SAE TECHNICAL PAPER SERIES

1999-01-2142

Mars Surface Science Laboratory Accommodations and Operations

Marc M. Cohen
NASA Ames Research Center

The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL

29th International Conference on Environmental Systems
Denver, Colorado
July 12-15, 1999

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-5760

ISSN 0148-7191

Printed in USA

1999-01-2142

Mars Surface Science Laboratory Accommodations and Operations

Marc M. Cohen
NASA Ames Research Center

ABSTRACT

The NASA Mars Exploration Design Reference Mission asserts two equal goals: scientific exploration of Mars and human habitation on Mars. However, at present, the Design Reference Mission does not provide a substantive accommodation for the science component of Mars Exploration. This essay describes the design strategy to develop the Mars Surface Science capability as embodied in the crew, lab facilities at the base and mobile laboratories in the pressurized rover.

Clearly, NASA has a great deal of work ahead to supply the mission requirements and design rationale the science laboratory capabilities at a human Mars Base. The purpose of this essay is to begin to create a specific focus on Mars's surface science laboratory requirements, operations and accommodations

INTRODUCTION

The purpose of this essay is to make explicit the parameters for developing and supporting the scientific exploration of Mars by human crew members on the Mars surface. Probably the best – and most expansive – statement comes from Carol Stoker (Stoker, 1996, p. 558).

> Laboratory analysis of samples in the Mars base lab would involve cutting and sectioning samples and using various analytical instruments. For geological samples, standard techniques for determining mineralogy, petrology, grain size, elemental composition, age dating, isotopic composition, and trapped volatile analysis could be used. For samples of biological interest, macro and micro-scale inspection of any prospective fossils would be performed as well as organic analysis, biological culturing, and wet chemistry.

SCIENCE IN THE DESIGN REFERENCE MISSION – The NASA Mars Design Reference Mission (DRM), which focuses on overall mission architecture, says even less about the Mars Base Science Lab. The DRM calls for the launch of this "Hab/Lab" 26 months before sending the first crew to "pre-position" it before their arrival. In the Part One Overview, it states:

> The Mars surface laboratory, sent out, landed, and verified prior to the launch of any crew members, will operate only in 3/8 gravity. It contains a large, nonsensitive (that is, no special environmental control required) stowage area with crew support elements on one level and the primary science and research lab on the second level. Future development of this element includes possible retrofitting of the stowage level into a greenhouse as consumables and resources are consumed and free volume is created (Hoffman and Kaplan, ed, 1997, pp 1-22 to 1-23).

The Mars Design Reference Mission's Part 3, Mission and System Overview reiterates and reinforces of the Lab as an opportunity to provide stowage and greenhouse space. Then, it goes on to reassure the reader that all the functions and capabilities within the Science Laboratory "will be identical to the other habitats with a few exceptions" (Hoffman and Kaplan, 1997, p. 3-97). However, the Design Reference Mission does not state what those exceptions might be.

DRM 3.0 SCIENCE MASS – Version 3.0 of the DRM finds substantial cost savings in eliminating the first Hab/Lab pre-positioning launch, which effectively eliminates the Mars Surface Science Laboratory as a discrete and identifiable element from the Mars Base:

> "Elimination of Initial Habitat Flight: While reviewing the original mission strategy, the initial habitat lander (Hab-1) was identified as a launch component that could potentially be eliminated." (Drake, 1998, p. 7).

Elimination of the first Hab/Lab prepositioning launch saves the mission architecture about 50 mTons. Roughly half of the Hab/Lab would have been devoted to the Science Laboratory, comprising about 25% of the total preintegrated pressurized volume and about 20 mTons of dedicated mass. Beyond this Habitat Module related elimination, DRM 3.0 reduces the mass allocated for science equipment from 2.37 mTon to 1.77 mTon. This mass reduction expressly includes all “Discretionary Science.” Of this allocation, the Exobiology Laboratory receives only 50 kg, (Drake, 1998, pp. 14-15) which suggests that perhaps the Astrobiology discipline has yet to make its case for the Mars Science Lab. Meanwhile, the DRM 3.0 mass reductions affect science in ways that are not yet clear.

FOCUS ON SURFACE SCIENCE LAB REQUIREMENTS – This effort supports the Astrobiology Objective 8 in search of past or extant life on Mars -- (Astrobiology Program Office, 1998, p.7). Developing these explicit parameters encompasses design, instrumentation, system integration, human factors and surface operations.

APPROACH

This essay derives from a concern that assumptions may be made that are counterproductive regarding astronauts conducting actual, real-time science on the Mars surface. Such faulty assumptions, which will lead inevitably to an inadequate Mars Surface Science Laboratory, are:

ASSUMPTION 1 – Astronauts are essentially just extensions of telescience for principal investigators back on the Earth.

ASSUMPTION 2 – Crew sizing to staff the laboratory and planetary rovers is a function of “mission architecture” rather than determined by exploration or Astrobiology goals, objectives and requirements.

ASSUMPTION 3 – The Laboratory serves the mission to perform a triage level of analysis, and sends the “interesting rocks” back to Earth for the serious analysis.

ASSUMPTION 4 – A Mars Surface Laboratory is essentially just a slightly modified Habitat

ASSUMPTION 5 – The use of a crew rover pressurized or unpressurized is just to pick up rocks and back to the lab for further study.

ASSUMPTION 6A: – Robot Landers will Prove there is No Life on Mars.

. . . but if they don’t . . .

ASSUMPTION 6B – Sterilize everything.

IMPLICATIONS OF THESE ASSUMPTIONS

This essay critically examines each of these potential assumptions noted above toward developing viable design requirements and mission operations scenarios for the Mars surface science laboratory.

1. ASTRONAUTS ARE JUST EXTENSIONS OF TELESCIENCE – This view extends the paradigm of conducting science remotely by uncrewed space probes and instruments – telescience – from the status quo of space probes to the human exploration challenge. To make truly creative and productive use of human explorers, it will be necessary to give them meaningful autonomy in pursuing their own scientific investigations. Making this autonomy possible and realistic will require significant, substantial, and highly capable facilities and vehicles on the Mars surface.

2. CREW SIZING IS A FUNCTION OF “MISSION ARCHITECTURE” INSTEAD OF EXPLORATION OR ASTROBIOLOGY REQUIREMENTS – Mission planners tend to elevate the “Mission Architecture” as its own internalized and closed system of logic, and to quickly lose sight of the reasons for exploring in the first place. The typical manner in which this occurs is early decision-making or rather speculation about the best life support economy or propulsion system. The potential early casualty is the crew selection for appropriate skills and the number of crew members necessary to conduct the science work on the planetary surface. Doing serious design research for the Science Lab is the main, central key to the biggest cost driver for the whole mission: the crew size.

