APPENDIX 1: MARS SURFACE REFERENCE MISSION, STEPHEN HOFFMAN, 1998: EXCERPTS

Exploration Field Work

A key objective of the Mars surface mission is to get members of the crew 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.

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

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 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; this contingency is discussed in a later section. The EVA crew walks, or rides if rovers are planned for the traverse, towards 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, either by an EVA team or a robotic device, 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 “waypoint” 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 the planning for the traverse. Similar activities will be carried out by the crew at these unplanned sites. Real time voice and data, along with some amount of video, are sent back to the outpost to those members of the crew that are monitoring the progress of the traverse (along with other duties). On returning to the outpost, the EVA crew will insure 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.)

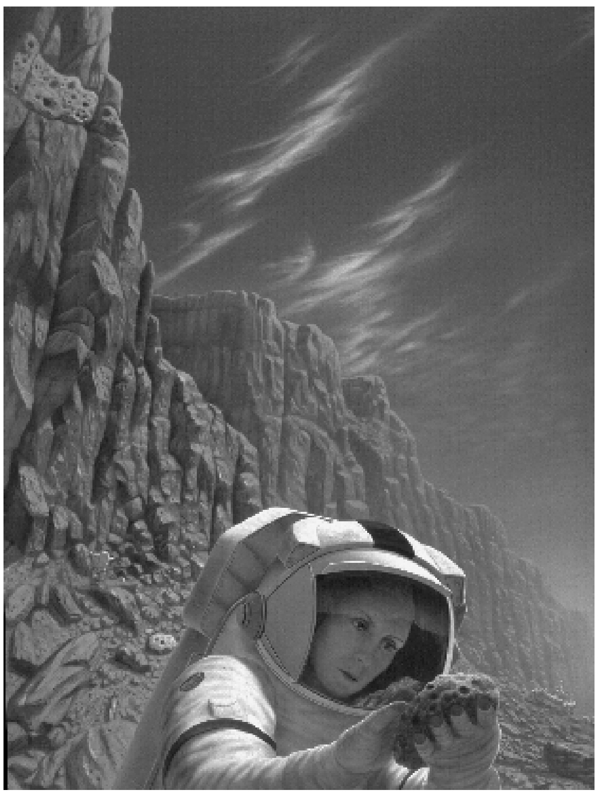

Fig. 2.3-1. An EVA crew member examines a rock sample gathered from the base of a vertical wall. Unpressurized rovers, such as the one seen in the background, will be used by the crew to gain access to site such as these that will likely be located beyond walking distance from the landing site.

Intensive field work at a single site may involve one of several activities associated with science payloads carried in the DRM manifest or comparable activities which may be part of the unspecified “discretionary PI” science. Two specific examples for which there are manifested payloads include the set-up of geophysical/meteorological stations and the 10-meter drill.

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 set up process will likely be automated but with the potential for intervention by the crew. Drilling operations are also likely to be automated but under close supervision by the crew. (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 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 they have 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 the section devoted to this topic) and an extensive interaction with tools and equipment at these sites.

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 ISS, and current knowledge of the Mars surface mission, this transformation process has already begun (*Griffith*, 1998). While these discussions are on-going 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*, 1998, 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/equipment problems.
- Time delays between Earth and Mars require that primary support for the EVA crew be provided by the habitat crew. Earth-based personnel may participate, but as backup. In both cases, real-time voice, video, and data between the EVA crew and the habitat support personnel are required. Loss of these links may, depending on distance, terminate the current EVA.
- Nominally only one pair of crew 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 and possible, but not nominally planned, and will be constrained to 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.

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 vs. 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 the field activities envisioned for the surface crew.

References

Eppler D. (1997) *Geological Field Work and General Implications for Planetary EVA Suit Design.* Internal Memo, February 7, NASA Johnson Space Center, Houston, Texas.

Griffith A. (1998) Personal communication.

NASA (1998) *Human-Rating Requirements.* JSC Publ. No. 28354, NASA Johnson Space Center, Houston, Texas.

