Final Report 1975
"Technology for Return of
Planetary Samples"
Contract No. NASW-2280

Prepared for:

National Aeronautics and Space Administration
Headquarters
Washington, D.C. 20546

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August 1975

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ACKNOWLEDGEMENTS

The participation and assistance of the following Biospherics' personnel is gratefully acknowledged:

Patricia Ann Straat, Ph.D.

J. Rudolph Schrot, Ph.D.

The participation and most helpful suggestions of Dr. Richard S. Young, Chief Planetary Biology, NASA Headquarters, Drs. Michael B. Duke and Michael A. Reynolds, NASA/Johnson Space Center, Houston, are also gratefully acknowledged.

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LIST OF ACRONYMS

BAC	Biohazard Assessment and Control
PRS	Planetary Return Sample
TRP	Technology for Return of Planetary Samples
PRL	Planetary Receiving Laboratory
LRL	Lunar Receiving Laboratory
PRSM	Planetary Return Sample Mission
MRSM	Mars Return Sample Mission
AMML	Automated Microbial Metabolism Laboratory

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ABSTRACT

A study of the technological requirements of a Planetary Return Sample Mission was conducted. The state-of-the-art for problems unique to this class of missions was assessed and technological gaps were identified.

The problem areas where significant advancement of the state-of-the-art is required are:

- Life support for the exobiota during the return trip and within the Planetary Receiving Laboratory (PRL).
- Biohazard assessment and control technology.
- Quarantine qualified handling and experimentation methods and equipment for studying the returned sample in the PRL.

Concepts for solving these problems are discussed.

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1.0 SUMMARY

We have reviewed the fragmentary literature on planetary return sample technology and selected what we believe to be meaningful contributions. To these we have added our own innovations to bridge some of the important gaps and to extend this relatively sparse technology. Our objective is to define an approach which meets the practicalities of Planetary Return Sample Missions.

We have addressed the problem of acquiring and transferring a sample to the returning spacecraft. A quarantine qualified concept for accomplishing this objective without requiring in-flight sterilization is presented. The major steps in the technique, which is based on maintaining physical biobarriers around the returning spacecraft and sample, are:

- The sample is collected, sealed in a container and placed in a sample collection capsule on the planet.
- A flexible bioshield is deployed around the second stage of the return vehicle prior to docking with the ascent vehicle.
- An electrostatic precipitator is used to minimize the bioload transfer from the ascent vehicle to the bioshield at docking.
- The sample is transferred to the sample return container using flexible biobarrier and heat sealing techniques, thus effecting aseptic transfer without in-flight sterilization.
- The electrostatic precipitator is jettisoned with the ascent vehicle at separation.

- The biobarrier is jettisoned with the first stage of the return vehicle during the initial phase of the return orbit injection maneuver.

In addition to obviating the difficult sterilization procedures, the described technique also provides for verification of the integrity of the bioshield during the critical sample transfer maneuver.

We have addressed the problem of sequestering and preserving a planetary sample for the return voyage from Mars to Earth. A JPL study (1) defining the contamination and preservation criteria for a Mars Return Mission was used as the point of departure. The criteria were analyzed for impact on the sample cannister design and sample life support strategy.

A materials study was conducted to define acceptable construction materials for use in the sample cannister. Each of the elements and representative glasses including fused silica were evaluated on the basis of:

- gaseous permeation
- chemical reactivity including catalytic action
- biological reactivity and toxicity
- radioactivity
- naturally occurring isotopes
- other physical parameters

Gold was found to be the only material which satisfies all known requirements.

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A review of sealing technology was conducted to identify sealing concepts capable of meeting the desired leak rate of 10^{-10} cc/sec STP of He under a differential pressure of one bar. Ultra-high vacuum technology has produced two seal types which have demonstrated performance at these levels:

(1) Metallic knife-edge seals, in particular, a concept described by Wishart and Bancroft (2) which offers advantages for cylindrical containers.

(2) Liquid metal and low melting point eutectic seals.

Design concepts for the sample container using these seals are described.

A generalized analysis of the life support problem during the return voyage was conducted. We found that a basic disparity exists in the risk/reward functions for a given life support strategy depending on the intended end use of the sample. Specifically, a conflict arises between the optimum strategy of life support for the biological component and contamination risk which is of paramount importance to the physical sciences. We conclude that separation of the sample into at least two, and possibly more, smaller, separately sequestered and maintained portions, is desirable.

