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53. Discussions leading to this article started with M. L. Heinselman and E. J. Cushing around a winter campfire in the BWCA, and I thank them and numerous students for continued incentive to evaluate the time factor in landscape evolution and to demonstrate a scientific rationale for wilderness preservation. I also appreciate the editorial and the substantive critique of R. A. Watson.

From Mars with Love

Missions to return a Mars surface sample are feasible, but pose potential back-contamination problems.

Richard S. Young and Donald L. DeVincenzi

Soil samples can now be returned to the earth from another planet by using unmanned spacecraft. One possible consequence of this ability is the potential for returning a viable extraterrestrial organism that may interact with terrestrial life forms.

The bioscience community is polarized on the issue of back-contamination of the earth; some believe the risk is virtually nonexistent while others believe it is high. There is no question that scientific interest in exploring the surface material of another planet is great. The problem arises in determining the method of study that is the most productive and cost-effective, that is, in situ on the planetary surface with automated landers or by direct study of returned samples in terrestrial laboratories.

The purposes of this article are to outline the mission possibilities for returning surface samples from Mars, to review experience gained from returned lunar samples, and to discuss the scientific value of sterilized samples compared to unsterilized samples. This is not a statement of NASA policy, and there is no intention to take sides on the issue of back-contamination. Our aim is to describe the mission options and the potential back-contamination problems they pose and thus to stimulate thought that we hope will generate solutions.

Historical Considerations

In July 1964, a conference on the potential hazards of back-contamination of the earth by returned extraterrestrial samples was held under the auspices of the Space Science Board of the National Academy of Sciences (*1*). The participants included representatives of the Space Science Board's Life Science Committee, the Department of Agriculture, the National Institutes of Health and Public Health Service, and NASA, as well as selected scientists with backgrounds in public health and pathology from various universities. The committee considered the question of returning samples from the moon and the .planets, the potential hazards to terrestrial life, and the need for action to assure the safety of life on the earth.

The committee stated its belief that the existence of life on the moon or on the planets could not be precluded, and that the likelihood of life on the moon was much less than on Mars. It reviewed the history of the harmful spread of biological agents on the earth (for example, tuberculosis, smallpox, and measles), where disease agents were inadvertently introduced into human populations that had not previously been exposed to the disease and therefore had not evolved protective mechanisms. The committee also reviewed the history of nonhuman epidemics (such as the Irish potato famine, in which a fungus infection literally destroyed the potato crop on which Ireland depended). The group pointed out that organisms harmless to man but pathogenic to plants or animals might be as deleterious to man as those which affect him directly. It was felt that the introduction of a completely new (extraterrestrial) organism must be considered a potential catastrophe since terrestrial forms of life would have had no previous history of exposure and therefore no opportunity to have developed natural immunities or artificial vaccines. The committee concluded that extraterrestrial life, and the concomitant possibility of back-contamination, must be presumed to exist, and that any "policies of defense against back-contamination must be based on the proposition that if infection of the earth by extraterrestrial organisms is possible, it will occur."

The committee therefore strongly

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recommended, on the basis of available information, that astronauts returning from lunar or planetary missions be placed in strict quarantine for 3 weeks on their return to the earth; that all spacecraft, suits, equipment, and returned samples be received in an isolation environment and maintained there for the duration of the quarantine; and that all samples be examined, behind absolute biological barriers under rigid biological and chemical isolation, for evidence of pathogenicity or danger by competition or disease to terrestrial plants and animals.

Three agencies of the U.S. government [the Departments of Agriculture, Interior, and Health, Education, and Welfare (Public Health Service)] have had statutory responsibilities to prevent the introduction of harmful biological agents into the United States. In recent years, NASA has entered the picture by virtue of the fact that it has provided the means of introducing material of extraterrestrial origin and therefore of unknown composition and potential danger to the earth and thus to the United States. The first such events were the return of lunar soils to the earth during the Apollo program.

