1 The transit habitat vehicle with the first human crew descending on parachutes before using terminal descent propulsion. This vehicle will land in the near vicinity of the previously deployed surface assets—the ascent vehicle, the ISRU plant, the power plant, and other surface equipment not needed by the crew during the outbound journey.

Determining the crew’s physical condition will be the next activity once the vehicle has been placed in a safe mode. Observations of astronauts returning from Shuttle flights and long-duration *Mir* stays indicate that they will initially have limited capabilities during the first few days to weeks on Mars (Stegemoeller, 1998). Their ability to take on a variety of tasks will gradually increase as they readapt to a gravity field. Crew adaptation time from a microgravity to a 0.38-g environment is currently uncertain, although it can be expected to vary from individual to individual. “Observations on Shuttle crew members indicate that postflight recovery takes about the same length of time as the flight duration, at least for flights of about two weeks. Long-duration *Mir* crew members undergo rehabilitation (including prescribed exercise and physical therapy) for at least one to two months postflight before they are released to continue readaptation to Earth’s gravity during their regular routine,” (Stegemoeller, 1998). Additional research will be needed in this area to understand and mitigate the effects of extended flight in a microgravity environment. However, not all effects are expected to be mitigated during the first few hours or days after landing. This implies a high degree of automation will be necessary for nominal activities during at least the first several days, or possibly longer, to carry out necessary functions while the crew adapts to the Martian gravity field.

Because the landing vehicle will be operating on internal power (i.e., batteries or fuel cells) during entry and landing, the next major event will be to connect the habitat to an external source of power. Nominally, the habitat will be autonomously connected as soon as possible to the surface power and thermal control systems. Again, status information during this process will be displayed to the crew and sent to Earth-based support teams. The interplanetary transfer vehicle internal power supply will be sized to provide minimal power for vehicle systems and crew needs for several days after landing. The crew will also have override control of the robotic vehicles that will be used to connect power and thermal control should that contingency be necessary.

Finally, the habitat will be connected to the previously deployed high-data-rate communication system. The connection could be a cable or could be wireless. This action will expand the volume of data that the crew can send to and receive from Earth. Again, this connection process will be automated with status information displayed to the crew and sent to Earth-based support teams.

Once these activities have been completed, the crew can assess the status of the habitat and supporting systems. If all of these systems are operating normally, the crew can consider itself "ground safe"—capable of surviving on the surface in this condition for a long period of time given no failures.

### *2.2.2 Later Priority Events*

The crew's adaptation to the Martian gravity environment will continue to be monitored and measured by the crew itself and by support teams on Earth. Despite any previous research on this subject, these crew members will represent the first humans in the Martian environment and their reaction to it will provide important data for the life sciences community and for subsequent crews.

If the biological-based life support system has been shut down for the entry and landing event (due to the current lack of maturity of this technology, the necessity for this has not yet been determined), the crew will initiate the start-up process to restore this capability. After this system is verified to be functioning properly, the open-loop life support system will be placed in a standby mode, available to take over from the biological life support system if necessary.

### *2.2.3 Subsequent Events*

The crew and support teams on Earth will continue to monitor and measure its adaptation to the Martian gravity environment. As they are able, the crew members will begin performing activities around the interior of the habitat, including deployment and activation of experiments and other equipment stowed for the outbound journey or teleoperation of the small rovers to begin a reconnaissance of the area. When their physical condition permits, the crew will also begin EVA activities such as unloading cargo. One of the first EVA activities will be to unload an inflatable habitat module and attach it to the landed interplanetary transfer vehicle, significantly enlarging the pressurized volume available to the crew (NASA, 1998c).

Once the various outpost systems have been deployed and placed into normal operation, the crew can consider itself "ground operational" and can proceed with exploration activities at and around the outpost.

### *2.2.4 Summary*

This section has discussed the sequence of activities the crew will perform during the first several days on the surface of Mars. These activities are focused on reaching a "ground operational" state which allows extensive exploration activities to commence. Key points made in this section include:

- The crew habitat must be connected to surface power, thermal control, high-volume communication, and the ISRU-produced life support system cache within the first several days (typically on the first day) after landing.
- Extended exposure to a zero-gravity environment has caused deconditioning of the human body. Depending on the extent of their exposure to this environment on the outbound portion of this mission, the crew should not be expected to be available for critical tasks during the first several days after landing due to the need for adaptation to a Mars gravity environment. Research directed at understanding this adaptation process as well as ways and means to mitigate the negative effects is needed.
- Most, if not all, of the tasks that occur during the first several days may be automated because of the crew's physical condition and the restrictions this places on the tasks that can be performed.

### *2.2.5 References*

NASA (1998c) Reference Mission Version 3.0; Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Team, SP-6107-ADD (also EX13-98-036), NASA Lyndon B. Johnson Space Center, Houston, TX.

Stegemoeller, C. (1998) “Life Sciences Response to Human Mars Mission Scenarios,” Internal Memo, SA-98-039, NASA Lyndon B. Johnson Space Center, Houston, TX, February 9, 1998.

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## 2.3 Exploration Field Work

A key objective of the Mars surface mission is to get crew members into the field where they can interact as directly as possible with the planet they have come to explore. This section will discuss one of the means by which this will be accomplished, the use of EVAs to carry out field work in the vicinity of the outpost.

### *2.3.1 Field Exploration Campaign Process*

Although the list of these field exploration activities will undoubtedly grow as specific objectives are chosen and the means to accomplish them are defined, two examples serve to illustrate the range of these activities: field geology and/or mapping and intensive field work at a specific site. The following paragraphs describe some of the key characteristics of each of these activities, as they apply to EVA.

The activities of a field geologist on the surface of Mars will differ greatly from EVA activities of the Space Shuttle and International Space Station (ISS) eras. These differences will impact both the design and use of EVA systems for surface activities. Some of these activities and the impacts that will result include the following (Eppler, 1997):

> "Geologic field work involves collecting data about the spatial distribution of rock units and structures in order to develop an understanding of the geologic history and distribution of rock units in a particular region."
>
> "It is an oft-stated but correct maxim that the best field mappers are the ones who have seen the most rocks. Geologic field work on the planets, if it is to be worth the significant cost needed to get the geologists there, will require both EVA suits that will allow EVA crew to walk comfortably for hours at a time, and rovers that will allow the crew to see as much terrain as possible."
>
> "One distinction that needs to be emphasized is the difference between field mapping and pure sampling. A popular misconception is that geologists conduct field work purely for the purposes of sampling rock units. Sampling *is* an important part of field mapping, but sampling in the absence of the spatial information that field mapping provides leads to, at best, a limited understanding of the geology of a particular area. Having said that, the nature of the rock exposure in a given area can limit the amount of field mapping that can be done, and *can* drive field work efforts to conducting a sampling program that, with some ingenuity, can provide the basics for understanding the broad geologic context of a particular locality."

With this background, a typical field exploration campaign will begin with one or more questions regarding the geology in a particular region and the identification of specific surface features, based on maps and overhead photos, that offer the potential for answering these questions. Traverses are planned to visit these sites, typically grouping these sites together (into multiple traverses if necessary) to meet the limitation of the equipment or environment (e.g., EVA suit duration limits, rover unrefueled range, crew constraints, local sunset, etc.). Depending on the anticipated difficulty of the planned traverse, the crew may choose to send a teleoperated robot to scout the route, sending back imagery or other data for the crew to consider. (Note: these robot scouts are probably surface rovers, specifically the teleoperated rovers mentioned elsewhere in this document, but small aerial vehicles should not be discounted as options for this activity.) In addition, crew safety concerns when entering a region highly dissimilar from any explored before or an area with a high potential for biological activity may dictate the use of a rover in advance of the crew (see Section 2.9). The EVA crew walks, or rides if rovers are planned for the traverse, toward the first of these planned sites using visible landmarks and cues available through the surface navigation system. The crew stops at this site to make observations, record data (e.g., verbal notes to be transcribed later, imagery, sensor readings from those instruments brought on the traverse, etc.), and gather samples as appropriate. If a return visit to this site is deemed necessary to gather additional data or samples, then the position is marked with a small flag or other visible marker or as a "way point" for future use within the navigation system used for surface traverses. The crew then proceeds to the next site in the plan until all sites have been visited or until they are required to return to the outpost. At any point in the traverse it may be desirable to stop at unplanned locations due to interesting features that may not have been recognized as such during planning. Real-time voice and data, along with some amount of video, are sent back to the outpost to those crew members monitoring the progress of the traverse. On returning to the outpost, the EVA crew will ensure that all curation procedures are carried out and that information gathered in the field is transcribed or otherwise stored in the outpost data system. (Sample curation and sample analysis are described in later sections.)

Intensive field work at a single site may involve one of several activities associated with science payloads carried in the design reference mission manifest or comparable activities which may be part of the unspecified "discretionary principal investigator" science. Two specific examples for which there are manifested payloads include the setup of geophysical/meteorological stations and the 10-meter drill. (More recent studies indicate that drilling to several hundred meters may be possible for a comparable mass allocation.)

Figure 2.3-1 An EVA crew member examines a rock sample gathered from the base of a vertical wall. The crew will use unpressurized rovers, such as the one seen in the background, to gain access to sites such as these that will likely be beyond walking distance from the landing site.

Expanding on the case of the 10-meter drill to illustrate this type of activity, there will be several key scientific and operational questions requiring subsurface samples acquired by this tool. Examples include searching for subsurface water or ice, obtaining a stratigraphic record of sediments or layered rocks, or obtaining samples to be used for a search for evidence of past or extant (possibly endolithic) life.* A traverse of the type discussed above will probably have been carried out to examine candidate sites for the drill, with the acceptable sites being placed in a priority order. Drill equipment will be moved to the site, most likely on a trailer pulled by either the unpressurized or robotic rovers, and set up for operations. The setup process will likely be automated but with the potential for crew intervention. Drilling operations are also likely to be automated but under close supervision. (At present, drilling is still something of an art, requiring an understanding of both the nature of the material being drilled through—or at least a best guess of the nature of that material—and of the equipment being used. While drilling is a candidate for a high level of automation, it is likely that human supervision for purposes of "fine-tuning" the operations and intervening to stop drilling, will remain a hallmark of this activity.) Core samples will be retrieved by the crew and put through an appropriate curation process before eventual analysis. After concluding drilling at a

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*Endolithic – living within or penetrating into stony substances (as rocks, coral, or mollusk shells) particular site, the drill equipment will be disassembled and moved to the next site, where this procedure will be repeated.

Because of the nature of the drilling process, there is a high probability that the above-surface equipment will fail or the below-surface equipment will break or seize. Crew intervention is highly likely in either event. In the first case, the crew must decide if the failure can be fixed in the field or if the equipment must be returned to the outpost for repair. Either option will involve some amount of equipment disassembly. If the subsurface equipment fails, the crew must decide how much of this equipment can be retrieved with the tools it has available and whether it is worth the effort and resources to make this retrieval. Due to cargo mass constraints, the drill will not have an unlimited supply of drill bits, auger bits, or drill stem. This makes it worthwhile to expend some effort to retrieve as much of the salvageable subsurface equipment as possible and attempt a repair—the alternative being to halt drilling operations until adequate replacements arrive, probably with the cargo flights supporting the next crew.

The two key characteristics that should be noted here are that drilling activities, and by inference other intensive field work, will involve repeated trips to a single location (or the use of a remote field camp; see Section 2.5) and an extensive interaction with tools and equipment at these sites.

### *2.3.2 EVA Design and Operational Guidelines*

As a practical matter, the examples described above, and other EVA tasks that are identified as the surface mission matures, will be translated into more specific design assumptions and operational guidelines. These will in turn lead to specific requirements and flight rules. Based on past experience, plans for the ISS, and current knowledge of the Mars surface mission, this transformation process has already begun (Griffith, 1998). While these discussions are ongoing and will be subject to change as systems and operations mature, the following list indicates some of the assumptions being proposed for Mars EVA activities:

- The buddy system of paired EVA crew members will always be used.
- Standard EVA protocols such as gloved hand access, no sharp edges, touch temperatures within supported limits, and simplified tool interfaces must be applied to every element expected to be handled or encountered by suited crews.
- A safe haven must be readily available at all ranges beyond walkback distance. (See NASA, 1998b, for additional discussion of safe haven requirements.)
- Seasonal effects, such as number of daylight hours, dust storms, and possibly radiation events, will be taken into account during planning, timing, and support of EVAs.
- Planned EVA contingency support will account for sickness, injury, and potential incapacitation of an EVA crew member in addition to suit and equipment problems.
- Time delays between Earth and Mars require that the habitat crew provides primary support for the EVA crew. Earth-based personnel may participate, but as backup. Both cases require real-time voice, video, and data between the EVA crew and the habitat support personnel. Loss of these links may, depending on distance, terminate the current EVA.
- Nominally only one pair of crew will be allowed outside the habitat or a pressurized rover at a time. It may be possible to have two pair outside in extreme cases, but only for local maintenance/support or one pair rescuing the other.
- EVA during nighttime will be trained for and possible, but not nominally planned, and will be constrained to a local area (i.e., in the vicinity of the habitat or a pressurized rover).
- The EVA suits will have minimal prebreathe and require minimal turnaround maintenance between uses.

### 2.3.3 *Summary*

To summarize, examples described in this section point out several guidelines for surface operations and for development of surface EVA suits and the equipment used by the crews while in these suits:

- "[F]irst is [the] ability for suited crew members to observe the environment around them. First and foremost, geologic field work is an exercise in seeing rocks and structures. The accommodations that allow observation must allow as wide a field of view as possible. …. Further, the visibility provided must be as free of optical distortion [as possible] and preferably without degradation of color vision. In particular, seeing colors allows discrimination between otherwise similar rock units." (Eppler, 1997)
- "The second major implication is that EVA suits and other exploration accommodations must allow as much mobility as possible, both in terms of suit mobility and the ability to see as much countryside as possible. …. Where suit mobility is difficult or disallowed by the mechanics of inflated suits (e.g., bending and squatting down), an easily used suite of tools should compensate for the lack of mobility, so rock samples and dropped tools can be picked up with as little effort as possible." (Eppler, 1997)
- Tools and equipment must be maintainable in the field and the EVA suit/tool interface must accommodate the environmental conditions under which this maintenance will take place. The level of maintenance that must be accomplished in the field versus maintenance at the outpost has yet to be determined. However guidelines on maintenance activities are discussed in a later section of this document.
- Communication between the EVA team in the field and the outpost, as well as navigational aid for the EVA team while in the field, are two capabilities that apply to all of the field activities envisioned for the surface crew.

### 2.3.4 *References*

Eppler, D. (1997) "Geological Field Work and General Implications for Planetary EVA Suit Design," internal memo, NASA Lyndon B. Johnson Space Center, Houston, TX, February 7, 1997.

Griffith, A./DD (1998) NASA Lyndon B. Johnson Space Center, Houston, TX, personal communication, December 1998.

NASA (1998b) Human-Rating Requirements, JSC-28354, NASA Lyndon B. Johnson Space Center, Houston, TX.

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## 2.4 Surface Transportation

Surface transportation for EVA crews will be a requirement from the outset of these Mars missions, due to several factors. First, safety considerations for landing may drive landing site selection to a location that is free of terrain features that have the dual distinction of being both “landing hazards” and “interesting geological sites.” Second, a crew will exhaust interesting sites within walking distance during an 18-month surface mission, even with only a modest number of EVAs allocated for the mission. Third, regardless of how well mission planners can “centrally locate” the landing site, there will undoubtedly be important sites either located at a significant distance from the outpost or at which extended times are necessary to fully explore the area. Thus the capability to travel easily and quickly away from the landing site will be necessary for the crew to remain fully productive throughout the surface mission.

There are two options for crew surface transportation typically mentioned in Mars mission studies (e.g., NASA, 1997): unpressurized (and thus limited-duration) rovers, and pressurized (and thus extended-duration) rovers. Each has its advantages, which tend to be complementary, and the availability of both types will provide flexibility for surface operations.

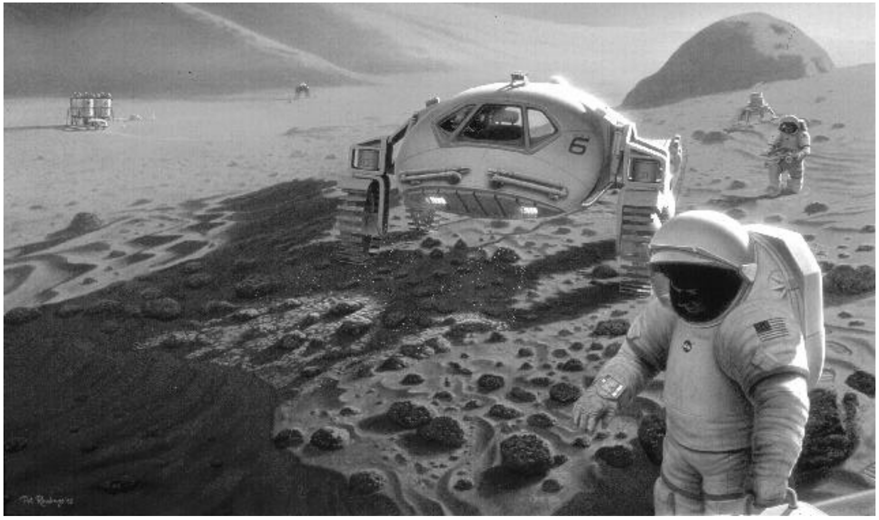

Figure 2.4-1 EVA crew members begin to explore the region in the immediate vicinity of the landing site. Pressurized rovers, such as the one illustrated here, will be used for a variety of tasks both close to and distant from the pressurized habitat. These rovers will allow the crew to conduct EVAs, as required, in the vicinity of the rover.

### *2.4.1 Unpressurized Rovers*

Unpressurized rovers will obviously require the crew’s use of EVA suits. This implies that the capabilities and interfaces of the unpressurized rover will be intimately tied to those of the EVA suit. Along with the previously stated reliance on surface transportation for the crew to remain at a high level of effectiveness over a long duration, this allows the unpressurized rover to be viewed as an extension of the EVA suit. From this perspective, many of the heavier or bulky systems that would otherwise be an integral part of the suit can be removed and placed on the rover, or the functionality of certain systems can be split between the suit and the rover. In the case of off-loading capabilities to the rover, navigation, long-range communication, tools, and experiment packages can be integrated with or carried by the rover. In the case of splitting functionality, any of the various life support system consumables (e.g., power, breathing gases, thermal control, etc.) can be located on both the rover and within the EVA suit. This division or reallocation of EVA support functionality may restrict the maximum duration in the EVA suit to something less than that which has been previously demonstrated. However, analysis of Apollo EVA activities using the lunar rover vehicle (LRV) indicate that the crew spent approximately 20 percent of the total EVA time on the LRV moving from site to site (Trevino, 1998). Mars surface operations can be assumed to be comparable. Thus the EVA team will have sufficient time for recharge of EVA suit consumables or switching to rover-based support systems to preserve EVA suit consumables. Providing multiple sources of consumables and support systems in the field also enhances crew safety by providing contingency options should EVA suit systems degrade or fail.

Operationally, Mars surface EVAs will be conducted by a minimum of two people and by a maximum of four. (This will always provide for a buddy system while on an EVA but will also leave at least two people in the surface habitat if contingency operations are needed.) If unpressurized rovers are used, then an additional operational constraint will be imposed on the EVA team. If one rover is used, then the EVA team will be constrained to operate within rescue range of the outpost. It is reasonable to assume that, while operating in terrain similar to that seen in images of the Martian surface, a rover could easily become stuck or otherwise unable to move but still be functional.

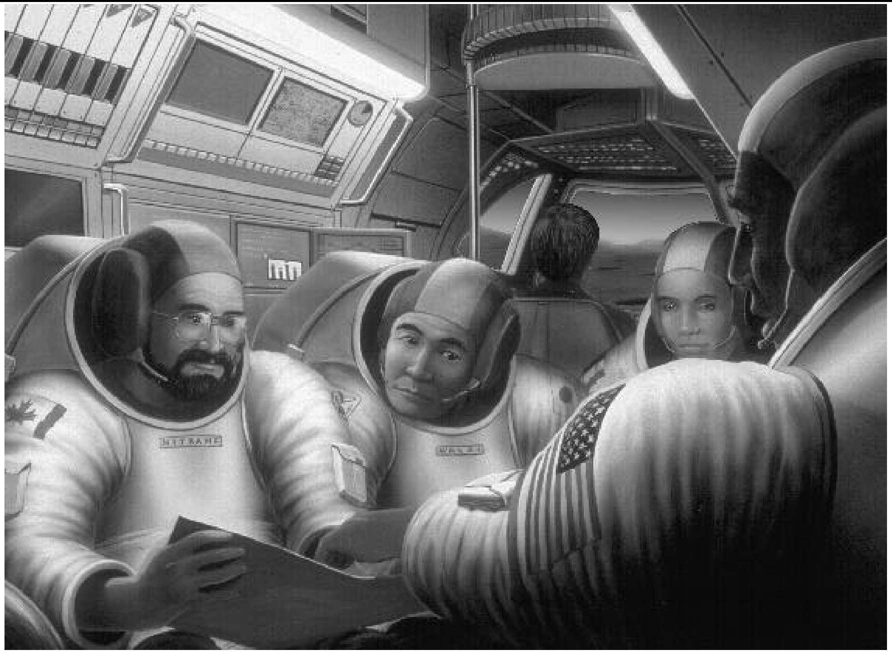

Figure 2.4-2 Interior view of a pressurized rover as the crew prepares for an EVA at a site located some significant distance from the pressurized habitat.

Thus, rescue means either the team has sufficient time to walk back to the outpost if the rover fails, or there is sufficient time for a rescue team from the outpost to reach them. Taking multiple, and identical, rovers into the field allows the EVA team to expand its range of operation because these vehicles are now mutually supporting and thus able to handle a wider range of contingency situations, such as the functioning rover's crew providing power or lighting for repairs, rescuing riders of an immobilized vehicle, or helping to extract a stuck rover.

This description points out two additional characteristics of the unpressurized rovers. It points out that these rovers must be reliable but also easily repairable in the field (or at least have the capability to be partially disassembled in the field so the failed component can be returned to the outpost for repair). It also indicates that the rover must be sized so it could carry the crew of a disabled rover if its cargo were off-loaded.

Within these constraints, the unpressurized rovers will be capable of supporting any of the various EVA activities discussed in previous sections.

### *2.4.2 Pressurized Rovers*

Pressurized rovers are typically included in the Mars mission studies because of their ability to extend the crew's EVA range, in terms of both distance and duration. While exact distances and durations will be dependent on the specific site chosen, the intent of a recent NASA Mars mission study (NASA, 1997) was to reach locations several hundred kilometers from the outpost for durations measured in days to weeks between resupply. It was also the intent for the crew using the pressurized rover to be capable of performing many of the same functions as at the outpost, but at a reduced scale. Thus a crew using a pressurized rover can be expected to be capable of commanding and controlling teleoperated rovers, conducting EVA activities (comparable to those discussed earlier) within the vicinity of the rover, and otherwise being supported for the duration of the excursion.

If only a single pressurized rover is available, operations will be constrained in a manner similar to that imposed on multiple unpressurized rovers: the pressurized rover must remain within range of the unpressurized rovers to allow for rescue should the pressurized rover become immobilized or disabled. While this circumstance does not allow for the rover to be deployed at great radial distances from the outpost, it does offer some interesting uses that can be equally productive. In one example, the pressurized rover can be used as a temporary base camp at a location where intensive field work will be carried out for an extended period of time (e.g., the drill) but still within unpressurized rover "commuting" distance of the outpost (see Section 2.5). Crews can be exchanged and consumables can be resupplied for as long as the field work continues at that site. In a second example, the pressurized rover can be used to “circumnavigate” the outpost site at a distance defined by the range of the unpressurized rover rescue constraint. This will allow a traverse of potentially hundreds of kilometers to be conducted, visiting a significant number of sites along the way. As with the fixed site scenario, crews and supplies can be delivered periodically to the pressurized rover as it makes its way around the outpost site.

If a second pressurized rover is delivered, the radial distance away from the outpost can be significantly expanded. These distances will preclude resupply and thus the maximum range will be limited by the consumables brought along with the pressurized rovers. The following scenario illustrates a potential long-range deployment of two pressurized rovers:

> An interesting site with potential lacustrine deposits, and thus a potential site for evidence of past biological activity, has been identified at a range beyond that which can be supported by unpressurized rovers. A teleoperated rover is sent to the site to test for toxic or biological hazards (see Section 2.6) and returns with a small sample for analysis at the outpost. After determining that no immediate hazard is posed to the crew, a four-person team is deployed to the site in the two pressurized rovers. These rovers are towing the 10-meter drill, a teleoperated rover, and at least one unpressurized rover. On arrival at the site, the teleoperated rover and a two-person EVA team using the unpressurized rover(s), perform a more detailed reconnaissance of the area and specifically examine candidate sites for the drill. The entire crew prioritizes the candidate sites, collaborating with colleagues on Earth. The pressurized rovers are moved to a central location among these sites where they will remain as a base camp, primarily to conserve as many of the pressurized rover consumable resources as possible. An EVA crew uses the unpressurized rover to move the drill to each candidate site in turn. The EVA crews “commute” to each site, using the unpressurized rover, until drilling operations are completed at that site. Core samples from the drill are tested for biological activity or toxic substances using sensors on board the teleoperated rover before contact by the EVA crew. The core samples are then put through an aseptic curation process and stored for return to the outpost where further analysis will be performed if appropriate. After collecting core samples at all of the candidate sites, the crew will use any remaining time (as dictated by its consumables supply) to continue a reconnaissance of the area or to return to the outpost by a different route, visiting other sites of interest along the way.