Surface Transportation

Surface transportation for EVA crews will be a requirement from the outset of these Mars missions. There are several factors contributing to this. 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 if there are 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.

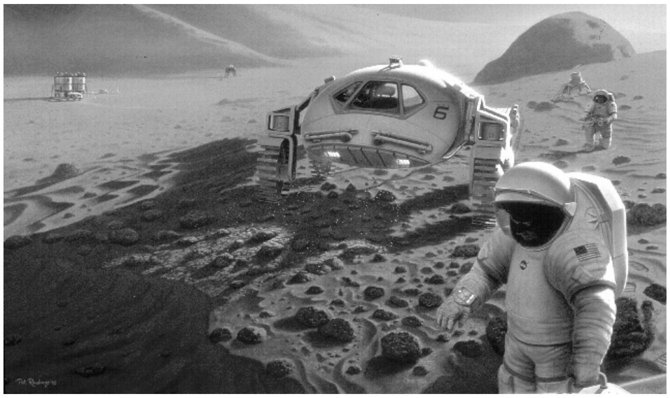

Fig. 2.4-1. EVA crew members begin to explore the region in the immediate vicinity of the landing site. Pressurized rovers, such as the one illustrated here, will be used for a variety of tasks both close to and distant from the pressurized habitat. These rovers will have the capability to allow the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

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.

Unpressurized Rovers

Unpressurized rovers will obviously require the use of EVA suits by the crew. This implies that the capabilities and interfaces of the unpressurized rover will be intimately tied to those of the EVA suit. This, along with the previously stated reliance on surface transportation for the crew to remain at a high level of effectiveness over a long duration, allows the unpressurized rover to be viewed in may ways 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 of 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 approximately 20 percent of the total EVA time was spent by the crew 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 for contingency operations should they be 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. This could mean 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. It is reasonable to assume that, while operating in terrain similar to that seem in images of the martian surface, a rover could easily become stuck or otherwise unable to move but is still functional. In a single rover operation, this would be sufficient cause for the EVA team to start walking back to the outpost or to call for assistance from the personnel remaining at the outpost. However, under these circumstances rovers not immobilized are available to help extract the temporarily immobile vehicle. In the case of a disabling component failure, the other rover(s) are available to provide power, lighting, etc., as field repairs are attempted or, in a worst case, transport the crew of the failed rover back to the outpost.

Fig. 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.

This description points out two additional characteristics of the unpressurized rovers. First 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). Second it indicates that the rovers must be sized to carry cargo which, if off-loaded, is of a sufficient capacity to carry the crew of a disabled rover.

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

Pressurized Rovers

Pressurized rovers are typically included in the Mars mission studies because of their ability to extend the range of the crew, 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, conduct EVA activities (comparable to those discussed earlier) within the vicinity of the rover, and otherwise support the crew for the duration of their excursion away from the outpost.

Due to the size and mass of a pressurized rover, only one of these vehicles is manifested in any one cargo flight. Based on the mission architecture described in section 1.2 of the addendum to the Mars Reference Mission document (see *NASA*, 1998) the first pressurized rover will arrive on the cargo flight for the second crew. Due to the sequential deployment of these cargo vehicles, this pressurized rover will arrive in time for the first crew to use it (see Fig. 1.2-2). But the availability of only one of these pressurized rovers will impose operational constraints on its use until a second rover arrives.

During that period of time when only a single pressurized rover is available, operations will be constrained in a manner similar to that imposed on multiple unpressurized rovers: namely 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 the following section on field camps). 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.

Once a second pressurized rover has been delivered, in time to support the second crew as currently planned, the radial distance away from the outpost can be significantly expanded. These distances will preclude resupply as mentioned previously 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 the following section devoted to this topic) 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 candidate sites are prioritized by the entire crew, 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. The drill is moved to each candidate site in turn by an EVA crew using the unpressurized rover. 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 onboard the teleoperated rover prior to 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 their 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 capability for the crew to repair it in the field.

Summary

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

- Both pressurized and unpressurized rovers will 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.