To determine a satisfactory quarantine procedure for returned lunar samples, the Interagency Committee on Back Contamination was formed with representatives from Agriculture, Interior, Health, Education, and Welfare, and NASA. This committee ultimately agreed to a quarantine protocol that included a spectrum of animal and plant test systems they felt would provide sufficient data on the pathogenicity or nonpathogenicity of lunar material. A series of prescribed biological assays was performed, behind an elaborate system of biological barriers at the Johnson Spacecraft Center (JSC) in Houston, Texas. These tests were performed on lunar material collected by astronauts, starting in 1969, on Apollo 11, Apollo 12, and Apollo 14. The samples had been returned to the earth in hermetically sealed containers that were not opened until behind the barrier system at JSC. In addition, the astronauts themselves were quarantined for a prescribed period. These procedures are well documented (*2*). Table 1 is an outline of the test organisms used for the quarantine testing.

The scientific community and the regulatory agencies of the government generally felt that the likelihood of a viable pathogen in the lunar soil was very small. The environmental hostility of the moon seemed virtually to preclude the possibility of life now or in the past. However, it was felt that even a remote chance of an alien life form must be guarded against because of the presumed high risk of catastrophic biologic interaction between such a life form and terrestrial life. Thus it was felt that precautions must be taken for the extreme "long shot" eventuality.

The results of the lunar quarantine assay tests for viable organisms were uniformly negative (*3*). After Apollo 14, the astronauts were no longer quarantined and quarantine testing of lunar material was discontinued, although routine study for the presence of life in lunar material was continued throughout the Apollo series.

Now we are faced with the prospect of a similar problem, but one in which the odds on finding life forms may be quite different than in the case of the moon. Serious thought is now being given to a mission that will return surface material from Mars, whose environment (unlike that of the moon) cannot be arbitrarily considered to be so extreme as to preclude the possibility of life, although it is still hostile by terrestrial standards. The environment of Mars has been reviewed elsewhere on the basis of data from the Mariner 9 mission (*4*). The temperature ranges, the presence of water vapor in the atmosphere as well as water ice in polar regions, the possibility of transient liquid phases in the soil in some latitudes, and the presence of a thin atmosphere make Mars much more capable of supporting life than the moon. How then do we react to the possible return of martian soil to the earth? In this article we consider the potential hazard and outline several schemes whereby such samples can be studied on the earth or in earth orbit.

Scientific Value

The direct examination of a returned Mars sample provides fundamental information essential to understanding planetary composition and evolution—information difficult, if not impossible, to obtain by unmanned lander vehicles. Just as there are many first-order scientific investigations that can only be done remotely, there are equally or even more fundamental tests that can only be done adequately on returned samples. Clearly, the atmospheric, seismic patterns, heat flow, and gravitational and magnetic fields are among those features that need to be measured in situ. However, into the second category fall experiments like age dating, isotope fractionation, and trace element and petrological analyses, and certain basic biological investigations including direct observation by light or electron microscopy and detailed biochemical analyses. The design and flight of automated instruments for such analyses are extremely difficult and costly. In addition, since one experiment usually leads to the design of the next, a comprehensive study of the surface of a planet would require a substantial number of flights to follow up on the results of earlier flights. A single sample in a terrestrial laboratory with all its sophisticated equipment could take the place of many such flights, although there will certainly be a desire for many samples from a variety of sites and depths below the surface (as in Apollo flights 11 to 17).

The analytical capability of planetary lander vehicles is limited because of spacecraft weight, power, and volume constraints. As a result, remote analyses are limited to the macroscale rather than microscale, and significant data can remain undetected. For example, one approach in elucidating the history of water on Mars involves the identification of mineral species such as clays and carbonates. The x-ray fluorescence experiment on Viking 1975 has the capability of describing the chemistry of clays or carbonates if these minerals comprise a significant fraction of the sample. On the other hand, analysis of a returned sample can detect these species at the single-grain level; and from the point of view of the formational processes, the single grain is as important as the bulk sample. Similarly, the biology instrument on Viking 1975 will detect an indigenous biota if it is present in the sample in quantity or if it can be stimulated to reproduce and thereby amplify the biological signal. In either case, the biota must be able to respond to only a few selected experimental stimuli. However, even in terrestrial laboratories, large populations of soil organisms are sometimes not detectable because of their physiological state or metabolic properties (*5*). Hence, microanalyses will be required for the complete biological characterization of the martian soil as well. In fact, if organisms exist in martian soil, we will eventually want to isolate and culture them in large numbers for detailed metabolic and genetic study.