As discussed for the unpressurized rovers, dual pressurized rover operations allow for mutual support in the field. It also implies that limited maintenance and repair in the field should be possible, with the contingency capability for a single pressurized rover to bring the entire deployed crew should one of the pressurized rovers be disabled beyond the crew’s capability to repair it in the field.

### *2.4.3 Summary*

This section has discussed the types of surface transportation that will be available to the crew and the variety of missions on which the equipment can be deployed. Important points include:

- Both pressurized and unpressurized rovers should be available to the crew.
- The two types of rovers complement one another in the field activities that can be accomplished.
- Crew safety and the number of rovers deployed will determine the maximum range and duration that can be attained.
- Field maintenance will be a necessity.
- The unpressurized rover can be viewed as an extension of the EVA suit; allocation of functionality between the two systems needs further research.
- Dual pressurized rovers will allow distant sites to be visited or extended operations to be accomplished at selected sites.

### *2.4.4 References*

NASA (1997) Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, NASA SP-6107, NASA Lyndon B. Johnson Space Center, Houston, TX.

NASA (1998c) Reference Mission Version 3.0; Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Team, SP-6107-ADD (also EX13-98-036), NASA Lyndon B. Johnson Space Center, Houston, TX.

Trevino, R. (1998) NASA Lyndon B. Johnson Space Center, Houston, TX, personal communication, 1998.

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## 2.5 The Field Camp

A primary objective of sending human crews to Mars is to allow them to explore, in person, a region containing diverse, interesting surface features. However, operational and safety requirements will impose constraints on those locations where the crews and their cargo vehicles will be allowed to land before they can begin these explorations. Planetary protection protocols may also limit landings to those regions from which samples have been returned to Earth by a robotic spacecraft—samples that have proven sterile and biologically safe. Additionally, landing sites may be restricted to those areas that are relatively benign in terms of hazards and trafficability. These requirements of diversity and safety may well work against each other, perhaps placing the interesting sites only within reasonable proximity to the safe/benign landing sites. It is to be expected, given the diversity of Martian geology, that one or more of the key sites the crews identify for exploration will be located some significant distance away from the landing site.

It is also reasonable to assume that the crews will select some of these remote sites for extended, detailed study. Activities such as deep drilling, trenching, and other forms of surface excavation, or simply detailed study of certain features (e.g., sedimentary layering found in ancient lake beds or that are exposed at a cliff face) will require periods of time greater than are reasonable for a single EVA.

The capability to remain at one or more of these remote sites for extended periods of time—through the creation of a field camp—will greatly enhance the productivity of human exploration. Reducing the need to commute from the central base to the site and back again will provide the crews the means for exploring a site for periods of time longer than are possible in a single EVA.

In addition to the previously mentioned drilling and digging activities, this capability will allow walking or unpressurized rover traverses to extend beyond what is possible from the central base before the arrival of multiple pressurized rovers. In this case, the field camp could be located at the maximum range allowed by operational considerations (e.g., the unsupported walk-back distance allowed by EVA suit consumables or crew fatigue limits) and would then serve as the staging base from which additional traverses would be carried out (see Figure 2.5-1). Communication systems at the field camp will serve as a data relay between parties in the field and the remainder of the crew at the central base.

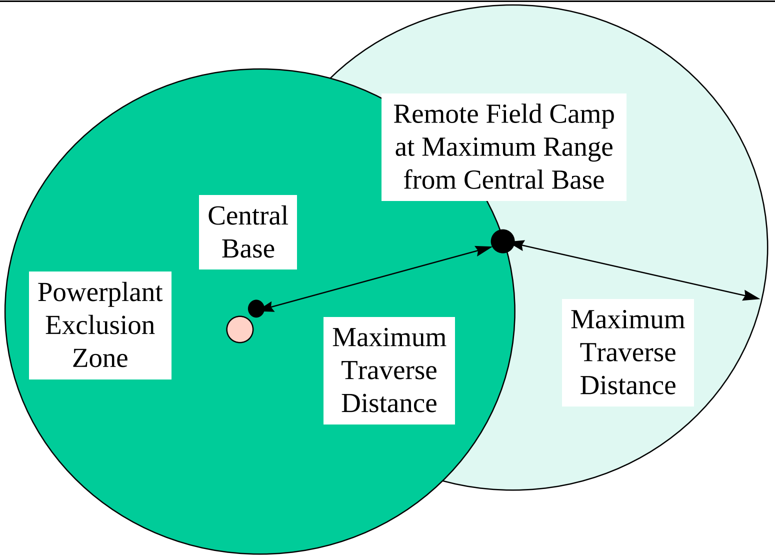

Figure 2.5-1 Use of a remote field camp to extend the range of operation before the arrival of long-range roving capability.

A secondary use for this field camp capability is to provide an emergency camp to which a crew could walk in case of a rover breakdown beyond walk-back distance to the central base. It would also be the agreed-to point from which a search and rescue group would start its search in case it lost contact with a team in the field (the assumption being that if a crew should lose contact but is otherwise OK, then this crew will make its way back to the field camp to meet the search and rescue group from the central base).

Typically, site(s) for a field camp will be chosen to meet certain mission objectives; there may be several field camps established during the course of the 18-month surface mission. Each site will be selected based on remote sensing data gathered from orbit or by teleoperated robots (either airborne or moving across the surface) or identified by the crew during the course of a previous surface traverse. Supported by their terrestrial colleagues, the crew will plan the content and timeline of likely activities to be performed at this site, allowing necessary equipment and supplies to be identified. Unpressurized rovers (and, when available, the pressurized rovers) will be used to transport equipment and supplies to the site. More than one trip by rover to the site may be required. Sample payloads that could be transported to this remote site are listed in Table 2.5-1 (these values are taken from Tables 3-5, 3-7 and 3-9 from NASA, 1997).

**Table 2.5-1 Sample Payloads and Associated Mass Values**
**That May Be Used at Remote Field Camps***

| Payload Description | Payload Mass (kg) |
|---|---|
| Field geology package: geologic hand tools, cameras, sample containers, documentation tools | 335 |
| Traverse geophysics instruments | 400 |
| Geophysics/meteorology instruments (8 sets) | 200 |
| 10-meter drill | 260 |
| 1-kilometer drill | 20,000 |

* mass estimate derived from Budden, 1994

Other field camp infrastructure, such as a pressurized habitation structure, power system, and life support consumables, must also be transported to the field camp site. The mass of these items is implementation-dependent and has not yet been specified. However, two possible implementations are readily envisioned and will be noted here to illustrate the range of options.

The first possible implementation is to use one of the pressurized rovers as the habitat and power system for the field camp. This rover will have already been designed to support several crew members for many days away from the central base and thus will meet these needs for the field camp. The pressurized rover can tow at least a portion of the other equipment to the site and then be parked in a convenient location near the other activities taking place. Unpressurized rovers can provide crew mobility while the pressurized rover is in this fixed location.

The second implementation is to use a smaller version of the inflatable habitat already in place at the central base. Such a system could be towed into position and set up by the crew. The technology used for the inflatable pressure vessel as well as other rigid structure (such as the airlock door) would be the same as that used at the central base. Other systems, such as power and life support, could be variations on the technology used for the pressurized rover or that used at the central base.

The first activity for the crew at the field camp will be to choose specific sites for the major elements of the camp, such as the habitat, associated support equipment, and major scientific experiments. Equipment to be used at the site are assumed to be designed to require minimal site preparation (i.e., moving rocks, surface leveling, etc.), with one exception. If a radiation storm shelter capability is not included in the equipment brought to the site, construction of such a facility may be required. The same equipment used for the trenching activity discussed elsewhere in this section can be used to excavate a suitable subsurface location that could be covered with regolith. The crew will then set up and verify the readiness of the habitat, and the life support, power, and communication systems. Only after these elements are operational will the crew begin to set up and operate the science equipment.

The primary purpose for a field camp capability is to place the crew in close proximity to features or items of interest. Thus the capability for daily EVA activities is assumed for these field camps. As mentioned in other places in this section, EVA activities may be as uncomplicated as walking traverses in the vicinity of the field camp, or as complex as the setup, operation, and maintenance of substantial equipment, such as drills or trenching tools. The capability for delicate excavation, such as might be used at an archeological dig, will also be necessary for those activities designed to carefully “peel back” layered deposits.

Figure 2.5-2 Crew operating from a field camp will allow interesting sites to be explored in more detail than would be possible if the EVA were staged from the landing site.

Because of the emphasis on external activities while at the field camp, activities internal to the habitat will tend to be focused on supporting these activities. Basic capabilities for meal preparation, personal hygiene, and sleeping accommodations will be provided. Other activities likely to be carried out by the field camp crew will focus on preparation for the next EVA. These include any required maintenance or minor repair of the EVA suits, logging data from the experiments, and preparing samples (such as core samples from the drill) for transportation back to the central base. Major repair of equipment, if needed, is assumed to be accomplished at the central base.

Because this field camp will be within a reasonable distance of the central base (possibly no more than walk-back distance) it affords the option of resupplying the camp with materiel from the central base. This capability can allow systems to be sized for a smaller capacity than might otherwise be required and opens the possibility for using open-loop systems (e.g., power or life support) supplied by the cache of life support and propellants being produced by the ISRU plant. It also opens the option for changing crews at the field camp so that no one group is away from the amenities of the central base for an extended period of time. The amount of supplies on hand should exceed the resupply frequency by several days to allow for contingencies. A nominal resupply frequency of one week is suggested to coincide with other cyclic events observed by the crew. In addition, a field camp is assumed to be capable of supporting a nominal crew of three people between resupply events.

Once activities at the field camp have been completed, the crew will dismantle equipment and structures for return to the central base or relocation at a different site. An alternative use for some of the field camp equipment is to leave it in place to serve as an emergency camp and supply cache. At a minimum, the radiation storm shelter (if constructed in place) will remain at the site and could be used as a storage location for emergency supplies. The crew will return all data and samples gathered at the field camp to the central base where the data will be archived and samples will be put through the curation process and may be analyzed with the equipment available.

### 2.5.1 *Summary*

To summarize, this section has discussed the key mission objectives satisfied by and functional capabilities of a remote field camp. These include:

- Improved use of the crew by providing the capability to remain in the field for many days or weeks, with resupply, at sites of significant interest.
- The ability to perform daily EVAs.
- The ability to support a diversity of experiments ranging from walking traverses to operating large and/or complex machinery.
- The ability to accommodate a nominal crew of three.
- The ability to periodically resupply consumables from the central base on a periodic basis, nominally once per week.
- The ability to relocate the field camp once activities at a given site are complete.

System definition and trade studies remain to be performed on the habitation and supporting systems needed to implement this capability.

### 2.5.2 *References*

Budden, N.A. (1994) Catalog of Lunar and Mars Science Payloads, NASA RP-1345, NASA Lyndon B. Johnson Space Center, Houston, TX.

NASA (1997) Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, NASA SP-6107, NASA Lyndon B. Johnson Space Center, Houston, TX.

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## 2.6 Toxin and Biohazard Assessment

Two highly interrelated and possibly conflicting aspects of human missions to Mars are the maintenance of a healthy crew while at the same time actively seeking out evidence of extinct or extant Martian life. The means by which both of these aspects of a Mars mission are satisfied will be a combination of equipment and procedures designed to alert the crew to potentially toxic materials or to the presence of biological activity while keeping the crew safely isolated should either be encountered.

Toxicity at some level is a likely property of the Martian dust. Viking analyses demonstrated two pertinent characteristics of Martian surface material that leads to this conclusion. First, the dust contains an active oxidant at levels of 100 parts per million and, second, no carbon compound could be found in the dust. This has been interpreted to mean that the surface of Mars is sterile and that oxidation processes have destroyed any carbon that may have been brought to the surface from the interior or from outside by meteoroids. For comparison, the lunar regolith contains detectable carbon from carbonaceous chondrite (asteroid) sources. Chemical and physical effects of oxidants in the Martian soil on humans could range from none, to annoying, to potentially dangerous if steps are not taken to remove or modify the contaminants. The dust is very fine-grained, with windblown dust sizes typically in the 1-2 micron range, based on settling properties in the Martian atmosphere. This material is exposed to an ultraviolet radiation environment, which could activate mineral grain surfaces. The mineralogy of the dust is unknown. However, it is likely that some of it is highly soluble in water and could react with the respiratory system of astronauts if not somehow removed. This dust could also, in principle, include metallic chlorides or nitrates with noxious properties. It will be difficult to prevent the contamination of the interior of the Martian habitat with at least some amount of surface dust if EVAs are a major activity, as they are proposed to be in the exploration strategy.

Most scientists also believe that the Viking data showed that the surface does not contain living organisms and thus is not expected to impede the first robotic sample return missions. However, initial biological studies with these returned samples will be aimed at verifying the results of the Viking analyses. If the current interpretations are incorrect and there are viable Martian organisms in the Martian soil, then additional precautions will be needed for the human missions. If the organisms are found not to be harmful, or are shown not to be viable in the Earth’s atmosphere, then they should pose no problem to future human missions. If the organisms are found to be harmful to humans or dangerous if released into the terrestrial biosphere, then the level of danger will have to be assessed and additional precautions taken for human missions, to avoid exposing unprotected astronauts to the organisms and introducing untreated dust to the Earth’s biosphere. In an extreme case, it might be prudent to not send humans to Mars.

If, as expected, the surface of Mars is sterile, the concern for biological activity in Mars will remain. This is because one of the objectives of human missions is likely to be the search for life in isolated environments, particularly below permafrost at depth and in areas of hydrothermal activity. In these cases, samples will be needed from below the surface and new, unoxidized environments will be encountered, which will have to be treated as if they contained harmful organisms until proven otherwise. The crew will have to be protected from encountering primary contamination by direct exposure to the samples or anything that has contacted those samples (drilling tools, containers, etc.).

The potential for discovering Martian life also requires that the environments in which life may exist be protected from contamination or disruption. For scientific purposes, these environments must remain uncontaminated by terrestrial organisms that could confound results, change the environment, or otherwise disrupt or destroy the indigenous organisms. (It is also held by some that ethical considerations will require that no contaminants be introduced until it is known that the environment does not contain viable Martian organisms.) This will require that any procedures used to obtain samples in these environments be treated with at least the same level of control now required for life detection experiments on robotic missions. Because humans will be in the vicinity, however, protection procedures will be more complicated and they will have to be performed on Mars. Learning about the fate of terrestrial organic contaminants in the Martian surface environment is also an important aspect of the design of such systems. If, for example, the surface environment is self-sterilizing on a rapid time scale, contamination protection will be less difficult than if organic constituents survive for significant time periods in the surface environment. It is likely that terrestrial microorganisms will either die or be unable to reproduce in the cold, dry, oxidizing, high-UV-radiation environment of Mars’ surface. If, however, terrestrial microorganisms do not die, become inactivated, or react quickly when exposed to the surface environment, the potential exists for dust storms to distribute them widely over the planet.

Initial assessments for toxicity and biohazards will be part of the robotic missions that precede humans to Mars. Robotic missions will be used to gather data about the soil and dust found on the Martian surface and will be used to return small samples to Earth so that these questions, among others, can be addressed. Analyses of surface soil and dust samples will allow the magnitude of the threat, if any, to be determined, and will provide a basis for the mitigation of the toxic or deleterious effects of soil on humans. It will also be possible to define the potential interactions of the dust with mechanical and electronic systems, and to develop procedures for removing or modifying the dust in the habitat interiors.

Once the Martian surface has been found to be generally safe for humans to occupy (or satisfactory mitigation processes have been developed), toxicity/biohazard assessment activities will focus on those new or isolated environments where the crews will continue their search for evidence of past or present life. In support of these forays, robotic vehicles will be sent in advance of the crews, carrying appropriate sensors to allow them to function as “mechanical canaries.” These robots will search for known toxins or evidence of biological activity and relate their findings to the crews. This implies that a single-purpose robot should be kept in isolation to avoid contamination by contact with the crews or that adequate cleaning/sterilizing procedures be developed to avoid false positive signals from these sensors.

A similar warning capability will be needed to perform the same function in bore holes or other subsurface excavations, particularly if these activities penetrate into regions containing liquid water. The alternative is for samples taken under these circumstances to be considered hazardous a priori and to provide the crew with the means for containing and isolating the samples until proper handling can take place. The astronauts may take two approaches with such samples: they may collect and package them immediately for return to Earth, or they may make some analyses on Mars. In either case, continued separation of the crew from the samples is needed. The level of analysis that is reasonable to conduct on Mars is not yet determined; however, a principal reason to have humans on Mars is to conduct analyses as exploration proceeds, so that discoveries can be folded back into the exploration plan. Thus, it is likely that the full range of analytical capability of the Martian laboratory facility will be applied to the samples, in addition to biological activity determinations. This indicates that there will be a need for a sample isolation chamber, perhaps a stand-alone facility external to the habitat, where samples can be handled, split, packaged, either for return to Earth or transfer into the Mars analytical laboratory. It may be necessary to provide a capability to sterilize samples, as well (see Section 2.8).

If these assessment activities have determined that the new environments do not pose a toxicological or biological hazard to the crew (or conversely, that the crew does not pose a hazard to the environment), then the crew will be allowed to approach the site for detailed exploration. This will also be the criterion that will be used to decide when the crew can safely handle samples within its Mars analytical laboratory.

Despite these various precautions, EVA crew members or equipment may become contaminated during the course of their exploration activities. A final set of sensors will be in place at the entrance to, or within, the airlock to check crews returning from EVA activities. Cleaning/sterilization procedures will be needed for both the EVA suits (or associated equipment brought into the airlock), and for the sensors used to detect possible hazards, to remove the hazardous material before allowing the crew members to reenter the habitat facility.

When humans were sent to the Moon, a quarantine system for the crew and samples on return to the Earth was instituted. For Mars, the analysis of samples returned robotically could provide data and guidance to procedures that would significantly reduce the risk of bringing uncontrolled dangerous materials into the Earth’s biosphere (robotic sample returns from the Moon came after the first human missions). However, even with the information from robotic sample return missions, it is likely that samples collected by humans will continue to be quarantined throughout the Mars program and that the crews will be isolated for some period of time on returning to Earth. This will continue as long as human missions encounter new environments. This suggests that requirements for crew quarantine be considered when designing sample quarantine facilities for robotic sample return missions. It also suggests that quarantine testing and certification for controlled distribution of samples that are developed for the robotic program will be continued, at least for some samples, during the human program.

### *2.6.1 Summary*

In summary, there will be an ongoing need for crews to evaluate the level of toxicity or potential for biological activity throughout all phases of the surface mission. The active search for evidence of past or present life will inevitably lead these crews to environments where such assessments will be necessary to ensure their own health and safety and to protect Earth’s biosphere from contamination. Such assessments will be derived from equipment and procedures that exhibit the following characteristics and capabilities:

- Control of the potential toxic effects of Mars’ dust on humans, through separating humans from the environment, cleaning, and deactivating toxic materials.
- Special precautions to protect crews from samples taken from isolated environments that may harbor Martian organisms.
- Capability to analyze the characteristics of samples taken from these isolated environments without exposing the astronauts to potential Martian organisms.
- Special aseptic sampling and packaging procedures for samples with possible Martian organisms.
- Quarantine procedures for samples and crews to be used whenever new environments are sampled that may contain Martian life.
- Capability to prevent contamination or disruption by human activities of isolated Martian environments that may contain organisms.

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## 2.7 Sample Curation

During the course of its 18-month stay on the Martian surface, the astronaut crew will conduct many EVAs and teleoperate many robotic rover traverses. A large subset of these EVAs and robotic rover traverses will be focused on collecting geologic samples from a variety of sites around the outpost. The proper handling and curation of these samples is critical to ensure that any specimens chosen for shipment to Earth are minimally contaminated.

Sample curation includes documentation, sample tracking, sample splitting, preliminary examination, contamination control, and storage. This discussion focuses on the handling of rock samples and soil scooped from the surface, and is primarily based on curation concepts developed for a lunar outpost (Treiman, 1993). The schemes described below would not be appropriate for core samples (drill or drive tube) or volatile-rich (i.e., icy) samples. These special cases will be discussed at the end of this section.

The curatorial history of a rock or soil sample begins when a crew member, or a robotic explorer, observes something of special interest or finds an object specifically being looked for. Before that sample is actually collected, the crew will document its location, orientation, and surface setting, with photographic and/or video equipment and a recorded verbal description of the sample and its surroundings. This documentation step is important in that once a sample is removed from its environment the context of its relationship with the local area will be physically lost, and only good records will allow researchers to recreate the surface setting.

If possible, the sample will then be split in place into two representative subsamples. If pieces are being chipped off exposed bedrock or a large boulder, two similar samples will be taken. This is done so that one subsample can be used for preliminary examination at the outpost habitat, while the other can be put in storage away from the habitat for possible transport to Earth. In this way, at least one minimally contaminated sample will be preserved from every collection site. “Minimally contaminated” refers to samples only exposed to contamination derived from sample collection and storage. The mere act of collecting samples on Mars contaminates them due to the outgassing from an astronaut’s space suit, a robotic rover vehicle, or even EVA tools and containers. This level of contamination is unavoidable, as it was during the Apollo program, but experience with lunar samples suggests it will not impede or prevent detailed analyses on Earth (Treiman, 1993).

After splitting, the subsamples will be “bagged and labeled.” The bags used to hold the samples should prevent cross contamination between samples, and will most likely be similar to those used on the Moon during the Apollo program (Allton, 1989). However, the choice of materials needs further study because Teflon, like that of the Apollo bags, abrades and rips easily and can lose much of its strength from long exposure to solar radiation (Treiman, 1993). The small sample bags will then be loaded into a larger storage bag or container which can be carried on the astronauts’ space suits, mounted on their roving vehicle, or mounted on a robotic rover.

When an EVA or robotic rover traverse is completed, the collected samples will be delivered to two separate storage areas. One area will be distant from the outpost to avoid contamination from gases emitted from the habitat, local surface activity around the outpost, and exhaust gases resulting from spacecraft launches and landings. The exact distance between this remote storage area and the outpost will generally be on the order of one kilometer to a few kilometers. The subsamples earlier referred to as “minimally contaminated” will be stored at this area, and will include those specimens ultimately chosen for shipment to Earth. The second storage area will be located at the outpost, where subsamples can be easily retrieved for preliminary examination in the habitat’s laboratories (see Section 2.8). These samples will experience varying degrees of contamination during examinations and tests, and will likely remain on Mars near the outpost.

The storage areas can range from simply organizing the collected samples in a grid on the surface (i.e., a “rock garden”) to housing the samples in a container, structure, or building. While the “storage shed” concept was considered optimal for samples on the Moon (Taylor and Spudis, 1990), it is possible that the storage structure on Mars might increase the contamination level of the samples, and might have a considerable cost in terms of mass delivered to Mars. Some sort of deployable shelves open to the Martian environment may be a good compromise.

Once placed in a storage area, data such as a field description of the sample (i.e., crystalline, breccia, soil, etc.), a sample identification number (preprinted on sample bags) and physical location where the sample is stored (i.e., bin number), would be entered into a computerized database for tracking purposes. During the span of 18 months many samples will be accumulated, and there is the potential for samples getting mixed up or lost. Sample tracking will become more important as the number of collected samples increases and as preliminary analyses begin. It is quite possible that certain samples may need to be retrieved from storage more than once as preliminary examination results promote a better understanding of the local geologic setting. However, after the initial data entries (which could simply be a voice transcription) by the EVA crew or by a crew member teleoperating a robotic rover, all maintenance of the tracking database can be done by personnel on Earth.

As mentioned at the beginning of this section, cores (from either drills or drive tubes) and volatile-rich samples will require special treatment. On Earth, cores are extruded, excavated in several phases, and sampled continuously over their whole length, a process requiring a considerable amount of time and equipment (Treiman, 1993). This level of handling and processing quite likely will be impossible at a Mars outpost, due to the confined volumes in a habitat and the amount of crew time that will be required. One possible approach to overcoming these limitations is to not withdraw continuous coring sections but rather to sample the bottom of the drill hole from time to time with a sampling device. This will require a change in the tool for each sample, which may allow for a single-use, sterilized sample acquisition device to be used for these samples. However, this is a substantial problem that warrants more discussion, as subsurface information derived from cores will be significant in understanding the local geology around the outpost and thus for real-time planning of further research and exploration.

Keeping volatile-rich samples in their pristine state also will present significant challenges. Samples such as permafrost or clays, if found, would require specialized containers to provide a constant temperature for the preservation of any ices and to control any pressure increases due to outgassing. How to handle these volatile-rich samples deserves special attention because the discovery of water in any form would be extremely important in the search for signs of past or present life.

### *2.7.1 Summary*

In summary, astronaut crews on the Martian surface will conduct the following curatorial activities during any extended stay:

- Sample documentation—to record the geologic and physical setting of the sample before collection, and to describe everything done to that sample during examinations
- Splitting of selected samples—to provide subsamples for preliminary examinations and minimally contaminated subsamples for remote storage and possible shipment to Earth.
- Sample storage—to maintain readily accessible samples in as pristine and secure a condition as possible.
- Sample tracking—a database of current information pertaining to the location and condition of all samples and subsamples.
- Preliminary examination—to identify and characterize each sample and subsample.
- Contamination control—to maintain samples in as pristine a condition as possible.

### *2.7.2 References*

Allton, J. (1989) Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers, NASA JSC-23454, NASA Lyndon B. Johnson Space Center, Houston, TX.

Taylor, G. and P. Spudis (eds.) (1990) "Geoscience and a Lunar Base: A Comprehensive Plan for Lunar Exploration," NASA CP-3070, workshop held at the Lunar and Planetary Institute, Houston, TX, August 25-26, 1988.

Treiman, A. (1993) Curation of Geological Materials at a Lunar Outpost, JSC-26194, NASA Lyndon B. Johnson Space Center, Houston, TX.

