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## ABSTRACT

NASA must hold samples returned from Mars in quarantine until the Sample Science Team determines their biological character and safety. A significant challenge, unique to NASA's needs, is how to contain the samples (to protect the biosphere) while simultaneously protecting their pristine nature for scientific studies. This paper presents an analysis of several mission architecture considerations for receiving, handling and analyzing these samples, known as Mars Returned Sample Handling (MRSH). The criteria in this design analysis include: location and types of facilities, transportation of samples or the Earth return vehicle, modes of manipulation; capability for destructive as well as non-destructive testing; avoidance of cross-contamination; sample storage and retrieval within a closed system.

## INTRODUCTION: THE MRSH CHALLENGE

The Centers for Disease Control in Atlanta and the Army Biomedical Lab at Ft. Detrick regularly employ the ability to rigorously contain biologically hazardous materials to a high degree of reliability. The CDC and Army facilities meet the specifications of the Center for Disease Control Biosafety Level 4 standard (CDC, 1993). Any standard for Mars Returned Sample Handling must provide comparable containment for returned Mars sample, while meeting the added requirement of assuring that the samples remain pristine. This latter requirement derives from the need to avoid contamination of the samples that would compromise science analyses by instrumentation of the highest possible sensitivity. Among the goals, this protocol will assure that there is no false positive detection of organisms or organic molecules – a situation that would delay or prevent the release of the samples from quarantine. Protection of the samples against contamination by terrestrial organisms and organic molecules makes a considerable impact upon the sample handling facility.

The use of conventional glove boxes appears to be impractical because of the rubber gloves' tendency to leak and to outgas. As an alternative, a returned sample quarantine facility must consider the use of automation and remote manipulation to carry out the various functions of sample handling and transfer within the system. The problem of maintaining sensitive and bulky instrumentation under the constraints of simultaneous sample containment and contamination protection also places demands on the architectural configuration of the Sample Receiving Facility (SRF) that houses it. Mancinelli, Landheim, Briggs and Farkas wrote about the stringent requirements for the SRF:

> The SRF must be capable of near-absolute containment of the samples, as well as protection of the samples from contamination to a level consistent with the cleanliness of the Mars sample return spacecraft. . . . .
>
> It is required that the SRF ensure that the probability of accidental release of the samples into the Earth's biosphere shall be no greater than that specified by NASA's Planetary Protection Office (yet to be determined). Further, the probability of contamination of the samples by terrestrial microorganisms shall be no greater than that specified by NASA's Planetary Protection Office (yet to be determined). . . .
>
> Sample protection is needed both to avoid confusion in the experimental assessment of life detection, biohazard; [sic] and also to ensure that the integrity of the samples is maintained for subsequent analysis by the scientific community. (Mancinelli, Landheim, Briggs and Farkas, 2001, p. 1).

After Mancinelli, et al, wrote this statement, the Office of Planetary Protection circulated a draft for such a standard [Office of Planetary Protection, (DRAFT 2001, May 31). *A Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth,* Washington DC: NASA.]. This DRAFT Protocol extends the level of protection that Mancinelli et al describe to all portions of the Mars Sample Return mission, not just handling in one

facility. The PPO's DRAFT Test Protocol defines a standard called Planetary Protection Level Alpha (PPL-α) that requires proving bioisolation and containment to a reliability of 1/1,000,000 or .999999 to ensure against contamination involving planetary samples. This requirement is at least an order of magnitude more stringent than the Center for Disease Control's Biosafety Level 4 (BSL-4) standard that would prevent only "back contamination" from the sample to the Earth. Once informally called "BSL-5," the DRAFT PPL-α goes further qualitatively in also requiring an comparable level of protection against contaminating the returned planetary samples with earth organisms. The core of this protocol is the set of techniques to determine if life or biohazards are present.

**TECHNOLOGY READINESS LEVEL: ZERO**

No such technology exists today that approaches these requirements. Because of the fact that no integrated prototype bioisolation chamber to meet PPL-α requirements has been built or tested, the technology readiness level does not reach "TRL-1," which John Mankins defines as:

> *Basic principles observed and reported — TRL 1*
> This is the lowest "level" of technology maturation. At this level, scientific research begins to be translated into applied research and development [original emphasis] (Mankins, 2001, p. 3).

Indeed, the very nature of the existing bioisolation systems militates against meeting the two-way protection requirement of the DRAFT PPL-α standard. The Lunar Receiving Lab at NASA-JSC employs a one-way overpressure system pushing ***outward*** to protect the lunar samples from "forward" contamination, with the volume of the highest pressure corresponding to the greatest level of "cleanliness" (Allton & Agee, 2000, pp. 4-6). The CDC BSL-4 protocol employed at both the Centers for Disease Control and the Army Biomedical Lab requires the air conditioning over-pressure pushing ***inward*** to contain any pathogens from escaping as "backward" contamination of the terrestrial environment.

Neither one-way protocol would be adequate to achieve the DRAFT PPL-α requirements. The DRAFT PPL standard takes these limitations into account in proposing a new and substantially more rigorous standard. Thus, developing a successful and demonstrably reliable PPL-α technology, including remote manipulation and analysis of samples in the bioisolation chamber is a mandatory first step toward Mars sample return. Although a number of techniques that would be useful in MRSH exist, to properly regard them as a technology will require a concerted effort to develop them further, integrate and test them in the testbed that Mancinelli, et al, propose (Mancinelli, Landheim, Briggs & Farkas, 2001, pp. 3-4).

This effort may lead to manifold applications:

- It provides a foundation for biosafe Mars Returned Sample Handling activity, including sample receiving, identification, preparation, analysis and testing with automation, robotics and teleoperations.

- It defines a new level of protection against cross-contamination and infection for medical laboratories.

- It offers a new capability to safely handle suspected bioterrorism attacks.

- Ultimately, it will afford critical technology to protect Astronauts conducting Astrobiology research on the surface of Mars.

- Conversely it will help to protect the Martian environment from forward contamination from human explorers.

**MRSH: THE STAKEHOLDERS**

The project begins by identifying the issues the MRSH Team must tackle, and the knowledge domains that they encompass. Each of these issues relates to aspects of the missions or to the stakeholders, which demand careful consideration.

TABLE 1 outlines the initial list of MRSH stakeholders, what are their interests and what role should they play. To an extent that is not yet clear, some of these stakeholders play a direct role in the MRSH project. Each of the three main players – the Scientific Community, the Public and NASA have their own system of priorities, which inform the top-level issues. The Science Community seeks maximum capability and opportunity for discovery and the advancement of knowledge. The Public seeks minimal risk and cost. NASA seeks Maximum Control consistent with Maximum Customer (Science and Public) satisfaction. An essential "next step" will be for NASA to establish a MRSH Science Advisory Committee that meets regularly to review and advise the planning, science and technology development efforts.