Results obtained in the lunar pro-

gram are exemplary of the magnitude of the scientific return made possible by direct sample analysis. Lunar exploration proceeded through a graded series of discrete steps that included earth-based observation, lunar orbiters, unmanned landers, and finally in situ investigations together with sample return. As the missions increased in scope, the scientific return and new knowledge increased dramatically. For lunar geochemistry and mineralogy, the most significantly rewarding phase exists now with the continuing multidisciplinary intensive studies of lunar soil samples in laboratories around the world.

An assessment of the scientific return a Mars sample will provide is better made by noting the amount of information gained through the analysis of lunar soil returned to the earth by two Russian unmanned spacecraft (*6*). Luna 16 and Luna 20 returned about 100 and 50 grams of lunar soil, respectively, compared to the nominal 200-g sample proposed for a Mars mission. Although the scientific investigations of Russian lunar samples and the resulting interpretations were overshadowed by the sheer magnitude of the Apollo sample analyses, such analyses represent a major advancement over the instrumental capabilites of, and knowledge gained by, the earlier unmanned landers, before sample return. It should be pointed out, however, that serious attempts to perform these analyses in situ on the moon by automated instrumentation guided by man on the earth were not made. We therefore have no real basis for technical and cost comparisons.

Anticipated Viking Results

Current designs for a Mars Surface Sample Return (MSSR) mission indicate that the scientific community will have ample time to react to Viking 1975 lander results before a Mars sample would be returned to the earth. From what we know of the Soviet Mars 4, 5, 6, and 7 missions, no definitive biological information can be expected. It is instructive therefore to examine the Viking instruments that will give biologically relevant information and to anticipate the results they may yield. In this way, we can predict the kind of data that will be available when the potential hazards of returned Mars samples are assessed or when control procedures are devised.

Table 1. Biological systems challenged with lunar materials in Apollo 11 or Apollo 12 quarantine studies.

Category	Types used
Vegetables	Onion, cabbage, pepper, cucumber, soybean, lettuce, tomato, mung bean, common bean, radish, potato, spinach
Fruit	Watermelon, cantaloupe, lime
Algae	Blue-green, green, red, diatom
Grains, cereal, tropical grass	Rice, sorghum, wheat, corn, popcorn, sugarcane
Pines	Slash, sugar, longleaf (pitch)
Animals	Insects, flatworms, protozoans, fish, shrimp, oysters, Japanese quail
Miscellaneous	Various weeds, club moss, liverwort, tobacco (nightshade), sensitive fern, fern
Germfree systems	Mice, plants, plant tissue cultures, viral assay tissue culture

The Viking 1975 mission to Mars and its scientific payload have been described (*7*). The spacecraft contains a life-detection instrument that has three component experiments: pyrolysis, label release, and gas exchange. In the pyrolysis experiment, a sample is incubated with $^{14}CO_2$ and ^{14}CO, with provisions made for illumination and addition of water vapor. After the sample is incubated and the unreacted gases are flushed out, the organic matter is liberated by pyrolysis and the amount of ^{14}C contained therein indicates the synthesis of organics from CO_2 or CO. The label release experiment involves the incubation of a sample with a medium containing ^{14}C-labeled organics. The appearance of radioactive gaseous products in the headspace indicates the presence of degradative metabolic processes. In the gas exchange experiment, soil is incubated with medium containing unlabeled organics and the headspace is monitored for H_2, N_2, O_2, CH_4, and CO_2 by gas chromatography. Changes in gas composition suggest respiratory activity. Immediately after a positive response in any experiment, a portion of the same soil sample sterilized by heat (160°C for 3 hours) is tested as a control.

If the biology instrument provides data that clearly indicate the presence of a martian biota, three questions immediately arise regarding sample return: What is the biochemical nature of the life? Is it pathogenic to terrestrial species? How can it be controlled? Positive results in the three biology experiments provide a limited start toward elucidation of the presence of major metabolic processes and pathways, energy mechanisms, and environmental conditions required for growth. These characteristics, however, would apply only to the responding species. No information is gained about the presence of other species that may not be stimulated into metabolic activity under the limited conditions used.