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## 2.8 Sample Analysis

A key, distinguishing feature of these Mars missions will be the interaction of field work (as discussed previously) and in situ sample and data analysis. During the Apollo missions to the Moon, all rock and soil samples collected were put directly in sample return containers; no preliminary analyses, other than the astronauts' verbal field notes, were conducted with the samples. In addition, all other photographs and observational field notes were recorded and stored without benefit of any time for reflection or opportunity to revisit any of the sites. This mode of surface geoscience operations was necessary due to the short duration of the surface stays (3 days at the most), the constrained volume of the spacecrafts' habitable volume, and the lack of time on the astronauts' schedule. The Mars surface mission, as currently envisioned, changes this paradigm with a much longer period of time on the surface and a planned capability for conducting some level of sample analysis before returning to Earth. Facilities on this kind of mission will never approach the capability of those in laboratories on Earth, however some level of on-site analytical capability will be needed for the crew to better understand its surroundings and remain adaptive to discoveries made. A key area of investigation as plans are made and technologies are developed for this mission is to decide where to divide the analytical capability that is needed on Mars from that which will be brought to bear on those samples and data returned with the crew.

The extended amount of time on the surface, approximately 18 months, will allow crew members to consider what they have seen and collected, in terms of samples and other data, before departing. This additional time will also allow for collaboration with colleagues on Earth to discuss thoughts and theories to explain these data, with the added advantage of opportunities to gather other samples or data from the same location or different locations to support or refute ideas put forth in these discussions. Also, because sample return capability is limited, analysis at Mars will provide data from a larger number of samples that will not be brought back to Earth.

Sample analysis will also support a number of other surface mission objectives. Key among the objectives of these preliminary examinations will be to:

- Develop an understanding of the local geology and geologic history.
- Assist in the planning of surface exploration activities and field work.
- "High-grade" the collected samples to determine which ones will be shipped to Earth.
- Look for any physical or chemical signs of life, past or present.

Previous sections have described the collection of samples, which will take the form of rocks, soils, and cores. The cores could be taken from a drill or drive tube and may be either dry or volatile rich (i.e., containing ices or liquids or gases that are soon lost if not contained or sampled).

The function of preliminary sample examination presents a great variety of options depending on where it occurs, how it occurs, and who conducts the examination. Initial sample examination will occur in the field, carried out by an EVA crew member and/or a teleoperated robot, depending on how the sample analysis equipment is distributed between the EVA crew member and the robot. Once the necessary curatorial tasks have been completed, including packaging a minimally contaminated sample, the crew member or robot may examine the rock or soil sample with a hand lens (or its equivalent) or with relatively simple analytical equipment that has been brought into the field. The crew member (either in the field or at the robot's teleoperation station) will use this quick initial assessment to decide if more time should be spent in this area or to place some priority on the order and degree to which this sample is examined at the habitat. For preliminary examinations on the Moon, the geoscience community has recommended that examinations be performed outside of a habitat, and far from the habitat to reduce sample contamination to a minimum (Taylor and Spudis, 1990). However, by introducing a sample splitting scheme to provide for minimally contaminated subsamples (as discussed in Section 2.7), others have advocated examinations inside the habitat (Treiman, 1993). For the reasons discussed by Treiman (1993), detailed examination of the samples within the habitat (with suitable protection for the crew and for the sample) is currently assumed for the Mars surface mission.

The sample(s) may require some amount of preparation before bringing it into the habitat for a more detailed examination. For example, core samples brought up by the drill are likely to have already been divided into lengths that the EVA crew can place into whatever storage system is used to transport these samples back to the habitat. However, the customary procedure for handling cores is to divide them in half lengthwise, with one half stored as a minimally contaminated “archive” and the other half used for more detailed examination. At Mars, the crew may use this procedure for those core samples it acquires, with one half of the core sections place in the same curatorial facility as the other minimally contaminated rock and soil samples. (Note: special handling and storage may be required for these core samples if they contain volatile components that must be preserved.)

How rock and soil samples are handled and examined inside a habitat laboratory has not yet been defined in specific detail and planetary scientists have a wide range of opinions on the subject. However, it is reasonable to assume that there will be two general categories of examination and analysis that will take place—those focused on geological investigations and those focused on biological investigations. It is also reasonable to assume that, while some members of the crew will specialize in the geological or biological sciences, others will be cross-trained to provide support in these areas, in particular, operating laboratory equipment and conducting analyses.

The majority of the geoscientist’s time will be spent determining the geologic units and the contacts between the units, describing the geomorphology of the surrounding landforms and the processes that shaped them, and mapping the area around the outpost. While this is occurring, other crew members will be analyzing samples and data that the geoscientist has brought back to the habitat. Laboratory facilities to support this field work will, at a minimum, be very basic and probably include a binocular microscope for mineral identification (possibly enhanced with a reflectance spectrometer), a simple chemical analyzer (e.g., alpha proton X-ray spectrometer) for elemental classification, and simple handheld equipment to determine a sample’s physical properties (e.g., magnetism, hardness, etc.). This equipment will permit general classification of the samples and allow a reasonable judgment about which ones to transport to Earth. As time and equipment capabilities permit, more sophisticated analyses of the samples will be conducted. For example, a petrographic microscope can provide more detailed mineralogical information, including the fabric and texture of the minerals, to help determine the environment in which the rocks and minerals formed. However, this will require the ability and time to make polished thin sections. In a similar fashion, an X-ray fluorescence system for measuring bulk rock compositions will not only permit more accurate and detailed classification of rock chemistry, but will also make possible the identification of unusual samples (Taylor and Spudis, 1990). More sophisticated analytical equipment may also be available as the size and power requirements of these instruments are reduced. For example, scanning electron microscopy, differential thermal analysis and gas chromatography, or Mössbauer and gamma-ray spectroscopy are all possible, and desirable, analyses that could be accomplished in a more sophisticated laboratory.

The search for chemical or physical signs of life can be accomplished in concert with the geologic examinations in the same laboratory, using some of the same instruments. Surface and subsurface mineralogical, petrological and geochemical analysis provides indispensable basic information regarding the general planetological setting of the site being analyzed, as well as the local environment and traces of biological activity (European Space Agency, 1998). Life can leave its imprints at the surface of rocks as etch pits, reaction product deposits, or organic matter deposits (bio-crusts), and it also can leave them underneath the surface. A search for such biomarkers has to be accompanied by the proper mineralogical and petrological characterization of the environment. Knowledge of the relative abundance of the biologically significant elements carbon, hydrogen, nitrogen, oxygen, sulfur, and phosphorus, and their distribution between organic and inorganic matter is particularly important.

Examples of equipment that could be used for both geologic examinations and the search for life include:

- A binocular microscope to search the surface of rocks for the biomarkers mentioned above.
- An alpha proton X-ray spectrometer to determine the light elements carbon, nitrogen, and oxygen.
- A scanning electron microscope to search for shapes morphologically similar to organisms on Earth and indications of biomineralization or biodegradation of minerals.

Protocols for handling samples that may be biologically active have yet to be defined and will require additional research. However, in addition to the instruments mentioned above, the crew will have several capabilities available to it that will assist with handling and analyzing these materials. The first is the nuclear reactor that is providing power to the outpost. This could be the source of sufficient radiation to sterilize any samples for which this process is deemed necessary. The same robotic vehicle used for inspection and maintenance of the reactor could also deliver the samples to an appropriate location near the reactor and return them to the habitat after an appropriate exposure period. Another facility likely to be carried within the habitat is a glovebox capable of Biosafety Level 4 containment. This glovebox is likely to be connected to the exterior by a small airlock, allowing samples to be transferred directly to the glovebox without being carried into the habitat. Such a facility will protect the crew from the sample as well as protecting the sample from the crew.

Data and results from all of these facilities will be stored in an onboard data system for archiving purposes. Portions of the data can be sent back to Earth to assist with the interplanetary collaboration between the crew and Earth-based colleagues as well as to disseminate some of the knowledge gain to the public.

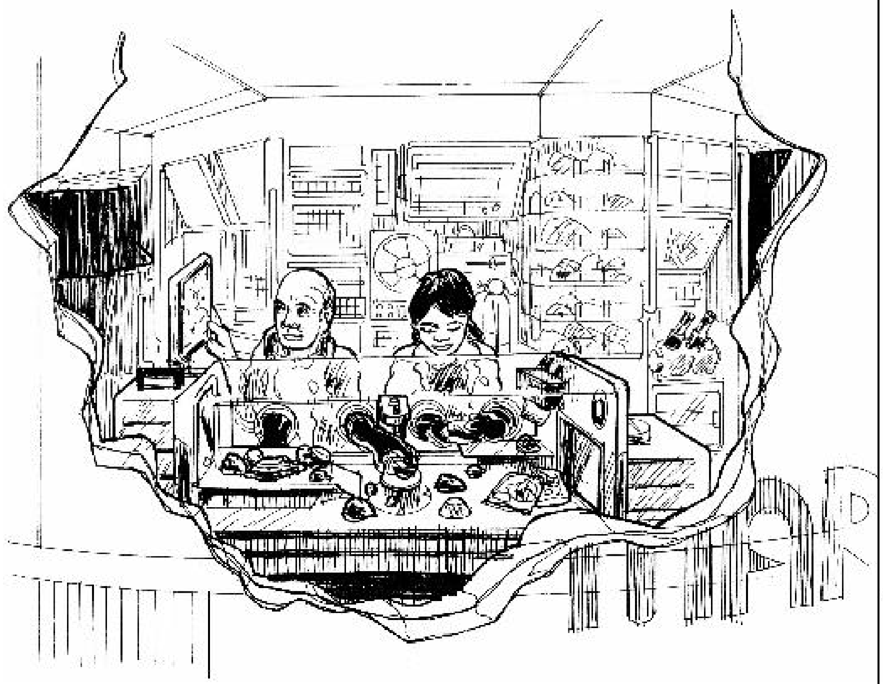

Figure 2.8-1 Crew members examine a number of collected surface samples inside a glovebox facility. This facility will not only protect the crew from potential hazards associated with the sample, but will also protect the sample from contamination by the crew.

### 2.8.1 Summary

This section has discussed the sample examination and analytical capabilities likely to be used on the Martian surface. These capabilities are a key, distinguishing feature of these Mars missions. Two general categories of examination and analysis will take place: those focused on geological investigations and those focused on biological investigations. Having these capabilities available will allow the crew to better understand the environment being explored and adapt to the findings made, allow for collaboration with colleagues on Earth, and "high-grade" the collected samples to determine which should be returned to Earth.

There are several key areas that require additional research and definition:

- Where to divide the analytical capability needed on Mars from that which will be brought to bear on those samples and data returned with the crew.
- How rock and soil samples are transferred to, handled, and examined inside a habitat laboratory.
- Protocols for handling samples that may be biologically active.

### 2.8.2 References

European Space Agency (1998) "ESA Exobiology Science Team Study on the Search for Life on Mars," Mid-Term Report.

Taylor, G. and P. Spudis (eds.) (1990) "Geoscience and a Lunar Base: A Comprehensive Plan for Lunar Exploration," NASA CP-3070, workshop held at the Lunar and Planetary Institute, Houston, TX, August 25-26, 1988.

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## 2.9 Teleoperation of Robotic Vehicles in Support of Science and Exploration

Exploring the surface of Mars with a human crew will require a balance between actively using the crew—the best exploration tool that can be employed in this endeavor—for all of the exploration tasks in and around the outpost with safety and priority concerns associated with this limited resource. Mobile robots are thus assumed to be an integral part of the tools available to the crew for leveraging its time and accomplishing its scientific and exploration objectives. Previous sections have discussed a number of the activities that these mobile robots will accomplish. In many of these cases, the robots are required to accomplish their assigned tasks because either no crew members are present (e.g., exploring the Martian surface in advance of crews using EVA suits or pressurized rovers, as discussed in Section 2.3) or there are other reasons for delaying the crew's entry into a specific area (e.g., entering, for the first time, an area with a high potential for supporting Martian biological activity, as described in Section 2.6). The actions of these mobile robots will be controlled, or possibly just supervised, by crew members in the field or by those members of the crew that are in the outpost habitat. This section will expand on the types of activities that will be accomplished robotically as well as describe the means the crew will use to operate these mobile robots.

The presence of mobile robots, for exploration and safety reasons as mentioned above as well as for inspection, maintenance, and repair, allows for a number of other uses that amplify the effectiveness of the crew on the surface. Several examples of these uses are described in the following paragraphs:

> Reconnaissance in advance of an EVA traverse. A lesson learned from offshore oil drilling and from incidents such as the search and recovery of TWA Flight 800 (Anon., 1998) is that robotic vehicles perform a highly effective and integral part of these activities. These remotely operated vehicles (ROVs), typically teleoperated from the surface, are used to examine work sites or other targets at close range in advance of a human diver (Anon., 1998). Information gathered in this way allows the work crews to visually identify the target or inspect the work site to help decide what it is they are looking at, what problems need to be fixed, what tools may be needed, and perhaps most importantly, whether this is a place a human diver needs to go or if the task can be accomplished by other means.
>
> A similar situation will be present for human crews on Mars. The crew will use data gathered from a variety of sources to identify, in advance, specific sites it would like to visit and to prioritize these sites. Although EVAs are assumed to be a frequent occurrence during the surface mission, operational and safety concerns will still necessitate decisions regarding the appropriateness of sending an EVA crew to all of the possible interesting sites. Teleoperated or supervised robots can fill a role comparable to the ROVs that are now used to support underwater divers on Earth. These robots can investigate sites at close range to help determine the appropriateness of sending an EVA crew. In certain circumstances, such an advanced inspection of a site will be necessary due to concerns about the environment into which the crews will be entering (see Section 2.6 regarding the "mechanical canary"). Getting the rover to the site will also provide information regarding routes to use or to avoid on any subsequent EVA traverse. Crew members operating the robots from within the outpost habitat can gather these data while other members of the crew carry out an EVA traverse based on data gathered by a previous robotic sortie.
>
> Surface robots are not the only means for accomplishing this task. Small aircraft, comparable to the remotely piloted vehicles (RPVs) or unmanned aerial vehicles (UAVs), could be used to provide reconnaissance over a potentially wide area without concern for surface hazards or obstructions. A preprogrammed route or set of way points can be provided to the vehicle as one means of traversing a certain area to gather data; an override capability can also be used to fly the aircraft remotely, allowing the crew in the habitat to cause the aircraft to loiter over a feature worthy of additional investigation or not previously identified. The presence of an ISRU capability and the associated power supply implies that such a vehicle can be refueled or recharged for multiple uses.
>
> EVA assistance. There are several tasks that occur during an EVA that can be carried out by a mobile robot accompanying the EVA crew, several examples of which will be described here.
>
> If a site has not been previously visited by either a robot or the crew, these teleoperated rovers can be used to scout a reasonable route from the present location of the EVA crew to the next location. Once at the new location, the rover can use its sensor suite to identify particular items of interest and make this information

available to the crew when it arrives.  The rover can then move on to the next site on the traverse route just in advance of the EVA crew.

Figure 2.9-1  An EVA crew member peers at his own image as transmitted by a teleoperated rover in a wrist-mounted display and control system.  The crew will be able to use control systems similar to this as a means of operating robots that accompany the crew into the field.  (© SAIC)

Experience from underwater work with divers also indicates that ROVs are useful as platforms to which functionality previously carried by the diver can be off-loaded (Anon., 1998). ROVs are now routinely used to carry tools, lights, cameras, and even hot water for the divers.  Most divers are now accompanied by an ROV which, at a minimum, provides lights for the diver and camera views for support personnel on the surface— providing a "God's eye view" of the activity from which surface personnel can suggest to the diver directions and actions to take.  Divers consider the ROV a significant safety-enhancing capability and would always use them if they were available (Anon., 1998).

This also has implications for support of EVA personnel in the field.  While at a site, a mobile robot can function as a camera platform for the crew members remaining in the habitat that are monitoring the progress of the EVA and providing support as required.  This rover can also carry tools, equipment, EVA life support consumables, and any collected samples.  Sensors not carried by the EVA crew, particularly those requiring long integration times, can be positioned by the robots at crew-designated targets to gather data while the crew moves on to other features of interest.

<u>Follow-up investigation or data gathering</u>.  If additional data or samples are required from a site already visited, teleoperated or supervised robots offer an option for accomplishing this task.  Site positions will be marked in the navigation system (see Section 2.3 for more discussion regarding the navigation system) and a viable route will be known.  A rover used for this type of task can be supervised during its traverse to and from the site and can be teleoperated while at the site to gather the desired data or samples.

<u>Independent science and exploration traverse</u>.  Even when the surface crew has multiple pressurized rovers available for extended traverses, there will likely be sites beyond the maximum range of these vehicles that will be of interest to the crew or its Earth-based colleagues, ranges of several hundred kilometers away from the outpost.  Teleoperated rovers provide a means for reaching these distant sites to gather data or samples for return to the outpost.  A rover sent on such an excursion will likely require several days or weeks to complete the round trip.  Several factors will contribute to the overall duration of such a traverse—the difficulty of the terrain, the limitations of teleoperating the rover (if this is the mode used for the traverse), and the number of stops along the way.  Because this vehicle will be traveling beyond the range that the crew can safely reach should the rover become disabled or stuck, those planning the route of travel and controlling the motion of the rover should exercise caution.  However, with such a capability, the crew can continue its exploration activities even when restricted to the surface habitat.  This capability also provides

an opportunity for time-delayed Earth-based operators to explore various sites when no crew is present on the surface (i.e., before the first crew arrives or while crews are being rotated).

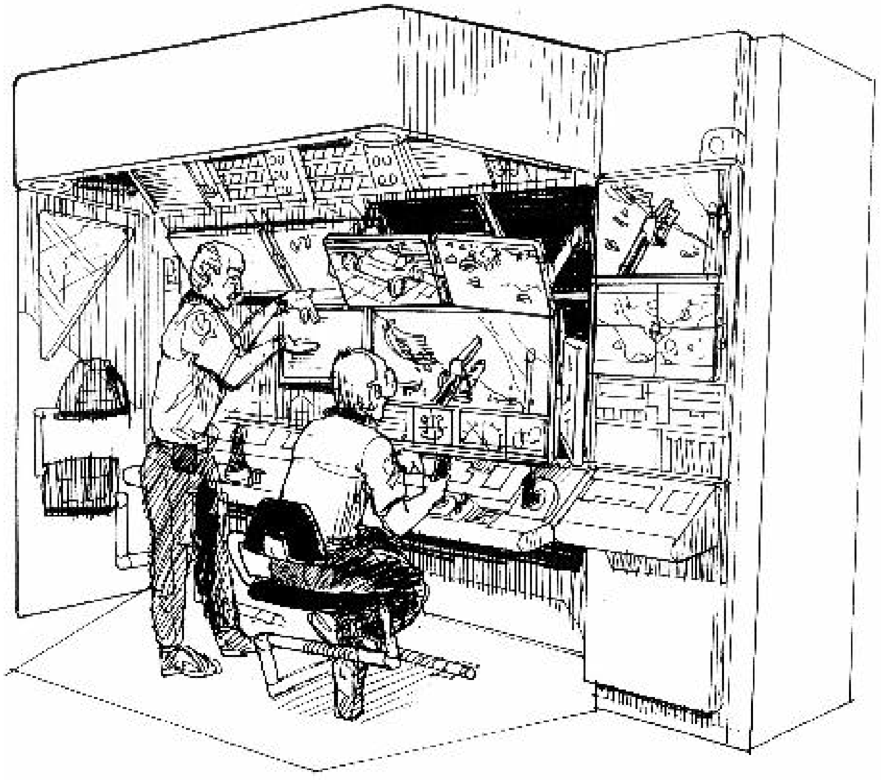

Figure 2.9-2. Artist's concept of a crew operating a rover via a teleoperations workstation inside their habitat. More than one workstation will probably be available to allow multiple rover operations to be carried out simultaneously.

These rovers are assumed to be controlled from various locations and with varying degrees of autonomy. The location and degree of autonomy are dependent on the task assigned to the rover and the level of interaction required with the crew member controlling the rover.

While supporting EVA crew members in the field, the mobile robots will be controlled either by the EVA crew or by those stationed in the habitat. In either case, the robot will be under active control or supervision, with built-in autonomous safeguards while in the vicinity of the EVA crew to avoid unintentional collisions. Control of the mobile robot during EVAs will likely be accomplished through a combination of voice commands and workstation inputs. Workstation controls are assumed to be easily accommodated computing facilities within the habitat. The EVA crew may accomplish workstation control through wrist- or suit-mounted systems or through computing capability built into the crew-transport rovers.

While operating independently of any EVA personnel, the mobile robots will be either actively operated by the crew (i.e., teleoperation) or will be supervised. (In a "supervised" operation, the crew issues a general or high-level command and the robot is allowed to determine the best set of steps necessary to respond to that command. If the robot is unable to complete the command or reaches a condition that exceeds certain preset constraints, it stops, informs the crew, and waits for additional input from the crew.) Long-range traverses are likely to be accomplished using a combination of teleoperation and supervision. As an example, the rover may be commanded to return to a previously explored site with the intent of using this location as the starting point for a more extensive traverse. The rover will be under supervision as it returns to the previously explored site, with the rover using local navigation aids and its own onboard sensors to retrace a path previously used. Once at the starting point, the crew will take a more active role in guiding the rover and directing the onboard sensors at interesting features along the way. Occasionally the crew will stop the rover to spend additional time examining an interesting feature or to gather samples for later analysis at the outpost.

Teleoperation of these mobile robots is currently assumed to be a necessity for several reasons. The pace of operations is assumed to be quicker given the close proximity of the crew and the resulting short time delay between issuing a command and receiving feedback regarding the outcome of that command. Studies have indicated that humans teleoperating a robot can adapt to a lag time of as much as one second (Ferrell, 1965); this should be feasible within a several-hundred-kilometer operating radius around the outpost site or, depending on the communications architecture, this could be accomplished on a global basis. Simulations in the field provide an indication of the gains that may be attainable. A small rover was recently operated in the Hawaii Volcanoes National Park as a simulation of rover operations on Mars and on the Moon.  When time delays and limited communications were accounted for in the Mars simulation, the estimated time for the rover to traverse 800 meters was 30 days.  A comparable traverse of 1200 meters, with time delays indicative of lunar operations, was estimated to require only 15 hours (Stoker and Hine, 1996).  Although several factors will determine the total time spent on a traverse, these results indicate that the effectiveness of rover operations will be enhanced through the use of the crew as part of the operations under appropriate circumstances.

### *2.9.1 Summary*

This section has described the use of mobile robots to support science and exploration activities on the surface of Mars.  Several key points can be derived from this section:

- Mobile robots will be an important tool for leveraging crew time and accomplishing scientific and exploration objectives.
- These robots will be active in many phases of surface exploration:  reconnaissance in advance of EVA traverses, EVA assistance, follow-up investigation or data gathering, and independent science and exploration traverses.  Simulation of these various activities will help to refine the appropriate division between robotic and crew activities.
- Teleoperation is currently assumed to be an enhancing feature to speed up the activity of the robot, thus improving the effectiveness of both the crew and the robot.  However, this conjecture needs to be tested through appropriate tests and simulations.

### *2.9.2 References*

Anon. (1998)  “EVA and Robotic Interaction; TWA Flight 800 Search and Recovery Operation Analogs,” presentation at NASA Lyndon B. Johnson Space Center, Houston, TX, Oceaneering Space Systems, June 8, 1998.

Ferrell, W. (1965)  “Remote Manipulative Control with Transmission Delay,” NASA Technical Note D-2665, National Aeronautics and Space Administration, February 1965.

Stoker, C. and Hine, B. (1996)  “Telepresence Control of Mobile Robots: Kilauea Marsokhod Experiment,” AIAA Paper 96-0338, AIAA Aerospace Sciences Conference, Reno, NV, January 1996.

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## 2.10 Life Sciences Experiments (other than routine crew health/medical activities)

A secondary benefit of placing humans on Mars for an extended period is the acquisition of a large set of data on the human (and possibly other biological specimens') physiological adaptations to the planet's surface environment. The environmental factor of greatest interest is Mars' 0.38-g surface gravity. The 18 months that the crews spend in that 0.38-g environment will almost certainly constitute the longest human exposure to date to a gravity environment different than the 1 g of Earth's surface and the 0 g of spaceflight, coming during what may well be the longest human exposure to any hypogravic environment, the projected 30 months from Earth departure to Earth landing. The Mars surface data will be invaluable in understanding the normal biological response to a range of gravity levels. In addition, the influence of other environmental parameters on human physiology will be investigated, such as prolonged exposure to the Martian light-dark cycle of 24 hours 36 minutes (perhaps just different enough from the human intrinsic circadian rhythm of 24.2 ± 0.15 hours to impede comfortable adaptation). Environmental contaminants, such as surface and airborne dust and soil, will be assessed for their toxicological potential, including possible pulmonary effects. Solar proton and galactic cosmic radiation exposure will be monitored for acute and chronic health effects.

More generally, the influence of 30 months of isolation and separation from home, family, and friends on human behavioral and psychological health can be studied in a setting of unprecedented remoteness. This will be important in planning and properly supporting the crew in its enforced isolation and prolonged interaction among a small number of individuals.

It should be remembered that most biomedical research on the Mars expedition crew members will be in support of—if not driven by—the medical monitoring required to ensure their health and fitness to continue their mission as planned. Thus, any studies conducted will have both scientific and operational results. In addition, any biomedical studies will undoubtedly be scheduled so they do not interfere with the high-priority surface exploration tasks which brought the crew to Mars in the first place.

The physiological assessment of primary interest will probably be that of bone integrity, such as the measurement of bone density. Use of a noninvasive, non-ionizing technique, probably based on ultrasound, will permit frequent repetitions of bone density measurements at a variety of sites within the body. This will document the effect of 0.38 g on retention of bone density, especially after the expected decreases (~1% per month) in density incurred during the six-month transit to Mars in 0 g. Information on the benefits (if any) of 0.38 g will permit/facilitate modifications of crew exercise and other countermeasures during the current expedition, planning for future expeditions, and may influence the design of future spacecraft which provide "artificial" gravity.

