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ASTROBIOLOGY SAMPLE ANALYSIS AS A DESIGN DRIVER

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INTRODUCTION:

This effort supports the Astrobiology Objective 8 the Search for LIFE ON MARS, PAST AND PRESENT -- (Astrobiology Program Office, 1998, p.7).

The essential trade analysis is between returning very small samples to the Earth while protecting them versus in situ analysis on Mars.

Developing these explicit parameters encompasses design, instrumentation, system integration, human factors and surface operations for both alternatives.

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.

A FOCUS ON ASTROBIOLOGY SAMPLE ANALYSIS -- LEADS TO THE REQUIREMENT FOR A SURFACE SCIENCE LABORATORY AT A MARS BASE.

MARS SURFACE ASTROBIOLOGY LAB
WORKING ENVIRONMENT FOR SAMPLE PREP AND ANALYSIS

- **There is an unfortunate history of the Human Space Program squeezing Science out of missions.**

PURPOSES FOR THIS DESIGN RESEARCH:

- Substantiate the continuum from
    - Terrestrial samples to
    - Mars Return samples to
    - In-Situ Laboratory Sample Analysis on Mars

- Demonstrate and Ensure a robust Astrobiology science capability from the beginning of Mission Architecture Design and the beginning of Mission Operations

Probably the best statement on Mars Surface Science Lab activities comes from Carol Stoker (Stoker, Strategies for Mars, 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.

ASTROBIOLOGY: THE SEARCH FOR SAMPLES

These environments correspond in the broadest terms to the three phases of matter:

Solid, Liquid and Gas.

Solid Samples

Scientists conceive living organisms as essentially solid.

The waste products they leave behind and fossils are solid.

Liquid Samples

Levin & Levin speculate that liquid water on may exist today on the surface of Mars, and these pools or reservoirs could serve as cradles of life (Levin & Levin, 1997, 1998).

Kuznetz and Gan produced liquid water in a bell jar under simulated Mars surface atmospheric conditions, at which the conventional wisdom says that liquid water cannot exist (Kuznetz & Gan, 2000).

Gas Samples

Atmospheric Samples are part of any solid or surface water sample.

In picking up a fascinating rock from the Mars surface, the astronauts will want to preserve in its native ambient atmosphere.

TABLE 1. Taxonomy of Astrobiology Sample Characteristics by Phase of Matter

Characteristic	**Solid (Rocks and Soil)**	**Liquid (Aqueous)**	**Gas (Atmosphere & Vacuum)**
Search for **"Pre-Life"**	Organic Molecules	Nutrients	Proto-Amino Acids
Search for Extant Life	Surface rocks, Subsurface deposits, "Bugs under rocks," Deep Drilling cores	Phytoplankton, Zooplankton, Algae, Thermophiles, "Acidophiles"	Airborne Microbes Respiration by products?
Search for Fossils	In Rocks and Sediments	Sedimentary Mats	??
Where to Search	Planetary surface & subsurface	Deep underwater, hot springs, caves, rivers	Atmosphere collection
Preserve Ambient	**Environment**		
• **Maintain Temperature**	Prevent thermal expansion or contraction	Stabilize organisms	Prevent temperature-induced changes
• **Maintain Pressure**	Maintain structural integrity	Prevent deep-water specimens from "exploding"	Essence of the sample
• **Collect with surroundings**	Preserve fossils in bedrock	Collect specimens in liquid medium	??
• **Maintain Chemistry**	??	Collect resupply medium	??
Protect from "Forward" Contamination	Protect from damaging or polluting sample	Protect from interaction with containment vessel	Protect from interaction with pump lubricants, etc.
Protect from "Backward" Contamination	Protect from microbes and toxics	Protect lab and water system from organisms	Protect from potential toxics or microbes

LOCATION & DISCIPLINE ISSUES:

• 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

APPROACH **--** Concern that **faulty** assumptions may lead inevitably to an inadequate Mars Surface Science Capability:

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 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.

In Situ Analysis

Rapid Sample Return is not possible from Mars or Europa.

Neither is it possible to preserve biotic samples in pristine condition for 3 years in space.

Therefore, it becomes necessary to perform comprehensive, high quality analysis

IN SITU.

Seigel, Clancy, Fujimori and Saghir On-Board (space station) specimen analysis for Life Science research (1989, pp. 77-78).