The Viking 1975 biology instrument cannot provide any information concerning the potential pathogenicity of detected life forms to terrestrial species.

On the question of controlling the detected biota, however, the instrument may yield very pertinent information about the susceptibility to sterilization by one method, heat. In view of the lower average temperatures on Mars compared to the earth and the known lability of terrestrial organisms at elevated temperatures, the results of the control experiments could be very significant.

If the Viking 1975 biology instrument returns ambiguous or negative data, then our ability to estimate the potential hazard of a returned Mars sample will be severely curtailed. Such results, however, will not obviate the need for concern about back-contamination. Viking 1975 cannot unequivocally demonstrate the absence of life on Mars. Negative results from the biology instrument would indicate that surface soil samples at one particular planetary site do not contain biological species capable of responding detectably, within the limited range of rather geocentric experimental conditions used and the limited sensitivity of the detecting instruments. This conclusion is far different from one that there is no life on Mars.

In addition to the direct biology instrument, the Viking 1975 lander also contains a molecular analysis instrument that will measure the organic content of the martian soil by combined gas chromatography and mass spectrometry, and an instrument that will determine the atmospheric composition by mass spectrometry. It is possible that atmospheric analysis will reveal chemical incongruities, analogous to the coexistence of methane and oxygen in the earth's atmosphere, which would indicate the presence of a biota. Furthermore, soil analysis over the mass range 12 to 200 can yield information on both the quantity and nature of any

organics present, and thereby allow some assessment of their biological relevance. However, the molecular analysis instrument itself cannot be considered as a life-detection experiment. At best, the identification of metabolically important chemicals could help to understand the biochemical nature of a detected biota. No useful information regarding pathogenicity or biological control will be obtained from this instrument.

The combination of negative results from both the direct biology and molecular analysis experiments would go far toward lessening the probability of finding life on Mars. However, such results would be subject to the same qualifications as indicated for the biology instrument alone.

Viking will also add much to our knowledge about the environment of Mars, both on a general scale and at the site of the lander. Such data (on water distribution, temperature, pressure, wind, and so forth) are relevant to the life question and are essential for planning future missions.

Another Viking-type mission, following the Viking 1975 mission but preceding a sample return mission, would augment our knowledge considerably, particularly concerning the question of life on Mars. A post-Viking biological instrument is being developed (*8*) which can, if Viking 1975 returns negative results, challenge a martian soil sample with a much larger array of substrates under many different experimental conditions. This instrument can perform inorganic and organic chemical soil analyses to aid in understanding why there is or is not a biological response. More importantly, if Viking 1975 returns positive data from the biology experiments, the advanced instrument could be optimized to characterize and to control the detected species. By judicious selection of the additives with which to challenge a soil sample, the effects of a wide variety of antimetabolites and germicides can be measured. The results of such tests would be significant to the back-contamination question.

Sample Return Mission Options

Recent studies (*9, 10*) indicate that unmanned MSSR missions of various types are technically feasible and could utilize much existing hardware and technology. Conjunction-type missions with the Titan III-E/Centaur vehicle or the Shuttle/Centaur used for launch, can return a nominal 200-g sample from Mars (several kilograms should also be feasible). Other technically feasible options for such missions are summarized in Table 2. One characteristic of these missions is a stay of 300 to 400 days in a Mars parking orbit after sample acquisition. This length of time is required to permit a low-energy return trajectory, and the total mission time would be about 3 years. Another feature of these missions aimed at reducing the cost and complexity is that little or no allowance is made for scientific examination of the sample before its return to the vicinity of the earth. The sample is maintained under conditions of temperature and pressure at near-martian values during the return flight. During acquisition, however, it is likely that only imaging can be used to provide sample documentation because of payload limitations. Finally, the return vehicle containing the sample can be designed either to make a direct entry into the earth's atmosphere or to orbit the earth for subsequent retrieval.

Table 2. Mars surface sample return mission options.