Other organ systems will be assessed for their responses to the 0.38-g environment and to the high physical workload expected to result from frequent, vigorous surface exploration tasks. Periodic assessments of cardiovascular and cardiopulmonary function may use such standardized techniques as electrocardiography, ultrasound cardiography, noninvasive blood volume measurement, measurement of vasoactive circulating factors (including norepinephrine and epinephrine), and perhaps the introduction of cardio- and vasoactive pharmacological agents. Testing may require measurements at rest, during exercise (perhaps on a cycle ergometer), and during orthostatic stress (perhaps using lower body decompression to simulate loads greater than the 0.38 g of Mars' surface).

Similarly, ultrasound or other minimally invasive techniques may be used to assess skeletal muscle status, including atrophy immediately after the six-month transit to Mars, and the possible protective and restorative effects of the surface environment and activities. Muscle strength and endurance and aerobic fitness will be measured regularly, using aerobic and resistive exercise devices that will also be used for routine conditioning and recreation (see additional discussion in Section 2.16).

Neurological function, including control of locomotion, postural stability, hand-eye coordination, fine motor control, eye movement control, etc., will be regularly assessed at rest and during appropriate stimulation, to document the effect of prolonged exposure to 0.38 g on the gravity-sensing elements of the neurosensory system.

Comparisons will be made to baseline measurements of cardiovascular, neurological, and musculoskeletal status which were made both before departing from Earth, and shortly after arriving on Mars. This will reveal the specific effects of the interplanetary transit deconditioning before strenuous surface activities, allowing modification of activity strategies as required.

The pharmacodynamics and pharmacokinetics of drug therapy in the surface 0.38-g environment will be assessed, both for comparison to the 1-g and 0-g databases, and to adjust medical therapeutics as required.

Crew member immune status will be tracked, to develop real-time health strategies and for future mission health planning. Interplanetary biological material transfer will be assessed, and strategies for biohazard containment (both Earth-to-Mars and Mars-to-Earth) will be devised and improved.

Crew nutritional status will be regularly monitored, to ensure adequate substrate to support the surface activities, and to provide a background for interpretation of other observed physiological changes.

Finally, the surface environment will be monitored for radiation levels and characteristics as well as for surface soil and dust with possible toxicological effects. Many of these data will be gathered by robotic precursor missions. Ameliorative strategies and modified monitoring procedures will be developed as necessary.

Habitability support features of the habitat will be evaluated in the partial-g environment of the Mars surface. Potential targets of evaluation are architectural layout and arrangement of the interior spaces of the living and working quarters with specific focus on the manner in which the partial-g environment either enhances or complicates daily work-related and self-sustaining chores. Particular attention will be paid to the interface of the crew with the living features of the habitat, and the manner in which the g-field influences mobility, accessibility, food preparation and consumption, hygiene activities, and any other aspects of interface with the overall interior environment of the surface habitat and vehicles. All aspects of habitability are subject to review and evaluation during the surface stay, but particular emphasis is on those that are specifically associated with the partial-g environment.

In addition to human-based research, certain astrobiology experiments will eventually be appropriate for the Mars setting. These can include Earth species transported to Mars for investigation. However, issues of planetary quarantine and ethical animal care must first be resolved.

Of particular interest is the long-term survival of simple and complex organisms from Earth in the Mars surface environment. Fundamental information can be obtained through a set of simple cross-species survival, adaptation and change experiments, including with Archaea, bacteria and simple eukaryotes (such as nematodes), each in an array of sample containers with necessary nutritional elements for their survival. At regular intervals, testing samples of each organism using DNA chips will quantify adaptational changes. If appropriately designed, these containers could be left on Mars for future missions to examine, even years later. A longitudinal ecosystem study can also be conducted, with an analytical approach similar to that described above. Organisms will be used which will derive their energy from the sun, and which will be able to survive the Martian temperature extremes. Experiments could be conducted at various depths in the Martian soil as well.

In addition, animal and plant-based research will reveal if the organism structure and function on Mars for 18 months are the same as those observed after equivalent periods of 0.38 g on the ISS centrifuge. This will validate the use of in-flight centrifugation as a simulator of the biological aspects of planetary surface gravitational environments.

Also in the domain of life sciences experiments (but primarily considered in the planetary science planning) are those experiments that will identify and document indigenous Martian life, past or present. This will require a comprehensive set of criteria to identify molecular, morphological, and planetary biomarkers, based in part on studies of Earth species in extreme environments, such as the hydrothermal vents. Similar signatures will then be searched for on Mars. This area of research is evolving rapidly and will continue to do so for the foreseeable future. Additional detail will be added as more is learned and objectives are clarified. Additional discussion regarding indigenous Martian life can be found in Section 2.8, Sample Analysis.

### *2.10.1 Summary*

To summarize, the life sciences research activities to be conducted on the surface of Mars will be shaped by several complementary requirements:

- Support monitoring for medical assurance of crew member health and fitness for strenuous surface exploration activities.
- Reveal the effects of a novel gravitational environment on the major organ systems.
- Support planning for design of future missions and spacecraft, especially those with the capability for artificial gravity.
- Document the presence, currently or in the past, of Martian life forms, and to compare them to corresponding Earth forms, for insights into the truly fundamental biological processes which may develop independently of planet of origin.

Research and development to ensure that these requirements are met will be required in the areas of:

- Identification of the critical questions to be answered in preparation for these expeditions.
- Minimally invasive, highly accurate physiological monitoring techniques.
- Development of appropriate biomarkers indicative of life on Mars.

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## 2.11 Crew Health and Medical Operations: Routine and Emergency

The mission profile of a Martian surface mission is one of primarily exploration. The crew will be actively involved with a variety of tasks, both internal and external to their pressurized habitat, designed to gain a better understand of Mars and its environment. Keeping the crew healthy and productive in this environment for approximately 18 months will undoubtedly involve some measure of medical care, typically involving routine activities but with a capability to handle more serious situations. This section will discuss the general approach that is planned for medical operations while on Mars. More specific discussions will be made of the medical activities likely to occur both inside the pressurized habitat and while the crew is some significant distance away from the habitat. Crew training and areas of necessary technology development will also be presented.

The remote nature of the Martian surface mission prevents any medical evacuation to Earth given the limited number of launch windows, prolonged transit times, and difficulty delivering medical care in microgravity. The treatment of illness and injury must therefore occur on the Martian surface. With no opportunity to learn from others' experience (the first crews on Mars will by definition be the first humans to experience this environment), the medical equipment and crew training will be kept basic and general purpose to deal with a wide range of potential events. However, there are certain mission-specific risks that could precipitate potentially catastrophic events that will require medical treatment (e.g., radiation exposure, effects of working in pressure suits, etc.) for which precautions can be taken and procedures prepared.

With this combination of known and unknown sources for medical treatment, the general philosophy for delivery of medical care to the crew will use an appropriate combination of prevention, countermeasures, and clinical treatment (Hamilton, 1998) (see Figure 2.11-1).

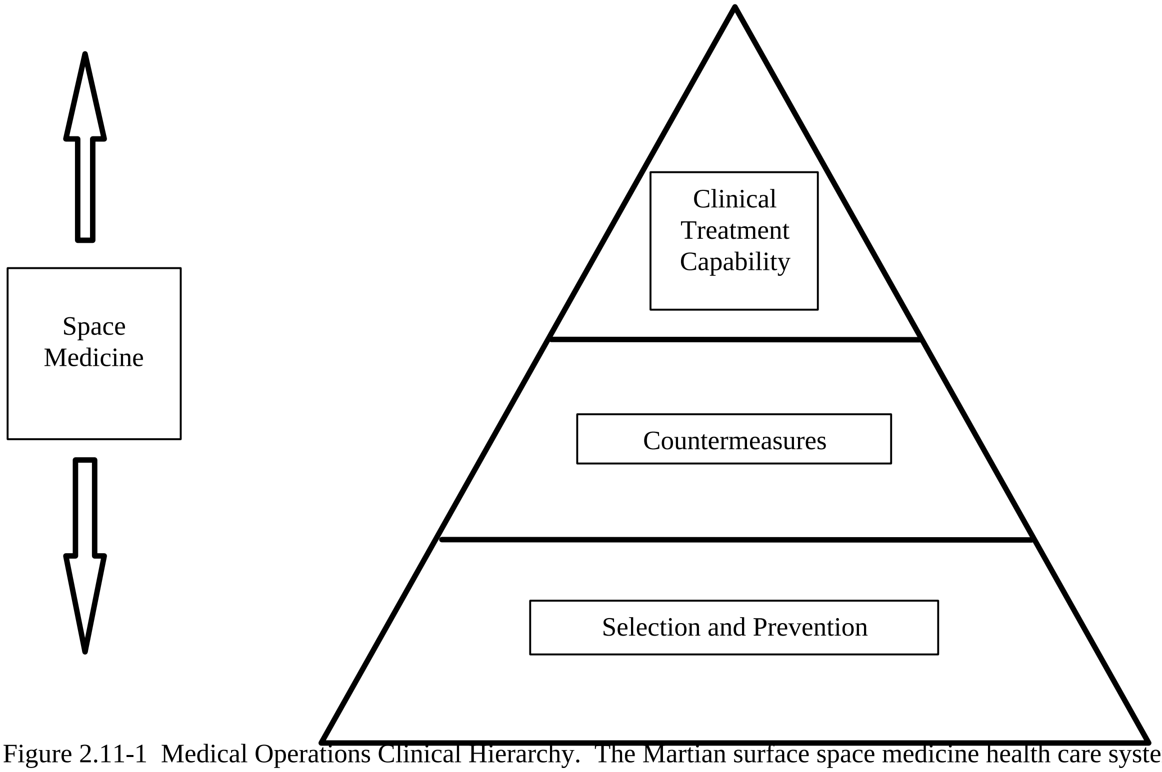

Figure 2.11-1 Medical Operations Clinical Hierarchy. The Martian surface space medicine health care system embodies the philosophy of minimizing clinical treatment requirements through a preventative medicine and countermeasures approach to health care. The capability to deliver clinical treatment is required in any medical system due to the stochastic nature of medical illness. The unusual environmental characteristics of space travel, with its commensurate occupational hazards, predicate the development of a robust clinical capability for the maintenance of astronaut health and performance.

The most effective and least expensive method of delivering medical care is through prevention. Thus, the medical care of the crew on the surface of Mars actually begins several years before the mission. This is achieved by applying previous epidemiological knowledge about space travel and potential known and predicted risks of the proposed mission to select the necessary characteristics of the crew.

The prevention of illness and injury is the most important aspect of medical care of any space crew—even on the Martian surface. There are, however, risks and risk factors associated with the Mars surface exploration portion of the mission profile that may not be mitigated through preventative measures. Those risks, and/or associated risk factors, must be mitigated through the use of countermeasures. Countermeasures are a secondary preventative medical care method which mitigates a particular risk or risk factor by changing the crew environment or prescribing a medical intervention on a crew member.

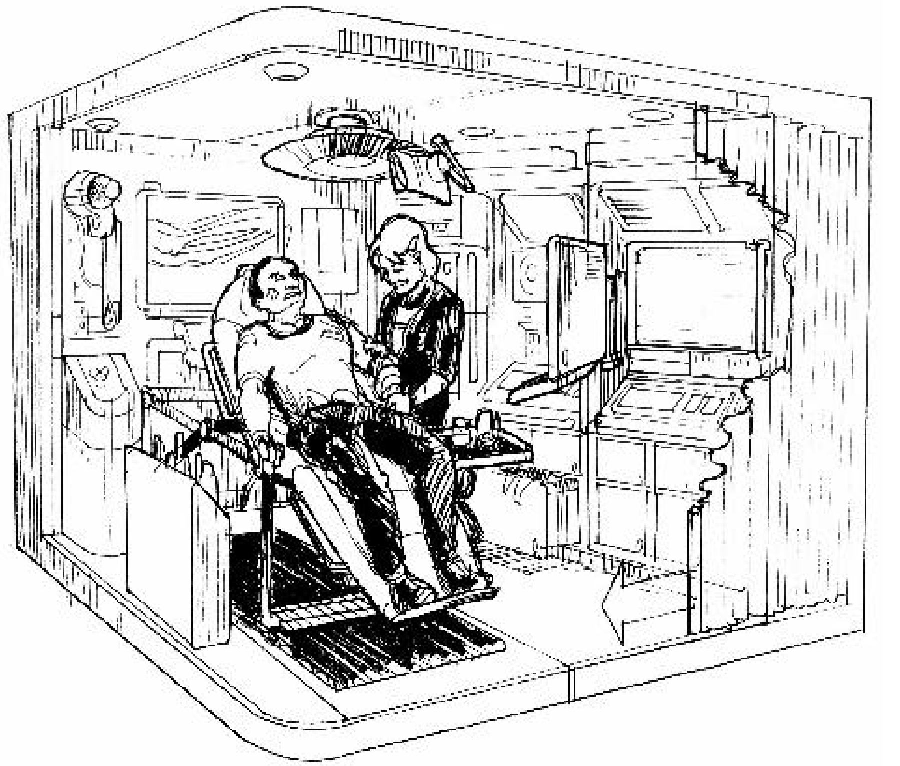

Figure 2.11-2 An artist’s concept for a centralized medical support facility will be located in the pressurized habitat. This facility will support both medical and life sciences activities associated with the mission.

Illness or injury that cannot be prevented or mitigated by countermeasures will require clinical treatment. Clinical treatment is a medical endpoint where intervention is required to mitigate illness or injury. The resources required to treat unexpected illness and injury are dependent on the mission profile and the success of prevention and countermeasures.

Medical care on the Martian surface will thus be a continuum of prevention, countermeasures, and clinical treatment. Due to the limited payload capabilities of a mission to Mars, the ability to deal with unforeseen illness and injury is very limited and, therefore, effective prevention and countermeasures are essential.

An example of this tiered medical care philosophy can be illustrated by considering radiation exposure.

- Prevention—One of the many criteria used to screen candidates for crew selection may be an individual’s natural resistance to the effects of radiation.
- Countermeasures—Drugs may be provided to the crew members to enhance their resistance to radiation effects. In addition to the suite of countermeasure drugs that may be available, engineers will examine the design implications of increased shielding, at least in selected areas (e.g., the “storm shelter” concept), to provide the crew with increased protection from radiation sources.
- Clinical treatment—In those cases where crew members fall victim to the effects of radiation, advanced life support for acute radiation sickness will be provided. The type and sophistication of the treatment capability will be the subject of study, taking into consideration the probability of this kind of event in light of the other factors (i.e., prevention and countermeasures) that have already been used to protect the crew.

There are several approaches to medical support on the Martian surface mission, including:

- Low to minimal level of care on Martian surface, accepting the commensurate risk.
- Maximal level of care, accepting lower risk but higher mass/volume penalties.
- Intermediate level, targeted toward the most likely problems encountered.

Current planning for the Mars surface mission tends to favor the latter approach, balancing the level of crew care with risk factors as well as the mass and volume constraints that will be placed on all systems carried to the Martian surface.

The facilities to care for the crew's medical needs will be concentrated in a single location in the habitat, but with provisions for emergency care distributed throughout the rest of the habitat and with those systems used for EVA, field camp, and pressurized rover activities. The central medical facility will contain most of the consumables and mass intensive medical equipment for the lengthy surface mission. These facilities should be able to deal with both routine and emergent medical problems, which can be reasonably expected given the mission profile. These problems include:

- Decompression sickness
- Radiation sickness
- Bone fractures
- Trauma
- Deconditioning
- Stress, depression, and acute psychosis
- Infection
- Dust and toxic exposures

This list indicates that the medical facilities should be capable of handling up to and including surgical procedures. (The extent or level of sophistication of these surgical procedures will be the subject of ongoing study for some period of time, taking into account the advances made in medical science both on Earth and in space over the next several years.) Sensors in the crew quarters will be capable of monitoring sick or injured crew members as they recover.

To illustrate how the philosophy of prevention first and countermeasures second may be implemented, consider the following example. The crew may wear miniature sensors to allow early detection of potential medical problems among them. These sensors are currently capable of continuous, real-time monitoring of the crews' individual physiological vital signs and may, with further technology development, track other important data such as blood chemistry measurements or the rate of bone loss in the reduced gravity environment on Mars. Continuous monitoring of these sensor readings combined with wireless transmitter technology will allow these data to be automatically stored for historical trending of individual crew members' vital signs. The crew's physician member and Earth-based support personnel will monitor these trend data (these data will be transmitted to Earth periodically for detailed study and archiving in a manner consistent with patient medical privacy) to identify potential medical problems among the crew before they become serious enough to warrant clinical treatment. These sensors can also be programmed with alarm limits so that other crew members can be alerted to an individual experiencing some sort of medical distress. (See "MICROTELESENSORS.html", 1998, for additional discussion of this technology.) A position location system tied into the local navigation/position determination system (see Section 2.3) will inform the rest of the crew as to the location of the sick or injured crew member.

It should be noted that the measurements generated during both routine and emergency activities in the medical facilities and the data gathered by the miniature sensor system will be coordinated with the life sciences experiments also taking place on this mission (see Section 2.10). All of these data will be accessible by the crew physician to monitor the general health of the crew. An onboard medical library will be available to assist with diagnoses and for review of specific procedures. The physician will also be able to consult with colleagues on Earth for specific assistance that cannot be found from other sources available to him or her.

Operations in the field, whether on an EVA, while working at a field camp, or while operating the pressurized rover, will place the crew in special circumstances with regard to medical care delivery. The majority of the medical facilities and supplies available to the crew will be concentrated in the pressurized habitat. Those members of the crew operating in the field will carry a subset of this equipment, with the focus on stabilizing injured or ill crew members so they can be transported back to the habitat for more extensive care. The medical sensor system worn by each crew member will transmit vital sign data that the physician, and other crew members in the field, can display on workstations within pressurized structures (e.g., the pressurized rover or a field camp habitat) or directly to EVA suit display systems (e.g., a heads-up display inside the helmet). If the physician is not present with the field party, data received from the medical sensors should be sufficient for the physician to direct the field crew's efforts regarding the best procedures to use (such as is presently done in many remote medical situations).


Figure 2.11-3 A crew member injured in the field is cared for by other members of the EVA crew. Sufficient equipment will be carried on EVAs to allow an initial assessment to be made of such injuries and to stabilize the crew member for transport back to the pressurized habitat.

The data provided by these advanced monitoring technologies will require a commensurate development of a set of clinical skills, knowledge, and experience among the crew members of a Mars mission. The development of advanced medical technology and the clinical diagnostic and treatment capabilities for the crew must be compatible with the "standard of care" expected for a Martian exploratory mission.

This example points out the need to train all crew members to support basic first aid for a wide variety of potential illness or injury situations that could occur in any of the locations the crew expects to explore on the surface. An assumption in previous mission designs (see Section 1.4) is that one member of the crew will be a trained physician and this person will be responsible for the basic medical care of the crew. However, all crew members will carry a responsibility for assisting the physician as the situation warrants. All of the members of the crew may need to be trained in other medical skills, such as nursing, emergency medical technician, or physiotherapy. An onboard medical library will contain training information that the crew will use for maintaining these first aid and other medical support skills throughout the mission. This library and the training information it contains can be updated from Earth as necessary during the mission.

The remote nature of the Martian surface mission and the implications of providing medical care under these conditions indicate that a significant effort should be directed toward development of appropriate technologies and procedures to support the crew. First and foremost will be an expansion of medical knowledge in those areas where known medical risks exist for this mission and development of appropriate preventative techniques and counter-measures to mitigate these risks. Research on Earth and at the ISS can be an effective means of expanding this knowledge. For those stochastic events that will undoubtedly occur, additional study is required to determine which are most likely to occur, given other preventative procedures and countermeasures, and thus require the development of equipment, procedures, and crew training for the Mars surface mission. Examples of technology development areas related to these medical support areas include:

- Development of clinically essential noninvasive procedures and diagnostics.
- Development of medical therapeutics and diagnostics unique to a Mars mission.
- Miniaturization of medical equipment, particularly imaging and analytical systems.
- Recycling of resources, particularly invasive instruments, sterile cloth, and biohazardous containers and tubing.
- Development of extended shelf life capability for medications and other medical consumables.

### *2.11.1 Summary*

This section has discussed the general approach that is planned for medical operations while on Mars. More specific discussions highlighted the medical activities likely to occur both inside of the pressurized habitat and while the crew is away from the habitat as well as crew training and areas of necessary technology development. Key points that can be emphasized from this discussion that are pertinent to developing an effective medical support infrastructure for future Mars surface crews include:

- Develop the medical knowledge and technologies needed to maintain human health and performance on the Martian surface.
- Develop systems and procedures to prevent, diagnose, and treat illness and injury on the Martian surface.
- Develop a group of physician astronauts with the appropriate clinical skills and training in space medicine to support a Martian surface mission.

### *2.11.2 References*

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“MICROTELESENSORS.html” (1998) <http://www.ornl.gov/~11r/TELESENSOR_ASICs.html> [Accessed 26 October 1998].

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## 2.12 Wardroom and Food Preparation

Previous long-duration, isolated missions have shown that a space large enough for the entire crew to interact with each other can be beneficial for individual emotional and crew morale purposes (Stuster, 1996). In the past, wardrooms served this purpose by providing the crew with "crew entertainment, eating and briefing area[s]" (pet.jsc.nasa.gov/alssee/demo_dir/ehti2/accom1.html, 1998). To satisfy this need, the Mars surface habitat will have a wardroom sufficiently large to accommodate the entire crew at one time. However, a Mars surface habitat will have limited amounts of usable volume. Thus, rooms designed to provide multiple functions will be essential. A wardroom combined with a galley will be one area where crew members can accomplish several mission-critical activities. The area will provide some food storage space, room and equipment for eating and associated activities, and a general office or entertainment area for the whole crew. The most relevant analogies available for study of wardroom activities and functional capabilities as used by small crews in isolated environments for relatively long-duration missions are experiences from Skylab, the Shuttle, the Amundsen-Scott South Pole Station, and inside the Life Support Integrated Test Facility at the Johnson Space Center (JSC). Plans for the ISS and the BIO-Plex facility at JSC also offer valuable insight. This section reviews these sources and suggests guidelines for layout and equipment to accommodate specific activities that may take place within this space during a Mars surface mission.

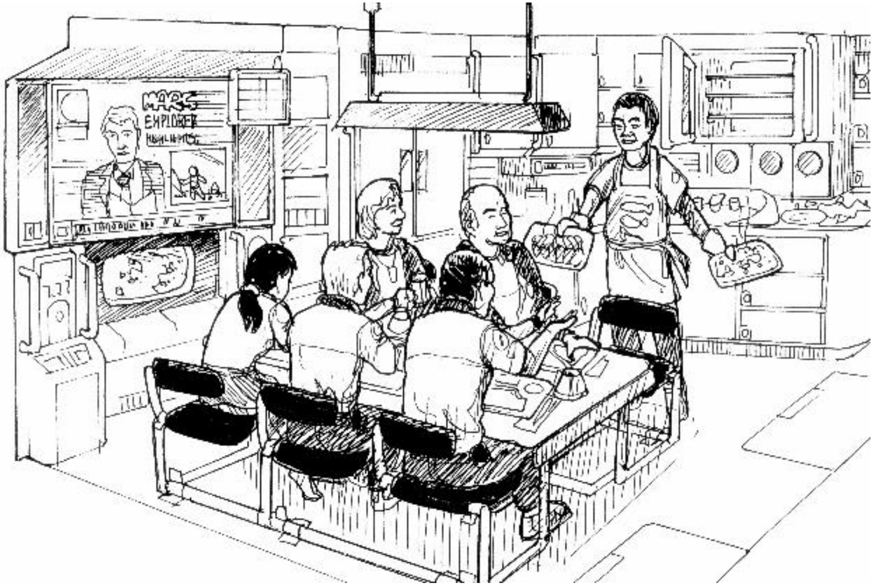

Figure 2.12-1 An artist's concept of the wardroom and galley area. This will be a space large enough to accommodate the entire crew for meals, meetings, or other special events.

The wardroom and galley areas should share one room or two connecting rooms in the habitat. The wardroom area will be large enough to hold the entire crew at one time. This layout is desirable in cases when the crew needs a place to talk in person, such as in the event of an emergency, important meeting, or celebration involving the full crew. The area should also have a central location within the habitat. The space will be useful in many daily activities, in addition to meals, so it should be easily accessible to the crew. The room design will accommodate the most likely users: groups of three or more people. It will also meet the needs of two people or a single person wanting to study or relax, so long as the traffic through such a high-use area is not bothersome. The wardroom should contain at least one window. Skylab crew members and designers fought hard to include a window in that wardroom and found it to be a popular feature of this space (Compton and Benson, 1983). During the Skylab missions crew members spent a great deal of time using the window provided. Similarly, Shuttle crews spend a great deal of their free time looking out of various windows in the crew module. Section 2.15 discusses the importance of a window in more detail.

One prominent feature of the wardroom area will be a large table. Skylab had a wardroom area containing a versatile central table with spaces for all three crew members (Belew & Stuhlinger, 1973). Similarly, the Life Support System Integration Facility has a large, popular wardroom table with a rolling chair for each crew member. Thus it is reasonable to assume that the crew members in the Mars surface habitat will need a large table for meals, as a place for meetings or discussions, as a workspace or desk, or as a site for Public Affairs opportunities.

An additional feature appropriate to this space is an “information wall.” This wall will incorporate one or more large projection screens and bulletin boards. With this and other equipment the crew can display information, watch videos, make presentations, or carry out other group functions. The wall can publicize information interesting to the crew such as the current date and time, a weekly menu, schedule information, a task list, and a variety of statistical information, such as the cumulative hours of EVA time or distance traveled to various sites. If the crew uses an intercom system to communicate with each other inside the habitat, the information wall is a suitable location for any main controls. The large screens could also show images from external cameras. Views of the surface of Mars will no doubt be intriguing to the first human guests on the planet. Crew members will also want to watch their team members performing EVAs, as well as be able to view external conditions and equipment.