## STAKEHOLDER INTERESTS

Based upon these Stakeholder interests, the top level issues are: mission capability, cost, cost versus benefits, security and containment risk, and the opportunity afforded to individual science teams. TABLE 1 lays out an overview of the stakeholders and their interests. The MRSH Team works closely with the Program Office at JPL and other NASA participants to develop a common strategy for working with the larger community of stakeholders.

## NASA MRSH TEAM AND STAKEHOLDERS

The NASA technical team for MRSH consists of four partners: Ames Research Center, Center for Mars Exploration (CMEX); Jet Propulsion Laboratory, MSR Program Office; Johnson Space Center; and the NASA Headquarters Planetary Protection Office. Each of these entities plays the role of both a technical partner and as a stakeholder because they have such a large professional and scientific interest in the MSR mission.

TABLE 1. Outline of the MRSH Stakeholders and their Interests

| Stakeholder | Interest in MRSH |
|---|---|
| US and International Public | • Safety, Biohazard Containment,<br>• Risk prevention,<br>• Intellectual curiosity about Mars. |
| Science Community | • Do world class science,<br>• Make great discoveries to advance our knowledge of Mars and the origins of life,<br>• Receive samples as quickly and directly as possible. |
| International Partners | • Contribute a manageable effort<br>• Commensurate scientific return on investment |
| White House | • International leadership, national pride<br>• Cost containment |
| Congress | • Bang for the Buck – Return on Investment<br>• Scientific Advances |
| NASA Headquarters | • Scientific Leadership<br>• MRSH Advocacy |
| NASA Planetary Protection Office | • Protect the Earth and Mars from contamination |
| ARC | • Search for Life on Mars<br>• Life detection technologies and science |
| JPL | • Mars Return Mission Management<br>• MRSH Program Lead |
| JSC | • Mars Sample Curation<br>• Support future human exploration of Mars. |
| Industry | • Develop hardware, technology<br>• Fly and conduct the mission |

## THE SAMPLES

A detailed discussion of the potential sample characteristics is outside the scope of this paper. One key point to make is the common assumption that NASA will return samples from Mars without sterilizing them. The main reason is because the sterilization process (typically exposure to 400° C heating for 12 hours or extended exposure to Cobalt 60 radiation) will cause significant changes that will degrade the scientific value of the samples. A secondary reason is that the sterilization equipment will add approximately 50 to 100 kg of landed mass on Mars, which will greatly increase the cost while diminishing the scientific results of the MSR mission.

In recent years, NASA and other organizations convened many workshops and study groups about potential sample properties and objectives. Many of these documents appear in the reference section of this paper. The most recent and relevant findings appear in Race, et al, *Mars Sample Handling Protocol Workshop Series* identifying

these six types of samples: gas (collected sample); head-space gas (in a sealed sample container); bulk fines (soil) rock fragments; cores of solid rocks; and soil cores (Race, Nealson, Rummel and Acevedo, December 2001, pp. 26-28). To conduct scientific studies to determine if life or biosignatures are present, the Workshop participants identified as many as 30 different scientific instruments or techniques (Race, Nealson, Rummel and Acevedo, December 2001, pp. 81-84).

A key question that has yet to receive the attention it deserves is what should be the relative proportion of these six sample types. The assumed constraint under which NASA labors is a maximum of .5 kg of returned sample mass, placed in a carrier that will accommodate up to 500 contained samples of one gram. The obvious stumbling block in this approach is: what if the sample-collecting rover finds some desired samples that are much larger than 1 gram? Alternatively, NASA could adopt an approach that anticipates collecting a series of samples distributed over a range of sizes and masses. Such an approach would make the design of the sample containers and carrier more challenging, but it would be a more realistic approach to what the MSR mission is likely to find and want to return to the Earth.

TABLE 2. Minimum Assumption Set for the MRSH Facility Elements

| MRSH Elements | Function | Comment |
|---|---|---|
| Landing Retrieval System (LRS) | Locate, isolate, secure, and retrieve the MSR Earth Entry Lander. | Based in the Landing Area, See FIGURE 1. Assumes landing in a secure area under the control of the US government. |
| Sample Transportation System (STS) | Collect and safely transport the MSR Earth Lander to the Sample Receiving Facility | May be separate from LRS *if* the SRF is distant from it, however, the design is primarily a function of the safety requirements NOT the distance to travel to the SRF. |
| Sample Receiving Facility (SRF) | Open the Lander under clean conditions. Open the sample containers in PPL-$\alpha$ conditions. Examine, process and analyze the samples. | The major sample analysis capability. This laboratory will be the subject of major architectural study and analysis. |
| Mars Curation Facility (MCF) | Once a sample analysis is complete at the SRF, and the complete biosafety of a sample is assured, NASA moves the sample to the Curation facility for archiving and final cataloging before release to the scientific community. | The specimen archive for access to samples by the Science Community |
| Sample Science System (SScS) | Provides support and collaboration throughout the Mars Sample Handling process. Once samples are proven safe for release, the MCF will release them according to protocols to university researchers. | Ultimate science beneficiaries of the MSR mission. Conducts research. They may come to the SRF for early assays, or participate remotely in those tests. |

TABLE 3. Candidate Scenario for MRSH Mission

| Assumptions | Comments |
|---|---|
| 1. MSR Mission launches 2013. | Optimistic launch date. |
| 2. MSR Mission returns sample 2015 or 2016. | MSR Mission Studies vary on mission duration. |
| 3. PPL–$\alpha$ protects Mars returned samples from terrestrial *forward* contamination. | *Forward* contamination protection is the greater challenge. |
| 4. PPL–$\alpha$ protects Earth from *backward* contamination from Mars and Mars samples. | *Backward* contamination protection is the most important to the Public. |
| 5. All Mars materials returned to Earth will be properly contained to PPL–$\alpha$. | The Mission Design will ensure the hermetic sealing soil and atmosphere on Mars. |
| 6. Mission Design will protect the samples from temperatures greater than natural Mars extremes. | To what degree does it protect samples from radiation? |
| 7. Sample return vehicle lands in the USA in a restricted area (e.g. White Sands, NM or Dugway, UT) under US government control. | No water landing planned |
| 8. NASA retrieves the return entry vehicle, inspects it and transports safely to the Sample Receiving Facility. | Decontamination of the landing site if there is indication of containment breach. |
| 9. At the Sample Receiving Facility, the staff cleans the return entry vehicle and prepares it for opening. | No elements of the containment system are opened from the time the sample is collected on Mars until it arrives in the pressure-controlled portion of the SRF. |
| 10. The SRF Team opens all containment layers of the Sample containment in a controlled, PPL–$\alpha$ isolated atmosphere. | All sample cataloging, inspection, testing, analysis, culturing and bioassay occur under PPL–$\alpha$ conditions. |
| 11. NASA & Science Community provide oversight to decide if the samples need sterilization. | Sterilization occurs at the completion of the sample analysis process in the SRF. |
| 12. Processed samples go to the Mars Curation facility for permanent storage and protocols for release to the Science Community. | |
| 13. Approved samples that are proven to be safe may be released to the Science Community for research. | |