Mission phase	Option
Launch vehicle (year)	Titan III-E/Centaur (1979) or Shuttle/Centaur (1981)
Mars entry	Direct or from orbit
Mars departure	Direct ascent or orbital rendezvous
Earth return	Direct entry or orbital capture

Clearly, the cost and complexity of MSSR missions vary greatly, depending on the mission options selected. The simplest and least costly option is direct descent and direct ascent at Mars with direct entry into the earth's atmosphere on return. A Mars orbital rendezvous option, where the lander leaves Mars and goes into orbit with the orbiting parent spacecraft, has the advantage of providing increased landed weight on Mars, but would be more costly. In addition, procedures will have to be devised for rendezvous and docking of unmanned spacecraft in martian orbit. Of course, any scientific investigations on the surface of Mars during sample acquisition (imaging) or during the return trip (sterilization) add to the cost and complexity. Another more difficult and expensive option, but more cautious, is to retrieve the sample from earth orbit by using the space shuttle/reusable upperstage combination and return it to a manned or unmanned orbiting laboratory for preliminary analysis.

The MSSR mission profiles in these early feasibility studies (*9*) define the engineering requirements for a baseline or minimum mission and were developed to identify what is required to reach Mars and return with a minimum useful surface sample. In spite of the potential uncertainties in interpreting the Viking 1975 results, the current lack of plans for further biological testing before or during the MSSR mission, and the general uncertainty as to the schedule for such a mission, we now address the question of back-contamination and the impact such considerations may have on the proposed MSSR missions.

Direct Return Missions

Probably the most desirable option for studying extraterrestrial material is to return a carefully protected sample to the earth for study in the laboratory. For mission simplicity and lower cost, a direct return to the earth is optimal. From the point of view of science, a sample that has not been sterilized or altered severely in any way would also be most desirable. The first problem is to determine our ability to return an unsterilized sample "safely." First, we must be assured that the probability of the return vehicle crashing on the earth would be very low. While this question is extremely difficult to analyze from the viewpoint of back-contamination, such an analysis is critical. For example, if the chance of crashing and thereby releasing the sample to the earth is only one in a million (a purely arbitrary figure for this argument), it may prove to be an acceptable risk. If the chance of crashing is substantially higher than one in a million, it may be unacceptable. In addition, we must calculate the risk involved in removing the sample and its (presumably hermetically sealed) container from the spacecraft and conveying it safely to the laboratory, where a biological barrier system has been designed, behind which the sample can be safely analyzed. Our experience with returned lunar samples is not encouraging. The lunar material was exposed to the terrestrial environment as soon as the spacecraft was opened and the astronauts boarded a raft for return to the recovery ship. Such a procedure was deemed safe in the lunar case because of the enormous dilution factor pro-

vided by the ocean. Presumably, this kind of exposure would not be necessary for the returned Mars sample, since astronauts would not be involved and the spacecraft could remain unopened until it was safely behind the biological barrier. However in the lunar case, even after the sample was behind the biological barrier in the lunar receiving laboratory in Houston, several people were accidentally exposed to lunar material. Therefore, the barrier system would have to be improved considerably to achieve a one-in-a-million or lower chance of exposure to returned martian material. This type of mission should be feasible since such containment technology exists. The exact methodology, however, must be defined.

Sterile versus Unsterile Samples

As indicated earlier, Viking 1975 will provide no information on the potential pathogenicity of martian soil to terrestrial species and only marginal information on how to control a detected biota. Under these circumstances, one MSSR mission option might be to return a heat-sterilized sample to a manned or unmanned orbiting laboratory or an earth-based laboratory (*11*). The question then is, what is the worth of a sterilized martian soil sample to the biological and geological communities in view of the scientific objectives of returned sample analysis (*12*).

By definition, the active biological processes of growth, reproduction, motility, irritability, and metabolism would be destroyed by heat sterilization. Depending on the sterilization conditions used, however, other meaningful biological measurements might be made on the sample. For example, some biological structure might be preserved and recognized. Certain classes of biochemicals could be detected and analyzed, with special attention paid to characteristics such as molecular structure and optical activity. The results of such observations could affect our estimates of the probability that Mars harbors an indigenous biota, but would contribute little else if that probability were heightened. In short, only inferences could be made regarding the existence of life on Mars, and the experimental approaches would be limited to chemical and optical techniques. No active biology measurements would be possible.