Another important function that the information wall can accomplish is the display of decorative images or artifacts. Research shows that teams in remote and isolated locations need and enjoy the ability to look at large and/or colorful pictures, especially outdoor landscapes; the use of holiday scenes or other select images is also acceptable (Stuster, 1996). Display of these illustrations on one of the screens is one method to accomplish this, as is posting these images on the bulletin board or wall space. These pictures might change with the seasons of a designated place on Earth, or rotate according to crew members’ personal choices. Certain colors that are pleasing to the eye, and posters that show familiar scenes of home will put the crew members’ minds at ease during their long journey and stay on the surface (Compton and Benson, 1983). Postings should be generic and acceptable to all crew members; nothing shown in public areas should be offensive to any crew member to help maintain crew cohesion and morale (Stuster, 1996).

The most common activity in the wardroom will be eating, making this activity a key factor in planning the accommodations in the wardroom. The following paragraphs discuss several suggestions on this process that again incorporate experiences from the Skylab, the Shuttle, and the Life Support System Integration Facility tests, as well as plans for the BIO-Plex and the ISS.

Food selection and menu preparation will be a collaborative effort involving the crew and dietitians. There will be several pre-mission taste tests in which crew members may choose to record personal preferences or make suggestions for changes. They will identify specific foods they like and dislike. It is important to note that crew members’ tastes can and will change over the duration of the mission, so some complaints about the food are likely regardless of the level of preparation. In addition to crew members' input, the menu planning process will directly involve dietitians. They will review crew members’ lists of likes and dislikes and take into account nutritional requirements in an attempt to create a set of meals acceptable to everyone. Specific nutritional requirements for long term spaceflight are currently unknown. However, menu planners will incorporate results of future research into this process as appropriate. A final joint review with everyone involved will produce a final menu plan.

Shuttle menus currently allow each crew member to select a unique combination of foods for each meal, none of which necessarily come from their own preflight selections (jsc.nasa.gov/pao/factsheets/nasapubs/food.html, 1998). To provide crews with nutritionally better meals, and combat weight loss problems faced in the past, there is currently an attempt to move towards cyclic menus. Isolated crews in tests up to 91 days successfully used 10- to 12-day menu cycles. Experts must determine a suitable interval for the Mars mission based on variety and volume of food available. Each meal should offer a few choices for crew selection (Stuster, 1996). Menu planners may choose to sort foods into the food groups and allow crew members to select one item from each group to make up a meal. Another option used in the Life Support System Integration Facility tests is to serve a standard main course and offer a choice among several drinks, side dishes, and desserts. Snacks between meals will also be available. This modularity will provide necessary variety for crew members. Menus may include vitamin supplements to ensure that crew members meet their daily nutritional requirements, no matter what foods they select for their meals.

Judging by past experiences, it is reasonable to assume that there are four main types of meals the crew will encounter during its mission. The crew must have equipment and plans in place to accommodate each type.

Meals eaten “on the run” will be common. Menu and schedule planners should not force crew members to use short meal periods. However, crew members may sometimes prefer to eat quickly or while performing other duties. Simple meals that require little or no preparation will be especially useful in these situations. More elaborate meals will occur when the entire crew eats together. Most isolated crews try to maintain a common, mutually agreeable dinnertime, no matter how hectic schedules become. Crew members should make every effort to plan for one group meal per day. Group meals provide necessary team bonding, as well as desired social interaction and organizational opportunities (Stuster, 1996). The responsibility for preparing a meal for the group will rotate periodically. There will also be milestones to celebrate during the mission such as birthdays, holidays, the first steps on the surface of Mars, or other special occasions. Theme dinners will help mark these events, and assist the crew in acknowledging the passage of time on its journey. Preparing meals from scratch in a more traditional manner may be one way to set these meals apart from everyday provisions. Meals that are more elaborate than usual or provide specific, authentic foods for the occasions are also suitable. This will give crew members something to look forward to, and add an extra bit of variety to the menu. Both of these things are important to the success of a long-duration mission (Stuster, 1996).

Menu and schedule planners, along with dietitians, must ensure that crew members performing EVAs receive adequate nutrition, especially if plans call for long or strenuous activities. Development is in progress that will allow suited crew members to eat during an EVA, as Apollo astronauts did while walking on the Moon. This will become useful to crew members if meal times before an EVA are short.

In addition to space provided for large group meals and other group activities, the wardroom and galley areas will provide accommodations for some food storage, storage for meal preparation and cleanup equipment and supplies, a meal preparation area, and facilities to clean these areas and the utensils used to prepare and consume meals.

Food storage space will house food for use in the near future, with long-term storage elsewhere in the habitat. This space will accommodate shelf-storable items as well as temperature-controlled equipment such as a refrigerator or freezer. This equipment should be near meal preparation areas for easier use.

Due to the length of the Mars surface mission, utensils for meal preparation and consumption are assumed to be reusable as opposed to disposable, to conserve both mass and volume. This implies that cleaning supplies and facilities will be required to sanitize these utensils to avoid possible health risks to the crew. Examples for storage for these items might include moveable racks, overhead cabinets, or under-the-counter bins.

Each of the different types of meals discussed will require different amounts of time, space, and equipment to prepare. Those in the “on the run” category will obviously require the least amount of all of these resources; the evening meals for the entire crew will require the most resources and will define accommodations located in the galley area. These evening meals will typically involve heating some portion of the food. Multiple small heating units or one large unit will be useful to reduce preparation times. A crew of four used two microwaves in the Life Support System Integration Facility and did not have problems (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). On the other hand, crews on the Shuttle complain that the oven warmer is too small and takes too long to heat food. During docked periods, Shuttle astronauts often used the faster heater on the Russian space station *Mir*. Redesigning and repackaging new machines to be smaller, faster, and capable of performing several different tasks will assist crew members in speedy meal preparation and will save both space and mass in the limited food preparation areas. The galley also needs hot and cold water dispensers for meal preparation since a few meals will include dehydrated foods that require water for reconstitution. These dispensers might be part of a small sink, or simply ports on the galley wall, as is the case on the Shuttle (liftoff.msfc.nasa.gov/academy/ASTRONAUTS/food-system.html, 1998). Another useful tool to have, in addition to dispensers, is a water heater. Shuttle crews use a water heater (shuttle.nasa.gov/reference/shutref/crew/food.html, 1998), and there are plans to provide one on the ISS.

To avoid food contamination and the associated risks to crew health, there will be ample facilities and supplies to sanitize all areas and equipment involved in meal preparation, meal cleanup, eating, and food storage. At present it is unclear if commonly used cleaning supplies pose a risk to the biological life support system that is used to recycle water within the habitat. Alternatives exist (e.g., steam sterilization) and will be investigated as the biological life support system technology, as well as the habitat design, evolves.

Another area that still needs development, is the actual food for the mission. Current plans show that frozen and dehydrated foods will be the most likely food forms available to Mars surface crew members. This is because of their long shelf lives, superior nutritional value, simple packaging, and the extensive experience using them. Current Shuttle flights rely on about 50% dehydrated foods and about 50% intermediate moisture foods (Vodovotz, 1998). These numbers reflect mass and volume constraints in the Shuttle; although different values will apply to a Mars mission, constraints will also exist. Dehydrated foods offer mass and volume advantages over frozen or shelf storable foods that retain most if not all of their original water content. The drive toward a higher percentage of frozen foods is due to the fact that frozen foods are higher in nutritional value than dehydrated foods. In the future, menu planners hope to use more frozen or microwave meals, similar to those commercially available today. They are easy to prepare, and there is a great deal of variety obtainable. However, frozen and microwave meals require more development before they are ready for use. Currently microwave dinners have a shelf life of about three to six months. This number needs to increase to meet the extended duration of Mars missions which, allowing for extra mission days and the time supplies will sit awaiting launch, could be as much as five years. Irradiated steak and turkey are now available for astronauts to consume on the Shuttle, and both have a shelf life of around three years. Further development in this area, particularly in commercial applications, may raise acceptance levels and provide readily available technology that will allow crew members to eat irradiated foods in the future.

Dairy products are another nutritionally important food group usually missing from astronaut diets. Vitamin supplements are one solution, but others should be investigated.

Finally, there is an ongoing complaint that space food is too bland. The addition of condiments to meal plans was helpful,[*] but experts should consider other solutions to this problem. One option to overcome the bland food complaint is to grow fresh herbs or other small edible plants in an onboard garden. Experience from the Life Support Systems Integration Facility tests show that the inclusion of a small garden will greatly enhance meal quality, as well as meal acceptance by the crew (Tri, 1998). This crew enjoyed wheat grown inside a variable pressure growth chamber and fresh foods from a small garden inside their habitat. American astronauts aboard the Russian space station *Mir* performed plant growth cycle experiments to occupy their time. There are also plans to include a small garden in the habitat module of the BIO-Plex in addition the planned Biomass Production Chambers (Tri, 1998). Truly fresh food will be scarce and certainly provide a treat for crew members if available. Dinners for special occasions might include fresh foods grown in the garden. Growing and nurturing the plants presumably also will become a recreational activity. However, menu planners should not rely on the garden to produce any significant percentage of food during the mission.

Meal preparation itself can also serve as a welcome diversion from other daily activities for every member of the crew. For those members of the crew that enjoy cooking, this also could become a means to satisfy a personal need for creativity while providing the entire crew with variety during this shared activity. However, meal preparation should also not require an excessive amount of the crew’s time.

Crew members on the surface will need and want to devote a large portion of their time to science and work-related activities. Meal preparation times cannot conflict with or constrict these activities. Schedules will allow plenty of time for actually consuming each meal, and meal preparation must not cut into this process either. Inside the Life Support System Integration Facility a crew of four had an average meal preparation time of 22 minutes during the 91-day Phase III test (Edeen, 1998). Most of the meals consumed (60%) were microwave meals similar to those proposed for use on Earth (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). Considering this, the process for one person to prepare dinner for the whole crew should take no more than 30 minutes. Times will be much faster for other meals, except for special occasion meals that might be more elaborate. Individuals will prepare their own meals when crew members choose to eat separately.

Any large-scale food processing will need as much automation as possible. If menu planners rely heavily on crop growth and therefore a large amount of food processing, habitat designers must provide more counter space, storage space, and associated equipment. Several problems exist with using crops as a major food source. The BIO-Plex and other tests are investigating most of these obstacles in hopes of finding adequate solutions. Too many unknowns in the process currently prevent the selection of plants as the primary food supplier. Significant advances in this area may allow plants to become a suitable source of food in the future.

Menu and scheduler planners should provide time and supplies for three meals per crew member per day, as well as snacks. Crew members should try to maintain a standard dinnertime, while individual crew members may choose

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[*] An exception is sodium. There must be a reduction in the use of sodium to preserve foods. Sodium cuts down on the amount of calcium bones can store, and calcium loss is currently a large concern during long-term spaceflight (Vodovotz, 1998).

other exact meal and snack times for themselves. Mealtime (consumption, between 30 to 60 minutes) does not include setup and cleanup, and is based on an average of actual Shuttle and Skylab times, and ISS and BIO-Plex plans. The time will vary depending on the meal, the number of people eating, and the items making up the meal. Table 2.12-1 shows the average times used by past crews for meal preparation, meal consumption, and meal cleanup:

**Table 2.12-1 Average Daily Total Meal Times for Past Isolated Crews**

| Mission or Test | Meal Preparation (minutes) | Meal Consumption (hours) | Meal Cleanup (minutes) | Number of Crew Members |
|---|---|---|---|---|
| 90-day test, 1970<br>(Pearson and Grana, 1970)) | NA | 2.1 | NA | 4 |
| Skylab 2*<br>(www.ksc.nasa.gov/history/skylab/skylab.html, May 1998) | NA | 5.7 | NA | 3 |
| Skylab 3*<br>(www.ksc.nasa.gov/history/skylab/skylab.html, May 1998) | NA | 5.5 | NA | 3 |
| Skylab 4*<br>(www.ksc.nasa.gov/history/skylab/skylab.html, May 1998) | NA | 5.5 | NA | 3 |
| Shuttle (generic)<br>(Vodovotz, 1998) | 10-60<br>(actual) | 3.0<br>(planned) | 5<br>(actual) | 2-7 |
| Phase III<br>(Edeen, 1998) | 22 | Unknown | 17 | 4 |
| ISS (plan)<br>(Alibaruho, 1998) | 10-60 | 3.0 | 5-10 | 3-10 |
| BIO-Plex (plan)<br>(joni.arc.nasa.gov, May 1998) | 45 | 2.0 | NA | 4-7 |

*Recorded as “Pre/Post-Sleep & Eating”
Note: All preparation and cleanup times listed as “NA” were recorded and are included in “Meal Consumption” times

Crew members will be responsible for cleaning up their own wastes after each meal. This will include finishing the entire portion of food served, compressing food packages, wiping clean all trays, utensils, and food preparation areas used, and storing all equipment and wastes. The whole cleanup process should only take about ten minutes. Shuttle meal cleanup takes about five minutes for up to seven crew members, and Phase III meal cleanup took an average of 17 minutes over 91 days for four crew members (Edeen, 1998). One part of the cleanup process that needs major investigation is the consolidation and storage of food packaging wastes. Dehydrated food packaging currently accounts for 40%-50% of the total mass (Vodovotz, 1998). Large amounts of waste from food packaging materials is a problem on Shuttle flights, and will be a much greater obstacle during long-duration missions. Section 2.17 discusses the storage of trash within the habitat in more detail. Planning and packaging menus together by meal, rather than separately for each individual person, will help solve this problem to some extent.

### *2.12.1 Summary*

This section focused on the proposed wardroom and galley area of a surface habitat and the activities that will take place there. Defined needs regarding the use and design of the facilities include:

- Adequate space and equipment in the wardroom for the whole crew to simultaneously perform various activities associated with eating, briefing, or entertainment.
- Temperature-controlled food storage and food-heating units.
- Further research into developing foods or food storage systems to meet a 5+-year shelf life storage requirement.
- Better information regarding nutritional requirements for long-duration spaceflight.
- Cyclic menu planning involving both crew members and dietitians.

- Plans for a group dinner at least once a day.
- Short meal preparation and cleanup times.

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## 2.13 Personal Hygiene

This section covers a number of crew activities collectively referred to as personal hygiene. As used here these activities include body cleansing and grooming, elimination of bodily waste, and cleaning clothing. Maintenance of good personal hygiene by all crew members will be important not only for obvious health reasons, but also as a means of maintaining individual and group morale (Stuster, 1996). The importance of this area is such that the mission commander or other leader should enforce the regular use of hygiene equipment and time allocated for these activities.

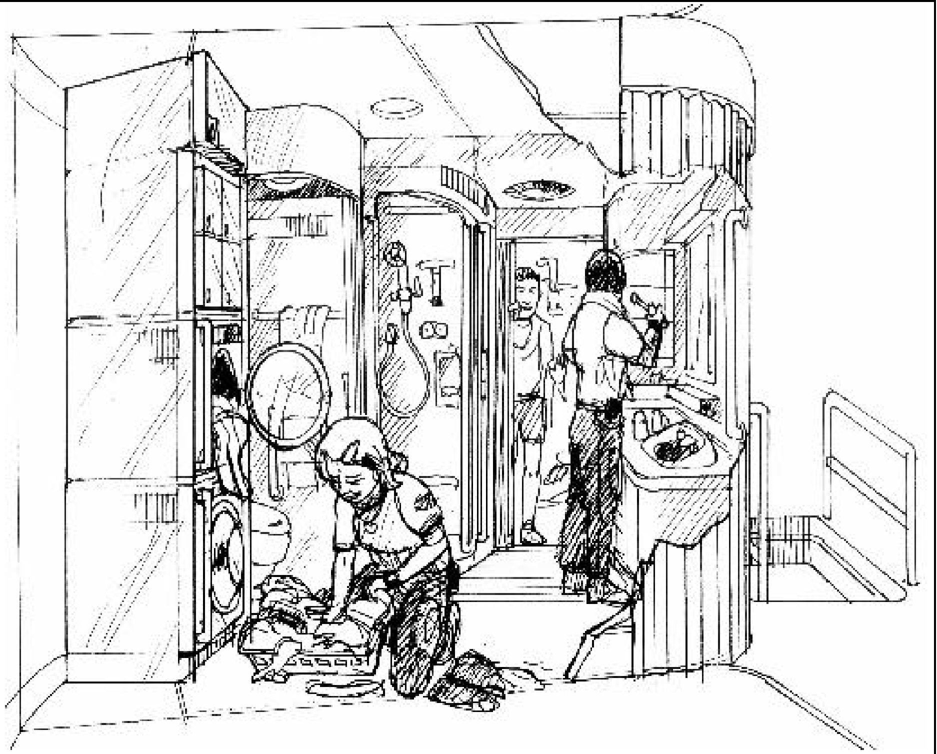

Figure 2.13-1 An artist's concept for the hygiene area in the pressurized habitat. This area will have accommodations for body cleaning and grooming, elimination of bodily waste, and cleaning clothing.

Skylab had only one bathroom that could accommodate one person at a time. All three crews complained about waiting to use the facilities, and how it interfered with their schedules (Compton and Benson, 1983). Therefore, the Mars surface habitat will contain space for two bathrooms. One bathroom will be larger, with space to contain several people at once. This will allow multiple crew members to perform hygiene activities, such as shaving or brushing their teeth, simultaneously if necessary. A second smaller bathroom will accommodate at least one crew member. The large bathroom will most likely be close to the crew members' private quarters. In addition to ample volume, the large bathroom will include a sink and countertop, storage, a large mirror, a toilet, and a full-body cleansing system. Each of these pieces of equipment proved valuable to crews in the past. The sink will perform as on Earth and in past space missions to accommodate hygiene activities such as shaving or brushing teeth. Just outside the big bathroom will be a personal storage area including some form of cubbyholes or lockers. For more convenient use, crew members can then keep bathroom supplies in close proximity to the bathroom and obtain them while the facilities are in use. A large mirror will "help reinforce crew members' personal image of themselves" (Stuster, 1996). There will also be a toilet or some kind of urine and solid waste collection device in the large bathroom. The second, smaller bathroom will be in a different section of the habitat than the larger bathroom, perhaps closer to a main work area, or next to the airlock. This bathroom will include a sink and countertop, a urine collection device, and a small mirror. The addition of a second solid waste collection device in the smaller bathroom is desirable, provided the life support systems can accommodate it.

The design for a full-body cleansing system within the habitat will be influenced by previous flight experience. Crew members rarely used their shower on board Skylab (ksc.nasa.gov/history/skylab/skylab.html, 1998) and Shuttle astronauts manage with only sponge baths during their missions. Although these may seem like arguments against including a full-body cleansing system, they are not. Skylab and other isolated crew members stated several times the desire to have full-body cleansing facilities for use after exercise periods or long durations without any personal hygiene. The process was either unavailable, or avoided because it was too cumbersome. There are several problems with past shower designs to correct in future full-body cleansing system plans. First, it is advantageous to provide a way to measure and restrict the amount of water used. This is different from limiting the actual time spent bathing. In other words, flow might stop after a crew member uses two gallons of water, rather than after two minutes of using the system. Crews in the Life Support System Integration Facility successfully used the first method, while crews on submarines and at South Pole stations still endure the time limit technique (http://www.southpole.com/log.html). Another problem the Skylab crews mentioned was the lengthy setup of shower-related equipment. Preparations sometimes took nearly an hour, and crew members skipped many showers simply because this process was too drawn-out. Crew members also complained that showers were too cold. After the water shut off, Skylab crew members spent up to ten minutes using a vacuum hose to extract all remaining water out of the shower and off their bodies. Again, Skylab crew members avoided showers because of the uncomfortable nature of the method (Compton and Benson, 1983). Full-body cleansing system designers must find a way to escape both of these problems in the future. The implementation of this full-body cleansing may change between partial gravity and zero gravity phases of the mission, but some form must always be available for use by the crew. Previous experience shows that crew members desire some form of full-body cleansing every day, especially if they rigorously follow their exercise routines.

Each crew member will obtain certain personal hygiene supplies. Shuttle crew members currently receive one full-body towel and two washcloths for use each day during their missions. Similar supplies in a Mars surface habitat must be washable; the mass of taking disposable clothes and other supplies for the entire mission surpasses the mass of providing a washer and dryer system and associated water recycling. Each crew member will also receive a personal hygiene kit. The articles in this kit allow for shaving, as well as hair, scalp, skin, teeth, and nail care (http://shuttle.nasa.gov/reference/shutref/ crew/hygiene.html). An additional kit will also provide feminine hygiene supplies. Based on current plans for providing some common hygiene items to the first ISS crew, Table 2.13-1 provides an estimate of the mass and volume associated with personal hygiene items (Watson, 1998). The three-person crew is all male and will be aboard the vehicle for 143 days.

**Table 2.13-1 Estimated Mass and Volume for Personal Hygiene Items**

| **Totals** | | |
|---|---|---|
| Total mass for 18-month surface stay | 48.46 kg | For one crew member |
| Total mass for 18-month surface stay | 290.76 kg | For six crew members |
| Total volume for 18-month surface stay | 0.1549 m^3 | For one crew member |
| Total volume for 18-month surface stay | 0.9291 m^3 | For six crew members |

Another important part of maintaining good personal hygiene is the availability of fresh clothing. Both expert opinion and past experience express the crew’s need for several types of clothing (Compton and Benson, 1983). They also state that these clothes should be colorful and allow crew members to exhibit individual personalities to some extent. These clothes include items for use inside the habitat while performing regular activities, garments to exercise in, and clothes to wear to bed. In addition, crew members will need undergarments, socks, and slippers or shoes for use inside the habitat. Crew members will have enough clothing to change outfits regularly. Disposable clothes are not practical for a mission of this duration due to mass and volume limitations.

Some experts suggest that the crew members receive a new set of outer garments every two weeks and different undergarments every other day. Crew members inside the Life Support System Integration Facility had a variety of clothing that lasted the time between their one personal load of laundry allowed per week (http://pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html). The first ISS crew members will receive one pair of shoes per four months, new undergarments every two to three days, and a change of outer garments about every week to ten days. Their exercise and sleep clothes will be good for three to seven days. Other items such as sweaters and jackets will last the entire 143 days (Watson, 1998). Crew members on the surface of Mars can expect to change their clothes at rates similar to those mentioned above. A washer and dryer system is desirable to allow crew members to clean their clothing on a regular basis. Some extra clothes will allow for anticipated wear and tear, and a basic sewing kit will permit crew members to mend their clothes. Crew members may hand wash clothes in bathroom sinks occasionally, but a more automated process would be better. In addition to the personal laundry loads allowed in the Life Support System Integration Facility each week (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998), crew members did one common load of towels, washcloths, and sheets each week. Crew members may also choose to use this method in the Mars surface habitat. However, water supply levels will also determine the frequency of washer use somewhat.

Each day crew members will have some time to perform personal hygiene. Schedules now include a standard 30-minute hygiene period in the morning as part of post-sleep activities and another 30 minutes at the end of the day as part of pre-sleep activities (Belew and Stuhlinger, 1998). These numbers were suitable in the past and should be adequate in the future. The schedule will also include additional time for personal hygiene after routine exercise periods. Crews that had the facilities usually preferred their routine full-body cleansing immediately following exercise periods, and this will most likely be the case in the Mars surface habitat. Also, immediately before an EVA crew member exits the habitat, they will perform any necessary personal hygiene. A bathroom near the airlock will be very convenient for this purpose.

### *2.13.1 Summary*

This section discussed crew members' requirements for personal hygiene. Important issues regarding the time and facilities necessary include providing:

- Hygiene facilities to accommodate multiple personal hygiene activities.
- A full-body cleansing system.
- A clothes-cleaning system to eliminate the need for disposable clothes.
- Supplies similar to the Shuttle and ISS personal hygiene kits.
- Standard personal hygiene times at the beginning and end of every day, after exercise periods, and before and after an EVA.

### *2.13.2 References*

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## 2.14 Crew Quarters

To remain productive and proficient during a long-duration mission, crew habitats will need to possess certain characteristics, the most meaningful of which are facilities and equipment for ample sleep, privacy, and personal space. A surface habitat must contain crew quarters and associated supplies to suitably accomplish these aspects of crew support. This section suggests several functions and configurations of crew quarters, taking into consideration lessons learned from Skylab and Shuttle designs and positive changes evident in JSC's Life Support System Integration Facility tests, as well as ISS and BIO-Plex plans.

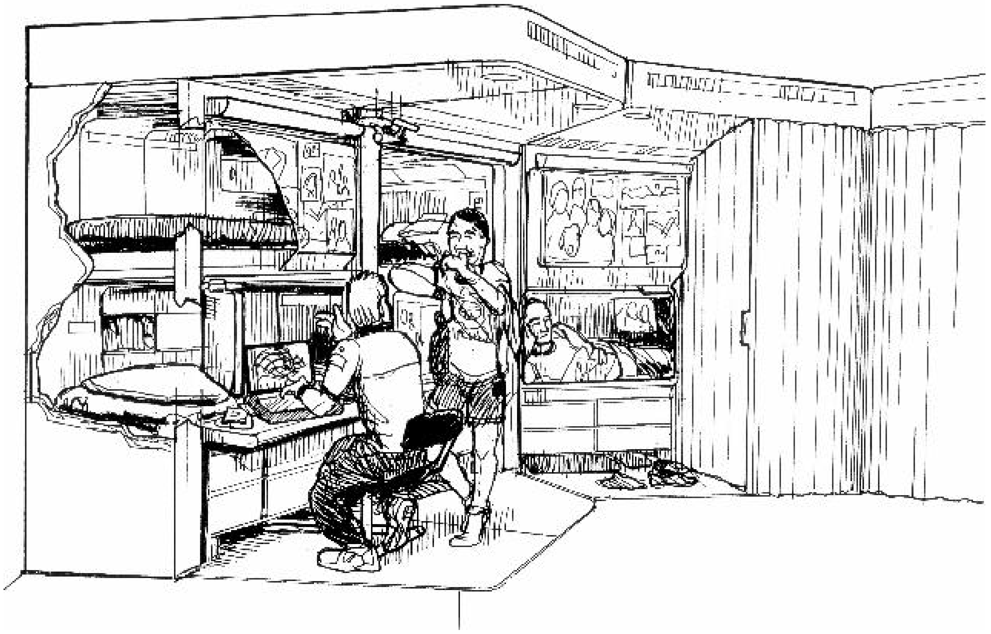

Figure 2.14-1 An artist's concept of crew quarters inside the pressurized habitat. These quarters will accommodate not only sleeping but personal working space. Partitions will allow individual areas to be closed off when desired or opened up to provide more space.