Against this background a number of distinct life support strategies was considered. Five of these, characterized as follows, are described:

- simple containment
- containment plus hypothermia
- containment with thermal control and radiation simulation
- hypothermia plus infinite reservoir
- simulated diurnal cycle plus active gas exchange

We have attempted to define critical information requirements necessary to make knowledgeable and prudent judgements relative to the life support strategies to be adopted for the return voyage. The information required generally involves understanding the transactions occurring across the boundaries between the sample and the atmosphere, the sample and the underlying soil, and interactions with incoming radiation. For example, if the photolytic component of photosynthesis occurs in the bulk of the atmosphere as suggested by Wolfgang (3) and Horowitz et al. (4) as opposed to occurring in biota as is the case on Earth, major adjustments in life support strategy may be necessary.

We have analyzed the sample headspace gas exchange problem and examined the data to be obtained by Viking for use in defining a life support strategy. We conclude that the Viking life detection and atmospheric analysis experiments will provide useful but incomplete information relative to the rates of gas exchange and atmospheric constituents involved.

A post-Viking mission using the backup spacecraft with minor modifications to the exobiology detection instruments could provide a much more comprehensive data base for a Mars Return Sample Mission.

Against the contingency that data from such a mission would not be available, we have studied and defined a "brute force" technique for improving the tolerance to disequilibra between the collected sample and its headspace gas constituents.

The methodology for compensating for sample-atmosphere disequilibria involves providing a scrubber for removing metabolic product gases and a supply reservoir of the metabolite gases normally existing in low concentrations in the planetary atmosphere. Both reservoirs are based on adsorption-desorption action by a zeolite, operate at low internal pressures, and, except for valving, are passive devices. A gas chromatograph based on Viking technology, but employing a new column and recycled carrier gas, could provide head space composition monitoring and act as the control sensor.

We have concluded that, unless post-Viking missions are undertaken that provide substantially more information than will be available from Viking on water, nutrient, and ion exchange across the sample boundaries, it would be unwise to attempt to provide nutrients, water, or ion compensation during the return trip.

In face of the uncertainty of adequate life support for the return trip, a historical record of a number of physical parameters within the sample could be an invaluable aid in reconstructing the original sample state from measurements on a possibly altered sample upon return to Earth. In many instances the act of obtaining this historical record would result in increased risk of contaminating the

sample and would also result in a significantly more complicated instrument. We have ordered the priorities for recorded data as follows:

1. Sample temperature
2. Headspace gas composition including water vapor, CO, CO_2, CH_4, H_2S, O_2, SO_x, NO_x, N_2, NH_3, formaldehyde, and ethylene
3. Visual image of sample surface interface with headspace atmosphere
4. Response to selected nutrient additions
5. Other physical parameters

To a large extent, the decision as to how far down the priority list one goes for a specific mission is coupled to the biohazard assessment and control (BAC) stategy adopted for the mission. For example, a reasonably comprehensive BAC package would provide a surrogate record of many of the desired parameters. In this case, the sample temperature would be measured to the exclusion of the other parameters. Maximum emphasis would be placed on maintaining a pristine sample.

A comprehensive biohazard assessment and control strategy should be given high priority for planetary return missions and in particular for a Mars Sample Return Mission. We have defined a BAC strategy based on contingency sterilization of the sample, growth and inhibition studies of the exobiota on the planetary surface under

terrestrial environmental conditions, and monitoring of interaction between a duplicate sample with selected terrestrial microecosystems in planetary orbit and during the return trip. We believe that updated Viking technology can be used to implement these critical experiments and we have described a concept which we believe would result in a prudent and practicable BAC plan. With the Viking biology package development experience as background, we recognize the long lead times and difficulty associated with this type of space experiment. We have identified below what we believe to be the most critical development problems and have recommended a plan for attacking these problems:

1. Life support for the exobiota during the return trip and within the PRL.
2. BAC technology.
3. Quarantine qualified handling and experimentation methods and equipment for studying the returned sample in the PRL.