Four Advantages of On-board/In Situ analysis:

- Allows rapid production of experimental results, enabling iterative research activity.
- Provides a quick-response science capability
- Is critical for characterization of samples which cannot survive return to Earth, or degrade with time.
- Significantly reduces sample storage prior to return to the ground, and reduces specialized return requirements (e.g. thermal conditioning).

Two Disadvantages of On-board/In Situ analysis:,

- Greater costs than performing the analysis on Earth.
- “High skill levels required of crew members” with the associated expenditure of crew time and effort.

ACTIVITY NODES --

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.** 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.

HUMAN ELEMENT 1--

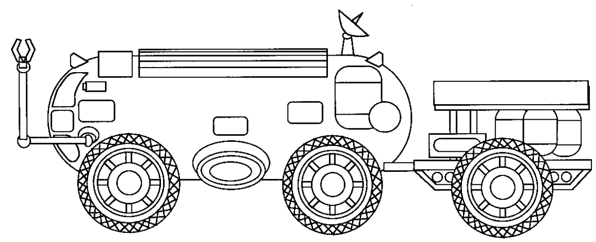
The human element is *the essential component* in the Mars exploration strategy.

What size crew and skill mix is necessary to conduct the Mars surface exploration successfully?

- Who is necessary to perform the science work?

• And who is necessary to keep everyone alive while the explorers do their job?

FIGURE 2. Example of a long-range pressurized rover
with robotic arm and power cart.
(Courtesy of Roger Arno, NASA-Ames Research Center)



HUMAN ELEMENT 2--

This study will address primarily science, 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?

• 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.

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 3. The crew attaches an inflatable laboratory to their lander to increase the internal pressurized volume of their Martian home.