There is a circumstance, however, under which a sterilized sample might be of great scientific worth to biologists. If life is detected by Viking 1975 (or a follow-on mission) and if the biota can be cultured and propagated, then sterilizing a culture and returning it to terrestrial laboratories would be valuable indeed. Detailed chemical analyses of such an "enriched" sample would help to partially establish the basic biochemical characteristics of the biota and its similarities or differences compared to terrestrial species.

A sterilized Mars soil sample would still retain much of its scientific value to physical scientists. However, if heat sterilization is used, the maximum temperature reached, as well as the kinetics, is crucial. For example, most of the standard radiometric methods of dating rocks would be unaffected at temperatures below 250°C. However, problems could be anticipated with argon diffusion between 300° and 400°C, depending on the mineral composition and size of individual crystals or mineral grains in rock fragments (*13*). For the types of samples considered most probable (igneous rock fragments and mineral grains, for example) analyses for the major and minor elemental and mineral constituents should not be affected if the samples are heated to only a few hundred degrees. However, water, sulfur, and other volatiles could be lost, depending on exactly how they are bound in the sample.

The effect of heat sterilization on the organic content of martian soil can also be predicted somewhat. Consideration must be given to both the possible forms of carbon in the sample (unpolymerized material adsorbed on mineral grains, macromolecular organics similar to kerogen, and organics implanted in mineral grains) and the changes that may occur as a result of heating (volatilization, decomposition, reaction, and racemization). On the basis of information obtained from thermal release (*14*) and pyrolysis (*15*) experiments on geological samples, it appears that heating samples at 200°C and below will volatilize some organic compounds, but will not destroy or totally alter all the organic material. Under these conditions, much information can be retained for organic geochemical and exobiological purposes, especially if the volatile products are trapped and later examined. Trapping volatilized organics (on silica gel or Tenax) for later terrestrial analysis should be practical. Combustion of volatilized species, after which the resultant CO_2 is trapped, will at least preserve isotopic information. If this process is done as a function of volatilization temperature, the results might be more informative.

Heating the sample to 400°C for prolonged periods will volatilize and decompose most of the organic compounds of significance to exobiology. Some large, highly condensed, aromatic molecules might survive, but these compounds would not provide much insight into possible biological processes. Treatment at 400°C does not completely destroy polymeric material such as kerogen, but the information to be derived from the heated material is greatly diminished.

If the biotic input to the martian sample is substantial, heating to 200°C will probably not destroy all trace of it. On the other hand, crucial details of biotic or abiotic chemical distribution may be seriously modified by heating to 200°C since, for example, racemization of amino acids may occur.

Although many of the physical and chemical investigations are compromised to varying degrees by heat sterilization, the impact can be lessened if the exact sterilization conditions are known and if the volatile substances are trapped and then analyzed. Laboratory work is needed to define more completely the full impact of sterilization on the biological, geological, and chemical significance of the treated sample. Also, other methods of sterilization (radiation or chemical) may be appropriate to preserve certain kinds of data.

Earth-Orbital Quarantine

A possible way to avoid the risk of contaminating the earth with unknown, potentially hazardous material is to place the returned sample in quarantine in earth orbit. A properly designed shuttle sortie laboratory could be used as a containment facility. Either of two approaches could be used: (i) the system could be designed to function as an automated laboratory so that the returned Mars sample could be analyzed remotely, or (ii) astronauts could be introduced into such a facility, protected from the sample by a barrier system, if a "foolproof" barrier system were devised. However, our experience with barrier systems leads us to assign a fairly high probability to the inadvertent exposure of one or more astronauts to martian material, which could

Table 3. Lunar receiving laboratory personnel and space requirements.