## FACILITY ELEMENTS FOR THE MRSH MISSION ARCHITECTURE

The MRSH mission architecture is neither self-evident, nor a given. After several years of participatory process, NASA and the sample science community developed the general construct that appears in this paper. TABLE 2 presents the minimum and fundamental set of five elements necessary to accomplish the MRSH Mission Architecture. This architecture begins when the Mars Sample Return entry vehicle lands safely and successfully on the Earth. This minimum assumption set consists of just these five basic elements: the Landing Retrieval System, Sample Transportation System, Sample Receiving Facility, Mars Curation Facility and the Sample Science System. This Mission Architecture Study focuses on the connections and interactions of these five elements of the MRSH Architecture. However, each of these five elements deserves detailed study and analysis.

TABLE 3 presents a candidate MRSH Mission Scenario, compiled from a variety of sources for the purpose of this study. In this sense, TABLE 3 describes a generic candidate scenario for the Sample Handling process as it works its way through the elements of the MRSH Architecture. The key point of this scenario is that at this time EVERYTHING IS AN ASSUMPTIION. There are not yet any firm decisions about how to design, organize, operate or conclude this mission.

**MRSH: THE BIG QUESTIONS**

The Stakeholders will need to respond to a set of five Top Level Questions about MRSH that derive directly or indirectly from the scenario outlined in TABLE 3. These questions are intended to be thought provoking and even controversial to bring out the greatest range of responses: They go to the core of some of the most difficult aspects of the sample return challenge (Geoff Briggs, personal communication, January 2002).

***1. Can a definitive assessment of the absence of life in a rock sample be made without being prepared to destructively test the whole sample?***

This question touches on many aspects of how NASA will conduct Mars sample science. At one level, it goes to cultural differences between geologists and exobiologists. The geologist wants to chip a crystal as small as possible off a sample, and put the rest in a display case to admire. The exobiologist wants to examine and test destructively a substantial fraction (~50% or more) of the sample in the pursuit of signatures of life. The determination of the absence of life is the ultimate proof or disproof of these methods.

***2. If so, what is a statistically significant fraction of the sample that can be subject to destructive testing?***

Since it is unlikely that any scientist will have the opportunity to test a complete population or sampling destructively or otherwise, in the course of "normal science," the scientist would develop a statistical model to sample representative pieces of the population – or in this case the sample itself. Constructing such a statistical model such that it could confer definitive proof of the absence of life -- and thus open the way for release of the sample from the SRF – will be a significant challenge that is part of the problem for the MRSH Mission Architecture.

***3. What will be the science impact of limiting sample analysis science to facility instrumentation under continued containment at a centralized sample receiving/curatorial facility? Are there any advantages including overall cost effectiveness?***

This question goes to the way in which the Mission Architecture will facilitate or impede the Mars science community in their ability to participate directly or indirectly in study of the returned samples. Since it is likely that a long time may elapse before any samples will be certifiable as void of life so the SRF can release them, the question turns on how it may be possible to involve the external science community at the SRF. This accommodation implies a highly centralized facility to which scientists can come to propose and conduct investigations either in person or remotely.

***4. What are the principal considerations that should determine the readiness schedule of MRSH relative to the time at which the samples return to Earth?***

The most conservative scenario would be that NASA must certify to some very high standard of reliability such as PPL-$\alpha$ that the entire MRSH architecture and the facilities and capabilities that constitute MRSH will contain any alien life *before the start of Mars sample return mission planning.* This scenario of placing the MRSH in series with MSR implies an extremely long time line. On the other hand, with the recent big slips in the MSR schedule (from 2011 for first launch as late as 2017), the timeline will be long regardless of that certification.

So why not start the MRSH effort now? The problem is that without an MSR mission "on the books" and funded, there is no political incentive to fund or pursue MRSH." On the other hand, If NASA now enjoyed the "luxury" of a tight schedule for MSR, there would be no choice but to work the MSR and MRSH in parallel, or even to "fast track" the MRSH to follow close behind the development of MSR. A reasonable, conservative compromise may be that NASA does not launch the MSR mission from earth until the MRSH Mission Architecture meets its PPL-$\alpha$ burden of proof. A somewhat less conservative but still reasonable compromise may be that NASA does not begin the Trans Earth Injection of the MSR return vehicle until the MRSH Mission Architecture meets its PPL-$\alpha$ burden of proof.

***5. What are the principal lessons to learn from the ALH840001 meteorite experience?***

The ALH84001 meteorite experience (McKay et al, 1996) showed the perils and pitfalls of making announcements prematurely about finding signs of life. From this author's perspective, there were several issues that MRSH must prepare to address. First is the need to put in place an "exo-micro-paleontology" capability. There is a growing discipline of exopaleontology (Farmer, Des Marais, 1994) that the ALH researchers could have

mobilized to their benefit. Second, is the question of biological contamination. In their presentation to the First Astrobiology Science Conference at NASA-Ames Research Center in April, 2000, A. Steele et al reported finding "the presence of a wealth of heterotrophic microbial species" all of terrestrial origin (Steele, et al, April 2000, p. 23). In their article *in Meteoritics and Planetary Science*, this same team stated:

> The detection of terrestrial organisms and their products in this meteorite do not necessarily negate the possibility that it contains evidence for early life on Mars. However, it becomes more challenging to separate such evidence from the terrestrial contamination (Steele, et al, March 2000, p. 240).

**METHODOLOGY FOR DESIGN RESEARCH**

The challenge that faces the NASA MRSH Team is how to develop the MRSH Mission Architecture from this outline scenario, and from these questions to which they are still seeking answers. Because the MRSH enterprise will have unavoidable political ramifications that require extensive government and citizen participation, it is essential to begin from a perspective of participatory design process. To treat Mars Sample Return as purely a technical design problem is a recipe for political suicide. The mandatory participatory dimension is where design methodology -- particularly a methodology for design research -- enters this picture.