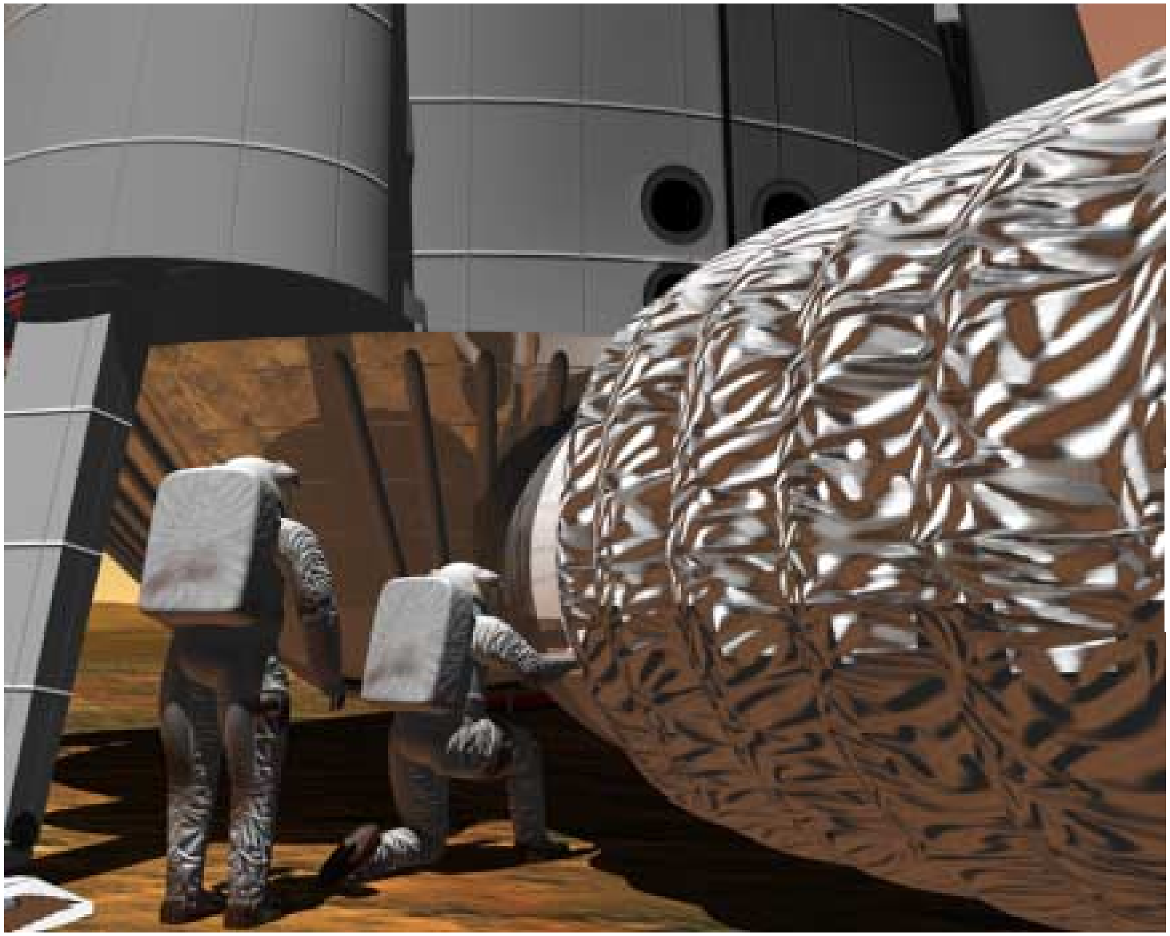
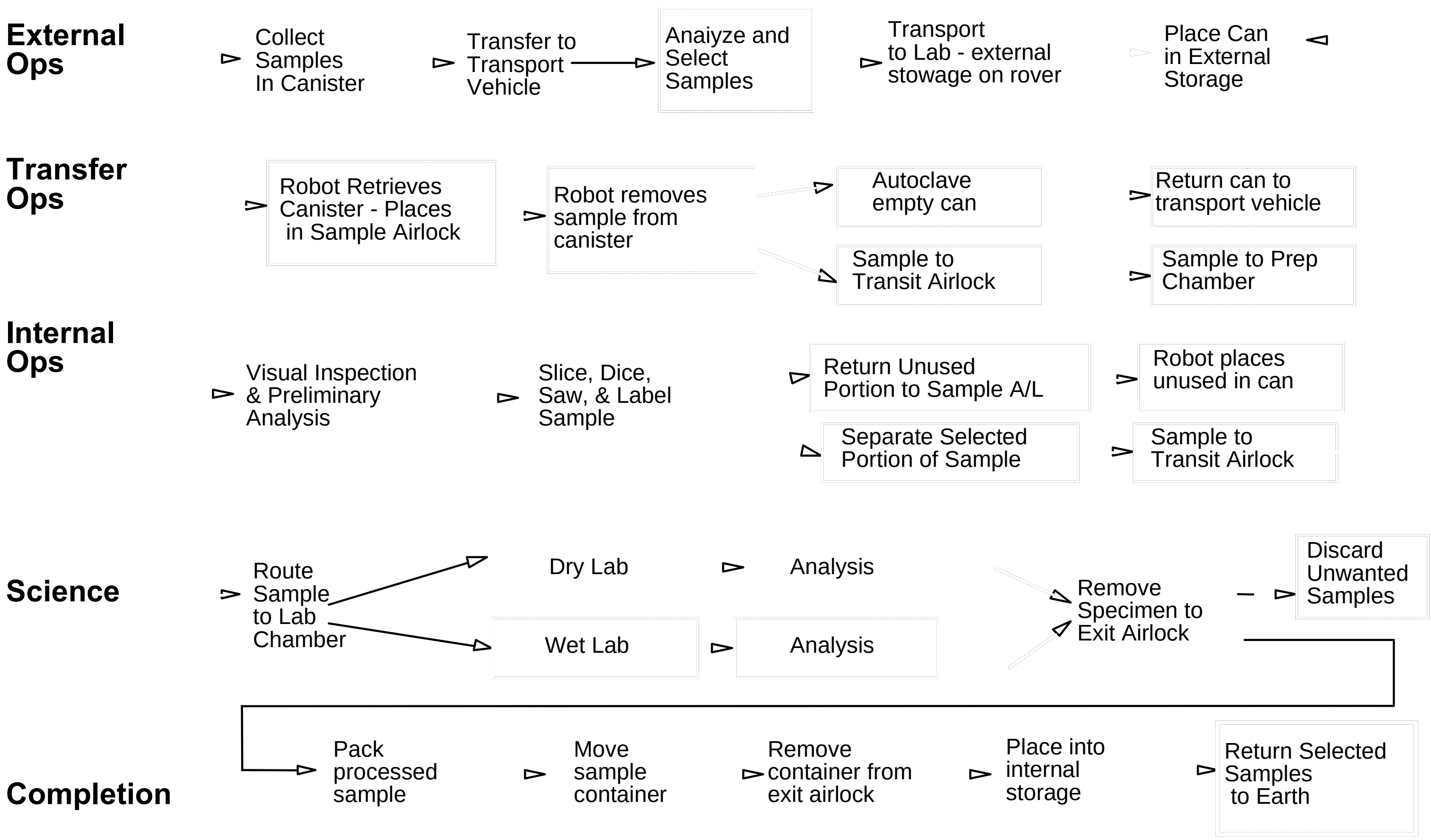