Requirement	Number or size
	Personnel
Plant personnel	
Professional	Two civil service, one in-house contract, two outside contract, one consultant
Technical	Four in-house contract
Animal personnel	
Professional	Five civil service, three in-house contract, four outside contract, two consultants
Technical	Fifteen in-house contract
Total personnel	Seven civil service, 23 in-house contract, six outside contract, three consultants
	Laboratory space for plants and animals
Space inside barrier	Five laboratories (186 m^2) with cabinets (62 m^3)
Space outside barrier	Laboratory and animal-holding space (492 m^2)

jeopardize their return to the earth. Another question is whether a shuttle sortie laboratory is adequate to quarantine martian material. When the array of terrestrial organisms (animals and plants) important for the survival of life on the earth and the diversity of test organisms used during the quarantine of lunar material (see Table 1) are considered, we must question the feasibility of performing a satisfactory quarantine in earth orbit. Placing a variety of germ-free plants and animals, tissue cultures, and so forth in orbit under self-sustaining conditions for an indefinite period, either completely unattended or attended by astronauts within the confines of a shuttle sortie module (Fig. 1), seems an almost insuperable obstacle. Such a laboratory is difficult to maintain even on the earth with large staffs of well-trained personnel. The problem of physical space to accommodate all the test organisms and equipment needed, plus the problem of maintaining these living systems, is obviously enormous. Table 3 is a summary of the personnel and laboratory space requirements for the lunar quarantine program at the Houston facility. Finally, in an orbital quarantine laboratory, all the test systems will be in an environment with zero or near-zero gravity, and that factor alone makes it difficult to perform the necessary experimental protocols.

During this discussion it has been assumed that a returned martian sample would be subjected to the same regimen of quarantine protocols as the lunar samples, as a minimum. Although the environmental conditions on Mars appear to be more conducive to life than those on the moon, quarantine testing could conceivably be altered on the basis of lunar experience. The question of quarantine protocols for Mars samples is open, and it should be addressed. At this point, however, it seems unlikely that a completely satisfactory quarantine protocol can be performed in an earth-orbiting facility.

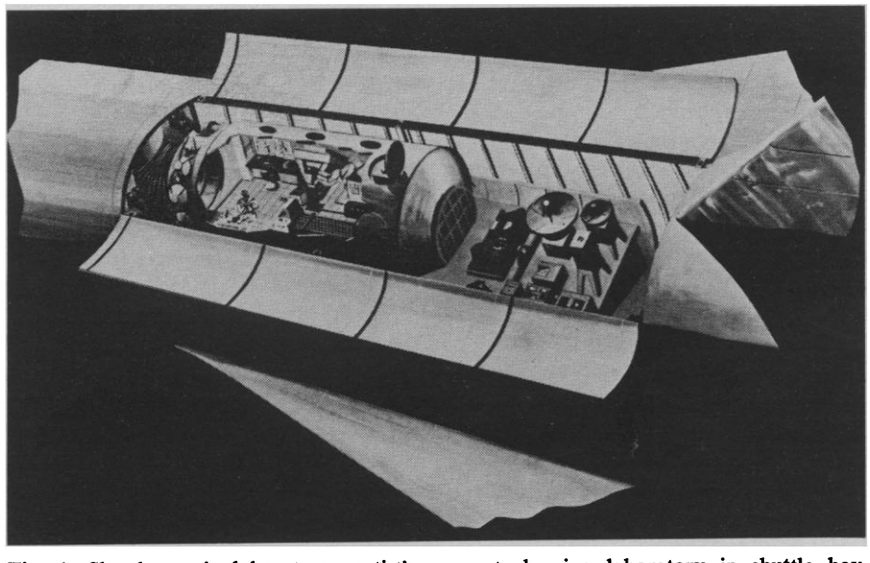

Fig. 1. Shuttle sortie laboratory: artist's concept showing laboratory in shuttle bay.

Perhaps there is a feasible compromise position. For example, if the sample in a shuttle sortie laboratory were split and part of it sterilized for return to the earth for analysis by disciplines capable of using a sterilized sample, the remainder of the sample could then be studied more gradually in earth orbit. This analysis could first be done by certain automated biological techniques, an example of which was described earlier. Advanced second-generation life detection and characterization instruments would be available for biochemistry, growth, and metabolism measurements under a wider variety of conditions and with greater sensitivity than are possible on a planetary lander. Procedures could then be devised for challenging a few biological test systems (bacterial cultures, a small mouse colony, and so forth) with the martian sample. As we gained confidence about the nonhazardous nature of the material, carefully protected astronauts could continue more detailed orbital investigations. Ultimately, the sample that remained unsterilized in orbit might even be certified for return and release to terrestrial laboratories.