3. THE LAB IS A TRIAGE STATION FOR ROCKS – This assumption derives from the habit of viewing planetary science as a remote occupation, conducted robotically by landers and solar-powered rovers that relay their instrument data back to Earth. Under the triage scenario, the Astronauts would point the same instruments at rocks as do the robotic rovers, then pick up any promising rock and bring them back to the lab. At the lab, the crew’s primary duty would be to catalog the samples and store them for shipment back to the principal investigators on Earth. If they had time from their busy day, the crew might saw into one or two for examination under microscopes. Still, the real work of analysis and theorizing remains on Earth -- because DRM 3.0 already indicates that the science lab facilities will be minimal at best. This approach will make it difficult to conduct serious laboratory science on the planetary surface. This essay steps beyond this conventional wisdom to suggest that the exploration crew members conduct primary science at the Mars Base, in the Surface Science Lab and in the Pressurized Rover as a mobile laboratory. Conducting this science at the investigation sites and in the laboratory on Mars is the most effective way to take advantage of the unique capabilities that the human crew brings to the mission.

4. THE LAB IS JUST A MODIFIED HAB – To insist that the Lab will be just like the Habitat simply because the Mission Architecture *already has* a Habitat misses the essential design problem. Given that the crew will work in a pressurized environment with life support, the Lab shares some functions with the Habitat. However, a suc-

cessful and functional Mars Surface Science Lab will have a large set of unique functional requirements and system demands. In many respects, it will constitute a unique element within the mission architecture. Even if it is possible to fit the lab into the same type of external pressure envelope as a Habitat, its other characteristics will make it quite an independent design. The laboratory is likely to require a system of airlocks, compressors, glove-box chambers and other large equipment that will make a significant impact upon the architectural design. It may prove very difficult to fit an appropriately designed laboratory into a "one size fits all" habitat.

FIGURE 1 shows an alternative design for an inflatable habitat or lab attached to the crew lander. FIGURE 3 shows a detail of EVA astronauts attaching the soft fabric envelope to the lander prior to inflating it. The practical difficulties of employing this inflatable arise in trying to outfit this pressurized volume with a complex set of hard-plumbed and hard-wired laboratory apparatus on the planetary surface. Normally, the comparable SpaceLab or Space Station Lab facilities require the efforts of hundreds of highly trained engineers and technicians to accomplish in a state of the art factory on Earth. How will a small exploration crew perform this assembly and construction under the unusually difficult conditions on Mars?

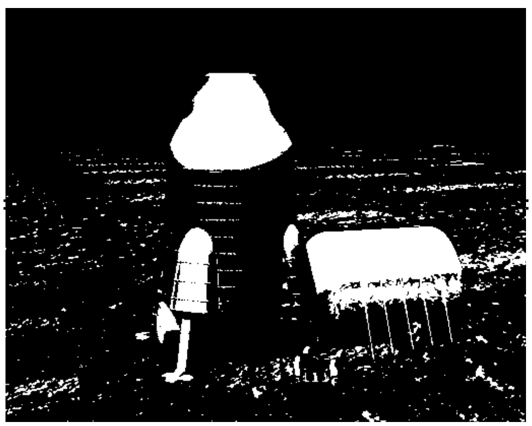

Figure 1. Design Reference Mission Lander with inflatable Habitat or Laboratory attached. (Courtesy of the Exploration Office at Johnson Space Center).

5. THE CREW ROVERS GO OUT TO PICK UP ROCKS – The Mars Design Reference Mission states the requirement for the pressurized crew rover to travel:

> Regional distances: a radius of up to 500 km in exploration sorties that allow 10 workdays to be spent at a particular remote site, and with a transit speed such that less than half the excursion time is used to travel (for example, for 10 workdays, no more than 5 days to reach the site and 5 days to return (Hoffman and Kaplan, 1997, p. 3-106).

It is essential that we ask: how does the crew know if they have a "good rock" or a "bad rock," a scientifically interesting rock or an uninteresting rock? Imagine travelling five days to a site and back – or better yet, ten days along a route picking up rocks – and never knowing if the rocks one finds are the samples one wants. The pressurized rover clearly should have an on-board science laboratory capability to examine the samples in real-time as soon as the crew collects them – or as soon as possible afterward. Only by providing, installing and utilizing this real-time science capacity will the crew members know if they should look for more rocks of the type they just found, or to toss out the last sample and move on to the next likely site.

Real-time analysis will enable any needed action (e.g., gathering of additional samples) to be taken with only *hours* or *days* of delay. This timeliness compares very favorably to *months* of delay if the analytical capability is confined to the Mars Base and *years* if the analysis is carried out solely on Earth.

6A. ROBOT LANDERS WILL PROVE THERE IS NO LIFE ON MARS – This assumption underlies much of the human Mars mission planning. Assuming there is no life on Mars, "backward" planetary protection will not be a serious concern of preventing contamination of the crew or the Earth upon their return. This assumption derives primarily from the analysis of the exposed Mars surface as too hostile to life as presently understood.

Yet there may well be completely different environments deep under the Mars surface as there is in permafrost or in deep oil shale/limestone formations on the Earth that support microbial life. Perhaps there are even "bugs under the rocks," that protects them from radiation and extreme temperature swings. However, if the Astrobiology investigation on Mars does find life, it changes the picture radically. If there is life on Mars, the assumption flips to the other approach: Sterilize Everything.

6B: STERILIZE EVERYTHING – This potential mindset owes perhaps more to the science fiction genre that Michael Crichton's Andromeda Strain exemplifies than it does to the actual scientific and medical biosafety standards in use today at the Centers for Disease Control (CDC). The precedent from the Apollo Program when the moon explorers returned with lunar rocks was to seal them in protective canisters and then to sterilize them in autoclaves to prevent the potential contamination of the Earth by unknown organisms.

While the bio-isolation and planetary protection concerns remain, they map neither neatly or cleanly onto the current CDC standards for biosafety nor do they correspond with the Astrobiology objectives of ascertaining the existence of life on Mars past or present. The combination of Astrobiology research objectives and biosafety requirements drives the Mars Surface Science Laboratory to both functionality and an architectural configuration that has yet to be conceived. Certainly, the biosafety and Astrobiology requirements of a human Science exploration mission do not converge yet with the NASA Design Reference Mission.

The National Center for Infectious Diseases created the working definitions of biosafety. NCID defines ***Biosafety Level (BSL)*** as: *Specific combinations of work practices, safety equipment, and facilities which are designed to minimize the exposure of workers and the environment to infectious agents*.

See TABLE 1 for the elaboration of this definition of four biosafety levels (BSLs). In its interim standard for safe laboratory procedures for handling respiratory hantavirus, the National Center for Infectious Diseases offers these guidelines for applying the four biosafety levels to the hantavirus.