Figure 5. Astrobiology Sample Processing Flow Chart



OPERATIONAL SCENARIO: NARRATIVE OF THE SOLID SAMPLE PROCESSING SCENARIO – FIGURE 5

1. Collect Samples -- Collect samples at drilling site or other location. Place samples into a protective canister.

2. Stow Samples for Transport -- 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.

3. Stow Sample Canisters for Retrieval -- Place canisters into robotic external storage.

4. Retrieve Samples -- Use robotic retrieval system to bring desired sample, place it in the sample airlock.

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

6. Move Sample to Working Environment -- 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.

7. Move Sample to Analysis -- Robots move the prepared sample to the Dry Lab Chamber or Wet Lab Chamber.

8. Prepare Lab Chambers -- Crew prepares lab chambers with tools and equipment, maintenance, repair, and cleaning.

9. Take Precautions -- 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.

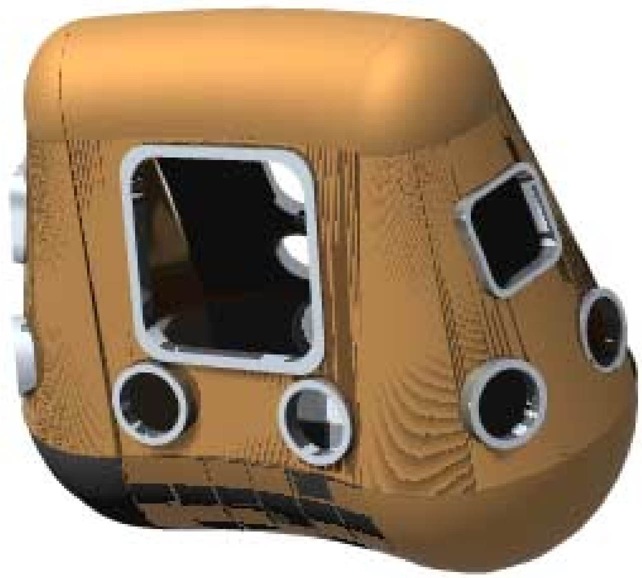


FIGURE 4. Pressurized □P Curved Plan ”Glovebox” Research Chamber.