Clearly, the cost and scientific tradeoffs of the various options described must be studied carefully before any decisions are made. However, a return sample mission from Mars is indeed technically feasible and, depending on the option selected, can be of greater or lesser scientific value. There is a trade-off between the scientific value of the sample and the questions of analysis in orbit versus analysis on the earth, and sterilization versus nonsterilization of the sample.

Summary

1) Sample return missions from Mars are feasible in the 1980's.

2) The least expensive missions (direct sample return without sterilization) may be criticizable because of the possibility of back-contamination, although upgrading the handling and containment facilities could make unsterile return acceptable.

3) Sample sterilization decreases the total scientific value appreciably, depending on the measurements to be made. Geology is least affected and biology and organic chemistry are most affected.

4) Quarantine in earth orbit, in the same sense as for the lunar samples,

would not be feasible without very large increases in cost. Orbital quarantine facilities, either automated or manned, would be very expensive, risky, and of limited use because of size limitations.

5) Orbital quarantine may be feasible if the sample is split, part of it sterilized and returned to the earth for study, and the remainder studied for pathogenicity in the automated mode as best we can in the limited space available in orbit. Ground studies of sterilized material plus "live" studies in orbit may convince us of the safety of returning the remaining sample to the earth under carefully prescribed conditions.

6) Additional unmanned, Viking-type missions to Mars can add considerably to our knowledge about a martian biota, or its absence, and thus increase the likelihood of being able to return an unaltered sample safely to the earth.

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11. Potential sterilization regimes must be carefully considered because the exact conditions used may affect the scientific value of the sample markedly. It is assumed here that a plausible sterilization procedure might be dry heat at 200°C for about 24 hours. Sterilization by irradiation is another possibility that should be investigated. Although an irradiated sample may be more useful for biological and organic chemical analysis, other physical measurements (such as isotopic measurements and age dating) may be compromised. Other problems associated with this technique include self-shielding of the sample and heat generation.
12. For this discussion, we have to put aside attendant major problems such as: How sterile is sterile? Sterile compared to what? Is the sample sterilized on Mars, in Mars orbit, or during transit? These are important questions that must be addressed, but they are beyond the scope of this article. Instead, we focus on the general scientific value of a returned sample that has been, for example, treated by heat.
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Are Scientists Obsolete?

What is happening to their social role, and where are the future markets for their services?

Harvey Brooks

It is by now conventional wisdom that a profound transformation has occurred in the environment for the conduct of research in the natural sciences and engineering in the United States since about 1967. All agree that such a transformation has taken place, but consensus seems to disappear, even among scientists, when it comes to describing the nature of the change or assessing its significance for the future. Among natural scientists and engineers the prognostication is uniformly gloomy. We have just come through a period of more than two decades in which the scientific community, especially that composed of natural scientists and engineers, could afford to comport itself as a largely autonomous and inward-looking enterprise. This was true to a degree not likely to be realized again in the near future. During this period also we have brought up an unusually large cohort of bright and highly motivated young scientists in a euphoric atmosphere, and it is they who bear the brunt of any adjustments that have to be made to a different kind of future.

The situation in the social sciences since 1967 has been somewhat less bearish than in the natural sciences, although financial support and public understanding of theoretical work in the social sciences have not been much better than in the natural sciences. After a brief period of public belief in the promise of the social sciences for the solution of the social ills of the early 1960's, the climate for them also has deteriorated.

Yet I hasten to add that the title of this article is rhetorical. I do not believe that scientists are obsolete. In fact my theme will be that the demand as well as the need for science and for technically trained people will resume its long-term growth, though not at the dramatic rate of the period from 1955 to 1965. This growth may assume a somewhat different character from that of the past, and will involve science and scientists much more intimately as a component of general social and economic development than during the golden age of academic and basic science of the early 1960's. Indeed it is the academic and academically oriented parts of the scientific and engineering enterprise that will probably face the greatest uncertainties and adjustments.

Recent History

Over almost three centuries science has become adjusted to continuous growth. Even during the great depression, between 1930 and 1940, the overall funding of U.S. science grew in real terms at an average annual rate of 9

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