May 5, 2022

To: Mr. Steve Slaten, NASA Jet Propulsion Laboratory
4800 Oak Grove Drive, M/S: 200-119
Pasadena, CA 91109-8099

From: Barry E. DiGregorio, Director
International Committee Against Mars Sample Return
www.icamsr.org
16 North Hartland Street
Middelport, New York 14105 USA

Dear Mr. Slaten,

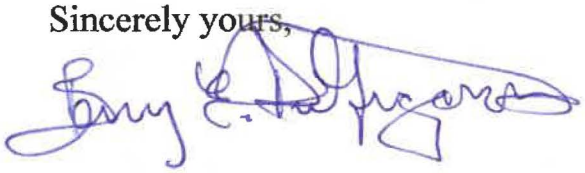
Enclosed are my comments and enclosures representing the position of ICAMSR on the issue of whether or not to proceed with a direct Earth return of Martian soil and rock samples. Without further assessment for extant life on the surface of Mars the risk to Earth's biosphere clearly outweighs any scientific benefits from a direct to Earth MSR. In order for Mars samples to be returned to Earth we of ICAMSR support further extant life detection instruments be sent to the surface of Mars on a number of landers and rovers to rule out the possibility of biohazardous contamination to Earth's biosphere by indigenous Martian microbes as outlined in Article 9 of the UN Outer Space Treaty.

We have laid out our case against a direct Earth return MSR mission and have provided the rational for our views in the required NEPA comments to you for the Mars Sample Return Campaign period open April 15th – May 15th.

Along with our comment letter sent to you at NASA's request, we have included a number of enclosures representing our views of MSR over the years including an article I wrote for the American Chemical Association entitled ***THE DILEMA OF***

MARS SAMPLE RETURN; A copy of ***Antaeus: Concept for a Sample Receiving Lab/ Planetary Quarantine Facility at the Gateway***; and an article I have written for ICAMSR entitled ***MARS SAMPLE RETURN AND INTERNATIONAL SPACE LAW.***

Sincerely yours,



Barry E. DiGregorio – Director for the International Committee Against Mars Sample Return (www.icamsr.org)
16 North Hartland Street
Middleport, New York 14105 USA
Phone: 716-735-7096

Comments from the International Committee Against Mars Sample Return (ICAMSR) www.icamsr.org provided to Steve Slaten, NASA's Mars Sample Return Campaign scoping period from April 15th to May 15th 2022 at NASA Jet Propulsion Laboratory, 4800 Oak Grove Drive, M/S: 200-119, Pasadena, CA 91109-8099

"When the entire biosphere hangs in the balance, it is adventuristic to the extreme to bring Martian life here. Sure, there is a chance it would do no harm; but that is not the point. Unless you can rule out the chance that it might do harm, you should not embark on such a course."

The late Dr. Carl Woese made that comment to me in a 2001 interview while discussing the NASA and French Space Agency (CNES) plan for its first two Mars Sample return projects for 2003 and 2005. For anyone that does not know his name, Carl Woese was a Nobel Prize-nominated biophysicist and microbiologist who while at the University of Illinois discovered the Third Domain of life on Earth - the Archaea (extremophiles).

Even back in 1996, the NASA/ CNES collaboration for a direct-to-Earth Mars sample return mission was complex. The plan was to return Martian soil and rocks in two separate missions, taking advantage of the alignments of Earth and Mars that occurs every two years with the goal of having the first Mars samples on Earth by 2008. NASA, as the lead agency would provide the landers and rovers to collect samples, and a Mars Ascent Vehicles (MAVs) to launch them into Martian orbit. The French Space Agency would then be responsible for the Earth Return Orbiter that would capture the NASA Mars Ascent Vehicle rocketed up to a parking orbit around Mars. Once there, the capsule containing the samples would then captured and returned to Earth aboard the CNES Earth Return Orbiter. Finally, once in Earth orbit, the capsule containing the Martian samples (called the Earth Entry Vehicle EEV) would then be released and hopefully remain intact to land unscathed by the fiery descent onto the Utah desert floor where it would be picked up and taken to a *BSL-4 Biohazard Containment Laboratory* for initial opening and examination. However, in 1999 there were over *5,000 cases reported of accidental laboratory infections and 190 deaths*. This calls into question the wisdom of bringing the first samples of Mars to Earth.

The NASA/CNES Mars Sample Return mission plan was estimated to cost more than $8 billion dollars and would use five or more spacecraft to return just one of the samples. If, however, only one of its components failed for any reason, the entire mission would be lost. The confidence for such a complex mission faded in 1999 when NASA lost four Mars-bound spacecraft in less than 3 months. One of the spacecraft lost was the NASA Mars Climate Orbiter due to spacecraft flight controllers who failed to convert metric units to English correctly. Two months later, the agency's Mars Polar Lander and the two Deep Space microprobes it contained crashed into Mars. Many astrobiologists thought such a mission was premature because NASA never sent a mission to "rule out" what harm if any, indigenous Martian pathogens (if they exist) might have on the Earth's biosphere if through some mishap the samples were accidently released.

Since that time, not much has changed with NASA's direct-to-Earth MSR plan. The only major difference is that the European Space Agency (ESA) will be collaborating with NASA. In this multi-vehicle mission it will land a vehicle to gather the samples collected in tubes by the Perseverance rover and store them for launch in a small rocket capable of boosting them into

Martian orbit. From here, another spacecraft called the Earth Return Orbiter (ERO) built by the ESA, will be waiting to capture the sample container and bring it directly to Earth. Once in Earth orbit, the Earth Return Orbiter (ERO) will then release the container with sealed tubes of Martian soil and rock to enter the atmosphere and to land on the floor of the Utah desert. Here again, just like the NASA/CNES plan, the capsule would be taken to a BSL-4 biohazard containment laboratory for analysis. This latest scenario tentatively has the first samples to arrive on Earth around 2031.

The following *abstract* was presented on Monday, December 13th, 2021 at the Fall Meeting of the American Geophysical Union:

All material that is collected from Mars (gases, dust, rock, regolith) will need to be carefully handled, stored, and analyzed following Earth return to minimize the alteration or contamination that could occur, and to maximize the scientific information that can be extracted from the samples, now and into the future. A Sample Receiving Facility (SRF) would be where the Earth Entry System is opened, and the sample tubes opened and processed after they land on Earth. The Mars Sample Return (MSR) Science Planning Group Phase 2 (MSPG2) was tasked with identifying the steps that encompass the curation activities that would happen within an MSR SRF and any anticipated curation-related requirements. To make the samples accessible for scientific investigation, a series of observations and preliminary analytical measurements would need to be completed to produce a sample catalog for the scientific community. The sample catalog would provide data to make informed requests for samples for scientific investigations and for the approval of allocations of appropriate samples to satisfy these requests. The catalog would include data and information generated during all phases of activity, including data derived from the landed Mars 2020 mission, during sample retrieval and transport to Earth, and upon receipt within the SRF, as well as through the initial sample characterization process, sterilization- and time-sensitive and science investigations. The Initial sample characterization process can be divided into three phases, with increasing complexity and invasiveness: Pre-Basic Characterization (Pre-BC), Basic Characterization (BC), and Preliminary Examination (PE). A significant portion of the Curation Focus Group's efforts was determining which analyzes and thus instrumentation would be required to produce the sample catalog and how and when certain instrumentation should be used. The goal is to provide enough information for the PIs to request material for their studies but to avoid doing targeted scientific research better left to peer-reviewed competitive processes.

Disclaimer: The decision to implement Mars Sample Return will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is being made available for planning and information purposes only.

Mars sample return and International Space Law

Those who have concerns of a direct to Earth MSR revolve around the precautionary principle defined as a "broad epistemological, philosophical and legal approach to innovations with potential for causing harm when extensive scientific knowledge on the matter is lacking". This scientific principal is at the heart of *International Space Law* drawn up by the United Nations Office for Outer Space Affairs. In Article 9 of the document (on page 6) it says:

"States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose."

While this ruling sounds decisive on issues involving the return of samples from Mars or other celestial bodies such as icy Moons orbiting Jupiter or Saturn, it is not until you continue reading the accompanying sentence below that confusion arises as to what another country or group of individuals can do about their concerns of back contamination from another planet as it reads:

A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, may request consultation concerning the activity or experiment.

According to Colorado Attorney Darlene A. Cypser who published a paper about space law for the journal *Jurimetrics* titled, *International law and policy of extraterrestrial planetary protection* says:

Parties to the Treaty are the nations that signed it. Only such state parties can request consultations with the other signatories. Individuals are not considered parties to the treaty.

Since all citizens of planet Earth have a stake in a possible back contamination event from Mars, international space law and policy on planetary protection appears inadequate to meet the challenges of a Mars sample return as envisioned by NASA. Right now any negative comments or opposition to the risks inherent in such a mission, would probably not be recognized by the United Nations Office for Outer Space Affairs.

The question remaining from the Viking Lander Labeled Release experiment

The first and only missions to look directly for life on Mars were the Viking Landers that were launched by NASA in the summer of 1975 and landed in 1976. Both were identical landers, each equipped with the same cameras, three biology instruments, Gas Chromatograph Mass Spectrometer and other scientific instruments. Each lander set down in a different geographical region on Mars that were separated by 6,500 km.

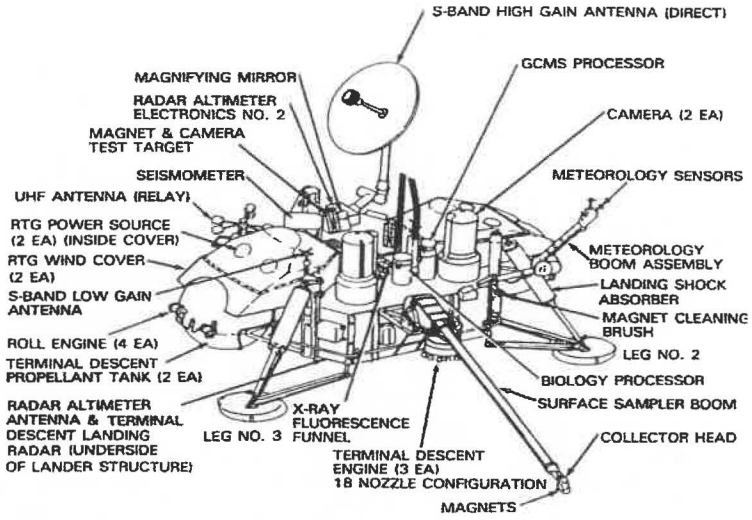


Figure 1. Schematic drawing showing the location of the Viking Lander biology and GCMS processors. Image credit: NASA

However, it was on July 30, 1976 that Viking Lander 1 in the region known as *Chryse Planitia* *detected strong evidence* for extant microbial metabolism coming from several soil samples that were analyzed by the Viking biology detection instrument known as the Labeled Release (LR) experiment.

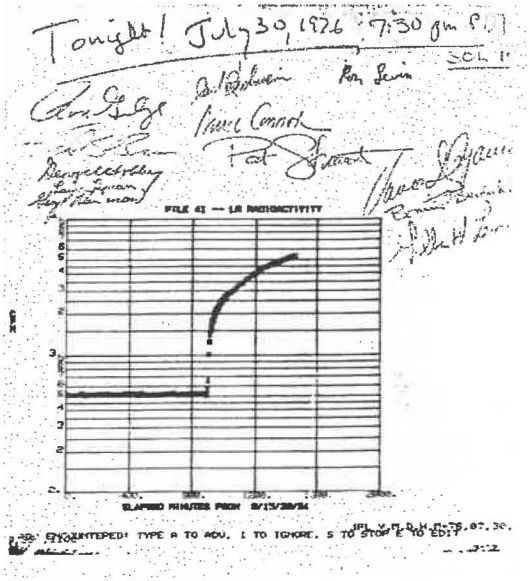


Figure 2. Copy of the first Viking Labeled Release experiment data strip from Viking Lander 1 showing positive indications for microbial metabolism on Mars, July 30, 1976 and signed by Principal Investigator Gilbert Levin and co-investigator Patricia Ann Straat along with others standing near the tele printer at NASA's Jet Propulsion Laboratory. Image credit: Gilbert V. Levin

Two months later, Viking Lander 2 touched down on the surface of Mars September 3rd 1976 in a large flat plain in the northern hemisphere called *Utopia Planitia* thought to be the remnants of an ancient ocean basin.