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

Figure 6. Stanford/Ames Direct Linkage Prehensor, invented by John W. Jameson

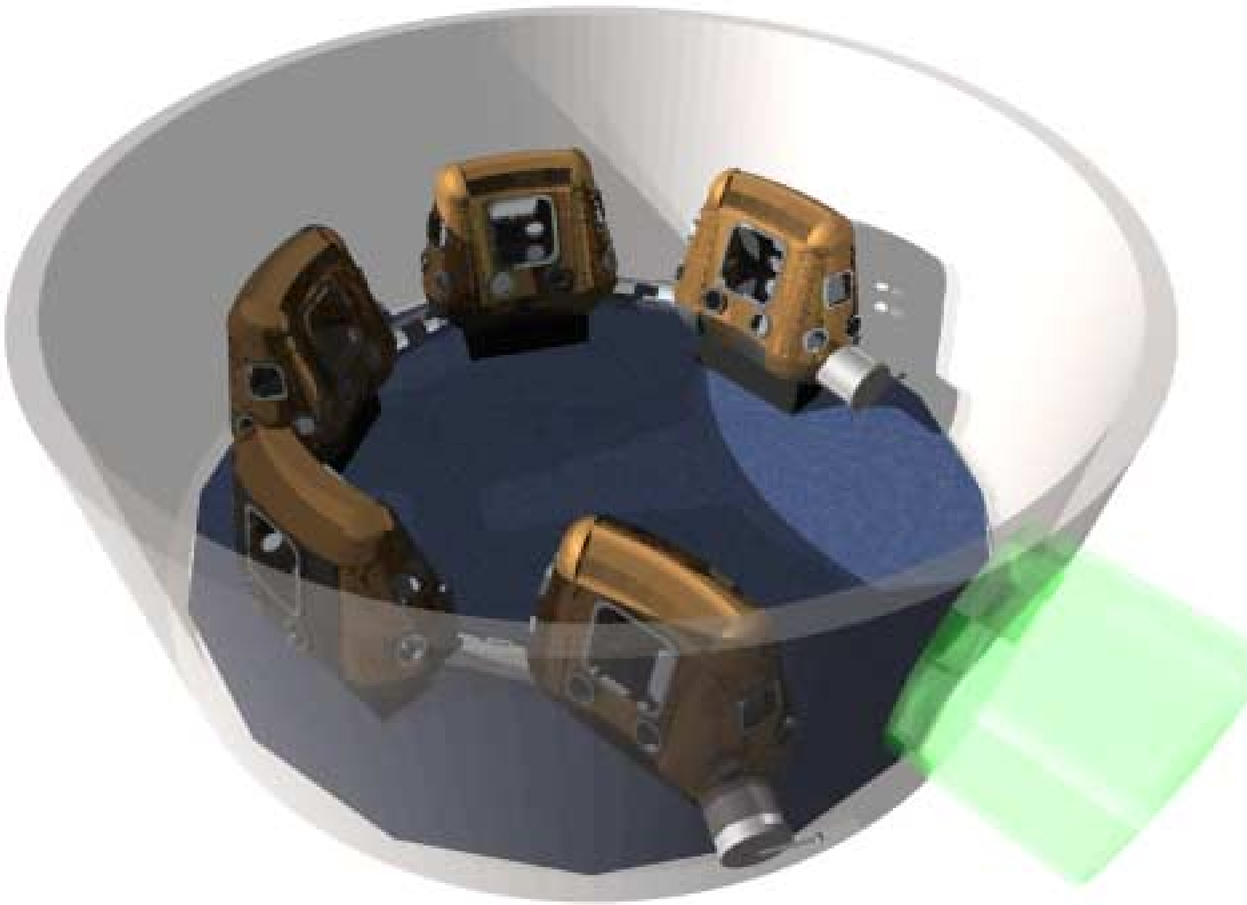


FIGURE 7. Astrobiology Laboratory comprised of P “glovebox” research chambers, installed in a circular arrangement.

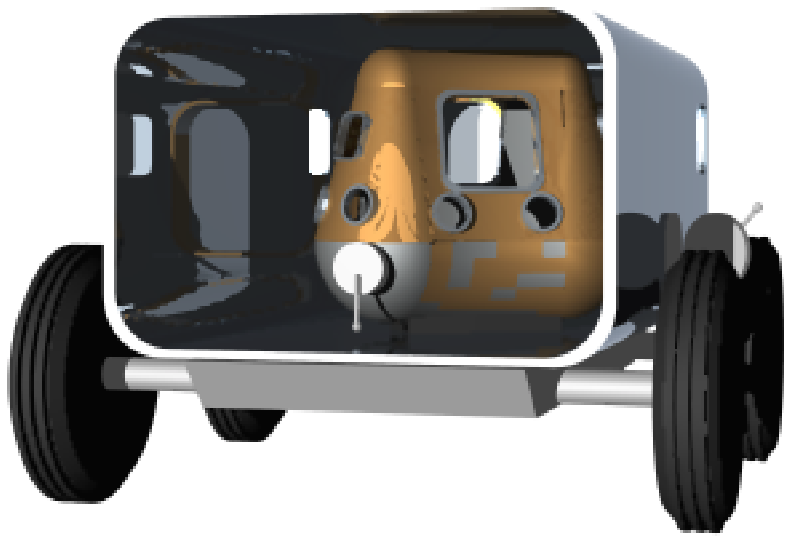


FIGURE 8. Rear view of a simplified planetary rover, with the aft bulkhead removed. The scientific sample airlock appears on the starboard (right) side, between the two wheels, with its handle projecting up at about 45°.

The sample airlock's internal hatch opens into the Astrobiology glovebox, which is essential to handle potentially biotic specimens in a safe manner that will protect both the crew and the sample from contamination.

The sample exit airlock appears in the center of the rover cabin, with its handle pointing straight down.

CREW SIZING – Perhaps the largest unresolved question:

What is the optimal crew size and skill mix to conduct a Mars Astrobiology and Exploration Mission of ten days duration, 500 km away from the Mars Base?

Pressurized rover as microcosm of a Mars mission?

Option A -- two crew members 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.

Option B -- three crew members 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.

Option C -- four crew members 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.

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

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

CONCLUSION

NASA needs to conduct a complete Mars Science Accommodations and Operations Study to understand the In Situ Astrobiology issue.

Developing the Mars surface science laboratory for astrobiology and all the allied sciences represents a great technical and scientific challenge for NASA.

The challenge consists in developing the ability to collect, transport, receive, prepare, process, and analyze exotic samples while preserving them in their ambient environment.

Design research for Mars science exploration requirements:

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.