> Potentially infected tissue samples should be handled in BSL-2 facilities in accordance with BSL-3 . . . . Cell-culture virus propagation should be carried out in BSL-3 containment facilities in accordance with BSL-3 practices. Large-scale growth of the virus, including preparing and handling viral concentrates, should be performed in BSL-4 containment facilities. (National Center for Infectious Diseases, May 1998).

The capability to “sterilize everything” may be critical. But the question of ***when*** and ***why*** to sterilize is even more critical. TABLE 2 describes the four questions: what to sterilize, where to sterilize, when to sterilize, and how to sterilize. Even with an extremely infectious pathogen such as the Ebola virus, the appropriate protective measures vary depending on the conditions in which it occurs. Ebola is extremely dangerous as an airborne aerosol, but on a laboratory surface, it is easy to kill with an alcohol wipe (Georges-Courbot, et al, 1997).

This brief discussion suggests the complexity of dealing with a potentially virulent agent and the variety of appropriate methods for dealing with it under different conditions and in different embodiments.

MARS LAB DESIGN METHODOLOGY

The Mars Surface Science Lab design must begin with a careful collection and documentation of scientific research. It must account for the scientific objectives such as the types of data the principal investigators seek, the types of samples in which they seek it, and the locations where they expect to find those samples. These locations suggest the environment and terrain in which the science crew will operate, and leads to assumptions about the site and proximity of the Mars base. The disciplines for the Project to accommodate include paleontology, geology, atmospheric science, exobiology, exopaleontology, and life science (life science includes study of human adaptation to partial gravity and possibly adaptation of other organisms from Earth).

After defining these scientific metiers, the next step defines the design requirements necessary to support the work and the operational scenarios to carry it out. These design requirements cover the allocation of capabilities on Earth, in the laboratory on Mars, In the field facilities in the rover and astronaut EVA tool kits, and the allocation of tasks and responsibilities among them. From these design requirements, the design research study can develop preliminary designs to support the exploration science. This discussion enlists the pressurized rover as a microcosm for all the science and crew issues involved in the Mars exploration and Astrobiology mission.

This ***allocation of capability*** approach incorporates a "humans and machines in the loop" model that recognizes that every exploration system involves both humans and automated systems. The question is where in the loop they occur -- whether on Earth, in the Mars Base, in the rover or creeping over the Mars surface.

This methodology recognizes the high degree of interdependence between the foci of design research and functional requirements. It analyzes these six foci in parallel as design foci: activity nodes, equipment capabilities, laboratory accommodations, architectural design, the human factor, crew sizing and the operational scenarios.

ACTIVITY NODES – A top level assessment is necessary to the optimal allocation of functions among activity nodes. These activity nodes include principal investigators and their institutions on earth; the laboratory in a Mars habitat; mobile instrumentation in both a pressurized and unpressurized rover; and what an EVA astronaut will use in exploring the surface.

The best allocation of capabilities or distribution of responsibilities among the nodes often is not obvious. For example, in planning a science rover traverse of about 500 km radius, mission planers must provide for selection of the investigation site traverse route and alternate routes, maneuvering around obstacles, set up at the investigation site, and selection of samples. An example of a solution might be that:

- Principal investigators on Earth select the investigation site,
- Mission planners on Earth plan the traversal route,
- The astronauts send a Mars airplane (Hall, Parks and Morris, 1997) ahead of the pressurized rover to survey the route in detail,
- The astronauts drive the pressurized rover to the investigation site, and
- The astronauts select and analyze the samples.

However, there are many more ways to divide these tasks, and mission planners will need a basis for selecting among the possible solutions. The same type of evaluation will be needed for all aspects of science and Astrobiology exploration.

LAB ACCOMMODATIONS – The laboratory accommodations in a pressurized habitat serve as a fulcrum for the whole science exploration enterprise. The laboratory is where the science crew will perform their most definitive analyses and assays. The design research must investigate the system parameters of the laboratory, including volume, floor area, mass, power demand, thermal cooling for equipment, heating, ventilating and air conditioning (HVAC), stowage volume, data systems, structural attachment conditions, lighting, and a preliminary architectural design. The study will examine data rate and bandwidth for sending analytical data back to Earth. These considerations of laboratory accommodations belong in the context of the allocation of capabilities between crew on Mars and scientists on Earth, and between the Mars base lab and the mobile lab in the rover.

Atmosphere and Pressure Systems – The definitive characteristic of this Astrobiology sample processing laboratory is that it must be capable of maintaining the samples in a pressure regime that is different and separate from the crew cabin atmosphere. The pressure differential -- •P – is the difference between the Mars-ambient apparatus pressure of about .01 Earth atmospheres (ATM), approximately1.0 KPa, and the breathable crew cabin atmosphere of about 1/3 to 2/3 ATM, approximately 33.5 KPa to 67 KPa. The .01 ATM apparatus pressure would be necessary within the system of airlocks, glove, boxes and associated chambers to preserve the Mars Astrobiology samples in as pristine a condition as possible, preserving not only pressure, but gas mixture, humidity and temperature as well. The crew cabin atmosphere will most likely range from about 29.6 KPa (4.3 psi), the typical EVA space suit pressure currently in use for the Space Shuttle EMU, to perhaps 69 KPa (10 psi), which would allow a more Earth-like, albeit, high altitude ambiance. To maintain sufficient oxygen in such a hypobaric environment, it is necessary to increase the partial pressure of oxygen relative to the buffer gas nitrogen in the atmospheric mix.

Structural and Mechanical Engineering Requirements – Overall the •P between the cabin atmosphere and the apparatus pressure will impose stringent structural and mechanical engineering requirements upon the design and construction of the laboratory apparatus. All these airlocks, glove boxes and attached chambers must resist the considerable force of the •P. This •P drives also the design of all the manipulator systems within the gloveboxes and work chambers. Astronaut experiences with various space suit gloves show that a •P of 34.5 KPa (5.0 psi) is approximately the upper threshold for a gloved hand against which to work for any extended period of time without great strain, soreness and fatigue. Building the laboratory apparatus to withstand this •P will add considerably to the mass and cost of any laboratory system, and certainly will drive it far beyond the 50kg allocated in the NASA DRM.

Protecting the Sample – Although most of the biosafety precautions are intended to protect the crew members (an humans back on earth) from any potential dangerous organisms, the lower pressure in the apparatus means that the main threat of contamination is from the cabin atmosphere leaking into the laboratory chambers. It is important to prevent this leakage to preserve the samples as much as possible in their natural state, and to protect them from contamination from Earth organisms.

Sample Handling and Processing Apparatus – FIGURE 4 shows two alternative sketches of the Astrobiology sample handling apparatus. FIGURE 4a and FIGURE 4b include all the same essential functional components, but the arrangement and complexity vary between the two. In both sketches, the crew keeps the Astrobiology sample canisters in an external, unpressurized storage facility, from which they use a robotic retrieval system. The robot places the sample in the sample airlock to bring it inside the pressure envelope of the laboratory. From the sample airlock, the crew move it by hand or by remote manipulator to a transit airlock and then into the working sequence of chambers and gloveboxes. After passing through this sequence, the crew may remove a sterilized sample to examine at first hand and store in the crew cabin.