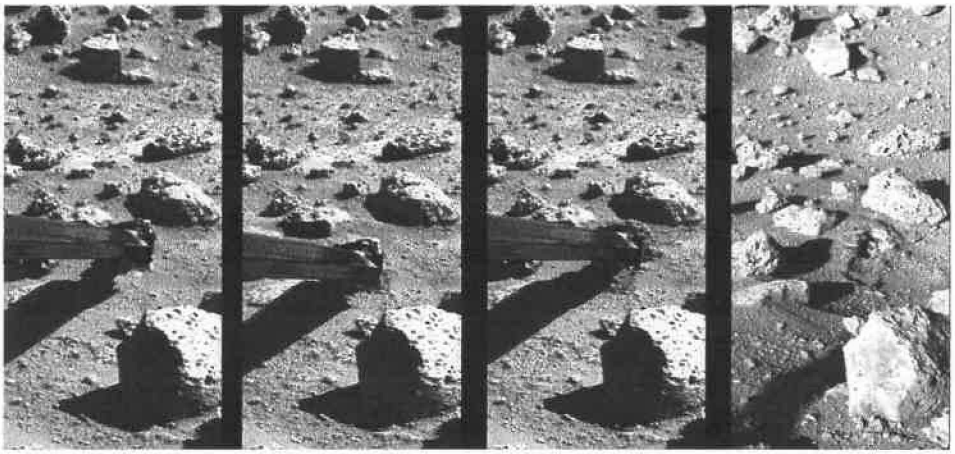


Figure 3. Sequence of images from Viking Lander 2 showing the robotic arm scooping up a Martian sample for delivery to one of the Viking biology instruments. Image credit: NASA/JPL

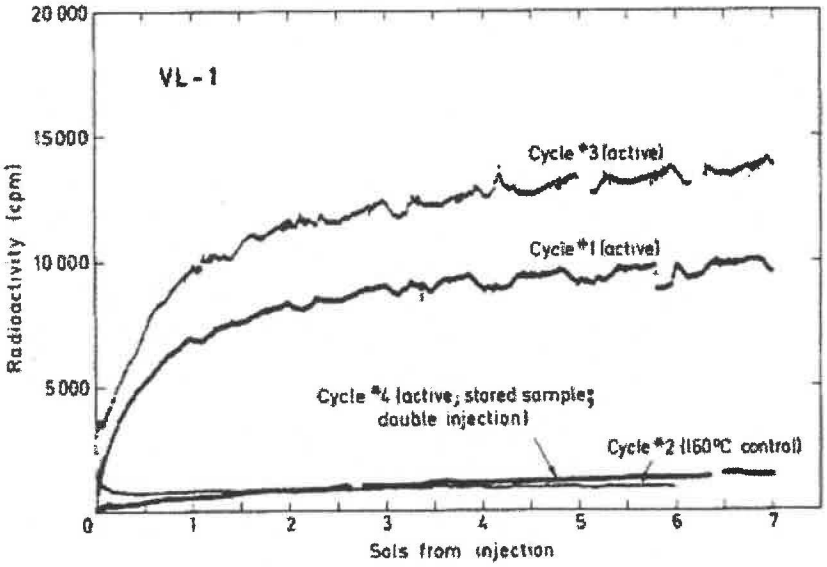


Figure 4 a.

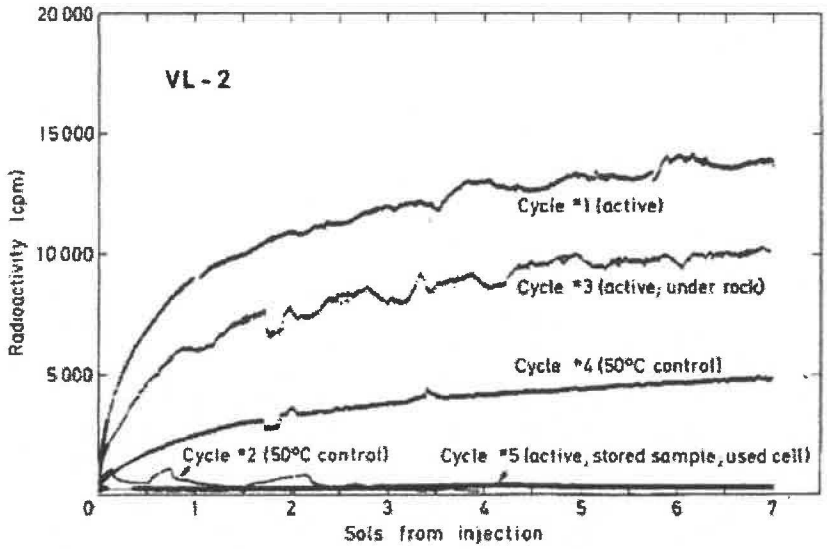


Figure 4 b. A comparison of the results coming from the Labeled Release experiment on Viking Lander 1 (4 a) above and Viking Lander 2 (4 b) showing that something inside the test chamber was consuming supplied radioactive nutrients and giving off CO2 gas just as microbes would do on Earth. To rule out any false positives between organisms or chemicals in the soil, the Viking Labeled Release instruments could vary the temperature inside their test chambers. Both the results from Viking Lander 1 and 2 showed results similar to preflight tests on terrestrial microbial colonies. Image credit: Gilbert V. Levin

However, another instrument placed on each Viking Lander called the *Gas Chromatograph Mass Spectrometer (GCMS)* was designed to look for any organic molecules in the Martian soil. Without the finding of organic molecules – the building blocks of life, doubt would be cast on any biology results. Oddly, the GCMS did not find any organic molecules on Mars down to the parts per billion level at both landing sites even though planetary scientists knew that at the very least some organic molecules should be found from meteorites that have impacted on Mars over billions of years - just as they have accumulated on Earth. It would be a few years (1981) after the Viking biology mission concluded that it was discovered that in preflight tests of the GCMS on an *Antarctic soil sample* containing thousands of bacteria, it did not find any organic molecules at all. This called into question: if the GCMS could not detect organics on Mars, then were the Viking Labeled Release results for microbial life correct all along?

Still, in spite of this report, NASA would rule in favor of the negative organic analysis from the GCMS. Many on the Viking science team believed that without evidence for organics, the Labeled Release findings for microbial life must be in error. Some on the Viking science team suggested that oxidants such as hydrogen peroxide or other *unknown oxidants* were responsible for destroying any organic molecules in the soil. Furthermore, those supporting this oxidant theory went on to claim that it may have caused the Viking Labeled Release instrument to report false readings that only seemed to "mimic life". What does "mimic life" even mean?

To this day, this is still unknown and is a critically important question to have answered before Martian soil samples are brought to Earth. It could mean the difference between contaminating

our planet with pathogens from Mars and bringing back samples that have been self-sterilized by oxidants.

Gilbert Levin was a member of NASA's planetary quarantine advisory panel from 1967-1973 and his company *Biospherics Incorporated* of Rockville, Maryland was under contract by NASA to produce *one of the first Mars Sample Return studies* in 1975. Later in 1986, Levin would file a report to the planetary quarantine advisory panel defending his *Viking Labeled Release data* from Mars.

In 1999, Levin would become a founding member and scientific advisor to the *International Committee Against Mars Sample Return* (ICAMSR) and stated:

I fear that, even if a safe Mars Sample Return container could be made and brought to Earth, there is a good probability that some of the sample would escape from the 'secure' lab where the container would be opened.

NASA in the years since Viking never sent a follow-up extant life detection mission to rule out Levin's data. Both Gilbert V. Levin and Patricia Ann Straat (both recently deceased in 2021 & 2020) would go on to *publish in scientific journals* over the next 44 years that their data from the surface of Mars indicating life, was correct.

As long as this doubt remains over the Viking Labeled Release findings there is the possibility that it found Martian life and that it could be pathogenic to Earth life. Good biosafety protocols should not depend on what scientists "believe is true" about the Viking Labeled Release results, it should only matter "what is true" regarding them, and to do that means sending more in-situ life detection experiments to the surface of Mars. As of this writing, none have been planned.

The importance of the organics findings from the Curiosity and Perseverance rovers

Beginning with its landing in Gale crater in the summer of 2012 NASA's Curiosity rover (still operating in Gale crater on Mars as of this writing) conducted a number of organic analyses with its *Sample Analysis at Mars instrument (SAM)* and found organic molecules in the soil, rocks and atmosphere of Mars. More recently, at the 2021 Fall Meeting of the *American Geophysical Union*, it was announced by the Perseverance rover science team that they have found organic molecules in both the rocks and dust analyzed on the crater floor.

The organic analyses results from the Curiosity and Perseverance rovers should now call into question the negative organics findings by the Viking Lander GCMS from 1976 and reinvigorate renewed interest in the Viking Labeled Release experiment. Armed with this new information about organics on Mars, good biosafety protocols should require that NASA, the ESA and China (CNSA) send additional extant life detection instruments in order to find out whether the Viking Labeled Release experiments found indigenous microbial life or some peculiar chemistry that seems to mimic life.

Now is the time for astrobiologists and policy makers to speak out and ask for more stringent planetary protection protocols involving sample return missions. Other voices are needed to weigh in on the safety and legality of a direct-to-Earth Mars sample return mission. These

include environmental organizations, microbiologists, virologists as well as those who work in infectious disease control fields such as the World Health Organization and the Centers for Disease Control.

Good science should require any space faring nation to first "rule out" the possibility that any returned solar system samples would harm Earth's biosphere before any samples are brought directly to the Earth for analysis. One could imagine a number of different scenario's where a direct-to-Earth sample return mission could go wrong, such an impact with from one of the hundreds of thousands of orbiting space debris surrounding our planet. There are other more expensive options that exist such as examining extraterrestrial samples in a specially designed *biohazard containment facility in lunar orbit or part of a lunar base* that offer a high degree of planetary protection.

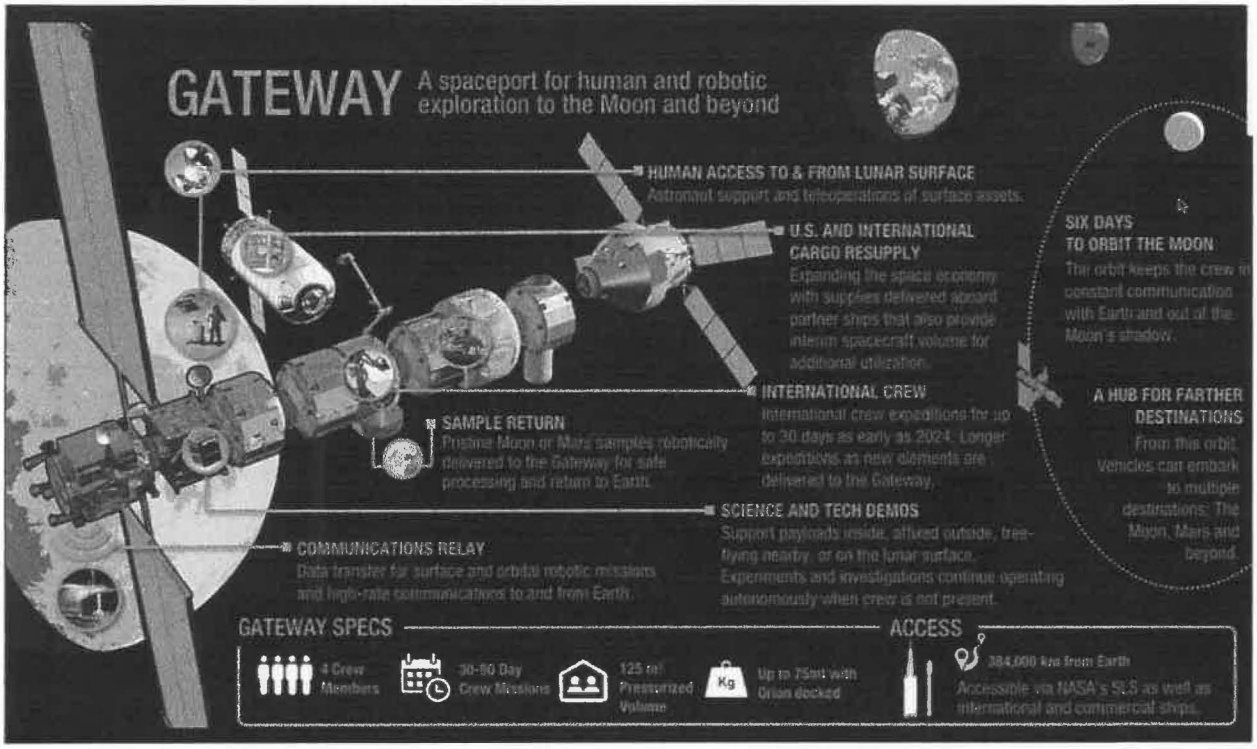
A reasonable but costly plan to examine samples from Mars without the risk of contaminating Earth could look like this four-phase scenario:

Phase 1) Increase the number of life sciences landers going to Mars and land them in different geographical locations. These landers will carry out in-situ testing of the Martian surface/subsurface to narrow the probability range of any life detected in the samples; a) define the environmental envelope for growth and survival of any life detected. Also, this phase would also test inhibitory agents for effectiveness on any life found.

Phase 2) a second series of tests will be conducted in Martian orbit aboard a newly designed automated life sciences laboratory for the purpose to determine any interactions between Martian microorganisms and selected terrestrial ecosystems.