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2.0 INTRODUCTION

In the previous reporting period (5), critical questions regarding the justification for, and potential risk involved in returning a planetary sample were considered. Specifically, the following topics were explored:

- Scientific justification for the return of a planetary sample.
- Biohazard assessment criteria.
- Types of information necessary to control, contain, or totally destroy extraterrestrial life and means for acquiring this information.
- Problems in educating the scientific and lay communities regarding the benefits, risks and associated safeguard measures for the return of a planetary sample.

2.1 Objective for Current Investigations

During the course of these preliminary considerations, it became clear that a number of critical technology gaps exist which would require detailed study in order to evaluate the feasibility of a mission to return a planetary sample. The following objectives were set for continued study to more clearly illuminate and fill in these technological gaps:

- Identify the critical technological problem areas which must be solved with respect to safety and quarantine considerations.

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- Identify the specific key technology deficiencies within each general area.
- Develop and test concepts for solving the specific problems identified.

2.2 Background Summary for a Planetary Return Sample Mission

In order to provide a clear and concise statement of the underlying assumptions which form a basis for evaluating existing technology against the probable requirements for a Planetary Return Sample Mission, a typical generalized mission is described. The presentation will first simply describe the mission. Then the implications of the mission constraints, biological considerations, and quarantine decisions will be more fully elaborated. It is assumed that the mission is unmanned, at least for the interplanetary portion. A Mars return sample mission of the orbital type (6) is assumed. Figure 1 illustrates the mission profile.

The first phase of the mission is comprised of the launch, cruise, and Mars orbit maneuvers of the spacecraft. This portion of the mission will be similar to the Viking Mission. Depending

SUMMARY OF PLANETARY QUARANTINE POSITION

- THE RISK ANALYSIS OF THE SEVERAL POSSIBLE MISSION MODES WILL REQUIRE THOROUGH EVALUATION, BUT AT THIS POINT THE MODE OF PREFERENCE APPEARS TO BE:

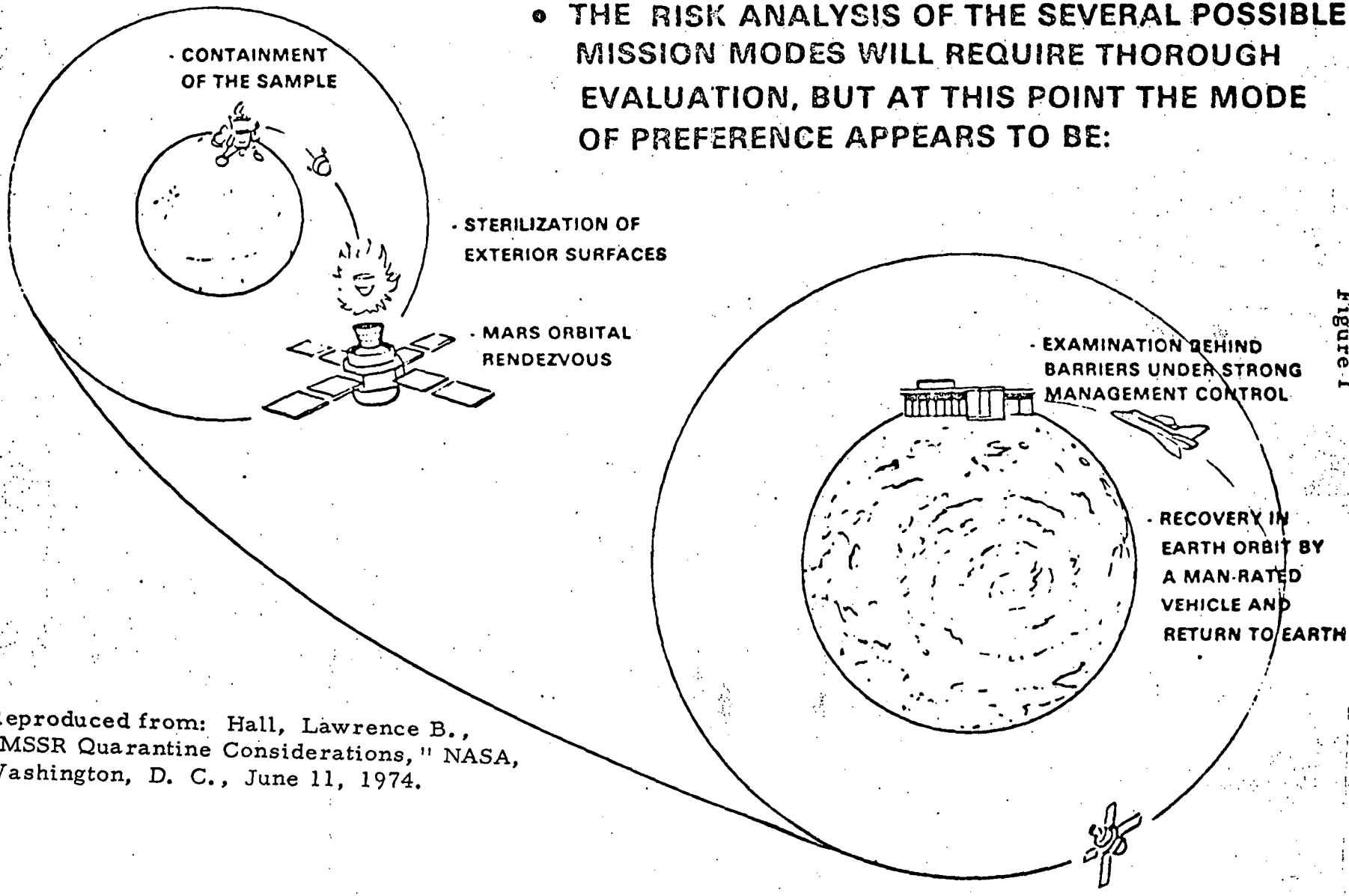

Figure 1

Reproduced from: Hall, Lawrence B., "MSSR Quarantine Considerations," NASA, Washington, D. C., June 11, 1974.

on the relative positions of Mars and Earth and the particular orbits chosen, the time span for this portion of the mission will be 250 - 700 days (7).

After arriving in the selected Mars orbit, the descent vehicle will separate from the main spacecraft and make a soft landing on Mars. The descent vehicle will carry the Mars sample collection capsule and perhaps a rover-type vehicle to allow multiple samples to be acquired over a wider variety of Martian terrain. The sampling system will obtain samples from the surface to a depth of four to ten cm and load these samples into the Mars sample collection capsule. The geometrical integrity of the sample strata will be preserved if feasible. The Viking collection system does not preserve the sample strata integrity and a new collection system design will be required for this feature.

It is probable that some sort of "quick-look" life detection system and/or physical assay system will be incorporated into the sample collection system or collection capsule. The use of this opportunity to select the most suitable samples for return can probably be realized within likely weight restrictions for the descent vehicle, particularly if the rover concept is not used. The Viking or AMML technology can provide the basis for this capability.

After collection of (a) suitable sample(s), the ascent vehicle will separate from the lander and achieve Mars orbit. It will be contaminated. One of the major areas for investigation is the problem of getting the contaminated Mars sample collection capsule into the Mars sample container without spreading this contamination to the return container exterior or to other portions of the return spacecraft. This problem is discussed in detail in subsequent sections of this report.

Assuming that some "sanitary" method of docking the sample capsule to the return container can be devised, the next step in the mission will probably consist of a series of experiments in Mars orbit. The return container will have much less stringent weight constraints than those applied to the sample capsule and the return container can be more highly instrumented. It is

anticipated that at least the following types of tests will be conducted before commiting to the return risk:

- Life tests under Mars and Earth environmental conditions.
- Interaction with typical Earth ecosystems †
- Inhibition reactions.

Depending upon the overall mission quarantine protocol and the results of the Mars orbit tests, the sample will begin the return cruise or the mission can be aborted. In addition to this basic decision, a range of possibilities with respect to sample sterilization treatment may be considered. If the sample is returned, more tests will be performed during the return cruise. In addition, depending upon the desired state of the sample, some life support and/or environmental control for the sample will be required. The definition of suitable life support/environmental control concepts which are compatible with the Planetary Return Sample Mission quarantine protocol is regarded as another major area of technological deficiency.

Assuming the tests during the return cruise indicate acceptable risk, the return spacecraft will achieve Earth orbit. At this point, two major scenarios could be employed. The first scenario involves docking the return spacecraft with a

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† If methods can be devised to allow transfer of viable Earth ecosystems to a Mars orbit within Mars quarantine constraints.

space station and transferring the sample to a special laboratory in the space station for preliminary experimentation. In the second scenario, the sample would re-enter directly without undergoing the preliminary tests in space.