FIGURE 4a shows a simple, linear arrangement of processing chambers, optimized for the minimum number of internal transit airlocks to pass samples from one work chamber to the next. The primary autoclave (or other sterilizing system) is an adjunct to the preparation chamber.

FIGURE 4b shows an arrangement that is optimized for flexibility in moving and handling the sample, with two separate "racetracks" or loops through which the sample can pass in either direction. The autoclave is part of one such loop, while the wet lab chamber, dry lab chamber, and exit airlock combine to form the second loop. Sketch B suggests that it may be desirable for the science crew to be able to separate, rearrange, and reconnect the various components depending upon the imperatives of the work.

These sketches suggest the potential advantage of designing the work chambers, gloveboxes and sample handling airlocks in a modular fashion, with as high a degree of commonality as is consistent with their specialized functions.

Environmental Monitoring – A key aspect of successfully operating the laboratory apparatus is to develop and implement an environmental monitoring system that will detect and help prevent any contamination of the samples or of the crew cabin. This environmental monitoring system will include its own suite of instrumentation for real-time monitoring of the "ecosystem chemistry" within the cabin and within the lab apparatus.

EQUIPMENT CAPABILITIES – This assessment includes both a recommendation for equipment assignments to support systems and for a division of crew labor and skills between the various tasks and undertakings. For example, an essential inquiry would be what analytical capability on-board the pressurized rover or back in the Habitat is necessary to enable the crew to make certain informed judgements in the field? If so, what is that instrumentation and what is the impact of installing it in a pressurized or on an unpressurized rover? What is the impact upon the Habitat on off-loading some analytical capability to the rover? How does such a decision affect the overall allocation of capabilities?

This study must make reasoned estimates about the types and models of equipment and supplies such as sample saws, chipping tools, microscopes, chemical reagents, dye penetrants, polariscopes, gas chromatograph, mass spectrometer, x-ray spectrometer, magnetometer, freezer, and panoramic and VR cameras. This suite of tools and instruments must be organized and deployable in the most convenient manner for the astronauts to use them where needed in the Mars Base lab or in the field.

WORKING ACROSS THE •P – The earlier discussion of the dual pressure regimes between the laboratory cabin atmosphere and the laboratory apparatus suggests that every instrument and tool must be able to work across this •P. While in some cases it may be feasible to keep tools inside the apparatus chambers at all times when in use, and so at a single pressure, in other cases it will be necessary for an instrument or tool to operate across the pressure differential. For some operations, it will be advantageous to have robotic and remote linkage manipulators that operate within the apparatus pressure chambers, without making any mechanical penetrations that could become possible leak points. Instead there would be only sealed electrical power and fiber-optic or other data connections. The fewer soft and mechanical penetrations in the apparatus chambers, the less the possibility of leakage.

ARCHITECTURAL DESIGN – This laboratory development effort will require a preliminary architectural design that integrates the laboratory into a detailed habitat, with a representation of reasonable ingress, egress, safety considerations, fire separations, floor plan, interior elevations, and furnishings. The study will examine methods of sample storage, handling, and processing. Stowage options include pressurized internal and unpressurized external stowage facilities with manual or automated/robotic retrieval. Handling systems include stowage and transport containers, a sample airlock, glovebox, and possible integration of the glovebox with the sample airlock. These insights apply to the larger habitat planning considerations such as type of EVA, sample and equipment airlocks and the laboratory's integration with them.

<u>Cabin Pressure Regimes</u> – One of the most provocative questions is whether the laboratory should share the same pressure regime as the rest of the habitat, or operate at a separate, lower pressure. The issue of •P between the laboratory breathable cabin atmosphere and the Mars-ambient glovebox pressure poses the question of how to minimize the laboratory pressure. In comparison, the main living quarters within the habitat would require a more Earth-normal atmospheric regime to help maintain crew health over the long Mars surface sojourn of up to 600 days.

This •P between the laboratory and the living quarters suggests a possible need for personnel airlocks between the two sections of the Mars base. If the crew must use such an airlock to pass between parts of the Mars base, all the considerations and precautions of diving and EVA safety come into play. Generally it is more hazardous to pass quickly from a greater to a lesser pressure because of the danger of “caisson disease” or “the bends.” The bends occur when nitrogen gas comes out of solution in the blood and forms bubbles that can collect painfully at the joints in the body. The bends can be painful or even fatal, and the cure consists of repressurizing the subject in a hyperbaric chamber up to six atmospheres to drive the nitrogen bubbles back into solution. The key to preventing the bends is to pass the human subject slowly from the higher pressure to the lower pressure, to ensure the safe physiological response to decompression. Although it requires a substantial and irreducible amount of time, this transition poses little difficulty for the personnel airlock itself, which is easy to bleed off gently from the higher to lower pressure.

Passing from a lesser atmospheric pressure to a greater one requires precautions also, but generally it is possible physiologically to do it more quickly. However, the necessity of pumping up an airlock from the lower to the higher pressure may add a practical time delay.

<u>Mars Base Planning Integration</u> – This discussion suggests that the Mars Surface Science Laboratory will place substantial demands upon the Mars Habitat and Mars Base. The potential need for an airlock entry suggests that the Laboratory would do well as its own separate module. The considerable complexity of the laboratory equipment -- and the critical need to integrate, test, and prove it before using it for potentially hazardous samples indicate that such a facility will require integration in an Earth-based factory. It will be extremely difficult and unreasonably time consuming to assign such a task to the astronaut crew. Ultimately, the architectural design research for the laboratory must address the overall design of the Habitat pressure shells and outfitting systems, and the integration of the science lab into the plan layout of the Mars Base.

HUMAN ELEMENT – The human element is an essential component in the Mars exploration strategy. The burning question is what size crew and skill mix is necessary to conduct the Mars surface exploration successfully. Two aspects of this question are: who is necessary to perform the science work? And who is necessary to keep everyone alive while the explorers do their job? This study will address primarily the former, with a focus upon Mars Base science lab and mobile field operations: how many science crew with what skills are necessary to carry out the work from the most physical to the most intellectual exertions? Who should explore in the rover and who should stay "home" in the laboratory? Secondarily, what are the crew requirements for supporting crew members in the pressurized rover and to maintain and operate the Mars base? The nature of sample collection will affect crew selection and work assignment also. For example, if the deep drilling equipment is installed close to the Mars Base, it may relieve a burden from the rover and its crew.