Phase 3) after numerous robotic spacecraft have conducted their life sciences survey of the surface of Mars in many different locations, the cautious return of samples to the vicinity of the Earth / Moon system may proceed. Upon achieving lunar orbit, the Mars Sample canister status would be evaluated by a qualified Biohazard Team aboard a lunar orbiting Space Station or as part of a lunar base.

Phase 4) once phases 1-3 have been carried out, the Mars Sample Return canister with samples inside would be transferred to the Earth's surface to be analyzed in a high security BSL-4 Planetary Sample receiving Laboratory.



How can ordinary citizens and environmentalists voice their opposition to the NASA/ESA direct- to-Earth Mars Sample Return plan?

One way citizens can add their voice to the conversation is to contact the NASA NEPA Manager at NASA Headquarters in Washington, D.C. *NEPA* is an acronym for National Environmental Policy Act. (NEPA) requires all Federal agencies to integrate environmental values into their decision making processes by considering the environmental impacts of their proposed actions and the reasonable alternatives to those actions.

According to the NASA NEPA Manager at NASA Headquarters the process is as follows:

"The NEPA scoping period will assist NASA with the preparation of the NEPA analysis, in this case preparation of an environmental impact statement (EIS). NASA will then publish a notice of availability (NOA) to inform the public when the Draft EIS is available. The NOA will again be published in the Federal Register with a link posted again on the NASA NEPA website. The NOA

will specify the dates of the 45-day comment period, where individuals will again have an opportunity to submit comments.

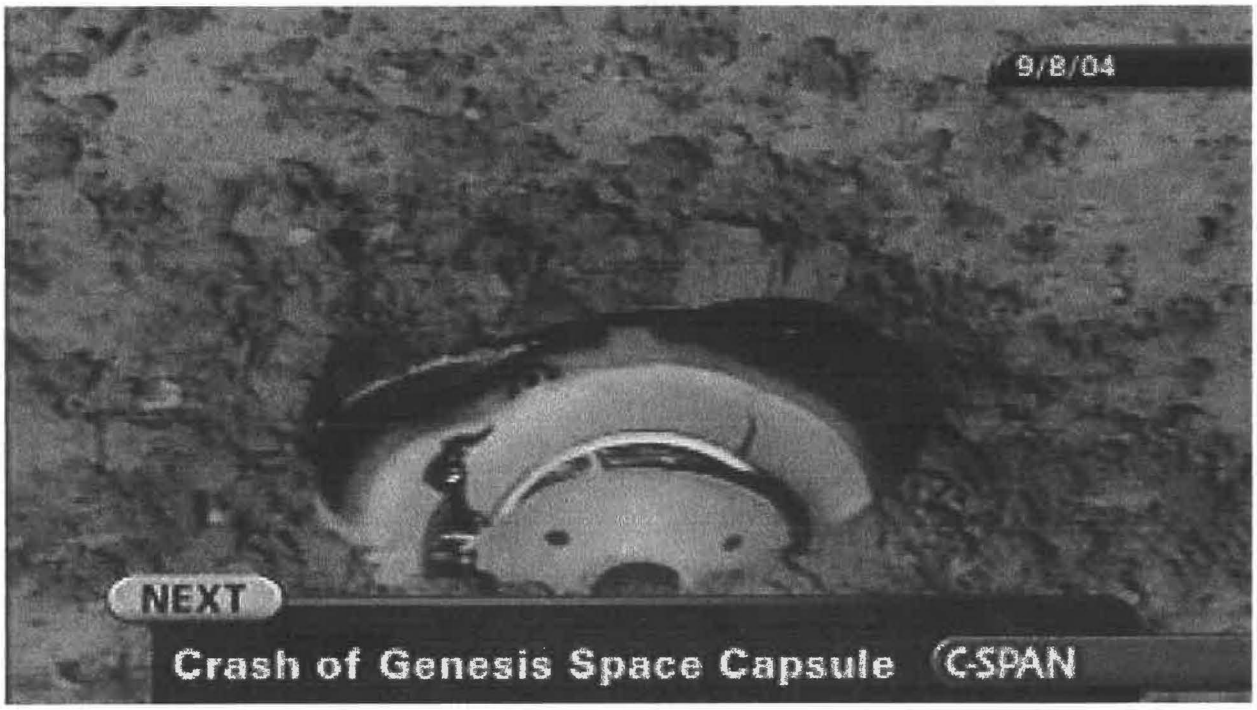
This is a lengthy US regulatory process within individual and groups will have several opportunities to provide input.

Perhaps if there are enough people to voice their dissent on the risks of a direct-to-Earth return of Mars samples we might spare our planet irreparable damage and untold consequences for all life.

Barry E. DiGregorio – Director for ICAMSR, May 5th, 2022

16 North Hartland Street, Middleport, New York 14105 USA

https://www.nbcnews.com/id/wbna5942268



How You Can Submit Your Comments

Verbal — *Provide spoken comments during the Virtual Scoping Meetings by calling 510-210-8882, May 4, 2022; 1pm – 3pm (Mountain) and May 5, 2022; 6pm – 8pm (Mountain)*

Webex — *You may submit written comments at the Virtual Scoping Meetings via Webex online chat at the dates and times listed above at:* **https://jpl.webex.com/meet/msr**

Internet — *Federal E-Rulemaking Portal:* **http://www.regulations.gov**. *Follow the online instructions for submitting comments. Please note that NASA will post all comments on the Internet without changes, including any personal information provided.*

U.S. Mail — *Steve Slaten, NASA Jet Propulsion Laboratory*
4800 Oak Grove Drive, M/S: 200-119
Pasadena, CA 91109-8099

The scoping comment period is open from April 15, 2022 to May 15, 2022. To ensure your scoping comments are considered for use in the Draft Programmatic Environmental Impact Statement, please submit them by May 15, 2022.

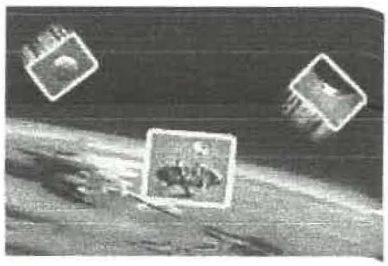
For additional information, visit our website www.nasa.gov/feature/nepa-mars-sample-return-campaign

August 2001
Vol. 31, No. 8, pp 18–27.

Barry E. DiGregorio

The dilemma of Mars sample return

The battle rages on: Does the scientific value of bringing Martian samples to Earth to study outweigh the risks of introducing alien organisms to our planet?



Corbis; National Geographic Society

Microorganisms cover the Earth and everything on it. Ever since the creation of microbiology by Louis Pasteur more than 100 years ago, more than 4000 species of bacteria have been identified. Yet microbiologists estimate that millions of species remain undiscovered. Human skin is a habitat for billions of bacteria; each square centimeter harbors about 100,000 microbes. In fact, an incredible 10% of human body weight is made up of microorganisms (*1*). The total weight of microbes living underground on our planet has been calculated at more than 100 trillion tons. They would form a layer more than 5 ft thick, if spread evenly over the surface of the Earth (*2*).

Often modern science is completely ignorant of how the microscopic world interacts with higher forms of life on our planet. Take, for example, the public statement issued in 1995 by British Health Secretary Stephen Dorrell on the ability of the bovine spongiform encephalopathy (BSE) prion ("mad cow disease") to be transmitted to humans: "There is no conceivable risk of BSE being transmitted from cows to people" (*3*). Dorrell had made the comment in an effort to ease public fears about buying and eating British beef before a complete scientific study of BSE was made.

How many people put their trust in Dorrell's "expertise" and continued to eat tainted British beef? The painful truth was that the BSE prion is a new pathogen—it is not a virus or a bacterium, but a protein that resists all forms of sterilization. A year later, Dorrell made a public apology for his statement, but insisted that is was made in good faith.

Similarly, our ignorance about toxins and pathogens from other worlds could lead to false assumptions if not investigated to the best of our ability. The best protection we can offer our planet against such a threat is a combination of ongoing in situ life science analyses using robotic spacecraft with the body of peer-reviewed scientific information that already exists. What if bizarre forms of pathogens exist on planets like Mars? Are we really prepared to bring them home?

The members of the Space Studies Board (SSB; formerly the Space Science Board) of the National Research Council (established in 1916 by the National Academy of Science [NAS]) are responsible for answering such important questions. The SSB is supposed to provide the National Aeronautics and Space Administration (NASA) with estimates—based on peer-reviewed scientific data—of the likelihood of microbial life on Mars and other planets. It also examines the survival skills of terrestrial microbes in extreme environments and the potential pathogenicity of alien microbes to Earth life. These estimates are then used to define and shape spacecraft missions to the planets as well as the sample return programs.

Yet, until very recently, the reports issued by the SSB on planetary contamination and Mars sample return (MSR) (*4–7*) did not mention the peer-reviewed papers written by Viking Mission scientists Gilbert V. Levin and Patricia Ann Straat, who conducted nine life-detection experiments on the surface of Mars in 1976. Levin and Straat claim their experiments indicated positive signals for microbial metabolism (*8–11*). Their papers appeared in such prestigious scientific journals as *Science* and the *Journal of Geophysical Research*, but were left out of the SSB reports until June of this year (*12*). Why?

Mars vs Earth

Of all the planets in the solar system, Mars is considered to be the most like Earth. Many millions, if not billions, of years ago, Mars had tremendous volcanic activity, which perhaps continues today on a limited scale. Mars also has gigantic polar ice caps that rival the Antarctic ice sheet and consist largely of frozen water. Mars has water vapor in its atmosphere that forms wispy white clouds and low-lying fogs. It has recently been conjectured that Mars may have liquid water in biologically significant amounts—something most scientists considered impossible only 2 years ago (*13*).

If it were shielded from the harsh solar UV light impinging onits surface, Mars would have all the right ingredients for a sustainable microbial ecosystem. (A mere centimeter or less of dust could easily shield such life.) It is no wonder then that returning samples from Mars to Earth for study is a high priority for scientists who want to know whether Mars has or once had an active biosphere.

Mars in the news

Travel to and sample return from Mars are hot topics these days. As we were preparing this article for *Chemical Innovation,* the National Academies' National Research Council issued a study (Reference 12 in the article) on Mars sample return. The accompanying press release is posted here, and a public briefing was held on May 29 in Boston in conjunction with the American Geophysical Union's spring meeting.

On June 6, Jeffrey L. Bada of the Scripps Institution of Oceanography, University of California, San Diego, spoke at ACS headquarters in Washington, DC, on the existence of life on Mars and the development of programs for detecting it before humans land there. Bada's remarks will be presented in our Postscript department in the September *CI*.

—*Ed.*

But do we really have to return samples to Earth to make this determination? The answer is no. The British are building an astrobiology lander that will fly to Mars in 2003 to attempt to answer the life-on-Mars question by using in situ instruments. It is the only life science lander scheduled to go to Mars this decade and the only one since NASA's Viking Mission more than 25 years ago (*14*).

The feasibility of returning samples from Mars has been considered periodically for more than 40 years (*15–17*), and its roots are entwined with the establishment of the planetary protection resolution initiated by NAS in 1958. However, since the historic 1996 NASA announcement of a Martian meteorite (ALH 84001) found in Antarctica that might contain fossilized bacteria from Mars (*18*), NASA has stated that its highest priority for the Mars exploration program is to return Martian samples directly to Earth. Since the 1970s, MSR studies have gone through a series of design options ranging from examination of samples in a Centers for Disease Control and Prevention (CDC)–like containment facility on the Moon to an Earth- orbiting laboratory.

The current MSR design uses Earth as a "catcher's mitt", a phrase coined by NASA Planetary Protection Officer John Rummel in 2000 (*19*). Engineers at the Jet Propulsion Laboratory (JPL, Pasadena, CA) describe this method as passive

Earth entry; it will use a cannonball-sized sphere filled with Martian soil and rock that will directly enter Earth's atmosphere without a parachute.

Only 2 years ago, MSR was going to be launched as two missions: the first in 2003 and the second in 2005. Each mission would have a Pathfinder-like Rover vehicle to look for and collect 500 g of Martian soil and rock and place it in a return canister. Then the sample container would be launched on a small rocket to rendezvous with a French-made Earth return vehicle (ERV) waiting in Martian orbit (*20*). The ERV would then bring the sample container to the vicinity of Earth and release it, after which it would enter the Earth's atmosphere and crash land in a predetermined area in the Utah desert sometime in 2008. The capsule and samples within would then be taken for analysis to a level-4 biohazard containment facility, a high-level biological containment facility for handling deadly pathogens such as the Ebola virus (*21*).

The MSR program is envisioned as an international effort involving Italy and France working in partnership with NASA (*20*). The mission is estimated to cost more than $8 billion and will use five or more spacecraft to return just one sample. If, however, only one of its components fails for any reason, the entire mission will be lost. The confidence for such a complex mission faded in 1999 when NASA lost four of its Mars-bound spacecraft in less than 3 months.