Crew quarters designed for these long-duration missions should balance the individual crew member's need for privacy and the desirable strategy for a means of mutual psychological and emotional support among the entire crew. The rooms should provide a place to sleep, relax, or work in private; simply closing a door or raising a partition should accomplish this, so long as other crew members recognize and respect these simple signs. Some amount of withdrawal into a private area, away from the rest of the crew, is normal and even necessary for individuals under these confining circumstances. However, if a crew member is excessively withdrawing into his or her room (a potential indication of depression; Stuster, 1996), other crew members should properly identify and address this problem. In one technique that was applied in such circumstances in the Antarctic, two people (same gender) share some portion of their room "as a form of enforced buddy system to help ensure physical and psychological survival in a hostile environment" (Stuster, 1996). Some type of removable partition can be used to separate the room into two distinct sides. People at the South Pole Station and other U.S. stations in the Antarctic choose to hang curtains from the ceiling to separate rooms shared by four crew members into private areas (astro.uchicago.edu/home/web/cbero/mainmail.html, 1998). The Mars surface habitat may employ this or other comparable methods to separate crew quarters. Figure 2.14-1 illustrates one possible means of incorporating these various features into the crew quarters area. Individual sleeping areas can be closed off to control light, sound, or other distractions. Partitions allow crew members to have privacy when the divider is up, or obtain more space if taken away. This variation in configurations is desirable for several reasons. Crew members will need a place to dress or think in private, and experts suggest that sleeping may be easier if crew members have their own rooms. However, additional space will help crew members avoid feelings of claustrophobia experienced by several people in cramped remote habitats. The partition will also allow crew members a limited ability to shape their rooms according to their own preferences.

Privacy concerns also extends to monitoring crew activities. Cameras inside the Life Support Systems Integration Facility at JSC constantly monitored crew activities during long-duration tests. It is probable that a similar system will be used on these Mars missions to monitor crew activity and provide information on the crew's adaptation to living in this harsh, isolated environment. It is important for habitat designers to note, however, that there were no cameras inside any crew member's private chambers of the Life Support Systems Integration Facility, nor could any external cameras provide a significant view into the rooms (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). Crew members should be able to achieve total privacy while in their own rooms.

The rooms should be similar in size and shape to permit crew members to switch rooms mid-mission without a problem. This may be necessary should serious conflicts arise or simply for a change of atmosphere. Each side of the room will have its own individual door. The inclusion of locks does not seem to be important. Doors inside the Life Support Systems Integration Facility did not have locks, and other isolated habitats studied did not either.

Without adequate amounts of sleep, crew members' efficient performance of daily activities decreases (Stuster, 1996). The most important function of crew quarters is to provide a place for crew privacy. A space-efficient bed design will certainly be useful. When gravity is present, these surfaces will be used for sleep and they may be used for limited visitor seating during other times of the day.

Soundproofing or noise reduction for the walls will also be important. Skylab crew members complained that it was hard to sleep with only thin walls separating them from noisy equipment. Many other isolated crews had similar complaints. This idea is also a part of providing privacy for crew members in their crew quarters. Locating these rooms away from the galley and its loud machines will help solve part of this problem. Positioning the crew quarters near the bathroom will allow for easier access during the night. However, the bathroom may also contain some loud equipment forcing habitat designers to include some noise reduction there as well. It may be wise to schedule "quiet hours" before major mission milestones to ensure the crew has adequate sleep and preparation time. The crew can decide for itself the necessity and exact rules and times of these periods. Designers should also consider Skylab crew members' comments regarding the location of crew quarters near an exit; several commented that sleeping was sometimes difficult because private sleep chambers were too far from an easy exit and thus subject to noise as other crew members moved past (Compton and Benson, 1983).

Shuttle astronauts each receive a sleep kit, which includes ear plugs and eye covers, to provide better quality sleep (shuttle.nasa.gov/reference/shuttle/shutref/crew/sleep.html, 1998). The Mars surface habitat will contain similar kits for each crew member. Sleep intervals should remain the same during the mission, except in the event of an emergency. Many isolated crew members in the past chose to stay awake past planned bed times, but this was a personal choice, not a necessity.

The crew quarters may also serve as a place for crew members to position themselves during descent to the surface of Mars. Certainly the crew members will experience some amount of deconditioning, no matter how rigorously they follow their exercise plans during the trip to the planet. They will need both time and equipment to comfortably survive the descent portion of the mission, as well as help them make the adjustment to life with partial gravity after being without it for many months.

Besides providing a place where they can sleep and be alone, the crew quarters should give crew members a sense of home. The room itself will provide each crew member with the capability for personalization. Crew members conducting long-duration tests in the Life Support Systems Integration Facility selected and decorated their rooms ahead of time (Tri, 1998). On the other hand, settling in and organizing personal belongings might provide a useful distraction during the beginning phase of the mission. To help in selecting miscellaneous items to bring as decoration, crew members will receive a mass and volume limit before the mission. The crew may bring anything, as long as all items pass materials inspections and are not offensive in content. There will be personal storage available inside the room for clothing, books, music, video recordings, supplies, or other personal items. Overhead lights with several settings will be desirable so that crew members can adjust their personal space to their liking. Skylab crew members complained that their interior lighting did not provide enough light or lighting flexibility to adequately perform some duties within the habitat (Compton and Benson, 1983). One or two moveable lights per individual room will provide extra lighting wherever and whenever necessary. If an intercom system is available for use by crew members, each individual crew chamber will have an interface using the latest technology.

A space-efficient desk with writing area and some type of personal workstation was part of every room in the Life Support Systems Integration Facility (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). Section 2.15 discusses other recreational uses for this equipment. A seat will be useful at the desk and to accommodate visitors. Most socializing will likely take place away from the crew quarters since these rooms will be too small to comfortably hold more than two or three people at a time.

The proper size for crew rooms is under investigation. Overcrowded rooms can reduce productivity, as on submarines where crew members complain about the lack of personal territory (Stuster, 1996). On the other hand, providing separate chambers for each crew member may be impossible in limited habitat volumes. The space should be larger than the cubicles in Skylab where crew members' major complaint was that the accommodations only served sleeping purposes (Compton and Benson, 1983). Crew quarters must be of acceptable size and contain sufficient equipment to function as a sleeping space, an office area, and a refuge during off-duty time. The room must accommodate sleeping and working in zero gravity, as well as in the partial gravity on the surface of Mars. Thus, there must be enough space to place a bed horizontally in the room for use while in the presence of gravity. Habitat designers may configure most other equipment in any fashion; only the existence of this other equipment is important, not its location. In addition, these crew quarters should be shared by at least two crew members, but with provisions to partition the space for individual privacy. If roommates choose to remove the partition, significantly more shared volume will be available. Table 2.14-1 lists sizes of several crew chambers in past remote area habitats, the results of several habitability studies, and indicates the wide variation in volume assigned to members of various crews for what can be considered long-duration, isolated missions.

**Table 2.14-1 Isolated Habitat Crew Quarters Volumes per Person**

| Mission, Test or Study | Size (m^3) | Crew Per Room |
|---|---|---|
| Skylab -- Commander's Room<br>(Stuster, 1996) | 1.8 | 1 |
| Skylab -- Crew Room<br>(Stuster, 1996) | 1.4 | 1 |
| South Pole Base<br>(www.southpole.com/log.html, June 1998) | 14.3 | 2 - 8 |
| Life Support Systems Integration Facility<br>(pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, May 1998) | 9.2 | 1 |
| BIO-Plex (plan 1)<br>(Adams, 1998) | 8.0 | 1 |
| BIO-Plex (plan 2)<br>(Adams, 1998) | 12.5 | 1 |
| Submarine<br>(Stuster, 1996) | 1.0 | * |
| Tektite I & II<br>(Stuster, 1996) | 1.0 | * |
| Lovelace intangibles study; "long duration"<br>(Stuster, 1996) | 3.7 | ** |
| Earth orbital station<br>(Stuster, 1996) | 4.8 | ** |
| Lunar habitability system<br>(Stuster, 1996) | 7.2 | ** |
|  | average = 5.9 |  |

* This size reflects the volume allotted per person, not crew members per room. Varying numbers shared one room.

** Specific figures on number of crew members per room not given

### *2.14.1 Summary*

This section discussed functions and related equipment associated with crew quarters in a Mars surface habitat. Important items regarding the time and facilities available include:

- Providing a reconfigurable bed, noise reduction, and time cues to allow crew members to obtain satisfying sleep.
- Respecting signals from crew members regarding their need for privacy and personal time.
- Placing two crew members in one room with sides separated by a removable partition to allow for both private space and extra volume, depending on the configuration.
- Providing storage space for personal belongings, a desk and workstation, and ample space for personal decorations within each crew chamber.
- Providing similar crew quarters for all crew members.

### *2.14.2 References*

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## 2.15 Off Duty and Recreation

Past experience with long-duration missions on Earth and the growing level of experience with extended missions in space indicate that the crew will encounter two extremes in its activity schedules—periods of time with too much to do and times with too little to do. They will also be faced with extended periods of time during which their activities will be largely repetitious, which can easily lead to feelings of monotony and boredom. All of these situations are not unusual for most people and the solution is equally well known—provide ample off-duty time and adequate entertainment options to provide the entire crew and individuals with relaxation, distraction, or amusement (Rasmussen, 1973). There is a drastic difference in performance from crew members who have had sufficient relaxation time and those who had overbooked schedules allowing no free time. Also, excessive amounts of free time with insufficient planned activities produce unnecessarily bored and underutilized crew members. Dealing with these situations will provide a challenge for the planners of the Mars surface mission. Past isolated missions such as the Skylab missions, Shuttle missions, Life Support System Integration Facility tests, and winters at South Pole bases provide valuable insight into popular off-duty activities, the most effective scheduling methods, and estimations of off-duty time to allow for crew members. This section will discuss specific means and facilities for dealing with these situations for the crew while it carries out its primary mission on the Martian surface.

Off-duty activities involving a majority of the crew—including mandatory daily or weekly group dinners (see Section 2.12)—will most likely take place in the wardroom area because it can hold the entire group. A library or lounge area away from the wardroom is desirable to allow some amount of privacy for smaller groups, such as two or three people. Depending on the activity, private crew quarters might also be a place for two or three crew members to enjoy their off-duty time. Anyone participating in free-time activities must be considerate of noise levels, since not all crew members will be relaxing at the same time. Groups in a surface habitat will be able to take advantage of games in their spare time; almost all isolated crews in the past enjoyed board games to help pass the time (Stuster, 1996). Crew members will want to avoid games that cause conflict among crew members, as the game Risk did for one isolated crew (Stuster, 1996). Off-duty entertainment should bring crew members closer together, not prompt arguments. Card games were also a fairly popular distraction for isolated crews, and have the additional advantage of being small, light, and easy to use almost anywhere. Any games taking advantage of the reduced or nonexistent gravity will also be fun for crew members, as golf was to the astronauts landing on the Moon.

Another popular form of entertainment is video material, especially movies, stored using various forms of media. Section 2.12 discusses large screens that may be present in the wardroom. The entire crew could fit in the room for a group movie night, or a few people might choose to watch something in their spare time. The surface habitat will have a wide variety of video available, and will include as many preselected crew favorites as possible. Because movies showing large, sweeping landscapes or outdoor scenes were extremely popular with isolated crews in the past, the library will include many movies or shows with this feature. Isolated crews at the South Pole also repeatedly requested tapes of recent commercial TV programming, so there will be a supply of recordings of some crew favorites (astro.uchicago.edu/home/web/cbero/mainmail.html, 1998). Some amount of blank media, in addition to adequate time in the schedules, will allow crew members to upload a variety of recent programming (sitcoms, sports, news, etc.) on a regular basis.

Music will also provide groups with some needed relaxation. A public collection of music will accompany the crew on its journey. The type, variety, and volume of music should be agreeable to all crew members, since these areas caused conflict in the past (Stuster, 1996). Individual crew members also will bring along musical selections that are not part of this public collection as part of their personal equipment.

Individual free time entertainment may be more common than group off-duty activities. Crew members may spend personal off-duty time anywhere within the habitat where they feel comfortable and are not disrupting another crew member's activities. Crew quarters will provide a quieter place for individual entertainment, and the library or lounge area will cater to small groups. There will be several forms of recreation available to occupy an individual's off-duty time. As in the Life Support System Integration Facility, each crew member will have a personal workstation in his/her crew quarters (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). This equipment is ideal for email or letter writing. Submarine crew members often express that their biggest concern is the inability to communicate with persons in the outside world, and worry for the welfare of family members ashore (Stuster, 1996). To avoid these feelings, the schedule will allow for personal communications with family and friends at home. The frequency of these communications will somewhat depend on the type of transmissions. For example, the exchange of simple text messages will occur more often than swapping video clips with voice attachments. There can be no real conversations between Earth and the crew during the mission; time delays in transmissions will make this impossible. Members of isolated crews at the South Pole and elsewhere were unable to stress enough the importance of receiving physical care packages and real mail (astro.uchicago.edu/home/web/cbero/mainmail.html, 1998) from friends and family. While it will be impossible for crew members on Mars to receive a box of goodies or a present in the mail, it may be possible to arrange a different sort of care package. Ground personnel and family members could provide small surprises or gifts to celebrate a birthday or special anniversary. These items could be left for the crew to discover on their own or they could be directed to them by ground support personnel. Crew members at the South Pole also find hidden goodies throughout their habitat left by previous researchers or other members of their teams. These small surprises brighten crew members' days and help break the monotony of long-duration isolated missions. Mission planners and habitat designers should consider this an important off-duty activity when planning the Mars missions. The World Wide Web also provided many isolated crews with interesting diversions in the past. For example, web sites allowed crew members at the South Pole station and inside the Life Support System Integration Facility to answer questions from curious members of the public (refer to southpole.com/log.html, 1998; pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). Internet connections will be very different for people on Mars, but can provide many hours of entertainment and education. Other established forms of entertainment available using the personal workstations include reading books, watching movie clips, listening to music, and playing games. Any of these are achievable using information stored on CD, disk, or other available methods using the latest technology. As with group entertainment activities, crew members must always consider noise levels. Headphones will ensure that sound does not distract others. Crew members will be able to request and bring their own literature, music, and videos in addition to the supplies for the entire crew.

Other off-duty activities will not need personal workstation equipment. Reading is always a popular activity among isolated crew members (Stuster, 1996). "Paperbacks" (some of which are likely to be printed on paper, but most will use an electronic book format) are a familiar media that crew members can take anywhere in the habitat, making them a useful entertainment tool. "Magazines" (probably exclusively using an electronic format) will be valuable for the same reasons, but also because they can provide current news. Portable music equipment such as CD players is another popular and lightweight distraction and will be part of the crews' personal equipment. Most members of isolated crews chose to keep a journal of events during their time away from home. Their entries provide valuable information about the hardships and triumphs of long-duration or isolated missions. Certainly crew members on Mars will keep logs of science and official work activities, but time and space for personal writing and reflection are also important (Stuster, 1996) and will be encouraged. Crew members may also use off-duty time and personal quarters for their religious activities. Mission planners should consider both sleeping and eating as acceptable off-duty activities. However, if any crew member performs either of these activities in excess, others must note the problem and take appropriate corrective measures. Exercise will be a necessary activity for crew members during the mission. Section 2.16 provides more discussion of exercise as entertainment.

Another important free-time activity is external viewing time. Submarine crews greatly enjoy this pastime (Stuster, 1996) and it was popular on Skylab as well (Compton and Benson, 1983). Submarine crew members often have a hard time dealing with the drab interior of their habitat. The dark, plain environment barely visible through the portholes only makes things worse. However, one activity that always lifts spirits and is now part of daily routines, is periscope viewing time for each crew member (Stuster, 1996). Designers, architects, and engineers on the Skylab project spent extreme amounts of time debating the inclusion of a window on the vehicle. They finally decided to add the window, and crew members used it quite frequently on all three Skylab missions; notably, the crew of rookies used it most often (Compton and Benson, 1983). Similarly, all humans on the mission to Mars will, in some sense, be rookies. Therefore, crew members will most likely want to spend time viewing the external environment, especially once they land on the planet. Time and additional equipment such as cameras and binoculars will allow the crew to accomplish external viewing using the wardroom or other windows. Cameras outside the habitat will show crew members performing EVAs, or give insights into local weather conditions. Images like these will project easily onto a wardroom screen. In addition to being an enjoyable activity, looking out the window also allows crew members to exercise their eyes. If they are not able to use the periscope regularly, members of submarine crews often suffer from vision problems when they return to the surface. This results from not having far away objects to focus on, either inside the habitat or in the outside environment. Crew members can avoid eye problems by spending time looking out the windows.

The amount of free time available for the crew and its placement in daily schedules is very important for productivity. Mission and schedule planners as well as the crew itself must develop a standard routine that balances free time with work. Daily schedules will typically leave at least one hour of uninterrupted time before bedtime for relaxation and sleep preparations. Crew members perform routine personal hygiene and prepare for sleep, but may not perform any mission-critical tasks during this time (Alibaruho, 1998). Also, most experts suggest that the establishment of a regular workweek will help crew members organize their time and stay on schedule. A specific workweek template has not been established for this misson (although a generic workweek template has been suggested; see Griffith, [1999], pages 16–18). However, several examples of similar space missions or long-duration missions on Earth can illustrate the likely range of possibilities.

- Current Space Shuttle crews accumulate off-duty time in proportion to the length of the mission at a rate of approximately ½ day per week (NASA, 1998d). They use this off-duty time in four-hour blocks. Due to the relatively short duration of Space Shuttle missions, these off-duty times are scheduled at an appropriate time within the other activities of the mission; there is no fixed number of days on/days off that is used across all Space Shuttle flights.
- The *Mir* space station uses a nominal schedule of five days on followed by two days off (Watson, 1998). However, the large number of repair activities typical of the later years of the *Mir* used up a portion of this off-duty time on a regular basis.
- The ISS agenda nominally plans for the crew to work for five days followed by two days off (NASA, 1998a). However, during these two days off, the crew will have housekeeping and activity planning for the upcoming week to accomplish. The ISS crew will also get eight holidays per year, which will be allocated at a rate of approximately two holidays per quarter. The crew will select which holidays it will observe. (Actually the eight holidays will probably be spread over 3-4 crews per year.)
- Finally, crews working at U.S. South Pole bases work six days of the week and rest on the seventh (astro.uchicago.edu/home/web/cbero/mainmail.html, 1998).

Free time should be as flexible as possible, giving crew members some say in when and how they use their off-duty hours. Also, scheduling and time constraints should protect this off-duty time. A reasonable balance of purposeful work and relaxation time is important to the success of a mission of this duration.

After problems with falling behind schedule on Skylab IV, the crew moved to a looser schedule format. Each crew member made more choices about what they did when. The crew enjoyed this and became much more productive (Compton and Benson, 1983). Crews in the Life Support System Integration Facility also practiced loose scheduling (Tri, 1998). Mission planners should avoid adding too many new tasks to the schedule if the crew does not ask for them, since this caused most of the problems on Skylab IV. These past experiences show that schedules should remain flexible and allow the crew to select for itself as many of its duties as possible. Maintaining a task list helped keep the Skylab IV crew informed of future chores. Crew members could post a similar list on the wardroom information wall in the Mars surface habitat, or any other prominent place, to keep crew members aware of current objectives.

### 2.15.1 Summary

This section discussed the need for free time and entertainment activities on a long-duration mission. Important issues regarding the time and facilities available include providing:

- Equipment and facilities for both group and individual off-duty entertainment.
- Variety in all entertainment supplies.
- A library or small room to allow groups of two or three crew members to socialize privately.
- Personal workstations in crew quarters.
- Adequate communication time with friends and family back home.
- External viewing time to prevent eye problems and help maintain psychological stability.
- A regular yet loose schedule which balances work and off-duty time to keep crew members organized and on task.

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## 2.16 Exercise

The long-term effects of microgravity and partial gravity (i.e., the 0.38 gravity on the Martian surface) on the human body are not well understood. Previous studies have shown that regular exercise is one means of providing adequate countermeasures for most negative results of long-term spaceflight. From a medical standpoint, exercise should retard muscle atrophy, cardiovascular deconditioning, and bone demineralization. For these reasons, it will be a requirement for crew members to continue to practice some type of routine exercise while in a Mars surface habitat in addition to the exercise they perform on the way to or from the planet. A NASA "Workshop on Exercise Prescription for Long-Duration Space Flight" identified the following other essential functions that exercise provides (Harris and Stewart, 1986):

- Preserve the appropriate level of aerobic capacity and muscular strength and endurance to facilitate crew members' ability to perform demanding physical work … such as repetitive EVAs.
- Maintain general physical fitness as it benefits the individual's health and sense of well-being.
- Sustain the ability to accomplish end-of-mission unaided egress.
- Minimize the time required for post-mission reconditioning.

The last two items are especially important to a crew arriving on Mars after a relatively long period in microgravity.

The limited experience available from the Skylab, the Shuttle, and some Russian space stations suggests a certain exercise regimen and recommended equipment. This section discusses the machines, volume allocation, and time necessary for crew members to accomplish exercise that counters negative effects of prolonged time in microgravity.

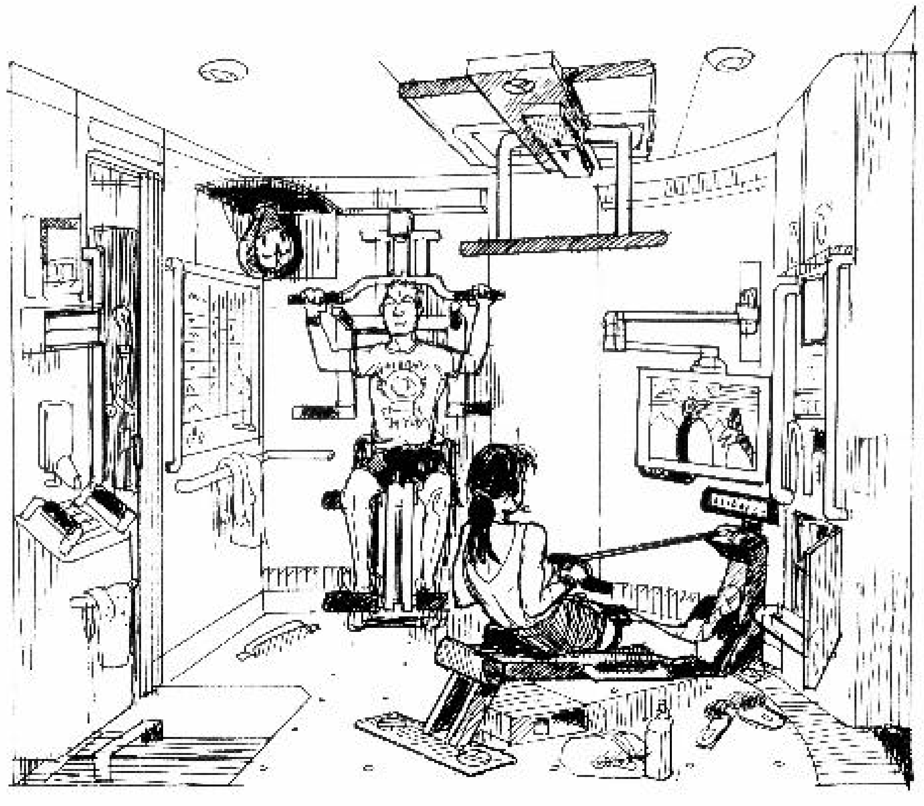

Figure 2.16-1 An artist's concept of the exercise area within the pressurized habitat. Several pieces of equipment may be available to the crew to allow more than one person to exercise at a time and to provide individuals a variety of exercises.

Crew members need several pieces of equipment offering some amount of variety. This is necessary since there will often be several people wanting or needing to use equipment at one time. Also, if crew members find pieces of equipment they enjoy using, they are more likely to take advantage of exercise periods. There must be exercise equipment capable of performing in both the absence of gravity and in the gravity found on the surface of Mars. One item used on the Skylab, the Shuttle, *Mir*, and several isolated ground tests is the treadmill (shuttle.nasa.gov/reference/shuttle/shutref/crew/exercise.html, 1998). Treadmills are beneficial for two reasons: previous crews enjoyed them and they can provide varying levels of exercise. Equipment must be easy to use, unlike the Skylab bicycle that required a large, awkward harness (Compton and Benson, 1983). Development of other machines and equipment will be profitable. The crews in the Life Support Systems Integration Facility used a resistive exercise machine, which might be effective with a few design changes. Isolated crews on the ground also used step aerobics and workout videos in the past, which, with a few alterations, might also be a possibility (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). Experts suggest a rowing machine of some type will also aid in reducing the loss of upper body strength (Harris and Siconolfi, 1989). There will also be some spare parts to allow crew members to make necessary repairs.