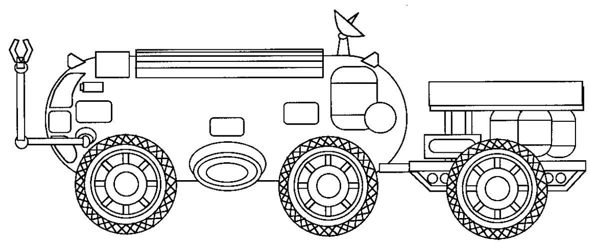

Figure 2. Example of a long-range pressurized rover with robotic arm and power cart. (Courtesy of Roger Arno, Advanced Space Projects Branch)

CREW SIZING – Perhaps the largest unresolved question is what is the optimal crew size and skill mix to conduct a Mars Astrobiology and Exploration Mission. Within the pressurized rover as microcosm of a Mars mission approach, there are many subsidiary questions and options: How many crew members are necessary to conduct a safe and successful rover excursion of ten days duration, 500 km away from the Mars Base? FIGURE 2 shows a conceptual sketch of such a pressurized rover. Possible options may include:

<u>Option A -- two crew members</u> constitute the minimum EVA buddy pair. One is a scientist and the other an engineer who divide the specialized tasks. They stop the rover to conduct an EVA.

<u>Option B -- three crew members</u> afford a buddy pair and a driver who remains in the rover. The skill mix includes both engineer and scientist. The driver can follow the EVA in the rover and use a robotic arm or digger to assist them in digging or turning over rocks.

<u>Option C -- four crew members</u> provide two full EVA buddy teams, involving a multiple mixture of scientists and engineers. While one pair is out EVA, and the driver is observing and following them, the fourth crew member may conduct real-time science investigations of the samples they pass through a sample airlock into a science glovebox in the rover.

<u>Option D -- five crew members</u> provide two full EVA buddy teams plus an engineer/driver in the rover.

<u>Option E – Redundant rover</u> for safety and backup. This reliability strategy could require from four to eight crew members.

These allocations of personnel time and capabilities raise a host of questions for mission operations. What is a reasonable amount of field time to carry out a mobile exploration of a particular Mars site? For how long can a group of two, three, four or five crew members stay away from the habitat without adversely affecting Mars Base operations?

OPERATIONAL SCENARIOS – The crew sizing question segues directly into the operational scenarios. One might expect the operational scenarios to be the beginning point of this entire study, but there are so many constraints upon launch mass and Mars base operations, that beginning with an operational scenario as a baseline requirement would be an self-deluding exercise. Although, the design research for a Mars Surface Science Laboratory must approach these six topics in parallel, it is for the purpose of understanding their interaction and ultimately the resulting capability on the planetary surface. Thus, the design research study outcome will apply largely to the operational scenarios that will ultimately be necessary and possible on Mars after all else is said and done.

NARRATIVE OF THE SOLID SAMPLE PROCESSING SCENARIO – This description outlines how the Mars science crew would collect, transport, handle and process a potential Astrobiology sample. FIGURE 5 illustrates this narrative.

<u>1. Collect Samples</u> – Collect samples at drilling site or other location. Place samples into a protective canister.

<u>2. Stow Samples for Transport</u> – Place canisters on transporter vehicle to carry them to the Astrobiology Sample Lab. The crew may conduct some on-board analysis to make a preliminary evaluation of the samples.

<u>3. Stow Sample Canisters for Retrieval</u> – Place canisters into robotic external storage system.

<u>4. Retrieve Samples</u> – Use robotic retrieval system to bring desired sample, place it in the sample airlock.

<u>5. Bring Sample into Lab</u> – In sample airlock, remove sample from its canister. Crew members use remote manipulators or robots to handle and sort the samples.

<u>6. Move Sample to Working Environment</u> – Robots move the sample through a transit airlock to the Preparation Chamber, where crew members examine it then slice, dice and spice it for analysis.

<u>7. Move Sample to Analysis</u> – Robots move the prepared sample to the Dry Lab Chamber or Wet Lab Chamber.

<u>8. Prepare Lab Chambers</u> – Crew prepares lab chambers with tools and equipment, maintenance, repair, and cleaning.

<u>9. Take Precautions</u> – Sterilize and autoclave samples, tools, equipment and chambers at appropriate times and opportunities.

10. Remove Sample after Analysis – Crew removes processed samples from the laboratory system via the exit airlock.

Caveats – The laboratory apparatus must maintain bioisolation across a pressure differential to separate samples from the cabin atmosphere. It maintains the natural ambient atmosphere of the Mars environment as required in the lab chambers. These airlocks and work chambers also have vacuum and purge capability.

CONCLUSION

NASA needs to conduct a complete Mars Base Science Accommodations and Operations Study to understand this issue and many questions. This study should result in an integrated design research product that would substantiate the Mars science exploration requirements. The first order question is why the Mars Surface Lab requires pre-integration in a hard module on the Earth before launch, and why assembling a Biological Safety Level 4 Lab in an empty inflatable on the Mars Surface is too difficult and impractical. This design research product should provide these seven main results:

1. Types of analysis and amounts of data.
2. The expected number type, location, depth, size, mass, etc. of the samples.
3. Mars Science Crew sizing and skill analysis – and overall crew sizing and skill analysis.
4. Mars science accommodation requirements and conceptual design for laboratory facilities.
5. Define the demands on the Mars Base and Habitat to support science laboratory activities and field operations.
6. Laboratory Subsystems modeling and prototyping.
7. The role of Mars surface mobility systems in conducting surface science investigations.

The best way to provide substantive and justifiable requirements to Mars exploration planners is to conduct this design research in cooperation with planetary scientists and astrobiologists.

ACKNOWLEDGEMENTS

I wish to acknowledge the support from Roger Arno, Larry Lemke, and Tom Wynn in the Advanced Projects Branch; Geoff Briggs in the Center for Mars Exploration; and David Morse in External Affairs at Ames Research Center for reviewing this paper and in encouraging me to pursue this line of design research.