One of these was the Mars Climate Orbiter. While the orbiter was en route to Mars, the spacecraft flight controllers failed to convert metric units to English correctly, dooming the mission (*22*). The incident stunned the scientific community and caused great embarrassment to NASA. Then, only 2 months later, the agency's Mars Polar Lander and the two Deep Space 2 microprobes failed and are assumed to have crashed on the Martian surface. Together, these missionscost more than $400 million. A full-scale investigation was mounted, and an independent commission re-evaluated the Mars exploration program (*23–25*). As a consequence of the investigation, the MSR project was postponeduntil 2011 (*26*). But discussions on setting a new launch date for MSR, perhaps as soon as 2005, are in progress.

In March 2001, Colin Pillinger, the principal investigator for the British-built Beagle 2 astrobiology lander (slated for launch to Mars in 2003 on the European Space Agency's Mars Express probe) held a meeting at the Royal Society in London billed as "Samples from Mars—How Shall Britain Proceed?" Pillinger not only probed British interest for returning Martian samples to Earth, but also sought ways to beat NASA's new MSR schedule in 2011, thus allowing the British to be the first to return samples to the Earth. Has a new space race begun—a race to return Martian samples to Earth?

The debate over MSR is a twofold argument and is a delicate balancing act based on whether or not the scientific benefits of such a mission outweigh the risks involved. So far, all that the SSB has said about the risk of back-contamination from Mars is that it is "considered to be low, but not zero"; therefore, any returned Martian samples will be treated as "biohazardous until proven otherwise" and taken to a level-4 biohazard containment facility (*6*). As the history of the planetary protection program has demonstrated, determining what level of planetary protection stringency is used on spacecraft missions depends on whether scientists believe that other worlds have life or the ability to sustain it. To fully appreciate how the risks of MSR should be weighed against the scientific benefits,it is necessary to reviewand understand how MSR evolved out of the planetary protection program (see timeline A & B).

1958: The birth of planetary protection

After October 4, 1957, when the Soviet Union's Sputnik ushered in the Space Age, astronomers began to think of ways they could place their scientific instruments on

spacecraft to examine the surface materials of the Moon and planets. With the advent of the interplanetary rocket came the realization that terrestrial microbes could ride as unwanted hitchhikers aboard spacecraft and that they might contaminate other bodies in our solar system.

In February 1958, NAS drafted a resolution that examined the problem of preventing such contamination. In the resolution, NAS pleaded with scientists planning future lunar and planetary missions to "use great care and deep concern so that initial operations do not compromise and make impossible for ever" analysis of celestial bodies by critical scientific experiments (*27*).

NAS urged the International Council of Scientific Unions (ICSU) to assist in evaluating the problem of forward contamination of celestial bodies by spacecraft. In May 1958, the ICSU set up an ad hoc committee known as CETEX (the Committee on Contamination by Extraterrestrial Exploration) to begin a systematic analysis of the issues raised by NAS, such as

- contamination of the lunar atmosphere, dust, and soil;
- contamination of cosmic dust; and
- especially the contamination of Mars and Venus.

By June 1958, NAS had set up its own internal space activities monitoring group—the Space Science Board—that later strongly influenced how the Mars sample return program would be conceived. In October 1958, CETEX presented its recommendations to the general assembly of the ICSU in Washington, DC (*28*):

> CETEX believes that there is a real danger that exploration attempts made within the next few years may produce contamination of extraterrestrial bodies, which would complicate or render impossible more detailed studies, when the technological problems of landing sensitive instruments on the Moon and planets have been solved.

Following the meeting, ICSU established a new organization that would take over the planetary protection functions of CETEX—the Committee on Space Research (COSPAR). As an international organization, COSPAR sought to define what the acceptable levels of contamination on an outbound spacecraft might be. The SSB appointed one of its founders,Joshua Lederberg (then professor of biology at Stanford University and winner of the Nobel Prize in Physiology and Medicine in 1958 for his research in genetics) to work with COSPAR to establish spacecraft sterilization protocols.

Another important event in 1958 was the creation of NASA, born out of the National Advisory Committee on Aeronautics. NASA's early role was to oversee U.S. Department of Defense space efforts and serve as an authority for making international recommendations for the prevention of celestial contamination.

Also in 1958, out of concern for contamination issues and nuclear weapons placed in space, the United Nations founded UNCPUOS—the Committee on the Peaceful Uses of Outer Space (*29*). By 1967, the U.N. Outer Space Treaty was signed by the United States, the Soviet Union, and the United Kingdom, and then ratified by the Secretary General of the United Nations and signed by every member of the U.N.General Assembly. Article IX calls for parties to the treaty to conduct exploration of the Moon and other celestial bodies "so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter" (*30*). The stage was set for one of the most interesting scientific debates in history.

Remember that the major concerns at this time were only about forward contamination of celestial bodies. Back-contamination was not foreseen because it would entail bringing materials from other planets to the Earth's biosphere. The only rocket technology available in 1958 was that of outbound spacecraft.

Contamination on the Moon

On September 14, 1959, the Soviet Union announced it had successfully crashed an 860-lb probe called Luna 2 on the Moon. Reaching the Moon at this time was an enormous achievement for rocket engineers, but the news of Luna 2 crashing into the lunar surface was disturbing to the newly formed SSB and COSPAR. The Soviet Union was not an active participant in COSPAR and would not provide any documentation about its planetary protection protocols other than oral assurances that the surfaces of its spacecraft had been treated with gaseous germicides.

Microbiologists knew that grenades and shells used in bacteriological warfare contained microbes that could survive the explosive force of impacts. Had Luna 2 contaminated the Moon? The Moon has an unimaginably hostile environment with an almost nonexistent atmosphere; it is exposed to harsh solar and cosmic radiation and has no liquid water. Surely no microbes from Earth could survive there—or could they? The answer to that question would have to wait until 1969 when Apollo 12 astronauts returned a section of the Surveyor III camera.

The various reports submitted to SSB and COSPAR indicated that complete sterilization of a spacecraft was impossible (*31*). Microbiologists knew that under favorable ecological conditions, just one surviving spore could multiply into billions. Still, they had to do their best to ensure that scientific instruments on future landers would not find terrestrial contaminants from earlier unsterilized orbiters. It was determined that the most rigorous method for limiting microbial spores on outbound spacecraft was to use a combination of dry heat sterilization (105–108 °C for 1–300 h) and treatment with ethylene oxide, a toxic gas (*32*). Ethylene oxide had to be used cautiously to avoid being adsorbed on spacecraft materials made from polymers such as rubber. The entire spacecraft payload would have to be assembled in a class 100,000 clean room—a room in which the concentration of >0.5-μm airborne particles does not exceed 100,000/ft^3. Electronic components had to be designed to withstand heat sterilization and that would mean added costs and time.

With the success of the Luna 2 probe, the Moon became a dartboard for early probes from the Soviet Union and United States as engineers tried to perfect their celestial navigation and targeting skills. Between August 1961 and October 1962, NASA launched six lunar probes in its Ranger series designed to take pictures minutes before crashing on the Moon. All six Rangers failed, and a NASA commission determined that prolonged heat sterilization of the Ranger probes likely damaged some electronic components, causing the spacecraft to fail. The agency immediately dropped the heat sterilization protocols on all lunar probe missions and opted to use the germicidal gas ethylene oxide. It was much the same method that the Soviet Union claimed it had used with the Luna 2 probe that SSB and COSPAR had earlier protested. NASA's unsterilized Ranger 7 successfully completed its mission in 1964 and was followed by Rangers 8 and 9.

The ethics of contaminating other worlds would have to be compromised to some degree if we wanted to strive for greater knowledge. It now appeared that science would have to accept the fact that the Moon would be contaminated in small local areas where incoming spacecraft spread their debris.

The Apollo back-contamination problem

As more information became available about the Moon, scientists at the Manned Spacecraft Center (MSC) in Houston began thinking about returning samples to Earth. In February 1964, two new geoscientists, Elbert A. King, Jr., and Donald A.

Flory, proposed a sample receiving laboratory to MSC's Space Environment Center. Reaction to the proposal was mixed; and in December 1964, Homer Newell asked the SSB to consider the "kinds of analysis that should be performed on the lunar samples . . ., the facilities needed to do that work, and the staffing that would be required" (33).

In early 1965, an SSB committee agreed that a sample receiving laboratory was needed, but it also raised the question of biological contamination and the need for quarantine. Biologists working with the U.S. Public Health Service also had raised concerns during the development of the Apollo program about astronauts bringing back pathogenic material from the Moon. In 1966, the Interagency Committee on Back Contamination (ICBC) was formed to study the problem. Their recommendations resulted in the building of the $16 million Lunar Receiving Laboratory (LRL) at the Johnson Space Center in Houston. The engineers responsible for designing the LRL used the U.S. Army biohazard containment facility at Fort Detrick, Frederick, MD, as a model. Fort Detrick is equipped to deal with the world's deadliest germs and chemicals, and the LRL was designed with that concept in mind (34).

One month before the first Apollo landing in July 1969, *Time* magazine featured a cover article entitled "Is the Earth Safe from Lunar Contamination?", with Carl Sagan gracing the cover (35). Sagan told *Time* that although scientists were 99% convinced that lunar contamination posed no problems, the 1% chance of contamination was too large to ignore.

Apollo 11 and 12

Originally, to ensure that the hatch remained sealed, a crane aboard the aircraft carrier U.S.S. Hornet was scheduled to lift the entire Apollo 11 capsule out of the ocean with the astronauts still inside. The capsule would then be placed in a special tent on the ship and the astronauts, wearing quarantine garments and gas masks, would be escorted to a mobile quarantine trailer aboard ship.

Unfortunately, to the horror of the biologists on the ICBC, the Apollo 11 capsule hatch door was opened prematurely in the Pacific Ocean, contrary to established planetary protection protocols. Someone on the ship had determined that the crane was unsafe, and frogmen were sent to open the crew hatch while the capsule was still floating in the ocean. This was a very serious breach of the planetary protection protocol—which was not pointed out in the news.

When the hatch door was opened, any lunar dust or microbes from inside the spacecraft could have been carried out into the air and the ocean. If there were any pathogenic organisms living in lunar soil, they now had a very warm and wet breeding ground in which to grow (36).

Years later, astronaut Buzz Aldrin said in a television interview that the mobile quarantine trailer in which the Apollo 11 crew was isolated had one serious flaw: Ants appeared to be going into and out of the trailer (37). If there were any Moon bugs, they would have gotten out with the ants.

Sagan accused those responsible of "playing loose with the biosphere". Most of the lunar geologists considered Sagan a thorn in their side and resented him for what they thought was his "alarmist commitment" to planetary protection.

"I always thought the most significant thing we found on the whole [expletive deleted] Moon was that little bacteria who came back and lived and nobody ever said [expletive deleted] about it," said Apollo 12 Commander Pete Conrad in 1991 (38). What was he talking about?

In April 1967, the unmanned Surveyor III landed near the eastern shore of Oceanus Procellarum on the lunar surface. It stayed on the Moon for $2^1/_2$ years—in a near vacuum, at temperatures of +250 °F in the sunlight and –250 °F in the dark, and completely exposed to solar and cosmic radiation (UV, γ-, and X-rays)—until November 20, 1969, when the crew of Apollo 12 landed only 535 ft away. Part of the mission's objective was to retrieve selected components of the probe's camera, place them in sterile containers, and return them to Earth for analysis.

Incredibly, scientists working at the LRL isolated a colony of 50–100 *Streptococcus mitis* bacteria that were still viable from a sample of polyurethane foam insulation taken from inside the Surveyor III camera housing (*39*). Here was strong evidence that NASA's decision to have COSPAR eliminate the sterilization protocols for lunar probes was completely wrong. Just as in the case of British Health Minister Dorrell's erroneous comments on BSE, NASA and COSPAR based their decision on belief rather than hard scientific evidence. If terrestrial microbes could survive on the Moon for $2^1/_2$ years, what might happen on Mars?

To contaminate Mars?

For most planetary scientists in the early 1960s, one thing was certain: Whatever terrestrial microbes would ride to the lunar surface on unsterilized spacecraft, the likelihood of any microbes surviving on the Moon was considered insignificant.

Microbial survival on Mars was another matter entirely. On November 30, 1964, the Soviet Union unintentionally focused attention on this issue when it lost contact with its Mars spacecraft Zond 2 and became embroiled in another heated controversy with COSPAR and SSB. Deep-space tracking stations calculated that the Soviet spacecraft collided with the surface of Mars (*40*). Because Zond 2 was designed to fly by the planet and take photographs, no attempts had been made to sterilize the vehicle. Soviet engineers did not consider that the vehicle might malfunction and crash into Mars.