Each crew member will have a scheduled time in the day for exercise, as opposed to a block exercise time for the whole crew (there will simply be insufficient amounts of equipment to allow the entire crew to exercise simultaneously). Most crews in the past scheduled one hour of actual exercise on the machines. Skylab and Shuttle crew members required up to 30 minutes before and after the exercise periods for setup and tear down of equipment (Belew and Stuhlinger, 1973). Preparations for exercise periods in a Mars surface habitat should take no more than 15 minutes. For convenience and to promote more frequent usage, equipment must already be in place or require minimal setup. Most schedules require six days of exercise per week; EVAs will replace daily exercise periods for crew members exiting the habitat. Previous isolated crews performed various physiological and medical checks on themselves that often involved exercise time and equipment (Compton and Benson, 1983). Crew members in a Mars surface habitat must have sufficient supplies to accomplish these tests as well. Some experts suggest that crew members monitor at least one workout period per week. Everyone will record their activities and progress for personal review, as well as for evaluation by doctors on Earth. Using these records, crew members may set personal goals for the trip. For example, a crew member might attempt to travel a certain cumulative distance on the treadmill over the course of the mission. Crew members would have personal exercise prescriptions and goals to work toward, which should encourage them to work out.

Almost every Skylab crew member expressed the desire for a full-body shower immediately following exercise periods (Compton and Benson, 1983). If the facilities are available, the schedule should allow for this. Section 2.13 discusses a smaller bathroom that contains a sink, toilet and mirror. It is desirable to locate this bathroom near the exercise room to allow crew members to refresh themselves during or after their exercise periods. Skylab crew members chose to workout in their underclothes so that their disposable workday clothes stayed clean for longer periods of time (Compton and Benson, 1983). Crew members on the mission to Mars will wash their workday clothes regularly, avoiding this problem. However, crew members may receive lighter or thinner exercise clothes so they do not get unnecessarily hot.

One thing missing for the Skylab and Shuttle crews was the entertainment side of exercise. Crew members in the Life Support Systems Integration Facility had workout videos and music to accompany their workouts (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). Displays on or near equipment might provide these distractions to crew members in a Mars surface habitat. The screens might show video scenes to simulate a run in the park or a bike ride through the mountains. Crew members could also listen to music using headphones. Displays could also show statistics about a crew member’s performance such as distance, average speed, or time elapsed. Some type of virtual reality interface could also provide these diversions. Simple methods of entertainment such as these will make the exercise process more appealing. Crew members have complained in the past that workouts were monotonous and they often skipped their assigned times (Compton and Benson, 1983). This was sometimes due to lack of time, other times simply due to lack of desire. It will be necessary to avoid excuses such as these on a long-duration mission where exercise is fundamental in keeping the crew healthy.

The location of exercise equipment within the habitat is another important factor. The gym area needs to have good air circulation. This circulation will cool crew members during their workout, as well as cool and dehumidify the area after its use. The collection of equipment needs to stay out of the way of general traffic, which may prompt the design of a dedicated fitness area. Another option is to stow all equipment out of sight, and only bring it out for periods of use. The problem with this is the time necessary for setting up the equipment, as well as finding suitable locations for storage and use.

### *2.16.1 Summary*

This section addressed the need for exercise on long-duration space missions, as well as the time and equipment required to accomplish it. Important items regarding the time and facilities necessary include:

- Conducting further research on the long-term effects of partial gravity and microgravity on the human body.
- Providing a variety of exercise equipment.
- Developing the entertainment side of exercise to encourage crew members to take advantage of available time and equipment.
- Providing a dedicated gym area with good circulation and removed from high-traffic areas.

### *2.16.2 References*

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## 2.17 General Housekeeping

Past experience indicates that habitat interior cleanliness is important not only for the health of the crew but also to maintain a positive collective image by the crew as reflected in the environment in which it must live and work (Stuster, 1996). This topic, as it relates to long-duration, isolated missions, has few suitable analogies available for study due to the fact that most isolated missions are short enough in duration as to avoid these duties. Some missions survived longer isolation periods, but had an exterior support network in place to dispose of any wastes created, which a Mars surface mission will obviously not have available to it. This section discusses the facilities and supplies available for the routine cleaning of a Mars surface habitat interior. Any suggestions made in this section take into consideration experience from the Shuttle, Life Support Integration Facility tests, and current plans for the ISS.

Keeping a surface habitat interior clean will require certain equipment and supplies, as defined by the cleaning activities that are likely to occur. For example, experience with the *Mir* space station indicates that molds, mildew, and other biological matter can easily grow on the interior surfaces of inhabited spaces; experience from Apollo surface EVAs indicates that dust and soil are difficult to remove from suits and thus are inevitably introduced into a habitat's interior.

The Shuttle now carries a biocidal cleanser, disposable gloves, and general-purpose wipes for cleaning activities (shuttle.nasa.gov/reference/shutref/crew/housekeeping.html, 1998). Similar resources may be sufficient to cleanse surfaces and equipment throughout a Mars surface habitat. At present it is unclear if these cleaning supplies pose a risk to the biological life support system that is assumed to recycle water within the Mars habitat. Alternatives exist but their impact to the biological life support system must be assessed as this life support technology evolves. If this means of cleaning interior surfaces is retained, it will be important to develop reusable resources, for instance gloves and wipes, to avoid serious mass and volume limit violations.

On the surface of Mars an essential type of housekeeping equipment will be a vacuum system. The Martian surface is known to be covered with a very fine-grained dust that has been distributed globally by dust storms. EVA activities are likely to be the source of a significant amount of dust and debris that is brought into the habitat. Collection and removal of this dust will certainly be a unique process. Apollo astronauts walking on the moon spent some small amount of time brushing dust off their partner's suit before returning inside their vehicle, but this approach did not remove all of the dust. A similar result can be expected on Mars, pointing to the need for a vacuum system to help manage a potential dust problem. The Life Support System Integration Facility included a small handheld vacuum (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998), while the Shuttle includes a vacuum hose and several attachments. A small vacuum was found to be useful on *Mir* (Thomas, 2000). Comparable systems may be useful in cleaning Mars dust, but further data on the properties of this dust are required to make such a conclusion. Future testing must also examine the effects of Mars dust on items inside the habitat, as well as procedures to prevent large amounts of dust from ever entering the habitat.

Past experience shows that several types of trash will accumulate inside the habitat. Wet trash, including food and hygiene products, is one category. Because these wastes are especially messy, disposal locations should be available near food preparation and cleanup areas, as well as in each hygiene facility. Dry trash includes items like paper and dry food packaging. Biohazardous trash may be payload-generated, or include a large amount of blood or blood cleanup items. Chemical hazards may also be payload-generated, or come from the environmental control and life support system system. Advanced life support systems will recycle most human wastes produced during the mission, however, the system cannot be 100% efficient, so some portion will need storage. This trash falls under the category of waste containment system trash. Other types of trash include batteries, packing materials, and sharps (items like needles or syringes). Efforts to reduce, reuse, or recycle waste should be employed at all levels (Connolly, 1998).

A collection system will be available to temporarily collect and store trash. The Shuttle currently uses two different kinds of bags, one for wet trash and one for dry trash. Future investigations will show if different types of storage are more applicable to a long-duration mission. Making the collection devices themselves reusable will save mass and volume. Multiple trash collection locations will be available throughout the habitat. The capability to seal waste is necessary due to odors produced by trash.

Another large problem to solve is where to store accumulated trash during the mission. Unfortunately, there is no adequate analogy to examine when looking for answers to this question. All isolated missions in the past found ways to avoid this obstacle. In past isolated tests on the ground, trash often passed through an airlock for external support personnel to dispose of elsewhere (pet.jsc.nasa.gov/alssee/demo_dir/lmlstp.html, 1998). Other tests included a compactor to collapse trash that crew members then stored and disposed of at the end of the mission (www.southpole.com/log.html, 1998). The Shuttle contains eight cubic feet of wet trash storage, which is sometimes full at the end of a two-week mission (shuttle.nasa.gov/reference/shutref/crew/housekeeping.html, 1998). If an adequate way to store trash is unavailable, the habitat will quickly become cluttered and unsanitary. The long-term effect of this problem is obvious. Advantage will be taken of every available location for trash storage, such as in empty propellant tanks, similar to the method used on Skylab, and in the empty food storage area after crew members consume the food. A compaction system is one possible asset to manage trash for a Mars mission. In all cases, trash will be either recycled, reduced (i.e., compaction or incineration), or contained. Regardless of the form or containment used, storing hazardous wastes near the crew's food is undesirable for safety reasons and will be given special consideration during disposal.

Reusing as many things as possible is another way of managing trash during the mission. For instance, sanitizing and reusing items, or making items durable enough to last through several uses, will reduce the volume of trash. Habitat designers should take special care when determining the number of locations and permanent positions available for trash storage. Proper ventilation or remote location of some of these areas will ensure that odors do not offend the crew. Also, it is unsafe and unwise to store harmful substances near spaces the crew frequently uses, such as food preparation or personal hygiene areas.

The crew members will share the cleaning duties within the habitat. Crew schedules will allow some amount of time at regular intervals for general housekeeping to take place. Every crew member will have the opportunity to perform the associated housekeeping tasks in all the public areas of the habitat. For example, everyone will use the bathroom and it will require some amount of routine cleaning to remain sanitary. Alternatively, this cleaning may involve collecting trash bins from different parts of the habitat and consolidating the contents, or removing dust from equipment. Some cleansing of the habitat will take place daily, such as after meals. Crew members must sanitize the food preparation and eating areas regularly to avoid contamination. In this case, crew members will be in charge of cleaning up after themselves. Section 2.12 of this document addresses some of these procedures. In the past, crew members used anywhere from 5 to 15 minutes of their off-duty time to tidy their personal quarters and belongings. Skylab crew members and those inside the Life Support System Integration Facility used free time or off-duty days for major cleaning of personal areas (Compton and Benson, 1983; Tri, 1998). It was each person's responsibility to keep his/her own rooms clean. This method worked well and crew members can easily follow similar routines in the Mars habitat. The recycling of human wastes, on the other hand, must be a totally automated process. These systems and pieces of equipment need more development, but their final configurations cannot require constant human intervention. Crew members may perform periodic checks of the systems, but the machinery should be capable of running continuously on its own. Some human assistance may occur when it becomes necessary to store leftover wastes.

### *2.17.1 Summary*

This section focused on the need for general housekeeping and trash storage within a surface habitat. Important issues regarding the time and facilities necessary include:

- Further investigation of the effects and expected quantities of Mars dust inside the habitat.
- Further investigation of the time expected for these activities.
- Better estimations of trash volumes expected.
- Further investigation of eliminating the source(s) of trash, not just providing storage after it has been created.
- The inclusion of supplies to allow each crew member to clean his/her own personal areas, as well as to share in the cleaning of public areas.

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## 2.18 Training

Crew members on a mission to Mars will require significant amounts of training both before and during their mission. Perhaps the most important training will involve maintaining proficiency and preparing the crew for contingency events and how the members plan to work together to handle unforeseen events that arise during their mission. During past space missions and as currently planned for the ISS, ground support personnel employ several different methods for exchanging information with crew members. Unfortunately the most common of these techniques, direct voice communications, will be inefficient due to the tens of minutes of time required for communication signals to travel between the Earth and Mars. This points to the need for the crew to be trained to respond autonomously when necessary and to have a means of maintaining those skills throughout the mission. Training approaches in the future must allow for the accurate and timely interchange of information between the remote crew and support personnel. This section discusses the advantages and disadvantages of several methods used in the past to support training for long-duration missions comparable to Mars missions, and suggests several topics that pre- and mid-mission training must address.

Crew members traveling to remote locations prepare for months and sometimes years before their excursions. Most if not all of this training involves face-to-face contact with an instructor. Training classes, computer lessons, and printed manuals are the most common methods currently used to instruct crew members before and sometimes during a mission. Scaled mockups are also used to simulate actual hardware. These methods involve constant supervision from trainers, or at least periodic interaction. Crew members then continue training at their remote destinations by employing similar methods, materials, and ongoing dialogue with support personnel.

While comparable programs may be suitable for the training before a Mars mission, instruction during the mission must be different. Because of the time required for round-trip communication, crew members will no longer be able to rely on support personnel as they have for previous space missions. Printed manuals will be too cumbersome to store during the mission, and are difficult to update once the mission is under way. Therefore, some form of electronic storage will be necessary to hold this information and updates, as they occur. The wardroom in the habitat might be a logical storage location. A crew within the Life Support Systems Integration Facility evaluated the performance of virtual reality tools, information stored on CDs, prerecorded videos, and interactive Internet sites in accomplishing remote training. The results of its investigation will provide valuable insight into a favorable method for use in the future (pet.jsc.nasa.gov/ehti3/demo01.html, 1998). The most effective and practical form of training materials requires further investigation.

Another area requiring more investigation is the set of topics on which pre- and mid-mission instruction should focus. The skills developed in several of the areas discussed above will prove valuable in the future. Conflict resolution and team development training will be essential to complete a successful mission. Without the ability of ground personnel to intervene, crew members must learn to cultivate a strong team environment and solve or avoid interpersonal problems. Crew members must also learn to effectively interact with each other so that they can creatively solve mission-related problems on their own. Crew members traveling to the South Pole and those who stayed inside the Life Support Systems Integration Facility practiced activities designed to improve these skills both before and during their missions (astro.uchicago.edu/home/web/cbero/mainmail.html, 1998; Tri, 1998). Crew members in the Life Support Systems Integration Facility also participated in several pre-mission discussions focusing on what to expect during their isolation test (Tri, 1998). Experts suggest that this sensitizing of crew members to living and working together in close quarters for long durations is a worthwhile activity, especially since most minor problems tend to become magnified in an isolated environment (Stuster, 1996).

In addition to interpersonal and habitability issues, the crew will require training on many technical subjects. These include topics such as operation of analytical and experimental equipment, maintenance procedures, emergency operations, and system knowledge requirements. Most of this training will involve a review of previously learned material. Crew members will need periodic group sessions to review the appropriate response to contingency activities such as rapid cabin depressurization or equipment fires. Some material, such as an emergency workaround to an unexpected failure, may be new. In order to deal with unplanned situations effectively, the crew members must continually practice their creative problem-solving and efficient communication skills. This applies especially to drills for procedures that are infrequently (or never expected to be) used.

Other activities that may be the focus of mid-mission training include those that occur later in the mission. For example, the crew should review initial surface procedures shortly before it lands on the planet, and study ascent plans in preparation for departure. New technologies intended for use on the planet such as propellant manufacturing or rover operation will also need frequent review as their planned usage time approaches.

All of the crews that visit Mars will be under significant pressure to communicate their experiences and lessons learned both for analysis by ground support personnel and to train future crew members. They must practice appropriately and thoroughly describing events and have ample supplies to allow for the recording and storage of these details. The return trip will provide time for crew members to update their journals and add more details to log books while events are still fresh in their memories. It may be possible for the returning crew of the first or second mission to contact the crew of the second or third mission, respectively, already on its way to the planet. Although a conversation between the two crews will be impossible due to delays in communications, mission and schedule planners should allow time for a significant amount of exchange of information, lessons learned, and advice.

The majority of instruction on all subjects should occur before the mission and must cover anything mission-critical that the crew might encounter early in the mission. Some amount of training and review will take place continuously throughout the mission. The unique situations encountered on Mars may also prompt the inclusion of training on other undetermined subjects. Further investigation in this area will determine how much time crew members should spend training during the mission, and which subjects are most important for study.

### *2.18.1 Summary*

This section focused on training methods for a mission to Mars, as well as several potential training subject areas. Important items regarding the time and facilities necessary include:

- Further investigation into preferred training techniques and easy ways to store associated materials within the habitat.
- The importance of providing training on both sociological and technical issues.
- Further investigation into the amount of time required during the flight for training to take place.

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## 2.19 Inspection, Maintenance, and Repair

The capability to perform inspections, maintenance, and repair on all systems will be required during all phases of the surface mission. This includes the period before the crew arrives (ensuring that the various systems will be operational when it arrives), and during the dormant period as crews are exchanged. Many of the vignettes presented thus far have alluded to the use of inspection, maintenance, and repair as a key attribute for assuring that the crews will meet their mission objectives. This section will discuss the philosophy that underlies the approach proposed for accomplishing these tasks on the surface and will present some specific examples to illustrate the approach in practice.

Figure 2.19-1 An EVA crew member changes a faulty line replaceable unit on one element of the surface infrastructure. EVA-accessible enclosures and compatible disconnects will be necessary to allow for effective use of crew time during maintenance and repair activities. (© Lockheed Martin)

Large amounts of hardware from many systems will be exposed to the Mars environment—surface and wind-borne micro-dust, wide-ranging temperature extremes, and a much thinner atmosphere than Earth—all life-span-shortening, problem-enhancing factors for hardware. Inspection, maintenance, and repair of these systems will be carried out by both robotic systems and by the human crew during some phase of the mission. This is particularly important for any external systems deployed before the first crew arrives—for example, systems responsible for manufacturing propellant or life support cache commodities as well as power and thermal control. A failure in any of these systems that is not repairable threatens the surface exploration activities of any of the human crews. During this time period, inspection, maintenance, and repair must be accomplished by robotic means. Other systems will require robotic maintenance even when the crew is present. The crew, while much more capable of detailed maintenance than robotic systems, will still be constrained by bulky, dexterity-reducing EVA suits when doing exterior work. Mass and volume restrictions will limit the types and amounts of maintenance equipment and spare parts the crew has available. The time devoted to maintenance will be borrowed from other activities that the crew (and others) may want to perform instead, and use skills in which the crew must be trained instead of deeper training in other skills. Distance from the Earth (and potential sources of information about problems and repairs) will hamper maintenance efforts. All of these factors must be taken into account early in the equipment design phase to ensure that the best use is made of the crew and equipment on the surface.

Time spent performing routine maintenance cannot dominate the crew’s schedule. As an example, several systems aboard the ISS require part change-outs as often as every three days. This strategy is time-consuming and involves a large number of parts, making it unacceptable for a long-duration mission such as the one to Mars. Estimates for U.S. on-orbit maintenance predict the following average work loads at ISS Assembly Complete: 8 crew hours per week of human EVA, 15 crew hours per week of extravehicular robotic activities, and 49 crew hours per week of human intravehicular activities (IVAs) (www.jsc.nasa.gov/df/oso/Training/Training.html, 1998). As another example, Russian repairs and upgrades of *Mir* currently require approximately 50% of the crew workday (Thomas, 2000). Further investigation will show whether these numbers are satisfactory for longer-duration missions; initial discussions suggest that these time estimates are too high. Better data on mean time between failures will help refine these numbers and provide a better basis of estimating in the future. Most current numbers are only best guesses since there is no long-term experience using the equipment. The ISS, BIO-Plex, and other future tests will provide more accurate information about actual hardware performance.

### *2.19.1 Inspection, Maintenance, and Repair Philosophy*

Systems and equipment will be designed such that inspection and maintenance actions can be easily performed by humans and, where necessary or applicable, by robots. Specifying a concept for inspection and maintenance for those items requiring these actions will be part of the design criteria established for these systems. This will be particularly important for those systems that must be serviced robotically. Experience with underwater systems shows that the system and the robotic device that will perform necessary maintenance and repairs should be designed concurrently (Anon., 1998).

Externally accessed equipment should be minimized for those habitat systems that will be maintained exclusively by humans—as much system hardware and equipment as possible should be accessible by interior activity. Anything that can reduce the amount of EVA maintenance work is desirable (by either bringing it inside a pressurized structure for work, or by making external systems accessible or primarily located internally), since this will reduce the complexity, duration, and manual effort involved in maintenance.

For those actions that do require external maintenance, making the maintenance actions easy begins with the architecture used to package elements and subsystems of those items as well as the interface the human or robot uses for the servicing. At present, the preferred architecture for these systems is one consisting of line replaceable units (LRUs), which themselves contain shop replaceable units (SRUs). As necessary, external LRUs will be grouped into assemblies of field replaceable units (FRUs). FRUs will easily be removed and replaced by an EVA-suited crew person or, in some instances, by a robot in the Mars environment. The characteristics of an FRU will be:

- The FRU is sealed from the Martian environment, protecting more sensitive LRUs inside it.
- The FRU has mechanical, electrical, fluid, and pneumatic connections that are easily broken, sealed, opened, and connected by humans in EVA suits or, where appropriate, by robots in the Mars environment.
- Surrounding items and support connections (like power, cooling, and instrumentation lines) connected to the FRU can also be sealed and opened in the Mars environment when the FRU is being removed and installed.
- The FRU fits into the outpost habitat through any openings from the airlock all the way to the maintenance area.
- If the FRU contains hazardous commodities or items, it can be safed or purged externally in an uncomplicated but verifiable manner, so that the crew and its habitat are not threatened.
- Once in the work area of the habitat, the FRU can be easily broken down into its component LRUs.
- The FRU can be tested as a unit after the required maintenance but before being taken back outside, simplifying post-reinstallation checkout.

Of course, some LRU components may be too large to be in an enclosure of some sort or it may be more appropriate to remove and replace only one LRU at a time. These LRUs will have to be designed to meet FRU standards. In extreme cases, LRUs may not be able to fit into the habitat. Large items may have to undergo some sort of time- and condition-sensitive disassembly to gain access to specific parts, then temporary reassembly (for protection from the environment, perhaps covering exposed sensitive openings and equipment) until the part is ready for reinstallation.

One of the most important tools the crew will have is an integrated health status information system that allows the monitoring of all the critical functions and systems (and many of the less critical but still important ones). This will be an integrated system, both for flight and for the surface mission. Once on the surface, it will include the cargo vehicle's active systems (i.e., the ascent vehicle and the propellant manufacturing and storage system) and the

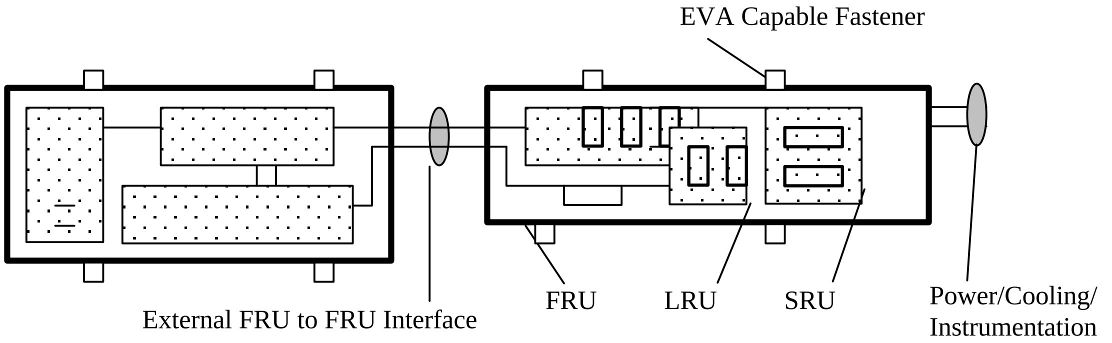

Figure 2.19-2 Example of hardware levels for equipment exposed to the Mars environment.

surface power system, along with any previous mission’s hardware. It will include both an active monitoring capability, plus some level of expert system that can evaluate long- and short-term hardware performance and alert the crew to developing problems or requirements. This system will be able to notify the crew of upcoming scheduled maintenance actions and provide the crew with the capability to forecast potential problems and schedule repairs based on the rate of loss of system function and the condition of redundant hardware. Much like the maintenance history, the historical data produced by this system will be downloaded to Earth periodically so that maintenance planning can be updated. This monitoring ability represents a considerable time- and labor-saving measure, allowing maintenance time to be reduced, but retaining a level of information that can be extremely useful for any maintenance effort.

Reducing the amount of time and labor the crew must spend on maintenance is a desirable goal. Achieving that goal may be difficult without adding significant amounts of mass, power usage, and complexity to an already complex, constrained mission. At the system and subsystem level, using built-in test equipment (BITE) will allow for reduced maintenance time and efforts. This capability will be key for mission-critical maintenance actions that will be assigned to robots because the crew is not present. However, usage of BITE will add complexity and mass to those systems, and must be balanced with the actual need. In flight-critical and crew-support-critical systems, the need for continuing use or critical period usage will make BITE worthwhile. In ground and science/ exploration systems, BITE may not be as cost-effective as a good testing facility for hardware. Also, equipment too large to be taken into a protected environment may need some level of BITE to help locate the discrepant hardware. That specific piece of hardware can then be detached and taken inside for repair. Thus as a general guideline, BITE should be included on all electronic, electrical, and electromechanical hardware, where clear benefit can be demonstrated, to allow failure isolation to the lowest, or next-to-lowest, repairable level. Those items that are assumed to be repaired only by the crew may require BITE at the next-to-lowest level because the crew will have test equipment that can isolate the failure at the lowest level.

The crew on Mars will need to be self-sufficient in terms of maintenance documentation—specifications, drawings, procedures, failure causes, and other information—for all the hardware on the mission. Even when the crew is not out of contact with the Earth (because of planet positioning or a communication malfunction), the time lag of normal communications from Earth to Mars will necessitate immediate access to maintenance documentation for emergencies. This information could be stored in electronic format, then accessed through a set of standard interfaces. This would include a normal computer interface, but could also utilize some sort of EVA/IVA usable interface, such as an eyepiece or a small flat-screen display which would have pertinent maintenance data loaded on it before a maintenance action. The main information database could be updated periodically from Earth as the hardware matures and a maintenance database (kept on Earth to minimize data storage requirements, since the data would not be of immediate use to the crew) is built up. On Earth, a significant capability for sustaining engineering and failure analysis will be maintained to test and evaluate hardware on Earth just like the Mars hardware. This will provide a follow-on capability to support testing by the crew on Mars, but will minimize the requirement for detailed failure testing equipment (and the inherent mass and volume requirements associated with it) with the crew on Mars. This will also aid the crew in the search for repair parts from previous missions' hardware with part history and design information. However, as more missions arrive at Mars, some method of determining how to utilize possibly different generations of hardware and piece-parts will have to be developed. The alternative to this is to freeze the design of Mars hardware at the first mission, guaranteeing commonality, but forcing the program to use old-generation hardware. This is a problem the Shuttle program faces now, causing increases in manufacturing, maintenance, training, and support equipment costs due to required usage of less-than-current technology items, primarily because the various manufacturers have left the older technology behind, and more must be paid to sustain it.