This section presents the proposed methodological approach for the MRSH Architecture Team to conduct the design research necessary to support successful design of the MRSH project. The approach incorporates five concepts that shape and inform the research: mission architecture, problem definition, solution seeking and system analysis plus participation in design and the science support system. In addition, it is necessary to introduce the notion of information risk and its uncertainty effect on complexity. The Mission Architecture Development Hierarchy appears as follows:

***MRSH Mission Architecture***
***Sample Receiving Facility (SRF)***
***Mars Curation Facility (MCF)***
***MRSH Sample Processing Testbed***

MISSION ARCHITECTURE

The Mission Architecture is the top-level integration of all components in the MRSH Project. In its traditional application, the Mission Architecture approach to design derives from a top-down problem decomposition in which mission architects and planners attempt to identify all the elements of the mission, the connections between them, commonality and differentiation of parts and shared or unique resources (Cohen, 2000, p. 3). The present MRSH Architecture Study includes this traditional approach, but also incorporates three other perspectives on design research: Problem Definition, Solution-Seeking and System Analysis.

PROBLEM DEFINITION

A design problem definition is the common set of objectives and values, shared view of design complexity and technical challenges within a conceptual structure as agreed among the parties to the project. The quality of a problem definition relates inversely to its complexity. In the traditional Mission Architecture approach, reducing complexity by a top-down design problem decomposition often corresponds to defining the problem largely by breaking it down into more manageable pieces. While this approach always has value, the requirement for extraordinarily high reliability throughout the mission suggests that a preconceived or immature decomposition may be counter-productive in taking unexamined risks or in making the challenge of problem definition worse. Problem Definition relates closely to Problem Structure, differing more in metaphor than in substance.

<u>Opportunistic Design</u>

Raymond Guindon gives three distinctive characteristics of ill–structured problems:
- Incomplete and ambiguous specification of goals.
- No predetermined solution path.
- The need for integration of multiple knowledge domains (Guindon, 1990, p. 308).

<u>Top-Down versus Opportunistic Approach</u>

Raymond Guindon looked at how designers decompose problems, comparing the hierarchical, "top-down" approach to the "opportunistic" approach. He found that

> Top-down decomposition is problematic in the early stages of design. Instead, an opportunistic decomposition is better suited to handle the ill–structuredness of design

> problems. . . . A top-down decomposition appears to be a special case for well–structured problems when the designer already knows the correct decomposition (Guindon, 1990, p. 305).

The challenge to the MRSH Architecture Team is how to develop a well-defined and well-structured problem definition that will create that "special case" to allow a valid top-down decomposition.

However, the MRSH project faces certain pre-determinants that in a sense amount to an incomplete and pre-emptive top down problem decomposition. These pre-determinants include the PPL-$\alpha$ requirement; the mass of sample to be returned (500 grams), and the nature of the sample return vehicle, its entry and landing. Although the PPL–$\alpha$ and derived landing requirement help to frame the design problem, the predetermined sample mass and sample sizes raise the concern that they preclude researching from first principles the leading question of what is the ideal sample for each discipline. This preconception in the MSR Program introduces a very significant dose of uncertainty at the outset, unless it becomes subject to design research.

## SOLUTION SEEKING

Solution Seeking involves a dual role for developing design solutions. 1) Solution seeking is a means of posing and testing hypotheses about what is the design problem. 2) Solution seeking presents a way to pose and evaluate the feasibility of design concepts and strategies to solve the design problem. In this approach, once complexity reduction proceeds to break the problem into smaller parts, resolving technical difficulty corresponds to solving the problem. However, for MRSH, it would be all too easy to do a brilliant technical job of ***solving the wrong problem*.**

### Familiar versus Unfamiliar Problem–Solving

Geir Kaufmann observes that these ***definitions of problems*** lead to associated ***definitions of problem-solving*** which suggest that "the essential core of 'problem solving' is . . . the process of reducing the unknown to the known." He argues that problem solving that "closes a small gap" to convert the unknown to the familiar "is essentially a ***conservative*** type of function." Instead, he argues for creativity in problem solving.

> We propose instead to link the concept of creative thought with the notion of transforming a known into a strange situation . . .. This operation essentially involves the generation of a new idea, which may extend far beyond the observations made, and thus make real discoveries possible. (Kaufmann, 1980, p. 10-11).

While Kaufmann finds this process to be a "reasonable description," he raises a momentous contradiction.

> A major aspect of problem–solving consists, not in transforming the unknown into the known, but rather in the exact opposite, i.e., in ***transforming a known situation into a strange one* . . .** [original emphasis] (Kaufmann, 1980, p. 9.)

Kaufmann cites Copernicus as a problem solver who transformed the known into the "horrifyingly unfamiliar." Kaufmann argues that this type of problem–solving involves not the "closure of a small gap in knowledge" but the creation of a new "general hypothesis" that reaches beyond the existing knowledge.

For MRSH, the ***known*** solution of CDC BSL-4 is analogous to viewing the problem as ***closing a small gap*.** The ***unknown*** design solution for PPL–$\alpha$ is analogous to ***creating a new general hypothesis*** that is quite ***unfamiliar*** and is likely to produce design products that are new and different. This new design departure may evoke anxieties such as Copernicus faced in the status quo of his time.

## SYSTEM ANALYSIS

A Systems Analysis approach to design embodies a "bottom-up" approach to how all the parts of a particular product or vehicle must work together. Sometimes the motive for entire system analysis derives from a desire to promote a particular subsystem, especially when that component appears particularly critical to success (Cohen, 2000, p. 5). In terms of MRSH Architecture, the main systems analysis considerations apply to the instruments and techniques necessary to test samples for the presence of life or biosignatures. These technical aspects may place significant demands upon the design of the MRSH Systems, especially the SRF.