BIBLIOGRAPHY

1. Astrobiology Program Office (1999, January) Astrobiology Roadmap, Moffett Field, CA: NASA-Ames Research Center. http://astrobiology.arc.nasa.gov/roadmap/index.html
2. Campbell, Paul D. (1992, January) Terrestrial Analogs of Space Exploration Human and Habitation Systems, LESC-29684, Lockheed Engineering and Sciences Company Houston, Texas: NASA-Johnson Space Center. http://www-sn.jsc.nasa.gov/explore/Data/Lib/DOCS/EIC030.HTML
3. Center for Disease Control /National Institutes of Health, (1993). Biosafety in Microbiological and Biomedical Laboratories. 3rd ed. Washington, DC: US Department of Health and Human Services, HHS publication no. CDC 93-8395.
4. Drake, Bret G., (1998, June) Reference Mission Version 3.0, Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, EX13-98-036, Exploration Office and Advanced Development Office, Houston, TX: NASA-Johnson Space Center.
5. Hall, David W., Parks, Robert W., and Morris, Steve, (1997, May 27) “Airplane for Mars Exploration: Conceptual Design of the Full Scale Vehicle – Design, Construction and Test of the Performance and Deployment Models,” Sunnyvale, California: David Hall Consulting.
6. Hoffman, Stephen J., and Kaplan, David I., ed., (1997, July) Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, NASA SP-6107, Houston, TX: Johnson Space Center.
7. Georges-Courbot, Marie-Claude et. al. (1997, January-March) “Isolation and Phylogenetic Characterization of Ebola Viruses Causing Different Outbreaks in Gabon,” *Emerging Infectious Diseases,* Volume 3, Number 1, Atlanta, GA: Centers for Disease Control and Prevention.
8. Mankins, John C. (1995, April 6) *“TECHNOLOGY READINESS LEVELS” A White Paper,* Advanced Concepts Office, Office of Space Access and Technology, Washington, DC: National Aeronautics and Space Administration. http://www.hq.nasa.gov/office/acrp/tr.doc
9. National Center for Infectious Diseases, (1998, May) “Laboratory Management of Agents Associated with Hantavirus Pulmonary Syndrome: Interim Biosafety Guidelines,” Atlanta, GA: Centers for Disease Control and Prevention. http://www.cdc.gov/ncidod/diseases/hanta/labguide.htm#part2
10. Stoker, Carol R. (1996) “Science Strategy for Human Exploration of Mars,” AAS 95-493 in Stoker and Emmart, Ed, Strategies for Mars: A Guide to Human Exploration, San Diego, CA: Univelt Publishers. pp. 537-560.

CONTACT

Please direct all inquiries to:

Marc M. Cohen, Arch.D, Architect
Advanced Space Projects Branch
Mail Stop 244-14
NASA Ames Research Center
Moffett Field, CA 94035-1000
mcohen@mail.arc.nasa.gov
TEL (650) 604-0068
FAX (650) 604-0673

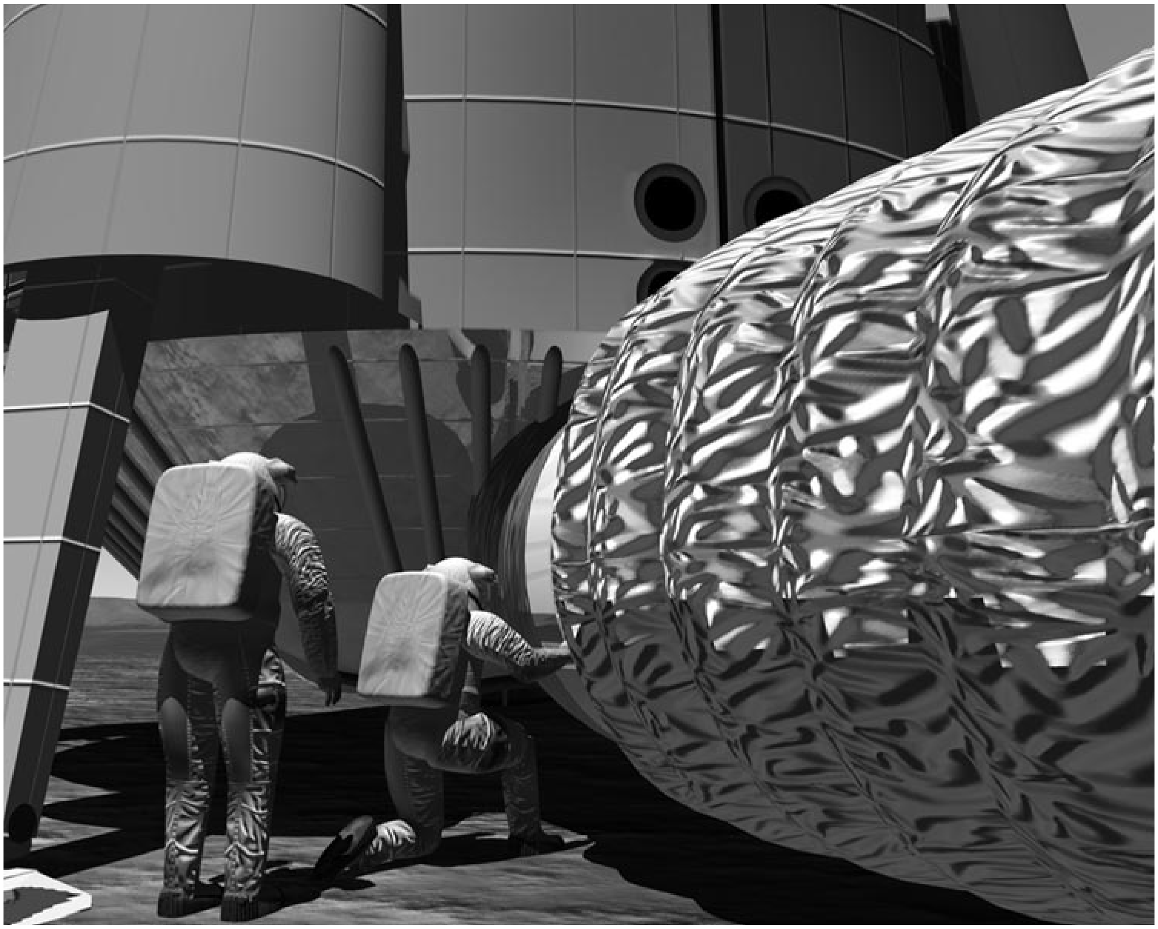

Figure 3. The crew attaches an inflatable laboratory to their lander to increase the internal pressurized volume of their Martian home.
(S97-07845) courtesy of the NASA-JSC Exploration Office

Table 1. Center for Disease Control's Biosafety Level (BSL) Definitions

Biosafety Level 1	Applies to agents that do not ordinarily cause human disease.
Biosafety Level 2	Is appropriate for agents that can cause human disease, but whose potential for transmission is limited.
Biosafety Level 3	Applies to agents that may be transmitted by the respiratory route, which can cause serious infection.
Biosafety Level 4	Is used for the diagnosis of exotic agents that pose a high risk of life-threatening disease, which may be transmitted by the aerosol route and for which there is no vaccine or therapy.

Table 2. Outline of Sterilization of System Issues
What—Where—When—How to Sterilize?

1. WHAT to Sterilize?

• Sample Canister	• Interior of all Lab Chambers & Airlocks
• The Sample itself	• Liners for inside of Prep & Lab Chambers
• Sample Airlock	• Equipment, Tools, Instruments

2. WHERE to Sterilize it?

• Sterilizer is separate from the Pressure Chambers & Airlocks -- put them in the Autoclave	• Localize autoclaves in a limited number of Airlock or Lab Chambers (e.g., Sample A/L & Exit A/L)
• Build Autoclave capability into each chamber and airlock -- like self-cleaning ovens	• Use different locations and methods for tools, equipment, instruments, samples, etc.