### *2.19.2 Spares Philosophy*

Spare parts are a large part of maintenance. Current missions include spares to cover most if not all anticipated repairs. This is simply impossible for a long-duration mission. For example, current ISS plans include a list of critical spares, covering mostly life support, power, and thermal systems. The remove and replace intervals and the mass of each unit would cost more than 5500 kilograms to provide enough spares to cover these systems alone for 18 months. If the same maintenance philosophy is followed for both in-space and surface systems of at least comparable complexity, the magnitude of the potential spare part inventory becomes apparent.

A different approach is proposed for the long-duration surface missions on Mars. Repair parts at Mars will represent a limited set of items, coming from three areas:

- Dedicated spare parts brought in the cargo vehicle or crew habitat. These items will be stored for use when needed, but due to the mission-imposed mass and volume restrictions, they will be limited in nature. In general, systems will be designed for commonality among their piece-parts to the greatest extent possible, allowing for fewer types of spares, but greater numbers of those fewer types. Also, parts to be stored will be at the lowest hardware level—electrical components, fasteners, seals, tubing, etc. This will make repair efforts somewhat more complicated, but also more flexible. Spares will be stocked "deeper" for critical systems, allowing for fast repair turnaround times.
- Use of the same item out of a different unused system (or a less-critical system). Part of the maintenance data with the crew will be a listing of where the same item can be found in every other system on the surface of Mars, including suggestions for which specific one to pull for repair use first. Thus the crew will immediately know where to look for a replacement.
- Use of a specific repair piece-part out of a similar item (or a less-critical system). Again, part of the maintenance data with the crew will be a listing of where the same piece-part item is in other non-critical systems, again with a suggestion for which one to use first. Also, as items fail they will be "harvested" for usable piece-parts, which will be stored until needed with the dedicated spares and marked as "harvested" parts. (The implication is that harvested parts will be available for use but only after the supply of unused spares has been exhausted.)

Crew departure preparations provide a specific example of this last point. As the crew enters into its final weeks on Mars, maintenance efforts pick up on the ascent vehicle. Spares for critical systems will be stored on board (for use during Mars orbit if a problem develops). Also, the crew will begin to disassemble unused external items, perhaps pulling entire FRUs and storing them in the protected environment of the habitat for the next crew's usage. Other items that may be too large for internal storage may be stored externally in some sort of protected area. However, any equipment planned to be stored in this manner will be subject to the adverse effects of the external environment. Additional analysis must be performed to determine the relative benefit of enhancing these systems so that they will be capable of handling the conditions of extended external storage and thus still be usable after the storage period, either by the crew that stored it, or by a subsequent crew. The capability to survive external storage may be met either by actual hardware design for storage, or by some sort of protective method that is generally applied to all externally stored items. Finally, parts storage may present a problem to the first crew, but as more pressurized infrastructure is added to the landing site on Mars, storage issues will likely be eased.

### 2.19.3 Repair Facilities

The need for spare parts and repair equipment, as well as the untidy nature of some anticipated repairs, justifies the inclusion of a separate area within the habitat devoted to repairs. The nature of the work area and the items used in it can reduce time and labor requirements for maintenance. Located in this area will be maintenance and test equipment, general and specific tools for maintenance, maintenance data access, and standard utilities. Some spare parts and consumable items will also be stored in this location. Other spares will be in storage locations around the site. A workbench is one extremely important item to include in the shop. Crew members and mission planners must expect repairs to include disassembly of equipment into their component parts. This activity will take place not only in the shop area but also at the site of failed systems, and thus could potentially occur anywhere within the habitat. Habitat designers should consider including a portable “tool box” of some kind in the Mars habitat, in addition to the room reserved as a shop and the tools it contains, to address this situation.

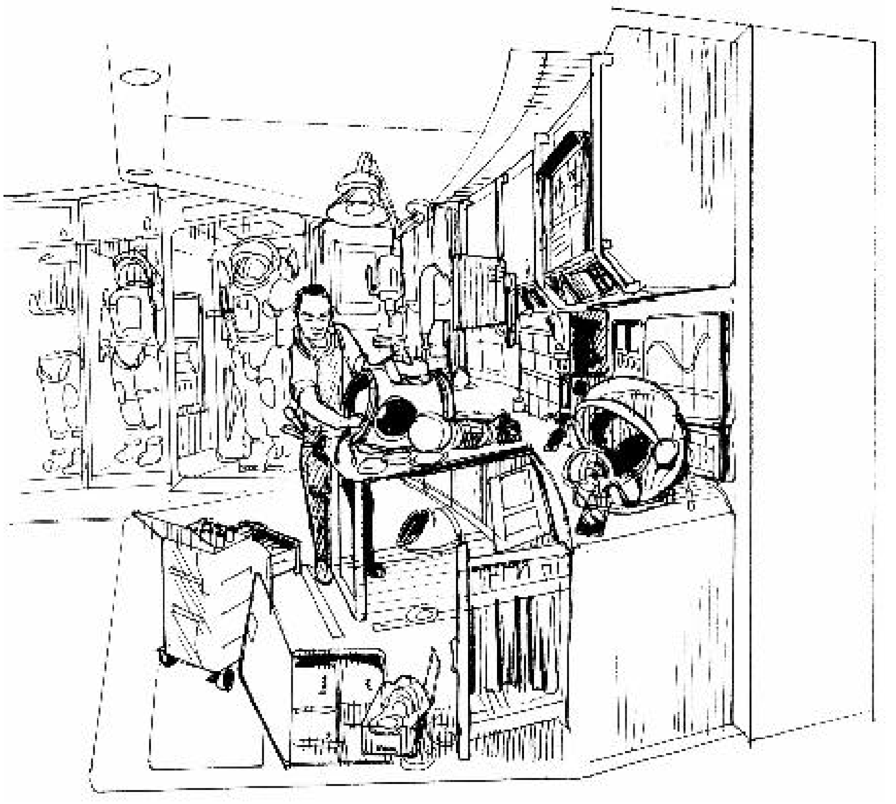

Figure 2.19-3 An artist’s concept for a maintenance and repair facility within the pressurized habitat. This facility will be capable of maintaining the EVA suits that will be a key element in supporting the crew’s exploration activities.

The fewer specific repair tools for specific pieces of hardware the better, because every specialized tool taken for only one or two uses deletes a place for a more common tool. Also, EVA tools and their interfaces must be designed for simplicity, with few moving parts (to limit their exposure to the Mars environment). Both of the above concepts also apply to test equipment—the more general the better, and for EVA, the simpler the better. One major problem facing ISS maintenance plan developers is the organization of the tools necessary for internal vehicle repairs. There are currently over 400 tools stored in 20 different storage kits. These kits fit into a larger tool box weighing 165 kilograms (Van Cise, 1998). Authors of ISS maintenance pro-cedures and crew members find this method of storage cumbersome, since the tool stockpile is not necessarily near the usage points of any certain tool. However, a useful ISS requirement states that hardware be designed to be maintained with the U.S. IVA standard tool kit. A developer deviating from this requirement will be responsible for providing the necessary maintenance tools. While specific tools that deviate from this standard exist, they are not encouraged. The Mars mission will also employ such guidelines for its hardware systems to eliminate as many specialty tools as possible, potentially through the early adoption of one measurement system, along with standard fasteners, components, and materials.

### 2.19.4 EVA Suit Maintenance

The EVA suit will be used for a large percentage of the exploration work carried out on this mission. This makes availability of the suit a high-priority item, which in turn places a high priority on reliability and ease of maintenance.

Suits[*] are assumed to use the built-in health-monitoring capability and BITE as discussed above. While a suit is in use, the health-monitoring system will be recording performance data that can be downloaded later for use in trend analysis, and will be logging maintenance actions that will be required once the suit is returned to the habitat. When the suit has been cleaned and brought into the habitat, the suit data system will be connected to the integrated health status information system for transfer of the performance data and the maintenance action log. The crew will be able to review the maintenance action log to determine the priority of those actions compared with other maintenance tasks on its schedule. The crew can also access, from the integrated health status information system, the specific maintenance procedures and a list of required repair tools and parts, as well as a list of the location of the required spare parts. The suit should be capable of being disassembled so that all moving parts susceptible to dust intrusion can be cleaned and, if necessary, lubricated. Disassembly using the FRU/LRU concept will allow those parts of the suit requiring maintenance, as noted in the maintenance action log, to be taken out of the suit and moved to the shop area. Component commonality among the suits and among other systems used at the outpost will allow discrepant parts to be replaced immediately, restoring the suit's availability and allowing the discrepant part to be repaired (if possible) at a pace that does not impede further EVA activities. BITE will be used to verify that the suit component(s) is functional and that the reassembled suit is ready for use.

The suit health-monitoring system is also assumed to be capable of discriminating between maintenance items that can be logged for later action and those that require immediate attention in the field. The health-monitoring system will provide appropriate notification to the crew (the crew member in the suit as well as the other crew member(s) participating in the EVA) of the nature of the emergency and advised action(s) to take. Examples of repairs that will require immediate action include a suit puncture resulting in an ongoing loss of pressure or a failure of one of the several systems contained in the PLSS. The EVA crew will have the capability to make temporary repairs (e.g., patch the suit puncture) or to isolate the failed component and switch to another system that provides the same functionality (e.g., tap into another EVA suit power supply or into an EVA consumables supply on board a rover). These emergency actions will be designed such that sufficient time is available for the EVA crew to return to the habitat where permanent repairs can be made.

### *2.19.5 Rover Maintenance and Repair*

Mobility for the EVA crew will also be important for accomplishing exploration goals. Maintaining a high level of rover availability will thus be key in sustaining both the number of EVAs anticipated and allowing these EVAs to reach those important sites beyond the safe walking distance of the crew.

Maintenance actions for the rovers will be in many ways comparable to that discussed above for the EVA suits—health status monitoring equipment recording performance data and logging maintenance actions, BITE verifying repairs. The FRU/LRU concept as used for the rovers must be EVA-compatible from the outset. These rovers are not likely to be of a size that can be brought into the repair shop without some disassembly outside of the pressurized habitat. An interesting option exists for the unpressurized rover spares that is consistent with the philosophy described above. If these vehicles are sized to carry a single person under normal operations, the possibility exists for a common chassis and power train to be shared with the teleoperated rovers discussed in previous sections. This gives the crew the option of gradually degrading its capability by cannibalizing parts from selected rovers to keep others in operation rather than simply losing all capability when a certain class of rover runs out of spare parts.

### *2.19.6 Automated and Teleoperated Maintenance of Surface Systems*

Certain key elements of the surface infrastructure must be capable of inspection, maintenance, and repair without the presence of the crew. The nuclear power plant and the propellant production plant, both of which must operate before the first crew arrives, are two examples. These systems, and in particular the FRU/LRU elements they contain, must be designed from the outset to be maintained by robotic devices. Because of the important role these teleoperated robots play—maintaining certain key surface systems while no crew is present—they must have the capability to maintain each other in the absence of the crew. It is unlikely that these robots will be as capable as humans in making repairs, which may limit them to making and breaking connections and replacing FRUs/LRUs. The dividing line between what maintenance the robots will be capable of doing and what must be left for the human

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[*] "Suit" as used here is assumed to include the garment worn by the crew member and the PLSS, the portable life support system.

crew to accomplish is currently uncertain and will be an area of significant research and technology development. This further implies that these systems and the robots that will service them should be designed concurrently, and indicates the importance of simplicity and reliability in equipment design to minimize the need for spare parts.

### *2.19.7 Summary*

This section addressed the maintenance philosophies for repairs required in and around a Mars surface habitat. Important issues regarding the time and facilities necessary include:

- Further investigation into this topic as a whole.
- The inclusion of a dedicated shop area and portable workbench with proper restraints for equipment, spare parts, and tools.
- Better management of tools and spare parts to reduce expected mass and volume of these items.
- The development of equipment and systems that do not require constant human intervention and periodic part replacement and that are easier to interpret.
- Further investigation into the type of equipment and training necessary for fabrication of spare parts from raw materials.
- The acquisition of better mean time between failure data for actual hardware proposed for use.

### *2.19.8 References*

Anon. (1998) "EVA and Robotic Interaction; TWA Flight 800 Search and Recovery Operation Analogs," presentation at NASA Lyndon B. Johnson Space Center, Houston, TX, Oceaneering Space Systems, June 8, 1998.

"On-Orbit Maintenance Training" (1998) <http://www.jsc.nasa.gov/df/oso/Training/Training.html> [Accessed 20 July 1998].

Van Cise, E./DF53 (1998) NASA Lyndon B. Johnson Space Center, Houston, TX, personal communication, June 1998.

Thomas, A. (2000) Personal communication.

Watson, J.K./EX13 (1998) NASA Lyndon B. Johnson Space Center, Houston, TX, "Flight Crew Support Equipment List," June 1998.

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## 2.20 Preparation for Departure

As can be seen in Table 1.4-1, there are approximately eight months between the departure of one crew and the arrival of the next. During this period of time, systems on the Martian surface will operate in a mode appropriate for the level of activity while no crew is present. For example:

- The power plant will continue to supply power to surface systems.
- The habitat support systems will be placed in a quiescent mode so that support teams on Earth can monitor them, but otherwise they will not perform typical functions.
- The biological-based life support system will be shut down while waiting for the next crew that will supply the raw materials it needs to function.

The Mars surface crew, assisted by Earth-based support teams, will spend several weeks before its scheduled departure making all preparations necessary to place these various surface systems in the appropriate operating mode. These preparations will involve both scientific- and infrastructure-related activities (Smith, T.H., 1998).

Throughout the surface mission, the crew will have been collecting data and samples associated with various experiments it has conducted or gathered from various sites visited. These data and samples will be associated with health-monitoring activities the crew has performed on itself and with the exploration activities it has carried out to learn about Mars. Throughout the surface mission, the crew will have gone through a process to determine which samples and data (i.e., data that could not otherwise be sent electronically to Earth) should return to Earth. A recent NASA study of a human mission to Mars carried an allocation of approximately 100 kilograms for all of these samples and data (NASA, 1997). This will make the selection criteria very stringent. The Mars crew will consult with colleagues on Earth to make the final selection. It will then package the selected samples and data appropriately and make them ready for the transfer to the ascent vehicle.

The crew will check scientific experiments and monitoring equipment that will be in operation while no crew is present, and verify that it is in good working order—or, if possible, repair it—and will perform an inventory and corresponding status check of all surface resources before departure. This will serve as a benchmark for determining the resources available for use by subsequent crews as well as input to planning for future cargo missions.

A much more thorough checkout of the ascent and Earth return vehicles will take place as the date for departure approaches, which will include the Mars surface crew performing some of the checkout and all of the needed repairs on the ascent vehicle. (All of these vehicles will have the capability to be monitored and their status checked from Earth. This capability is required due to the extended periods of time when no crew is present to perform such tasks. This monitoring capability will continue to be used periodically throughout the surface mission even when the crew is present, in part to off-load some of the activities for which the Mars surface crew is responsible.) The Mars surface crew will also assist with visual inspections of the ascent vehicle. The “go/no go” decision for launch of the first crew will be based, in part, on a determination by Earth-based support teams that the ascent vehicle is in a healthy state and that the Earth return vehicle is in a healthy state.

Consistent with the spares and maintenance philosophy discussed earlier, the surface crew will also remove any useful equipment from the ascent stage they will be using to provide additional spares for subsequent crews. All other non-essential surface systems and equipment will be shut down and placed in a safe area (e.g., moved away from areas of potential flying debris caused by the ascent vehicle, sealed against dust infiltration, etc.).

The surface crew’s final activity will be to shut down the closed-loop life support system and place the habitat in a quiescent mode. Shutdown of the biological-based life support system may require an extended period of time (i.e., several hours or possibly days) to place it in a mode for subsequent startup, if necessary, by the next crew. During this time the crew will use the backup, open-loop life support system with the cached air and water produced by the ISRU system. The crew, along with the samples and other payloads being returned to Earth, then move to the ascent vehicle using the rovers. Once all personnel and equipment have been transferred, the rovers are moved to a safe location (moving the rovers could be an automated activity or a manual activity by an EVA crew; the means for accomplishing this activity is not yet determined).

### *2.20.1 Summary*

This section has described the activities the Mars surface crew performs when preparing to depart. Key activities include:

- Selecting, in collaboration with Earth-based colleagues, those samples and data that will be returned to Earth.
- Performing, in conjunction with Earth-based support teams, a thorough checkout of the ascent vehicle and the Earth return vehicle.
- Placing all surface systems in an appropriate mode of operation for when no surface crew is present.

### *2.20.2 References*

NASA (1997) Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, NASA SP-6107, NASA Lyndon B. Johnson Space Center, Houston TX.

Smith, T.H. (1998) "An Operational Evaluation of the Mars Reference Mission," paper written with the personnel of the Exploration Office, NASA Lyndon B. Johnson Space Center, Houston, TX, April 1998.

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## 2.21 Cumulative Data

During the course of researching material for the various sections in this document, several items of data regarding the amount of time crew members spend in certain locations performing certain activities became apparent. These data have been collected in this section. This information may be useful in a number of situations, such as determining the integrated radiation dose for a particular habitat configuration or the relative location of certain rooms or spaces, as the activities and functional descriptions of the previous sections are translated into specific design concepts. However, because human missions to Mars are still being studied at many levels, the specifics of a future Mars mission are subject to change. Consequently, these data should be viewed as guidelines and should not be interpreted as a rigid schedule or constraints to be imposed on hardware designs or crew operations.

### *2.21.1 Total Time on the Martian Surface*

Due to the orbit mechanics of trajectories between Earth and Mars, each crew sent to Mars will spend a slightly different amount of time actually on the surface. Table 2.21-1 lists the duration of each of three typical expeditions as they have been studied recently for split-mission architectures (NASA, 1998c). Because the length of the Martian day is slightly longer than an Earth day (24 hours, 36 minutes versus 24 hours) the number of "days" will be different from the result expected when simply looking at calendar dates of arrival and departure. This has implications for the quantity of certain consumables (e.g. any consumables used or activities performed on a daily basis) that must be planned to support the crew.

**Table 2.21-1 Summary of Mars Surface Stay Durations**

| Crew | Arrival at Mars | Departure from Mars | Earth Days on Mars | Earth Months on Mars | Mars Sols on Mars |
|---|---|---|---|---|---|
| 1 | 7/22/14 | 1/10/16 | 537 | 17.9 | 524 |
| 2 | 8/23/16 | 3/27/18 | 581 | 19.4 | 567 |
| 3 | 11/17/18 | 6/14/20 | 575 | 19.2 | 561 |

Details regarding the length of a "standard" workweek have yet to be specified. However, it is known that the crew will be given time off on a regular basis. Section 2.15 discusses a number of different approaches to a "standard" workweek for the crew. Table 2.21-2 illustrates the number of off-duty days that the crew will accumulate for each of these missions depending on the assumed "standard" workweek. Until a specific workweek profile is selected, this table also illustrates the range of off-duty time that should be taken into account for planning purposes. (A suggested generic workweek can be found in Griffith, 1999, pages 16-18.)

**Table 2.21-2 Comparison of On-Duty/Off-Duty Cumulative Time for Various "Standard" Workweeks**

| Crew | Sols on Mars | ½ Sols Off per Week | | 1 Sol Off per Week | | 2 Sols Off per Week | |
|---|---|---|---|---|---|---|---|
| | | Total Sols On Duty | Total Sols Off Duty | Total Sols On Duty | Total Sols Off Duty | Total Sols On Duty | Total Sols Off Duty |
| 1 | 524 | 486.5 | 37.5<br>(75 half Sols) | 449 | 75 | 374 | 150 |
| 2 | 567 | 526.5 | 40.5<br>(81 half Sols) | 486 | 81 | 405 | 162 |
| 3 | 561 | 521.0 | 40<br>(80 half Sols) | 481 | 80 | 401 | 160 |

Table 2.21-3 presents a summary of representative amounts of time spent performing various activities in certain rooms for both an on-duty day and an off-duty day in the Mars surface habitat. The typical activities are listed, along with the duration for each (these activities are patterned after anticipated ISS activities). The numbers given are a total for one day for one crew member. Specific rooms suggested for inclusion in the surface habitat are also listed with examples of long-duration facilities with similar areas (listed at the bottom of the table).

**Table 2.21-3 Summary of Regular and Off-Duty Days and Use of Surface Habitat Spaces**

| Activity | Time (On-Duty Day) | Time (Off-Duty Day) | Wardroom | Galley | Crew Quarters | Bathrooms | Labs | Shop | Exercise Room |
|---|---|---|---|---|---|---|---|---|---|
| Post-Sleep | 2.0 | 2.0 | X | X | X | X | | | |
| Message Review | 0.5 | 0.5 | X | | X | | | | |
| Mission Support | 7.5 | 0.0 | | | | | X | X | |
| Mid-Day Meal | 1.0 | 1.0 | X | X | | | | | |
| Exercise* | 2.0 | 2.0 | | | | | | | X |
| Report Prep. and Planning | 1.0 | 0.0 | X | | X | | | | |
| Pre-Sleep | 2.0 | 2.0 | X | | X | X | | | |
| Off-Duty** | 0.0 | 8.5 | X | | X | | | | |
| Sleep | 8.5 | 8.5 | | | X | | | | |
| *Exercise may be deferred on one off-duty day per week; depends on number of off-duty days<br>** May include some maintenance or housekeeping activities | | | Life Support System Integration Facility, BIO-Plex, Skylab | Life Support System Integration Facility, BIO-Plex, South Pole | Life Support System Integration Facility, BIO-Plex, Skylab | Life Support Integration Facility (2), ISS (2), Shuttle (1), South Pole (many) | ISS (3), Shuttle (1), Skylab (2), South Pole (many) | South Pole | BIO-Plex, Life Support System Integration Facility, South Pole |

### *2.21.2 References*

Griffith, A. (ed.) (1999) Operations Concept Definition for the Human Exploration of Mars, DD-099-05, First Edition, NASA Lyndon B. Johnson Space Center, Houston, TX, pp. 101-104.

NASA (1998c) Reference Mission Version 3.0; Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Team, SP-6107-ADD (also EX13-98-036), NASA Lyndon B. Johnson Space Center, Houston TX.

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## 3.0 SUMMARY

This document has described current expectations for the activities of human crews, and the associated support equipment that will occur as they explore the surface of Mars. These descriptions, made at a functional level, were prepared assuming a split-mission architecture. It should be noted that these descriptions can, in general, be used in conjunction with other mission approaches.

The approach of discussing activities at a functional level was chosen for two reasons. First, it creates a starting point for continued discussion regarding the activities and functions that are appropriate and necessary for these human exploration crews to carry out. Second, it allows functionally equivalent designs or technologies to be proposed as implementations for these activities and then evaluated to find a best overall implementation for the exploration mission. Comparing alternative approaches provides the basis for continual improvement to technology investment plans and general understanding of future human exploration missions.

“Surface activities” are defined to be those that occur between the time that the crew lands and before it departs for the return to Earth. Activities associated with launch from Earth, interplanetary travel, and landing or departing from a planetary surface are discussed in other documents. However, in addition to crew activities, this document also described the activities of automated systems that arrive before the crew and that keep operating on the surface while no crew is present.

This document has been divided into several major sections. The first of these sections provided an overview of the split-mission approach (to provide a framework for the surface mission) for the Mars mission. The remainder of this document has been devoted to a series of vignettes describing key activities or functions that will be part of the surface mission. These vignettes include:

- Robotic/Autonomous Deployment
- Initial Surface Operations
- Exploration Field Work
- Surface Transportation
- Field Camp
- Toxin and Biohazard Assessment
- Sample Curation
- Sample Analysis
- Teleoperation of Robotic Vehicles in Support of Science and Exploration
- Life Sciences Experiments
- Crew Health/Medical Operations: Routine and Emergency
- Wardroom and Food Preparation
- Personal Hygiene
- Crew Quarters
- Off-Duty and Recreation
- Exercise
- General Housekeeping
- Training
- Inspection, Maintenance, and Repair
- Preparation for Departure

The information presented in all of these sections represents a “snapshot” of work completed through October 1998 and is intended to serve as design guidelines consistent with Mars mission architectures. These guidelines are intended to be used in future concept definitions and trade studies. It is anticipated that as these studies are completed, appropriate functional requirements and system specifications will be developed and documented in this or other reports. It is also anticipated that the lessons learned from these concept definitions and trade studies will be incorporated into future versions of this document. Publications of revisions to this document are planned.

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13. ABSTRACT *(Maximum 200 words)*

This document describes current expectations for the activities of human and robotic crews, and the associated support equipment, that will occur as they explore the surface of Mars. These descriptions, made at a functional level, were prepared assuming a split-mission architecture. It should be noted that these descriptions can, in general, be used in conjunction with other mission approaches.

The Mars Surface Reference Mission is a tool used by the Exploration Team and the exploration community to compare and evaluate approaches to surface activities. Intended to identify and clarify system drivers, or significant sources of cost, performance, risk, and schedule variation, it does not represent a final or recommended approach. The Exploration Team is currently studying alternative scenarios, including technical approaches to solving mission and technology challenges, and human exploration missions to the Moon, asteroids, or other targets beyond Earth orbit. Comparing alternative approaches in this way provides the basis for continual improvement to technology investment plans and a general understanding of future human exploration missions.

This document has been divided into several major sections. The first provides an overview of the split-mission approach, to provide a framework for the surface mission. The remainder is devoted to a series of vignettes describing key activities or functions that will be a part of the surface mission.

This document represents a “snapshot” of work in progress in support of planning through October 1998 for future human exploration of the Martian surface. Publications of revisions to this document are planned.

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