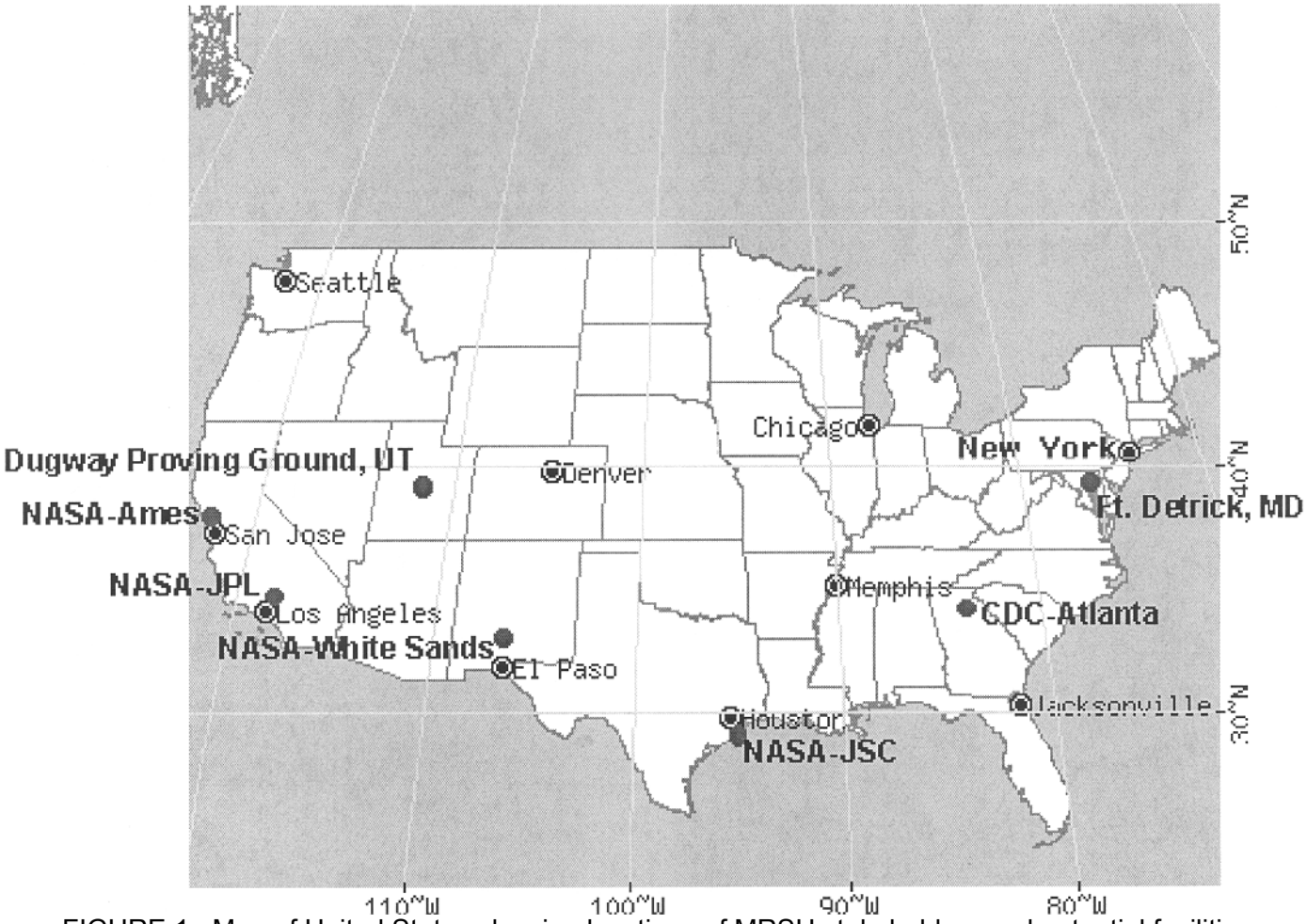


FIGURE 1. Map of United States showing locations of MRSH stakeholders and potential facilities.

TABLE 4. Location of Stakeholder Agencies and Potential MRSH Facilities

| AGENCY | FACI:LITY | ABBREV. | EXISTING CAPABILITY | LOCATIO N | STATE |
|---|---|---|---|---|---|
| NASA | Ames Research Center | ARC | Lead Center for Astrobiology | Moffett Field | California |
| NASA and CalTech | Jet Propulsion Lab | JPL | Mars Program Office | Pasadena | California |
| NASA and US Army | White Sands Test Facility | WSTF | Safety Testing | Las Cruces | New Mexico |
| NASA | Johnson Space Center | JSC | Lead Center for Planetary Sample Curation | Clear Lake | Texas |
| US Dept. of Health and Human Services | Centers for Disease Control | CDC | BSL-4 Facility and Staff | Atlanta | Georgia |
| US Army | Dugway Proving Ground | DPG | Chemical & Biological Agent Handling | Tooele County | Utah |
| U S Army Medical Research and Materiel Command | Fort Detrick | MRMC | BSL-4 Facility and Staff, | Frederick | Maryland |

Participation

Although system engineers would like to believe that there is a rational and controllable way to obtain empirically deterministic answers for the design problem definition in particular, and many other aspects in general, in fact there is much about the MSRH project that is not so neat and easy. MSR and MRSH will become of vital interest to the Public, government agencies and the Scientific Community. All will want to participate in a variety of ways and at many points along the way. The point of this part of the methodology is to plan for constructive participation as a way to make MSRH better, stronger and safer rather than as destructive participation to limit, constrain or stop it.

**MISSION ARCHITECTURE**

The Mission Architecture (Architecture with a "Big A") encompasses everything that happens to the returned sample from the time that it enters the Earth's atmosphere in a return entry vehicle. to landing, retrieval, transport to sample receiving facility, cleaning of the vehicle, opening the sample canister, inspection, analysis, testing, assaying, sterilization and release of the sample to the scientific community. The facility architecture (architecture with a "small a") addresses the design of specific ground-based facilities: the Sample Handling Testbed, Sample Receiving Facility, Mars Curation Facility, and Science Support System associated with those facilities. The facility architecture is a subset of the Mission Architecture. This study addresses both planes of architecture in parallel.

MRSH ISSUES

Many of the stakeholder issues translate into element and system-specific issues within the Mission Architecture. The major elements include: the sample containment system, vehicle ground transport, vehicle cleaning, SRF, MCF and SScS. These issues do not yet constitute requirements, but a thorough examination of them will lead to the generation of reasonable requirements.

Element-Related Issues

The issues that touch these elements include but are not limited to:

1. Risk of loss of sample containment given the unknown nature of the returned samples.
2. The desire of the Science Community to have NASA release samples as early as possible to their own laboratories.
3. The overall flexibility of the MRSH Mission Architecture to accommodate unforeseen events or serendipitous developments.
4. Convenience of the Mission Architecture to the Science Community.
5. Manageability of the Mission Architecture for NASA.
6. Overall Cost in Dollars, both in terms of direct project support and indirect institutional support at the NASA Centers.
7. The Cost and Benefits in Political Capital including the desire to "spread the wealth around" and the desire to satisfy the international partners by furnishing samples.
8. The Cost Trades among all these issues, especially between 2 and 4.

Integration Issues

These element-related issues give rise to a small set of System Integration issues at the highest level of the Mission Architecture. The top level Integration issues are:

1. The degree of integration of the elements -- both in terms of location and operations.
2. The consequences of separation – both functional and operational – of any two elements.
3. The interfaces -- between the several elements and their multiple systems, and how they are affected by propinquity and the allocation of operational responsibilities.