References

NASA (1997) *Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team.* NASA Special Publication 6107, NASA Johnson Space Center, Houston, Texas.

NASA (1998) *Reference Mission Version 3.0; Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Team.* EX13-98-036, NASA Johnson Space Center, Houston, Texas.

Trevino R. (1998) Personal communication.

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 crew 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 identified for exploration by the crew will be located some significant distance away from the landing site.

It is also reasonable to assume that some of these remote sites will be selected for extended, detailed study by the crews. 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. Such a capability will reduce the need for the crew to commute from the central base to the site and back again, thereby providing 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 prior to 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 walkback 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 Fig. 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.

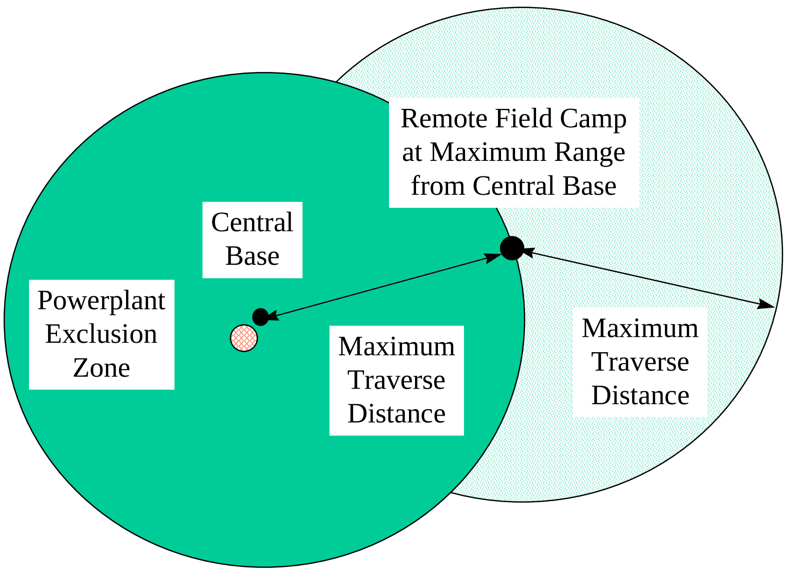

Fig. 2.5-1. Use of a remote field camp to extend the range of operation prior to the arrival of long-range roving capability.

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 walkback 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 contact is lost with a team in the field (the assumption being that if a crew should lose radio contact but is otherwise okay, then this crew will make its way back to the field camp to meet the SAR crew 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 may have been 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 spent 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 (mass estimate derived from *Budden,* 1994).

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

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 on 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 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. Crew mobility while the pressurized rover is in this fixed location can be accomplished by the unpressurized rovers.

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 is assumed to be designed such that minimal site preparation (i.e., moving rocks, surface leveling, etc.) will be required, 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, life support system, power system, communication system. 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 scientific interest. Thus the capability for daily EVA activities is assumed for these field camps. As mentioned in various other places in this section, EVA activities may be as uncomplicated as walking traverses in the vicinity of the field camp to the set up, 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.

Fig. 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. This includes any required maintenance or minor repair of the EVA suits, logging data from the experiments, and preparing samples (such as core sample 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 walkback 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 either be analyzed with the equipment available or will be put through the curation process.

Summary

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

- Improved utilization of crew by providing the capability to remain in the field for many days or weeks (with resupply) at sites of high scientific interest.
- The ability to perform daily EVAs.
- The ability to support a diversity of experiments ranging from walking traverses to operation large and/or complex machinery.

- The ability to accommodate a nominal crew of three.
- The ability to 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 that are needed to implement this capability.

References

Budden N. A. (1994) *Catalog of Lunar and Mars Science Payloads.* NASA Reference Publication 1345, NASA Johnson Space Center, Houston, Texas.

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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-µm 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 to be not 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. These new environments 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. They will also have to avoid coming in contact with 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 crew 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 be collected and packaged immediately for return to Earth, or it may be desired to 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 for conduct on the surface of Mars is TBD; however, it is pointed out that 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 standalone 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. (Sample analysis is discussed in a later section.)