Carl Sagan was an early member of COSPAR and a strong supporter of planetary protection measures. Aside from being one of the minority of scientists concerned about microbial survival on the Moon, he had an ongoing dispute with JPL scientists who wanted to ease the planetary protection burdens for spacecraft going to Mars to make them cheaper and easier to design (*41*).

Sagan, Lederberg, and Elliott Levinthal published a famous rebuttal to this argument entitled "Contamination of Mars" in a 1968 issue of *Science* (*42*). They wrote, "One terrestrial microorganism reproducing as slowly as once a month on Mars, without other ecological limitations, in less than a decade would result in a microbial population of the Martian soil comparable to the Earth." Although it was considered an esoteric exercise in math by most who read it, this single sentence illustrated how unforgiving microbial contamination could be, given the right conditions for reproduction.

Viking

There was no question that the Apollo 12–Surveyor III incident affected the planetary protection program in a big way. NASA knew its planned Viking mission to Mars would have to be the most microbe-free spacecraft ever built and sent into space. Because Viking involved two landers and a suite of biological detection instruments, expensive and complete heat sterilization had to be used. The biological instrument package alone was sterilized in highly filtered nitrogen gas at 120 °C for 54 h. The landers were assembled in a class 100,000 clean room and sterilized at 116 °C for 50 h. One-fourth of Viking's $930 million price tag was spent on sterilization. Even so, this expensive sterilization was not perfect; it was estimated that each Viking lander contained about 300,000 viable spores (*43*)!

Viking Lander 1 set down on the surface of Mars on July 20, 1976, and Viking Lander 2 on September 3, 1976. The biological results are discussed in detail elsewhere in the scientific literature (*44*), but all three Viking biology experiments from both landers returned positive indications of activity in the soil. However, based on the lack of evidence for organic molecules provided by the Lander's GC-MS organic analysis instrument (*45*), many of the scientists looking at the Viking data thought the positive reactions of the biological instruments were caused by chemicals that seemed to be "mimicking life".

Recent evidence suggests that the Viking GC-MS would not have detected certain carboxylate salts that could have been present as metastable oxidation products of high-molecular-weight organic species (*46*). Also, the possibility remained that very low levels of organic matter, below the GC-MS instrument detection limit, could have been present. Such low levels of organic matter would not have been inconsistent with the presence of very low levels of microbes. Other problems existed too: The high sulfur content of Martian soil (50–100% higher on Mars than on Earth) may have poisoned the Viking GC-MS hydrogen separator coil (made of palladium), thereby preventing pyrolyzed samples from entering the gas chromatograph portion of the instrument for analysis.

Levin, one of the three Viking principal investigators in biology, along with his co-experimenter Straat, maintained that the Viking labeled-release (LR) experiment found living micro organisms on Mars (*47*). They tested an Antarctic soil sample with their LR instrument before it went to Mars and found organisms thriving in it. The same soil was given to the Viking GC-MS team for preflight testing. They claimed the soil was sterile and contained no organic matter. This was reason by itself not to trust the results of the Viking GC-MS.

The origin of the MSR program

Levin and his company, Biospherics Inc. (Beltsville,MD),were contracted by NASA to provide one of the first exhaustive (>300 pages) studies on MSR (*48*). Levin and Straat were active in COSPAR planetary protection meetings and contributed material to *Advances in Space Research*, the official COSPAR journal.

With the incredible success of NASA's twin Viking landers, the prospect of returning samples from Mars became more of a reality. NASA grants were made available to scientists and engineers who wanted to study the problems associated with a Mars sample return mission. Not surprisingly, the issue of planetary protection was considered a high priority for any of these studies.

One of the most comprehensive NASA reports on MSR was published in 1981 (*49*); its focus was maximum planetary protection. A highlight of the 134-page report was the suggestion that NASA build a CDC-like Earth-orbiting facility for the analysis of planetary sample returns under conditions of maximum protection against contamination, with minimal damage to the samples. The idea was to have an MSR spacecraft with 1 kg of samples aboard that could be analyzed in low Earth orbit by a qualified biohazard team using automated procedures, tissue cultures, and microassays.

The orbiting quarantine facility was envisioned to consist of five separate modules of different sizes, each with a different purpose: examination facility, power supply, habitation, supplies, and waste storage. Donald L. DeVincenzi, editor and codirector of the Antaeus Project (the study to design the facility [*49*]) describes it thus: "Three barriers are envisioned to protect the biosphere from any putative extraterrestrial organisms: sealed biological containment cabinets within the laboratory module, the laboratory module itself, and the conditions of space surrounding the facility" (*49*).

Another study published in 1988 for the Lunar and Planetary Institute's Workshop on Mars Sample Return called for a laboratory setup on the lunar surface (*50*). The authors cited the advantage of the Moon over an Earth-orbiting laboratory as having gravity, being a protective distance from the Earth, and taking advantage of the vacuum of space. Again, the emphasis of this report was to protect Earth from contamination.

By 1990 NASA had asked SSB once again to evaluate and change the sterilization requirements for outbound Mars spacecraft so that landers without life-detection instruments could be sent economically to Mars. SSB cooperated and published new guidelines in one of their 1992 booklets distributed by the National Research Council (*3*). Then in 1994, a resolution addressing these recommendations was adopted by COSPAR and incorporated into NASA's planetary protection policy. Mars Pathfinder would be the first of NASA's new landers not to be sterilized.

Klaus Biemann, emeritus professor of chemistry at the Massachusetts Institute of Technology and principal investigator for the Viking organic analysis instrument, said in 1997 that a complete Viking-class sterilization was necessary for all Mars landers "because it had been calculated that contamination of Mars by terrestrial organisms living inside spacecraft could occur in as little as 25 to 100 years" (*44*, p 207).

NASA began to change its view of MSR as well. With the adoption of its "faster, better, cheaper" slogan and philosophy in 1992 (*51*), the agency now sought economical ways for bringing samples back to Earth. NASA Administrator Daniel Goldin saw MSR as being a crowning achievement of the Mars exploration program and put it at the top of his priority list. He waited for any engineering reports that might satisfy the new NASA philosophy.

Passive Earth-entry or Earth-orbiting examination?

In 1998, spacecraft design engineer Robert A. Mitcheltree submitted a report to the American Institute of Aeronautics and Astronautics, with which NASA quickly became enamored (*52*). Mitcheltree had won the admiration of his peers with the flawless performance of the Mars Pathfinder mission on July 4, 1997. Mitcheltree's expertise in planetary atmosphere entry made him the perfect candidate to direct NASA's new approach to MSR. Mitcheltree is now the lead design engineer of the passive Earth-entry vehicle NASA hopes will safely return Martian soil samples directly to Earth.

If everything went according to plan, Mitcheltree's passive Earth-entry MSR capsule would enter the Earth's atmosphere in a ballistic fashion, having no reaction control rockets to maneuver and no parachute. It would require only atmospheric drag to slow it down, provided that it came in on the correct trajectory. At journey's end, the capsule would be expected to hit the ground in the Utah desert at 80 mph.

However, in 1999 Mitcheltree experienced his first major failure. He designed the atmospheric entry shells of the two small deep space microprobes attached to the aeroshell (an atmospheric entry shell)of the Mars Polar Lander spacecraft. The two microprobes are attached to the outside of the aeroshell and are released into the Martian atmosphere before the aero shell is jettisoned. When the Polar Lander was lost, there was no indication of the fate of the small probes either. Both probes were designed to survive the shock of impact with the Martian surface. Where are they? To this day, no one knows.

The 1999 investigation into the loss of the four NASA Mars probes revealed that the agency's "faster, better, cheaper" philosophy was failing (23). The independent investigation team headed by Thomas Young concluded that NASA needed to re-

evaluate its entire Mars exploration program, and the MSR program was placed on hold until 2011.

In 1980, Henry S. F. Cooper wrote an excellent book on the Viking Landers (*53*), in which Sagan voiced his views on MSR capsule conceptsthat would directly enter Earth's atmosphere.Sagan challenged JPL engineers, stating that if they were confident enough in a design for a safe Mars sample return container, a prototype should be tested by placing living anthrax germs inside. Sagan said the capsule should be launched into space and returned on the same trajectory that a real MSR mission would use. Then, if the capsule survived the atmospheric entry and impact on the Earth's surface, it could be examined inside a sample-receiving laboratory. Sagan considered this a test run before Martian samples were returned. His point was that if we could not handle the MSR procedure using terrestrial anthrax, we might not be able to bring back Martian soil safely either.

Not surprisingly, none of the JPL engineers took Sagan's challenge seriously and said that they were appalled by his idea. However discomforting the challenge was, it illustrated how seriously the issue of back-contamination should be taken.

Several other notable scientists have said that they do not like the idea of a direct Earth-entry approach for MSR. Carl Woese, a Nobel Prize–nominated biophysicist at the University of Illinois, Urbana–Champaign, who discovered the third domain of life called Archaea, says,

> When the entire biosphere hangs in the balance, it is adventuristic to the extreme to bring Martian life here. Sure, there is a chance it would do no harm; but that is not the point. Unless you can rule out the chance that it might do harm, you should not embark on such a course (*54*).

Chandra Wickramasinghe, professor of astronomy and mathematics at Cardiff University, Wales, is a leading proponent of the panspermia hypothesis, which holds that life on Earth was "seeded" from space, and has studied comets and interplanetary dust since the early 1970s. He said,

> I feel that there is no question that the examination of Martian soil samples must be conducted in situ on the surface of Mars or in a laboratory orbiting the Moon or the Earth to protect the Earth's biosphere from any possible back-contamination hazards. We are really quite ignorant of microbial life on our own planet, let alone assuming that we know how microbes from another planet, such as Mars, would react here. The study of astrobiology and its implications is still in its infancy as a science (*55*).

Former Viking biology team member Levin says, "I fear that, even if a safe MSR container could be made and brought to Earth, there is a good probability that some of the sample would escape from the 'secure' lab where the container would be opened" (*56*). Levin also questions the scientific benefit of MSR and says, "How could we get a living sample to survive the 9- or 10-month trip without knowing what any Martian microorganisms present in the sample need in the way of substrates, water, temperature, atmosphere, environmental cycling, etc.? Would we ever know whether it started out alive or dead?" He recommends a 10-phase approach to MSR based on his experience working with the Lunar and Planetary Institute and COSPAR (see box, "Safe methods for MSR") (*56*).

David A. Paige, associate professor of planetary science at the University of California, Los Angeles, was a co-investigator for the Mars Polar Lander Mars Volatiles and Climate Surveyor experiment. Paige submitted a scientific abstract to

the Lunar and Planetary Institute Conference held in July 2000, in which he questioned the current wisdom of a faster, better, cheaper approach to MSR. In his abstract, he wrote (57),

> One of the most prominent aspects of the failed 1996–2000 exploration architecture plans was to accomplish the goal of sample return at the earliest possible opportunity. . . . For the case of Mars sample return, there has been a strong tendency to equate the analysis of returned samples with "good science", and while it is undoubtedly true that one could do a lot of good science on returned samples, we are a long way from a situation where sample return is *necessary* to make further scientific progress towards the overarching goal of understanding whether life ever arose on Mars.

Looking back over the history of the planetary protection program, it is clear that, although the participants started out with the purest of intentions, many decisions based on erroneous assumptions have led to almost the exact opposite of what the program tried to accomplish. Established to protect the Moon, Earth, and planets from biological contamination, the planetary protection program should not be manipulated to achieve the goal of producing more economically designed spacecraft. Because the risk of back-contamination from celestial sample return missions is an issue that effects everyone living on our planet, the decision process on how to proceed with such missions should not belong to one nation alone.

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Barry E. DiGregorio is a research associate of the Cardiff Centre for Astrobiology in Wales and is the founder and executive director for the International Committee Against Mars Sample Return (icamsr@buffnet.net; http://www.icamsr.org/). His book, *Mars: The Living Planet*, with co-authors G. V. Levin and P. A. Straat, was released in 1997, and reexamined the Viking biology evidence.

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Antaeus: Concept for a Sample Receiving Lab/ Planetary Quarantine Facility at the Gateway

Marc M. Cohen[1]
Space Cooperative, Los Gatos, California, 95032

Donald C, Barker[2] and Suzana Bianco de Olivera.[3]
Space Cooperative, Houston, Texas

Nathaniel R. Bennett[4]
Stanford University School of Medicine , Menlo Park, California, 94025

Shen Ge[5]
Houston, Texas

Rocco L. Mancinelli[6]
Bay Area Environmental Research Institute, Moffett Field, California, 94035

and

Kris A. Zacny[7]
Honeybee Robotics, Altadena, California, 91001

Antaeus will provide an integrated system in a module designed to receive samples with biological potential from the Moon and Mars to perform preliminary handling, processing, curation, storage, and analysis. Antaeus breaks the chain of potential contamination or infection with the Earth. By keeping Mars samples away from contact with the Earth, scientists can control any dangerous microbes, and if necessary, kill them without endangering the Earth or humanity. The Antaeus Architecture and technology ensemble would also serve to support with a crewed Mars base or habitat.