3. WHEN to Sterilize it (sample)?

• Upon placement on the transporter vehicle	• Upon first entering the Lab Chambers
• Upon placement in the sample Airlock	• Upon entering the exit airlock
• Upon entering the Preparation Chamber	• Never

4. HOW to Sterilize samples and the chambers?

• Autoclave (heat)	• Radiation
• Chemical	• Purge gas or vacuum

Table 3. Technology Readiness Levels Summary (From Mankins, 1995)

TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7	System prototype demonstration in a space environment
TRL 8	Actual system completed and “flight qualified” through test and demonstration (ground or space)
TRL 9	Actual system “flight proven” through successful mission operations

Table 3a. Existing Technology Readiness Levels for Mars Surface Astrobiology
Most Technologies have some degree of maturity in an agency or industry analog.

Technology Readiness Level	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Airlocks	Boeing Suitlock		Haynes Crewlock	Ames Suit-port			Space-lab sample	STS
Analytical Instruments					Academia	Industry		
Autoclaves					Medical Equip.	Biotech Industry	CDC	
Automation/ Op Systems				Ames	Industry			
EVA Excursion System				Ames Hazmat/ Suitport		Agency	Apollo systems	
Life Support Systems							Aero-space	
Pressure Systems							Industry	Aero-space
Pressure Vessels							Industry	Aero-space
Real-time Auto-mated Diag-nostics			SOFIA	Industry				
Remote Manip-ulators				EVA	Industry			
Robotics			Ocean-eering	Industry	Academia	Aero-space		
Sample Preparation Techniques				Academia	Academia			
Chemistry Sen-sors			JPL			Industry	Industry	Ames
Surface Transport				Ames	Hazmat			
Telescience				Academia	Agency			

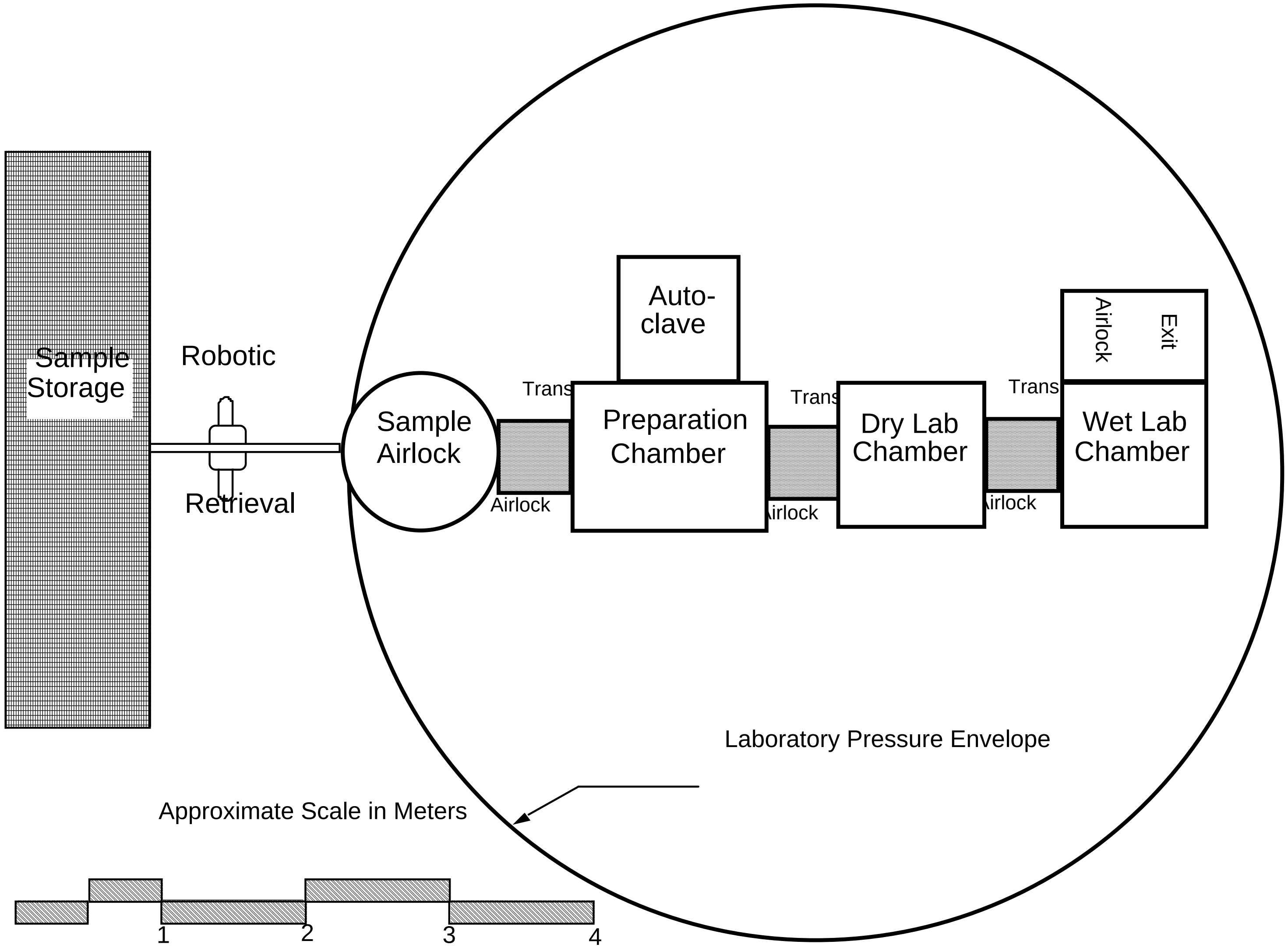

Figure 4a. Astrobiology Sample Processing: Schematic Plan of Apparatus in a Mars Surface Science Laboratory