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 their 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 prior to allowing the crew members to reentry the habitat facility.

When humans were sent to the Moon, a system of quarantine 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 new environments are being encountered on the human missions. This suggests that requirements for crew quarantine be considered at the time that sample quarantine facilities are designed 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.

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 inevitable lead these crews to environments where such assessments will be necessary to assure their own health and safety as well as protect to Earth's biosphere from contamination. Such assessments will be derived from equipment and procedures that exhibit the following characteristics and capabilities:

- Control of 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 make analyses of 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, whenever new environments are sampled that may contain martian life.

- Capability to prevent contamination of isolated martian environments that may contain organisms from contamination or disruption by human activities.

Sample Curation

During the course of their 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, documentation of its location, orientation, and surface setting will be recorded. This can be done by 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 would prevent cross contamination between samples, and will most likely be similar to the 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 Sample Analysis Section). 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 a better understanding of the local geologic setting is developed by the results of preliminary examinations. 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 will quite likely 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 overcome these limitations is to not withdraw continuous coring sections but rather sampling 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.

Volatile-rich samples will also present significant challenges in keeping them in their pristine state. 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 out-gassing. 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.

Summary

In summary, the following curatorial activities will be conducted during any extended stay by astronaut crews on the martian surface:

- Sample documentation: to record the geologic and physical setting of the sample prior to collection, and to describe everything done to that sample during examinations.
- Splitting of selected samples: to provide subsamples for preliminary examinations and "minimally contaminated" sub-samples for remote storage and possible shipment to Earth.

- Sample storage: to maintain samples in as pristine and secure condition as possible and be readily accessible.
- Sample tracking: database of current information pertaining to the location and condition of all samples and subsamples.
- Preliminary examination: conducted to identify and characterize each sample and subsample.
- Contamination control: to maintain samples in as pristine condition as possible.

References

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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 their 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 members of the crew 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.

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
- to assist in the planning of surface exploration activities and field work
- to "high-grade" the collected samples to determine which ones will be shipped to Earth
- to 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 for where it occurs, how it occurs, and who conducts the examination. Initial sample examination will occur in the field, carried out by either an EVA crew member or a teleoperated robot or possibly both, 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 the packaging of 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 sub-samples (as discussed in the Sample Curation Section), 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.

Prior to a more detailed examination inside the habitat, the sample(s) may require some amount of preparation exterior to the habitat. An example of this situation is the preparation of core samples brought up by the drill. These samples are likely to have already been divided into lengths that can be handled by the EVA crew and what ever storage system that 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 they acquire, 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, other members of the crew 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 hand-held 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*, 1988). 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 (*ESA*, 1998). Life can leave its imprints at the surface of rocks as etch pits, reaction product deposits, 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.

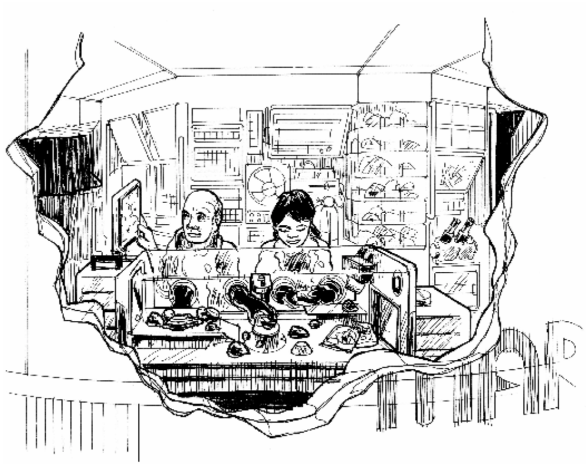

Fig. 2.8-1. Crew member examine a number of collected surface samples inside a glovebox facility. This facility will not only protect the crew from potential hazards associated with the sample, but will also protect the sample from contamination by the crew.

Data and results from all of these facilities will be stored in an on-board 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.

Summary

This section has discussed the sample examination and analytical capabilities that are 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 to them will allow the crew to better understand the environment in which they are exploring and adapt to the findings that they make, 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 that is 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.

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