The Antaeus Module docks to the Lunar Gateway. Antaeus will receive "pristine" samples delivered by robotic spacecraft to its airlock, from which the robotic system will place each sample capsule into an individual sample handling and analysis chamber (SHAC). Researchers may operate the Antaeus systems tele-robotically from anywhere. Once the scientists complete their preliminary assessment of lunar samples, they may choose to send a SHAC to Earth or archive it in place. For each sample, the researchers determine the sample's biological potential and decide whether to sterilize it or observe it in its "natural" state. The Antaeus module incorporates a standalone Environmental Control and Life Support System (ECLSS) including a shower enclosure to afford decontamination.

Antaeus supports analysis of lunar biological samples (Surveyor 3 Streptococcus, Apollo 17 jettison bag E. Coli, and Space IL crash site tardigrades) and lunar ice cores for heliophysics solar history. Antaeus provides a suite of capabilities to analyze samples in a cryo-vacuum state under laboratory conditions without the necessity of returning them all the way to the Earth. The prepared sample and lunar biologicals retrievals will afford practice and testing for contaminant control and simulated handling of potentially biological samples. For Mars Returned Sample Handling (MRSH), Antaeus affords planetary protection with respect to back-, cross-, and forward contamination of the sample.

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[1] Mission Architecture Lead, marc@space.coop 149 Carlton Ave Apt 3, Los Gatos, CA 95032 https://space.coop/.
[2] Aerospace Engineer, Space Architect & Geologist, Houston, TX.
[3] Space Architect, Space Cooperative, Houston, TX. https://space.coop/.
[4] Mechanical Engineer, Stanford University School of Medicine, Menlo Park, CA 94025. http://med.stanford.edu/.
[5] Aerospace Engineer, Houston, TX, http://shenge.us/.
[6] Microbiologist, Bay Area Environmental Research Institute, PO Box 25, Moffett Field, CA 94035 https://baeri.org.
[7] Vice President, Honeybee Robotics, 2408 Lincoln Ave, Altadena, CA 91001, https://honeybeerobotics.com/.

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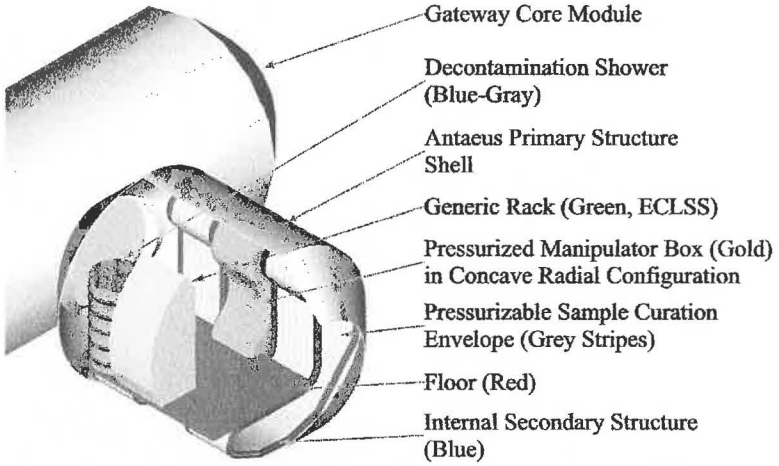

FIGURE 1. Schematic drawing for the Antaeus Sample Receiving Laboratory/Planetary Quarantine Facility core module berthed to the Lunar Gateway Station.

Key Words

Back Contamination, Biological Activity, Biosignatures, Cross Contamination, E. Coli, Forward Contamination, Helio-Physics, Lunar Gateway Station, Lunar Ice Cores, Mars Returned Sample Handling (MRSH), Mars Sample Return (MSR), Microbes, Microbial Life, Planetary Protection, Protection against contamination, Robotic glovebox, Solar History, Space Architecture, Spectroscopy, Streptococcus, Surgical Robot, Tardigrades.

Nomenclature

Δv	= "Delta-vee:" change in velocity, an analog for total propellant expended
EML	= Earth-Moon libration
Halo Orbit	= A periodic three-dimensional orbit about the EML 1, 2, or 3 Lagrange Point of gravitational stability
Gateway	= Lunar Gateway Station (Originally known as the Deep Space Gateway)
MRSH	= Mars Returned Sample Handling
MSR	= Mars Sample Return
SHAC	= Sample Handling and Analysis Chamber

I. Introduction:

THE ANTAEUS PROJECT will provide an integrated system in a module designed to receive "pristine," environmentally sensitive samples with biological potential from the Moon in Phase 1 and from Mars in Phase 2 to perform preliminary handling, processing, curation, storage, and analysis. The Antaeus module may be attached to the ISS or Deep Space Gateway for Phase 1 and to the Gateway for Phase 2. Antaeus will receive pristine samples delivered by robotic spacecraft to its airlock, from which the larger robotic system will place each sample into an individual sample handling and analysis chamber (SHAC). Researchers may operate the Antaeus systems on board ISS or Gateway, or telerobotically from anywhere.

Once the researchers complete their preliminary assessment of lunar samples, they may choose to return a SHAC to Earth or archive it in place. For Mars samples, the researchers will determine the sample's biological potential and decide whether to sterilize it in an autoclave or observe it in its "natural" state. The Antaeus module includes a standalone Environmental Control and Life Support System (ECLSS) including a shower enclosure to afford decontamination and bioisolation from the ISS, Gateway, or surface base.

A. Antaeus Mission Development

Antaeus fits into multiple mission contexts. Mission Phase 1a addresses lunar robotic exploration and sample return, providing a suite of capabilities to analyze lunar samples in a cryo-vacuum state under laboratory conditions without the necessity of returning them all the way to the Earth. Mission Phase 1b supports would support a lunar base or habitat with a surface laboratory. Phase 1 will afford practice and testing for contaminant control and simulated handling of potentially biological samples, such as the Apollo LM Jettison Bags (containing crew biological wastes). Mission Phase 2a is when Antaeus asserts its great advantage for Mars: to afford both forward contamination protection of the sample and backward contamination control for planetary protection.

B. Breaking Contact With The Earth

The story of Antaeus derives from one of the Greek myths. Antaeus was a mythical "half-giant" whom Hercules fought as one of his twelve labors. The only way Hercules could defeat Antaeus was to lift him off the ground, breaking his contact with the Earth from which he received his power. The Antaeus analogy is that by keeping Mars samples away from contact with the Earth, scientists can control any dangerous microbes, and if necessary, kill them without endangering the Earth or humanity.

The *Antaeus analogy* expresses the imperative that by keeping Mars samples away from contact with the Earth, scientists can control any dangerous microbes, and if necessary, kill them without endangering the Earth or humanity. The Antaeus Architecture and technology ensemble would also serve Mission Phase 2b, integrated with a crewed Mars base or habitat.

C. The Antaeus Concept

FIGURE 1 presents a cutaway view of the basic Antaeus concept for a "short" lab module to attach to a docking port on the Gateway. This figure shows the key features for Antaeus. The carrier spacecraft airlock is obscured behind the far pressure shell; it connects to the back of the pressurized manipulator box. The Antaeus lab stores SHACs both before and after they have been used to receive and analyze samples. FIGURE 2 shows an early CAD sketch of the full Phase 2 Antaeus module assemblage.

II. The Problem of Mars Sample Handling, Return, and Reception

Antaeus addresses the challenge of conducting the return of "pristine" samples from the Moon and Mars encounters several obstacles that to date have proven nearly insurmountable. The concept for Antaeus first emerged in a study led by Don DiVincenzi at NASA Ames Research Center, focusing on an Earth-orbiting quarantine station. This Antaeus concept includes the return of potential biological samples and frozen ice cores from the Moon, largely as preparation for returning potential counterparts from Mars. Although many relevant technologies have advanced, the fundamental challenges remain unchanged:

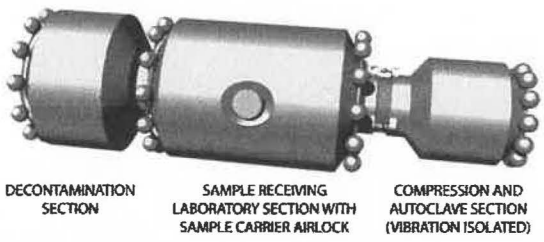

FIGURE 2. Sketch of Antaeus Phase 2 Early Concept for Mars Sample Return to the Gateway Station. The "Decontamination Section" would be launched as part of Mission Phase 1a to receive lunar samples. The larger Sample Receiving Lab and Compressor/ Autoclave section to receive Mars samples would be launched for Mission Phase 2a. Credit: Suzana Bianco.

1. Returning samples from Mars to the Earth in meaningful quantities for detailed analysis is prohibitively expensive for most researchers.
2. For samples from extreme conditions such as frozen cores from the Moon's permanently shadowed craters, the return system must maintain them in their natural cryo-vacuum state.
3. Martian samples involve the CO_2 atmosphere, temperature (average -63C), and pressure environment (average 600 pascals), which the return system must maintain.
4. Samples with biological potential need protection from forward-contamination from Earth biota while protecting humans and the Earth from back-contamination.

5. The analysis system must protect all samples cross-contamination from other samples.

A. Limitations of the Current Approaches

The current approaches – insofar as there are any -- are not suitable for a sustained and repeatable campaign of deep space sample return and analysis. During the "Mars Revival" of the 1990s, the preference was for astronauts to do sample handling on Mars in a laboratory (Hoffman, Kaplan, 1997; Cohen, 1999; Cohen, 2000). at a Mars base. The Mars Program Office at JPL has since contemplated a "Cache Plan" to collect samples on Mars in one location to pack them into a return vehicle to return them ***somewhere*** unknown, but that appears to be as far their planning goes. The NASA Ames Space Science Division published such a cache plan, but NASA had not yet defined that ***somewhere*** at the time of this study (Santos et al, 2009). Meanwhile, there are serious concerns and opposition to comparable "bioterror" research facilities in the USA, including safety, security, and accidents, all when staff are handling toxics with rubber gloves (National Research Council, 2010; GAO, 2009; Jarling, Rodak, Bray, Davey, 2009, pp. 135-143). The lack of consensus on Mars sample return to the Earth has become painfully obvious:

How and where can one "write the environmental impact statement to locate a Mars Sample Receiving Lab on Earth? (Cohen, 2002; Cohen, 2003).

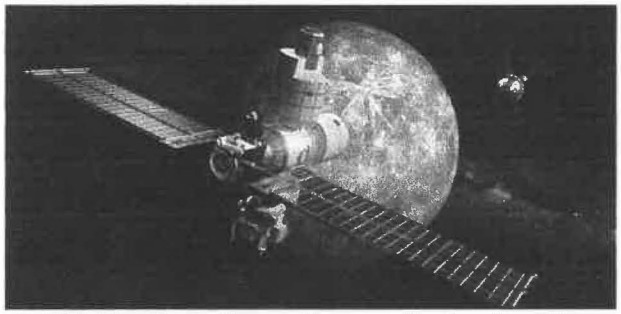

FIGURE 3. Deep Space Gateway Station in a Near Rectilinear HALO orbit at the Moon. NASA image.

B. The Antaeus System

Antaeus reduces cost substantially by not returning samples to the Earth, but handling them in lunar orbit. The **essential core of this concept** is to place samples in a Sample Handling and Analysis Chamber (SHAC) and keep them there throughout their period of analysis and retention. The researchers conduct all their scientific processes and sample analysis in the SHAC. The SHAC contains all the preparation and manipulation tools – that scientists operate robotically or telerobotically from anywhere: Earth, the ISS, or the Gateway. Antaeus minimizes the risks of moving samples from one container to another. Using the SHACs exclusively avoids the cleaning problem.

Antaeus as sketched in FIGURE 1 is a system to receive lunar and planetary samples in a space laboratory module or modules shown in FIGURE 2, and attached to the Gateway lunar space station portrayed in FIGURE 3 (Cowing, 2018). The Gateway station is in orbit about the Earth-Moon Lagrange Point 2 (EML-2) illustrated in FIGURE 4. The Gateway's orbit is a Near Rectilinear HALO orbit about EML-2 as shown in FIGURE 5.

Antaeus will receive "pristine" samples delivered by robotic spacecraft to its airlock (Downes, Crawford, Alexander, 2018), and then robotics will place each sample into an individual sample handling and analysis chamber (SHAC). Once researchers complete their study of a sample, they may return a SHAC to Earth or archive it place. For Mars samples, the researchers will determine the sample's biological potential and decide whether to sterilize it (Lupisella, et al, 2018). The Antaeus module includes a standalone Environmental Control and Life Support System (ECLSS) with a shower for decontamination.