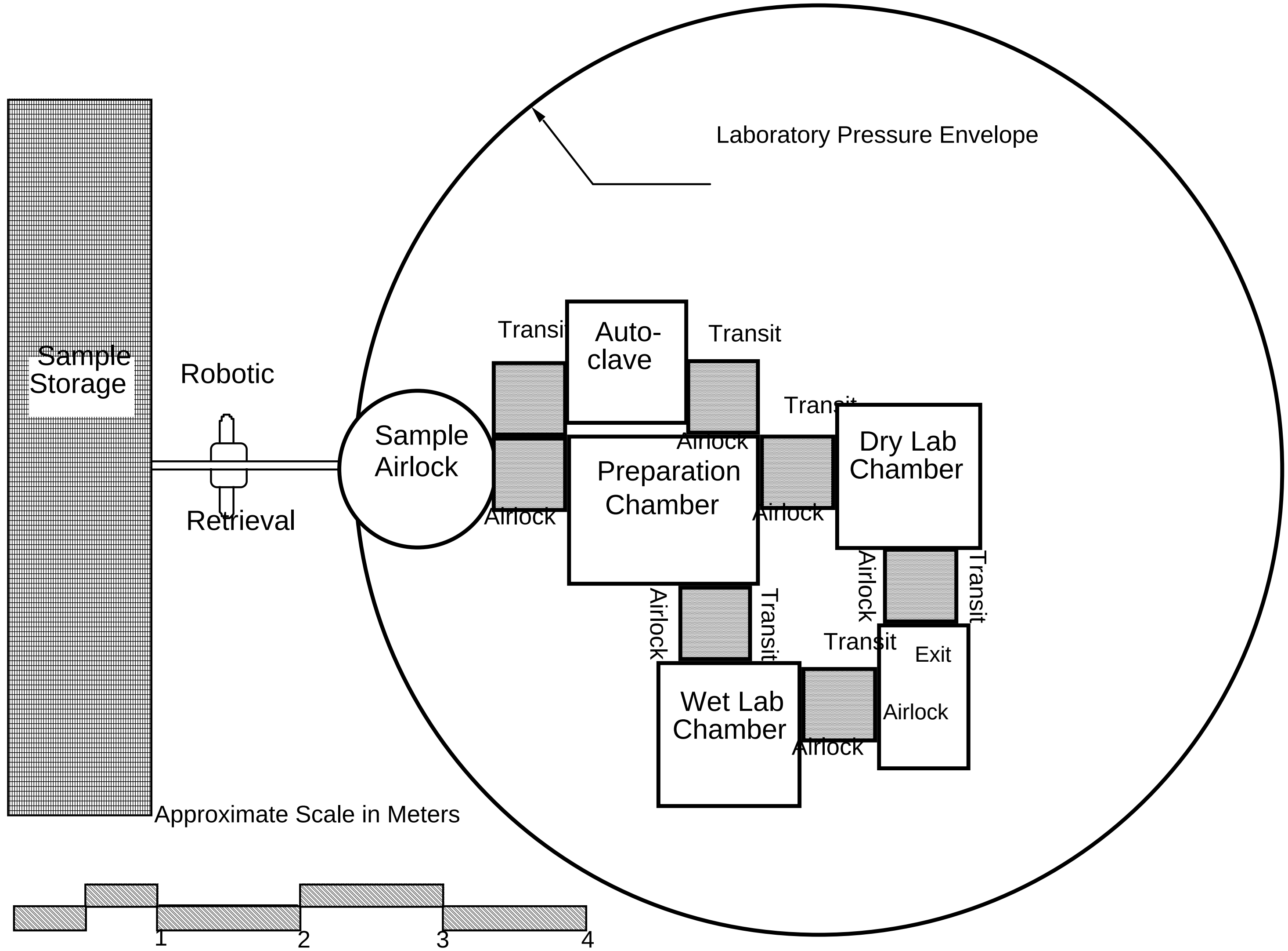

Figure 4b. Astrobiology Sample Processing: Schematic Plan of Apparatus in a Mars Surface Science Laboratory

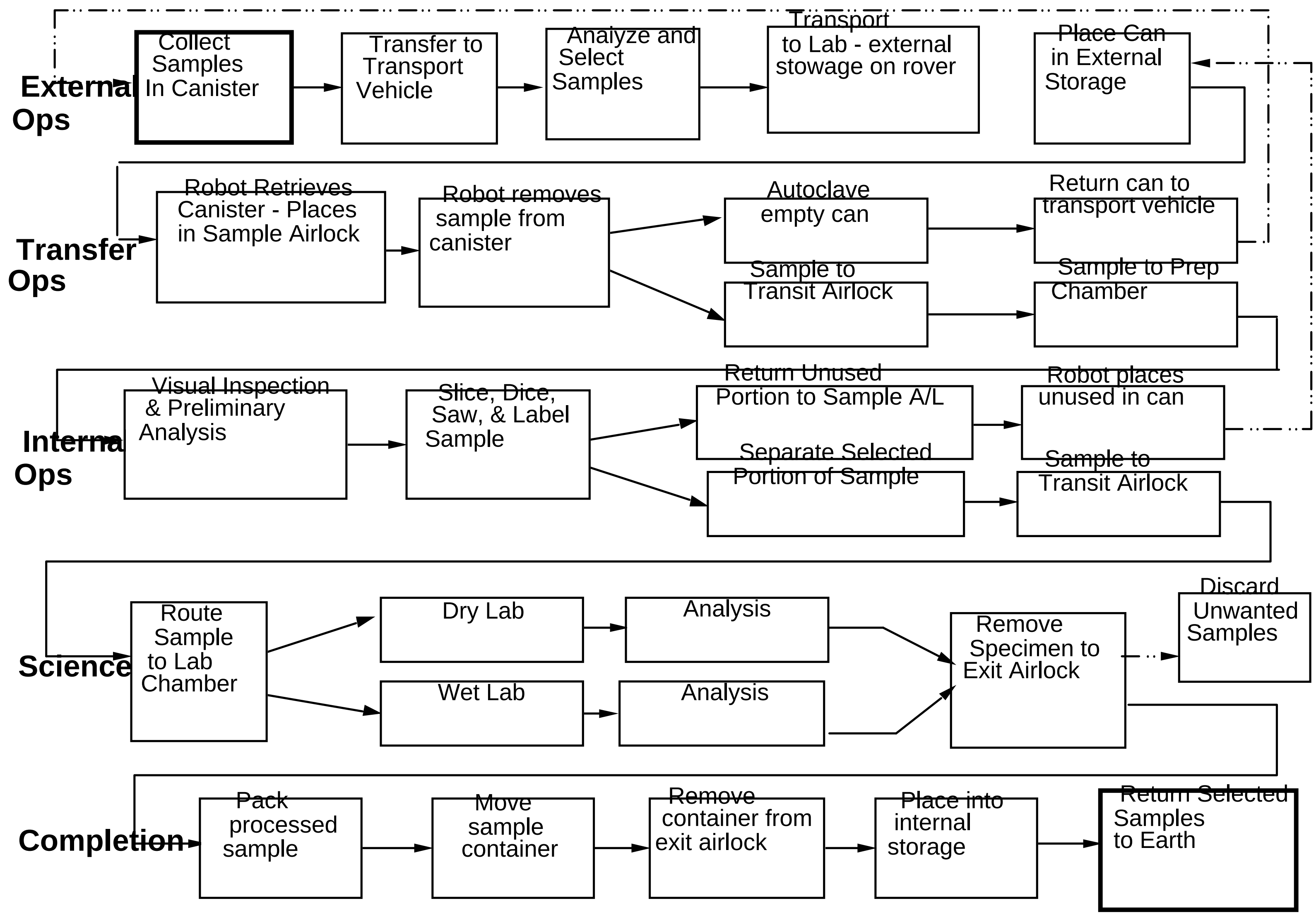

Figure 5. Astrobiology Sample Processing Flow Chart