PERMUTATION STUDY

The MRSH Mission Architecture must address the foregoing Mission, Element and Integration Issues. To do so, the MRSH Mission Architecture encompasses a set of permutations of element integration and location of the facilities. There are three elements: SRF, MCF, and SScS. They can occur singly or integrated in pairs or triples at any location, in any sequence. Within these parameters, 27 permutations are possible.

Location Options

TABLE 5 shows the three location options on the left as:

Landing Area (White Sands, NM, Dugway Proving Ground, UT, etc),

Existing Government Facilities (NASA Center, Army Biomedical Lab at Fort Detrick, MD, Centers for Disease Control, Atlanta, etc) and

University (as part of the Sample Science System, SScS).

Decision Rules

Across the top appear nine sets of permutations. Each permutation derives from identifying the degrees of separation of the elements rather than from positing a particular integration, and following four simple decision rules. These decision rules are:

Element Progress -- All MRSH process elements progress from the SRF to the MCF to the SScS.

Location Progress --All locations progress from the Landing Site to the Science Community at a University.

No Backtrack -- It is permissible for the sequence to "backtrack."

Allowable Combinations -- It is allowable to have two or more elements combine at any locations.

No Requirement for Facility Integration

There is no requirement to integrate any of the MRSH Facility elements or to locate them at a specific or pre-determined site. Following the decision rules reduces the number of possible permutations to 10. What this table does not address is whether one, two or three NASA Centers or Universities are involved in any of the integrated permutations. The MRSH Architecture Team will examine this permutation analysis for all the implications of how the stakeholders, their interests and issues map onto this menu of technical options.

TABLE 5. Permutations of Mission Architecture Integration and Location

| **Location** | **1** All Alone | **2** SScS Alone | **3** SScS Alone | **4** SScS Alone | **5** SRF Alone | **6** SRF Alone | **7** SRF Alone | **8** All In One | **9** All In One | **10** All In One |
|---|---|---|---|---|---|---|---|---|---|---|
| Landing Area | A | AB | AB | | A | A | | ABC | | |
| Existing Gov't Facility | B | C | | AB | BC | | A | | ABC | |
| University | C | | C | C | | BC | BC | | | ABC |

KEY:
Sample Receiving Facility (SRF) = A
Mars Curation Facility (MCF)= B
Science Support System (SScS)= C

ANALYSIS OF THE PERMUTATION STUDY

There are three principal system elements: SRF, MCF, and SScS. One other system element whose implementation may have significant implications in terms of the optimization of the MRSH system architecture is the Sample Transportation System. This is so because assured containment is a fundamental requirement for MRSH and such containment might be compromised by the need to transport the samples among multiple locations. Further, multiple federal agencies may have jurisdiction with respect to the transportation of unsterilized Martian samples within and beyond the continental USA.

## SRF Location Options

Sample transportation simplification issues have led to the consideration that the SRF should be located close to the planned landing site for the Mars return vehicle e.g. at White Sands.

On the other hand, the Space Science Board's COMPLEX recommended that the SRF be located adjacent to an existing Federal facility that specializes in the handling of biologically dangerous samples (e.g. Fort Detrick or the CDC, Atlanta) (COMPLEX, 2001).

Another general alternative for the location of the SRF is in association with some other federal facility where rigorous security can be maintained. This could include NASA Centers.

A fourth general location category for the SRF is at site to be proposed (and competitively evaluated) by a University or a Consortium in response to a NASA RFP. Below such a site appears as a "Consortium Site."

## Mars Curation Facility Location Options

In the event that the MCF is built as a facility separate from the SRF only one option is under serious consideration and that is to locate it at JSC where the lunar curatorial facility has operated with great success for decades.

Co-location of the MCF with the SRF is a second option.

## The Sample Science System Location Options

The Sample Science System can be implemented , as in the case of the Apollo samples, in a distributed way taking advantage of the existing planetary science and exobiology laboratories at many universities and institutions here and abroad.

The Mars samples will have to contend with a much more rigorous biohazard assessment than the lunar samples and they will be 100 to 1000 times smaller in overall mass. For these reasons there may be a case for an integrated facility where the samples can be maintained under quarantine for an indefinite period if necessary. Such an integrated facility might be physically separate from the other main system elements (SRF and MCF) or might be integrated with the MCF at JSC.

## MRSH CANDIDATE ARCHITECTURES

Based on the above location considerations and given that the samples must move in sequence from the Sample Receiving Facility to the Mars Curatorial Facility and then to the Sample Science System the following location permutations emerge as plausible system architectures:

## THE SAMPLE SCIENCE SYSTEM PERSPECTIVE

One way to simplify and reduce the number of permutations is to remove one of the major elements as a variable, and reexamine the set of options from its perspective. An attempt to capture this perspective appears in TABLE 6. In this approach, the Sample Science System becomes the "telescope" through which to view the location options. From the perspective of the Science community who will be the major "customers" or users of Returned Mars Samples, there is essentially one major choice. This choice is to determine whether the SScS will be integrated in the same locations as the two major MRSH facilities – the SRF and the MCF. Given this perspective, the options of where to locate the SRF and the MCF, and whether they should be separate or co-located, become a secondary concern. The primary concern of the Science community thus emerges as a question of where they will go to support the SScS. The concern is whether they will need to travel to one or two centralized MRSH facilities to participate in an "integrated" SScS or they will be able to remain mostly in their own laboratories and remotely support MRSH through a "distributed" SScS.

The implications of the locational decisions are potentially profound and far-reaching. If the SScS is integrated from the beginning with the major MRSH facilities, researchers from the science community may anticipate that they will need to travel to share time at this major facility. If the SScS is truly distributed, they may anticipate that their opportunity for a first discovery is better if they can access the samples sooner through their own lab.

From the Science Community perspective, the question of whether the SRF is co-located with the MCF or is separate from it becomes secondary. This perspective emerges as different from the NASA MRSH Project management perspective. From a NASA project and operations perspective, this decision of where to locate or to co-locate remains primary, given that the SScS would be available in some form under all scenarios.