III. The Antaeus Project

Marc Cohen, first author and PI, worked on the original Antaeus Project, specifically to develop a mockup of an on-orbit receiving lab (1980-81). The Antaeus Report: Orbiting Quarantine Facility (NASA SP-454) proposed to create an Earth orbital space station to quarantine Mars material:

> ". . .To detect the presence of biologically active agents—either life forms or uncontrolled (replicating) toxins—in the sample and to assess their potential impact on terrestrial systems. Only when the sample could be certified safe or controllable would it be transmitted to laboratories on Earth for physical analysis." (DeVincenzi, 1981, p. 1).

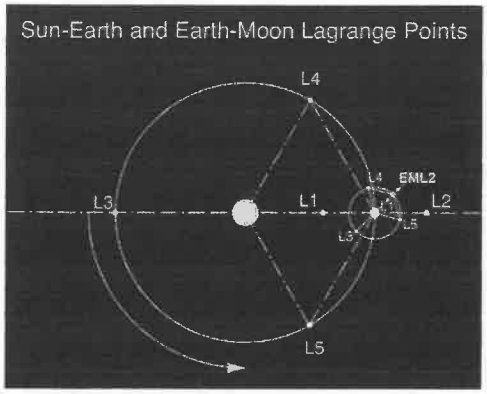

FIGURE 4. Sun-Earth and Earth-Moon Lagrange Points, highlighting EML-2.

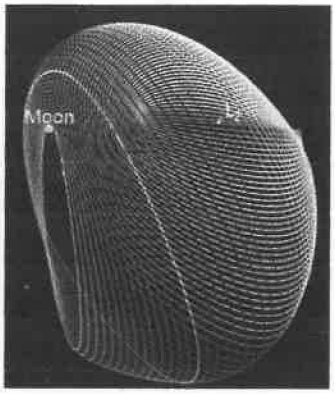

FIGURE 5. Halo Orbit about EML-2.

A. Scope of the Project

Having said all the above about handling samples from Mars with biological potential, the initial project focuses on learning how to handle the wide range of potential samples IN SPACE (and microgravity). It will require incremental progress, particularly how to maintain them in their wide range of ambient conditions, including extreme cold and hot environments, under vacuum or near-vacuum atmospheres. An intermediate step toward handling Mars samples would be to retrieve one of the 12 ***Apollo jettison bags*** left behind by the Apollo crews with their biological wastes inside as shown in FIGURE 6. That challenge would be to detect if any e. coli, for example, survived over 50 years of exposure to radiation and extreme thermal cycling. Ideally the Antaeus module will attach to the Gateway Station in a HALO orbit about EML-2, allowing a much easier delivery to Antaeus than a return to Earth.

B. Antaeus in Lunar Orbit at the Gateway.

The reasons for recovering such sample return missions to EML-2 are that it poses significant advantages compared to returning samples from the Moon, Mars, or beyond to the Earth or to the ISS in LEO. The comparatively modest ΔV requirements from the Lunar surface to EML-2 reduce the cost and mass of delivering the samples compared to recovering them back to LEO or reentering them to the surface of the Earth.

FIGURE 6. Apollo 11 Jettison Bag discarded at Tranquility Base.

IV. Technical Description

Attached to the Gateway Station, *Antaeus* will provide an integrated system in a module designed to receive samples from the Moon in Phase 1 and from Mars in Phase 2 to perform preliminary handling, processing, storage, and analysis (Cohen, Bianco, Avery, 2018). It will be capable of complying with NASA's 2002 Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth (Rummel et al, 2002), with the intention of maintaining compliance with any subsequent versions.

A. Antaeus Technology and Module Design Innovation

For Antaeus to succeed, it will require advances in both sample handling technology and space module architecture. The key points of innovation include:

1. Receive cryo-vacuum samples delivered robotically from the Moon.
2. Analyze pristine samples in a "manipulator box" at a controlled atmosphere, temperature, and pressure of their origin while preventing back-, cross-, and forward-contamination.
3. Since the most difficult task is cleaning the "box" between samples, the system will place each specimen into its own small Sample Handling and Analysis Chamber (SHAC), with an internal microsurgical robot, video, and windows to expose the sample to analytical instruments.
4. Combine autonomous, human, robotic, and telerobotic techniques to analyze the samples.

5. The Phase 1 Lunar Sample-Receiving Lab (approx. 4,000 kg, 45 m3) converts into the decontamination/buffer segment for Mars Phase 2. It incorporates a shower and other features to decontaminate the crew. Also, its atmosphere can be evacuated to the vacuum of space.
6. The Phase 2 Mars Sample-Receiving Lab is outfitted with more sophisticated "glove box chambers." Since "everything leaks," these chambers are vacuum jacketed and the air that flows through them passes through a compressor and autoclave before recycling the atmosphere.
7. This design concept protects the samples from forward organic contamination from Earth, prevents cross-contamination between samples, and protects the crew and the Earth from back-contamination.
8. Mars samples stay in their SHAC containers until determined to be inert or sterilized. Once are rendered inert, they may be returned to Earth.

B. Parametric Design

Our Phase 1 focuses on parametric design for *Antaeus* to be scalable from a mostly telerobotic technology demonstrator module to a larger, more highly automated system that offers refinements to direct human researcher management and control. It involves several trade studies including: 1) Methods of creating and maintaining the Moon-like or Mars-like environment inside the Manipulator Box and the SHAC; 2) The allocation of responsibilities among the three robotic systems 3) The competing approaches to selecting and prioritizing sample types for the technology demonstration phase; and 4) Efficiency versus Effectiveness studies, including power, conservation and recycling of artificial atmosphere gases, temperature and pressure control systems, and data bandwidth.

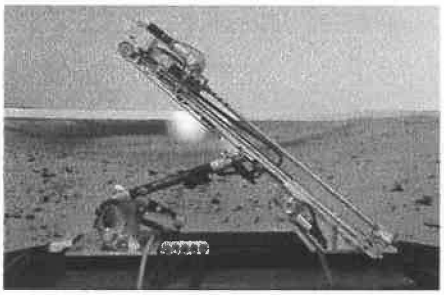

FIGURE 7. Honeybee robotics Icebreaker drill shown on Mars.

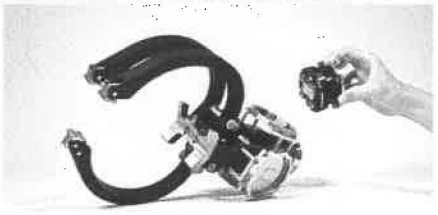

FIGURE 8. Honeybee Robotics satellite servicing manipulator.

C. Antaeus Mission Phases

Antaeus fits multiple missions, with allowances for variations in mission profile.

1. Mission Phase 1a

This first phase addresses **lunar** sample return, providing a suite of capabilities to analyze lunar samples with biological potential, notably Streptococcus, E. Coli, and tardigrades under laboratory conditions. It would include a cryo-vacuum environment capability in which to analyze lunar ice cores to study the history of the solar wind.

2. Mission Phase 1b

The second phase on the Moon would support a lunar base or habitat with a surface laboratory. Phase 1 will afford practice and testing for contaminant control and simulated handling of potentially biological samples, such as the ***Apollo LM Jettison Bags*** (containing crew biological wastes) as shown in FIGURE 5.

3. Mission Phase 2a

Antaeus can assess and hopefully assert its great advantage for **Mars:** to afford both forward contamination control of the sample and backward contamination control for planetary protection.

4. Mission Phase 2b

This phase entails the human exploration of the Mars surface from a base habitat. This phase would fulfill the original intent of MDRM 1.0, a human-tended Mars sample lab at a Mars Base.

5. Mission Phase 3

This post-Mars Sample Return phase would be to receive cryo-vacuum samples from the icy moons ***Europa and Enceladus.*** Phase 3 would be similar in many respects to handling lunar cryo-vacuum samples.

6. Mission Phase 4

This phase would handle ambient atmosphere samples from the surface of Titan and perhaps Jupiter or Saturn, which might resemble the procedures for handling Mars ambient-atmosphere samples.

D. The Three Disciplines: Geology, Robotics, Space Architecture

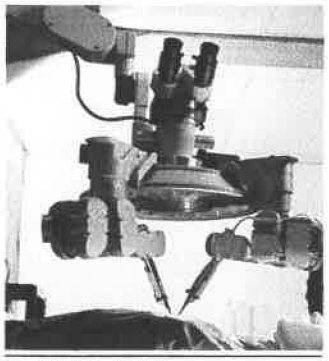

FIGURE 9. *Microsure* surgical telerobot.

This proposal represents three disciplines: Geology, Robotics, and Space Architecture. The PI and CoIs will coordinate their efforts to produce an integrated system approach to Antaeus concept formulation.

1. Geology

The science—is the primary driver to set the requirements for the capabilities Antaeus provides. Dr. Donald Barker is the CoI for Geology. The lunar sample sources map to four primary sources: cores, regolith, rocks and volcanic deposits. As most of the lunar surface has been heavily gardened through impact processes, regolith can be accessed everywhere to varying depths. Basement rock materials, either from the highlands or mare, are accessible in either outcrop, craters or through drilling. The regolith and basement rocks give insight into a variety of geological and environmental processes involved in the evolution of the Moon (e.g., lunar mantle/crust history, petrology and geochemistry). Lunar Dark Mantle Deposits (DMD) and volcanic glass provides insight into the history and evolution of the lunar mantle. Cryo-maintained materials from the lunar poles can provide insight into lunar environment evolution, impact histories and use as a barometer for historical solar activity. Lastly, many of these sample types can also be used to assess the potential for lunar resources for human habitation.

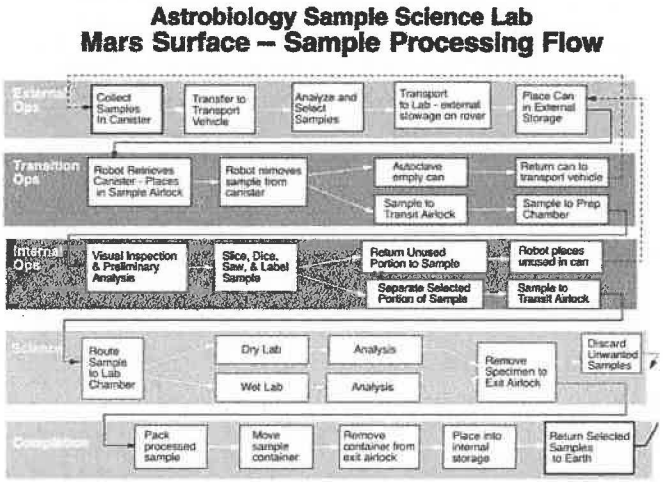

FIGURE 9. Sample handling process for the Mars surface science laboratory that provides a benchmark for the process in the Antaeus module (Cohen, 2015).

FIGURE 10. Ergonomically designed, "BSL–5" pressurizable "Manipulator Box" that can mount mechanical manipulators at the ports.

2. Robotics and Automation

The robotics for Antaeus encompasses three principal systems: The microsurgical robot in the SHAC, the larger manipulator robot in the Manipulator Box, and the automated archival inventory system. Microsurgical robots have advanced substantially in the past 20 years to where they are common in operating rooms (Mattos et al, 2016; Tan, Liverneaux, Wong, 2018). The Antaeus Team member, Honeybee Robotics, possesses world-leading expertise in space robotics. Their rock drills and abraders have been installed and used with great success on every NASA mission to Mars since Opportunity and Spirit, with an example of such a drill appearing in FIGURE 6. Honeybee has also pioneered manipulator systems for satellite servicing as shown in FIGURE 7. A further key step will be the survey

of commercially available microsurgical robots, an example of which appears in FIGURE 8. The Antaeus Robotics and Automation approach includes a plan to study the existing robotic surgery technologies. The Antaeus team will evaluate which of them make the most promising candidates for installation in the Antaeus system, and what tasks lie ahead to adapt and modify these systems for sample handling, manipulation, and analysis.

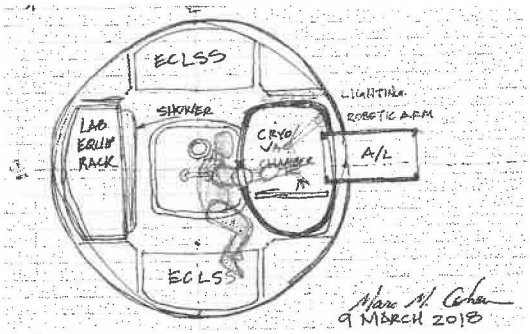

FIGURE 11. Transverse section through the Antaeus Module, showing the Manipulator Box, Airlock, and crew position to use AX-5 arms with the Jameson Prehensor.

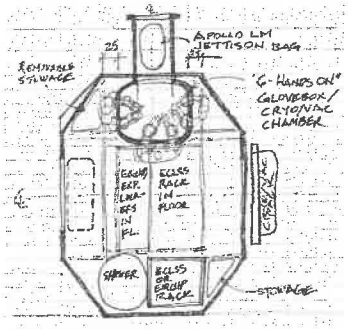

FIGURE 12. Plan View of a minimally sized Antaeus Module showing three possible crew positions to use AX-5 arms and Prehensor.