TABLE 6. MRSH Facility Location Options from the Sample Science System Perspective.

| | **Integrated SScS** | **Integrated SScS** | **Distributed SScS** | **Distributed SScS** |
|---|---|---|---|---|
| **Landing Site** | SRF separate from MCF | SRF/MCF Co-located | SRF separate from MCF | SRF/MCF Co-located |
| **Federal Biosafety Laboratory** | SRF MCF | SRF/MCF | SRF MCF | SRF/MCF |
| **Other Federal Facility** | SRF MCF | SRF/MCF | SRF MCF | SRF/MCF |
| **University Consortium Site** | SRF MCF | SRF/MCF | SRF MCF | SRF/MCF |

## CONCLUSION

This preliminary study of Mission Architecture for Mars Returned Sample Handling indicates that the location decisions for the main elements carry significant implications for how NASA conducts this critical operation. The further development of the returned sample Mission scenarios and design participation by the science community should help in reducing the number of likely options from about 10 down to a smaller and more manageable number. A necessary step is the establishment, funding and support of a permanent MRSH Science Advisory Committee.

Beyond this approach to defining scenarios and options, it will become essential to develop the content of each of the component systems: Sample Retrieval System, Sample Transportation System, Sample Receiving Facility, Mars Curation Facility and the Sample Science System. The Planetary Protection Alpha criteria may be the most challenging requirement for MRSH, but it is hardly the only requirement. The systems and facilities will need to meet a broad range of expectations and performance criteria for scientific instrumentation, automation, robotics, teleoperations, data systems, and support to the scientists. To provide these facilities and technologies to meet the complex and demanding MRSH requirements, NASA will need a concerted effort in design research and technology development.

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## REFERENCES

Allton, Judy & Agee, Carl B. (2000, August). "Glovebox Use at Johnson Space Center for Curation of Moon Rocks and Mars Rocks," *The Enclosure*, Vol. 13, No. 3, Santa Rosa, CA: American Glovebox Society. pp. 1-8.

Carr, Michael H; McLeese, Daniel J.; Bada, Jeffrey L.; Bogard, Donald D.; Clark, Benton C.; DeVincenzi, Donald; Drake, Michael J.; Nealson, Kenneth H.; Papike, James J.; Race, Margaret S.; Stahl, David; (1999). Mars Sample Handling Requirements Panel (MSHARP) Final Report, NASA TM-1999-209145. Pasadena, CA: NASA Jet Propulsion Lab.

Centers for Disease Control-National Institute of Health, (1993). Biosafety in Microbiological Laboratories, 3rd Edition. Health and Human Services Publication, CDC 93-8395, Washington DC: US Government Printing Office.

Cohen, Marc M., (2000, July 10-13) Pressurized Rover Airlocks, SAE 2000-1-2389, Toulouse, France, *30th ICES.*

Committee on Planetary and Lunar Exploration COMPLEX, Space Studies Board, National Research Council (2001). The Quarantine and Certification of Mars Samples, Washington DC: National Academy Press. *Prepublication.*

DeVincenzi, Donald L.; Bagby, J.; Race, Margaret; & Rummel, John D.; (1999). Mars Sample Quarantine Protocol Workshop, NASA CP-1999-208772, Moffett Field CA: NASA Ames Research Center.

Farmer, Jack ; Des Marais, David. (1994). "Exopaleontology and the search for a fossil record on Mars." *Lunar Planetary Science* , 25: 367-368.

Guindon, Raymonde, (1990). "Designing the Design Process: Exploiting Opportunistic Thoughts," Human–Computer Interaction, Vol. 5., Lawrence Erlbaum Associates, Inc.

Kaufmann, Geir (1980). Imagery, Language and Cognition: Toward a theory of symbolic activity in human problem solving, Oslo, Norway: Universitetsforlaget.

Mancinelli, Rocco L.; Landheim, Ragnhild; Briggs, Geoffrey A.; & Farkas, Stanley, R. (2001) A Testbed for the Mars Returned Sample Handling Facility, SAE 2001-01-2412, *31st ICES.*

Mankins, John C., (2001, Oct. 1-5). Approaches to Strategic Research and Technology (R&T) Analysis and Roadmapping, IAF-01-U.2.02, *52nd International Astronautical Congress* .

McKay, D.S.; Gibson, E.K.; Thomas –Keptra, L.L.; Vall, H.; Romanek, C.S., Clemett, S.J.; Chillier, X.D.F.; Maechling, C.R.; & Zare, R.N.; (1996). "Search for Past life on Mars: Possible Relic Biogenic Activity in Martian Meteroite ALH840001," *Science*, Vol. 273, 924-930.

Race, Margaret S.; Nealson, Kenneth H..; Rummel, John D.; Acevedo, Sara E.; (2001, December) *Mars Sample Handling Protocol Workshop Series*, Interim Report of the Workshop Series Workshop 3 Proceedings and Final Report, San Diego, CA March 19-21, 2001, NASA/CP—2001-211388, Washington DC: NASA.

Steele, A. et al (2000, March). "Investigation into an Unknown Organism on the Martian Meteorite Allan Hills 84001," *Meteoritics and Planetary Science,* Vol. 35, No 2., pp. 237-241.

Steele, A. et al (2000). "The Microbial Contamination of Meteorites; A Null Hypothesis," *Abstracts, First Astrobiology Science Conference,* April 3-5, 2000, NASA-Ames Research Center: Moffett Field, CA. p. 23.

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## ADDITIONAL SOURCES

Allen, Thomas J. (1977) Managing the Flow of Technology: Technology Transfer and the Dissemination of Technology Information within the R & D Organization, Cambridge MA: MIT Press.

Allmen, John; Blake, David; Harper, Lynn; Kliss, Mark; Moore, Jeff; Schmidt, Greg (2001, August) Mars Returned Sample Handling Project: Report of Internal Review Committee August 2001, Astrobiology and Space Research Directorate, Moffett Field: NASA Ames Research Center. *Internal report..*

Arno, Roger (2000, May 19) Mars Sample Handling Testbed Facility, Advanced Projects Branch, Moffett Field, CA: NASA-Ames Research Center. *Internal report.*

Arnstein, Sherry R., (1969, July) "A Ladder of Citizen Participation," Journal of the American Institute of Planners, Vol XXXV, No. 4, pp. 216-224.

B2HK, Smith Carter & CCRD (2000, May). Planetary Receiving Facility Feasibility Study, unnumbered NASA Contractor Report, Houston TX: NASA Johnson Space Center.

Beaudet, Robert A. (2000). Simple Mathematical Models for Estimating the Bio-Contamination Transported from a Lander or Rover to the Martian Soil, SAE 2000-01-2422, *30th ICES.*

Bernstein, William N.,(1994, Nov.) "Form Follows Safety: Biosafety labs are in demand by today's researchers," *Progressive Architecture*. pp. 68-69.

Briggs, Geoffrey; Akers, James & Mancinelli, Rocco (2002). Feasibility of a Containment System with Double Walls and Remotely Controlled Tools and Instrumentation, Center for Mars Exploration, Moffett Field: NASA-Ames Research Center. *MRSH Electronic Archive.*

Carr, Michael H.; McCleese, Daniel J.; Bada, Jeffrey L.; Clark, Benton C.; DeVincenzi, Donald; Drake, Michael J.; Nealson, Kenneth H.; Papike, James J.; Race, Margaret S.; Stahl, David (1999, April). Mars Sample Handling and Requirements Panel (MSHARP) Final Report, NASA TM-1999-209145, Pasadena, CA: Jet Propulsion Laboratory.

Cohen, Marc M. (2002). Mars Returned Sample Handling: Project Plan for the Architecture, Center for Mars Exploration, Moffett Field: NASA-Ames Research Center. *In progress.*

Cohen, Marc M., (2001). "Astrobiology Sample Analysis as a Design Driver," Science and Human Exploration Workshop, January 11-12, 2001, NASA-Goddard Space Flight Center, Greenbelt, MD. http://www.lpi.usra.edu/publications/reports/CB-1089/cohen.pdf

Cohen, Marc M., (2000, July 10-13). Design Development Strategy for the Mars Surface Astrobiology Laboratory, SAE 2000-1-2344, Toulouse, France*, 30th.ICES.*

Cohen, Marc M., (1999, July 12-15). "Mars Surface Science Laboratory Accommodations and Operations," SAE-1999-1-2142, Denver, CO, *29th ICES.*

Cohen, Marc M. (1995) Problem Definition in a Participatory Design Process, University of Michigan Rackham Graduate School dissertation, Ann Arbor, MI: Michigan Microfilms.

Dolgin, Benjamin; Sanok, Joseph; Sevilla, Donald; Bement, Laurence (2000). Category V Compliant Container for Mars Sample Return Missions, SAE 2000-01-2421, *30th ICES.*

Jonas, Wolfgang, (1993, April) "Design as problem–solving?" *Design Studies*, Vol. 14, No 2. pp. 157–170.

Jones, J. Christopher (1970), DESIGN METHODS: Seeds of Human Futures, New York: Wiley Interscience.

McKay, Christopher P., (1997, August) "Looking for Life on Mars," *Astronomy,* pp. 38-43.

Nash, Douglas B.; Plescia, Jeffrey; Cintala, Mark; Levine, Joel; Lowman, Paul; Mancinelli, Rocco; Mendell, Wendell; Stoker, Carol; Suess, Steven; (1989, June 30) Science Exploration Opportunities for Manned Missions to the Moon, Mars, Phobos, and an Asteroid, NASA Office of Exploration Doc. No. Z-1.3-001, JPL Publication 89-29, Washington DC: NASA Office of Exploration.

Nealson, Kenneth, Chair, Task Group on Issues in Sample Return (1997). Mars Sample Return: Issues and Recommendations, Space Studies Board, National Research Council. Washington DC: National Academy Press.

Parrish, Joe C., (2001) Long-Range Rovers for Mars Exploration and Sample Return, SAE 2001-01-2138, *31st ICES.*

Race, Margaret S. & Rummel, John D., Editors (2000, October). *Mars Sample Handling Protocol Workshop Series*, Proceedings of Workshop 1, Interim Report of the Workshop Series convened in Bethesda,

MD, March 20-22, 2000. Washington DC: NASA.

Race, Margaret S.; Kovacs, Gregory T. A.; Rummel, John D.; Acevedo, Sara E.; (2001, May) *Mars Sample Handling Protocol Workshop Series*, Interim Report of the Workshop Series Workshop 2 Proceedings and Final Report, Bethesda MD, October 25-27, 2000, NASA/CP—2001-210923, Washington DC: NASA.

Race, Margaret S. (2001) Summaries of Key Planetary Protection Documents, Mountain View, CA: SETI Institute.

Sample Quarantine Protocol Workshop, Final Report (1999) NASA CP 208772, June 4-6, 1997 Moffett Field, CA: NASA-Ames Research Center.

Sanoff, Henry, (1985, Oct.) "The application of participatory methods in design and evaluation," Design Studies, Vol. 6:4. pp. 178-180

Schrage, Michael (1990) SHARED MINDS . . . The New Technologies of Collaboration, New York: Random House.

Simon, Herbert A., (1973) "The Structure of Ill–Structured Problems," Artificial Intelligence, 4, New York NY: North Holland Publishing Co. pp. 181-200.

Space Studies Board (2001) The Quarantine and Certification of Martian Samples, Washington DC: National Academy Press.

Ventriss, Curtis, (1987), "Critical Issues of Participatory Decision Making in the Planning Process: A Re-examination," The J. of Architectural and Planning Research 4:4, Chicago, IL: Locke Science Publishing Co. pp. 281-288.

**DEFINITIONS, ACRONYMS, ABBREVIATIONS**

ARC: NASA Ames Research Center, Moffett Field, CA

BSL: Biosafety Level (Center for Disease Control, 1993)

BSL-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.

BSL-3 — Applies to agents that may be transmitted by the respiratory route, which can cause serious infection.

BSL-2 — is appropriate for agents that can cause human disease, but whose potential for transmission is limited.

BSL-1 — applies to agents that do not ordinarily cause human disease.

CDC: Centers for Disease Control and Prevention, Atlanta, GA

CMEX: Center for Mars Exploration at NASA-Ames Research Center

NASA CP: NASA Conference Proceeding

IAF: International Astronautical Federation

ICES: International Conference on Environmental Systems

JPL: NASA Jet Propulsion Laboratory, Pasadena, CA

JSC: NASA Johnson Space Center, Houston, TX

LRS: Landing Retrieval System

MCF: Mars Curation Facility

MRSH: Mars Returned Sample Handling

MSR: Mars Sample Return Program

PI: Principal Investigator

PPL: Planetary Protection Level, [Office of Planetary Protection.(DRAFT,2001, May 31). A Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth, Washington DC: NASA.]

PPL-$\alpha$ — for incoming samples and archived samples; maximum biocontainment and cleanliness; maintains an inert gas environment.

PPL-β — maintains maximum biocontainment and protection for workers and the environment; maximum cleanliness, but allows exposure to ambient terrestrial conditions.

PPL-γ — maintains maximum biocontainment with moderate cleanliness and ambient terrestrial conditions (i.e.., for animal testing scenarios).

PPO: Planetary Protection Office at NASA HQ

SAE: Society of Automotive Engineers

SETI: Search for Extraterrestrial Intelligence Institute

SScS: Sample Science System

SRF: Sample Receiving Facility

STS: Sample Transportation System