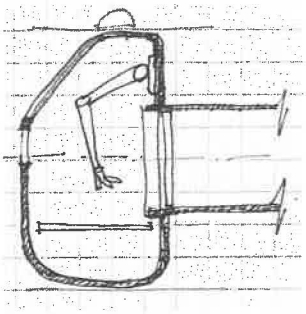

FIGURE 13. Cross-Section through a manipulator box with Robotic Arm mounted above the sample airlock.

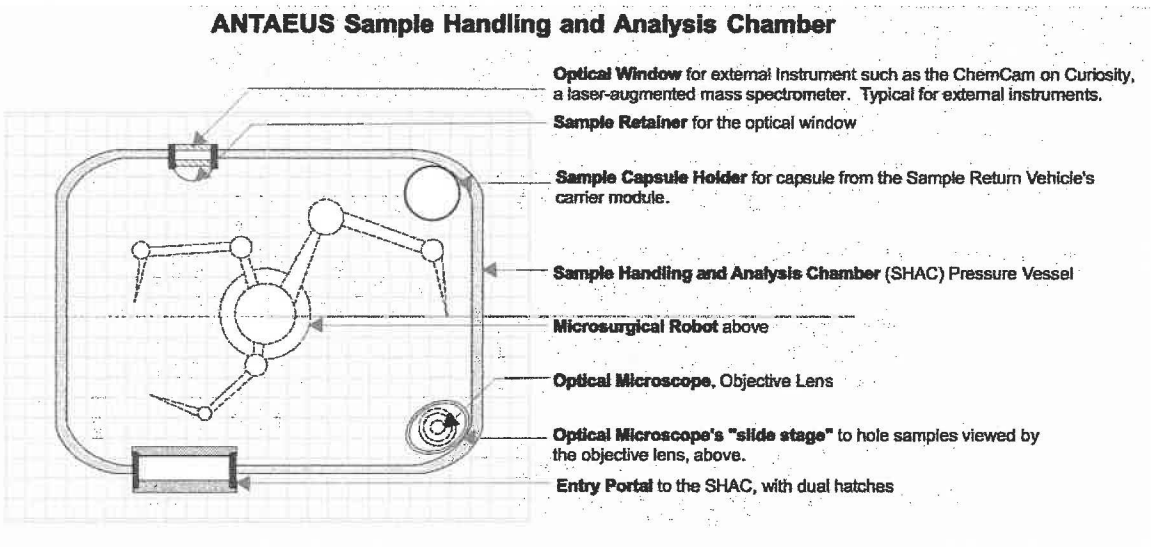

FIGURE 14. Diagram of the Sample Handling and Analysis Chamber (SHAC).

3. Space Architecture

The challenge of designing and physically integrating Anteaus means making all the systems work together in a crew-tended module. The Space Architecture design inquiry involved making many sketches and CAD drawings of the Module. "Thinking with a pencil" is a key design method illustrated in FIGURES 9 to 14. A key precept in this design effort was to not be bound by the "four stand-off" standard rack conventions from the ISS, but instead to be open to developing secondary structure and mechanical systems optimized to support the Antaeus tasks.

E. Specific Aims

1. Make Sample Return and Analysis Affordable and Efficient in Δv.
Significance: Eliminate the cost of Trans Earth Injection and Reentry. Eliminate the cost of a super-secure Earth-based laboratory.
Innovation: Afford inexpensive remote access to scientists and students anywhere.
Approach: Model the several structure envelopes to provide the volumes and platforms for the key functionality: Airlock, Manipulator Box, SHAC, Sample Archive System.

2. Analyze "pristine" samples in a controlled atmosphere.
Significance: Preserving the samples in their original condition is crucial for many of the scientific analyses.
Innovation: Design the Manipulator Box and SHAC as controlled environment chambers.
Approach: Adapt standard and customized ECLSS equipment to maintain a controlled Moon-like or Mars-like atmosphere, temperature, and pressure of original environment.

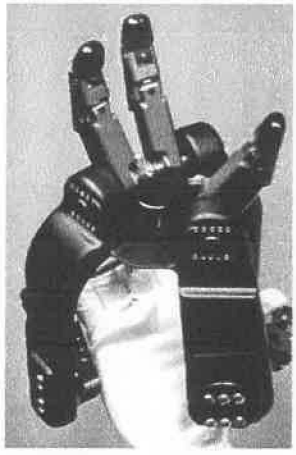

FIGURE 15. The Jameson Stanford/ Ames Direct Linkage Prehensor, shown out of its pressure shell, developed by John Jameson.

FIGURE 16. The Ames Research Center AX-5 hard, high-pressure space suit, developed by Hubert C. "Vic" Vykukal.

3. Prevent back-, cross-, and forward-contamination.
Significance: The great stumbling block for any Mars sample return is how to handle possibly biologically active samples. Antaeus solves that problem elegantly by breaking the tie to Earth.
Innovation: Antaeus confines each sample in its own SHAC, which protects it from external contaminants and contains its particles, gases and other materials.
Approach: Antaeus affords four levels of containment and protection against contamination: 1) Separation from the Earth, 2) The Antaeus Module, 3) The Manipulator Box, 4) The SHAC.

4. Eliminate the Need for Cleaning
Significance: Cleaning is difficult to guarantee and expensive to perform, especially when the requirement is to eliminate contamination.
Innovation: Don't clean. Make every SHAC a one-time use container.
Approach: Antaeus will place each specimen into its own SHAC, with an internal microsurgical robot, video, and windows to expose the sample to analytical instruments.

5. Provide diverse methods to handle and analyze the samples
Significance: The availability of these multiple modalities gives flexibility to Antaeus (Barnes, Haddock, Cruzen, 2018).
Innovation: Adapt the AX-5 Hard, High Pressure Space Suit arms and Jameson Prehensor to manipulation and servicing in the Manipulator Box as shown in FIGURES 15 and 16.
Approach: The design of the SHAC and Manipulator Box across all systems including automation, human, instrumentation, robotics, and telerobotics gives flexibility for varied ops.

6. Afford a "Head Start" for Phase 2 Mars Samples
Significance: This design provision allows the conversion of the Phase 1 module into part of the Phase 2 upgrade and expansion for *Antaeus.*
Innovation: The Phase 1 module serves a dual purpose as a quarantine/decontamination buffer.
Approach: The Phase 1 Lunar Sample-Receiving Lab (approx. 4,000 kg, 45 m^3) converts into the decontamination/buffer segment for Mars Phase 2. It incorporates a shower and other features to decontaminate the crew. Its atmosphere can be evacuated to the vacuum of space.

V. Discussion

The Antaeus project team first presented the concept at the NASA Deep Space Gateway Science Workshop on March 1, 2018, in Denver, CO and later that year at the NASA Exploration Science Forum at NASA Ames. The team put the concept together through a variety of ideas and sources. These ideas and sources had evolved over a period of nearly 40 years. While this effort clarified the design problem definition and, in a sense, prioritized the mission objectives over time, it did not produce a clean, crisp design solution. What the many sketches, diagrams, and models did accomplish was to serve as hypotheses about what the design problem is. The statement of the design problem stated above is crisp and clear.

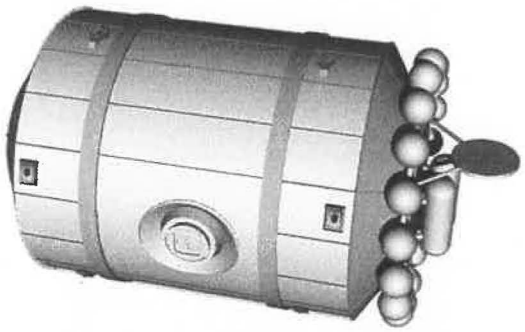

FIGURE 15. Antaeus Module concept with abundant high-pressure gas storage tanks, airlocks, and externally mounted compressors and gas autoclaves. Credit: Suzana Bianco.

A major source of ambivalence was whether to include all potential capabilities—automated, human, robotic, and telerobotic—for handling, processing, and analyzing samples, and to repair anything that might go wrong in the Antaeus systems. This emphasis on diversity of capabilities, while appealing in terms of potential versatility, also posed great penalties in terms of complexity, particularly the problem of protecting humans involved in the work from contamination.

Another source of ambiguity was the lack of a definitive "stopping rule." If the Antaeus occupies the optimal space-time coordinates to receive extraterrestrial samples and the team develops this capability for lunar samples and Mars samples, why stop there? Why not lay the foundation for a technology capable of ***safely*** receiving samples with biological potential from throughout our Solar System?

What has become self-evident is that the Antaeus project as shown in this record was too ambitious. It was trying to accomplish too many objectives with too many capabilities. Instead, the Antaeus team will need to reassess their progress as of this writing and find ways to refine and narrow the objectives and the capabilities by which to accomplish them.

Finally, at the pragmatic level, we must address the question of how large is a reasonable and affordable size for the Antaeus module? By eliminating the dual capability of human direct "hands-on" manipulation through gloves or mechanical "hands" such as the Jameson Prehensor and relying solely on robotics, it will be possible to reduce the mass and volume of the Antaeus module. How much of a reduction will be possible remains to be determined. However, the Antaeus team's goal now is to consolidate all the functions into a single module, approximately half the mass and volume of the module ensemble shown in FIGURE 2. FIGURE 15 illustrates this progress toward a consolidated module concept for Antaeus.

VI. Conclusion

All previous concepts for Mars Returned Sample Handling (MRSH) involve humans doing the majority of the work—hands on—through rubber gloves on an ongoing basis. What we have learned from the Antaeus design research is that the system can only function successfully as an entirely automated, robotic, or telerobotic system, or some combination thereof. The old paradigm for "BSL4+" bio-isolation with massive security, with dozens of researchers in full-body bunny suits stuffing their already sleeved and gloved arms into gloveboxes will be rendered moot by Antaeus.

The new concept for theaters system is that it will need crew attention only for maintenance, repair, and resupply. Researchers may operate the Antaeus systems tele-robotically and by tracking the autonomous systems telemetry from anywhere.

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MARS SAMPLE RETURN AND INTERNATIONAL SPACE LAW

Right now NASA and the European Space Agency are collaborating on the first Mars Sample Return mission with the first samples gathered by the Perseverance rover set to arrive directly to Earth as early as 2030. At this time there are no plans for any further in-situ biological testing in order to rule out the possibility that samples could contain dormant or active pathogenic organisms that could disrupt our planets biosphere in ways we do not understand.

The only NASA mission specifically sent to look for life on the surface of Mars were the twin Viking Lander missions in 1976. Each Viking Lander carried a complement of three biology instruments and a Gas Chromatograph Mass Spectrometer (GCMS). Although the GCMS did not detect any organic molecules (the building blocks of life), one of the Viking biology instruments called the Labeled Release experiment showed positive indications for microbial metabolism at both the Viking Lander 1 and 2 sites separated on Mars by 6,500 kilometers.

However it was because of the negative findings of the GCMS organic analyses that the majority on the Viking team ruled out the positive indications in the Labeled Release experiment. Both the Principal Investigator of the Labeled Release experiment, Gilbert V. Levin and his co-investigator Patricia Ann Straat (both now recently deceased) would publish over the next 45 years that their data from the surface of Mars indicated life not some exotic chemistry.

A recent study by a group of ecologists from McGill University in Montreal, Quebec, Canada that study invasive species on Earth are calling for astrobiologists, invasion biologists and policy makers to strengthen biosafety protocols for sample return missions. Their concerns and those of others revolve around the *precautionary principle* defined as a "broad epistemological, philosophical and legal approach to innovations with potential for causing harm when extensive scientific knowledge on the matter is lacking". This scientific principal is at the heart of International Space Law drawn up by the United Nations Office for Outer Space Affairs. In Article 9 of the document (on page 6) it says:

States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.

While this ruling sounds decisive it is not until you continue reading the accompanying sentence that reads:

A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, may request consultation concerning the activity or experiment.

What this statement is saying is that International law is between nations and it is rare that it can be used by individuals. In her paper *INTERNATIONAL LAW AND POLICY OF EXTRATERRESTRIAL PLANETARY PROTECTION* for the legal journal Jurimetrics, Attorney Darlene A. Cypser writes, *"Parties to the Treaty are the nations that signed it. Only such state parties can request consultations with the other signatories. Individuals are not considered parties to the treaty*".

At this time international space law and policy on planetary protection is inadequate to meet the challenges of a Mars sample return. Recent findings by both the Curiosity rover still operating in Gale crater and the Perseverance rover in Jezero crater have found organics in the rocks, soil, dust and atmosphere of Mars. This being the case, these findings should now call into question the negative Viking GCMS results and reopen the case for 1976 Viking Labeled Release experiments that indicated extant microbial life on Mars.

Barry E. DiGregorio - Director for the International Committee Against Mars Sample Return (www.icamsr.org)