Selection of the scenario for experimentation on the sample will clearly be a complicated function of the assessed biohazard, the reliability and risk assessment for the re-entry equipment, the effectiveness of the space and Earth quarantine protocols, and cost factors. For technology evaluation purposes, we can assume that a space station preliminary test phase will be required, but that the biohazard and quarantine protocol for Earth-based equipment will be the same as for the direct re-entry case. This assumption has the effect of including all the problems for either scenario.

In accordance with this philosophy, a series of biological tests and physical assays would be performed in the space laboratory under strict quarantine conditions. The tests would be similar to those for the cruise portion of the mission, however, the physical assay tests would be much more rigorous and additional biological tests in the areas of inhibition reactions and Earth ecosystem interactions would be conducted. On the basis

of the Lunar Receiving Laboratory experience, these tests represent a major technological challenge if a reasonable quarantine protocol is to be maintained. This subject is more extensively explored and discussed in subsequent sections of this report.

Assuming the space data warrants Earth-based investigation and the risk is assessed to be acceptable, the sample will then be transferred from the space station to an Earth-based receiving laboratory with significantly improved capability over the Lunar Receiving Laboratory. Additional experiments requiring specialized, bulky, heavy or cumbersome equipment will be performed under very strict quarantine conditions. If a space station is used for preliminary tests, the portion of the sample which re-enters may be sterilized prior to its leaving the space station. However, we will assume that the presence or absence of viable life has not been verified by manual experiments.

Finally, the sample will be studied, stored, disseminated to interested scientific parties, and/or destroyed. The decisions as to the protocol to be employed are strong functions of the assessed risk, sterilization technology and life detection technology.

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3.0 DISCUSSION OF CRITICAL PROBLEM AREAS

In attempting to fit the technological requirements for a typical Planetary Return Sample Mission to the existing technological framework, we found three major generic problem areas: (1) quarantine protocol, (2) life support and environmental control systems and, (3) biohazard assessment and control. These categories of problems are discussed.

3.1 Quarantine Protocol

The basic objectives of the Planetary Return Sample Mission quarantine protocol are to prevent contamination of the planetary environment with terrestrial organisms and to prevent back contamination of the Earth by extraterrestrial organisms or other hazardous material. The overall basis for planetary quarantine was established by the International Council on Scientific Unions (ICSU) and the Committee on Space Research (COSPAR). COSPAR established a total limiting probability for contaminating a planet throughout the entire space exploration quarantine period as 1×10^{-3}. The quarantine protocol for the Planetary Return Sample Mission will be established under the auspices of the U.S. Planetary Quarantine Program which will

allocate an appropriate portion of the total risk of contamination to the Planetary Return Sample Mission.

The underlying philosophy of the Planetary Quarantine Program in general, and the Planetary Return Sample Mission in particular, is one of risk management in terms of statistical probabilities. The approach (8) for analyzing the probability of contaminating the Martian environment with terrestrial microorganisms has proceeded along the following lines:

1) Environmental extremes under which terrestrial life forms can survive and grow are estimated. NASA Ames Research Center has assigned numerical limits to life-related factors of the environment which form a basis for these estimates.

2) The environmental conditions presumed to exist on Mars at the landing site were studied with respect to the data in 1) above. An estimate of one chance in 100 is regarded as reflecting the probability that minimum conditions for growth of terrestrial microorganisms exist on Mars near the Viking landing site.

3) The fraction of terrestrial microorganisms surviving on the spacecraft which are delivered to the Martian environment and which will grow is then estimated.

4) All of the above considerations are combined to estimate the probability of growth and survival of a single randomly selected microorganism which reaches Mars. The

estimates range from one in 10^9 to one in 10,000. The value one in 10^6 is being used for the U.S. Martian projects.

In considering the reverse problem, that of contaminating the Earth by a returning Martian microorganism, one is faced with implementing a quarantine protocol under conditions where the uncertainty in the first category above is very large. For the problem of contaminating Mars with terrestrial life, the major uncertainty lies in the estimate of the Mars environment at the landing site. For the back contamination problem, the major uncertainties lie in the existence of a Martian organism and its ability to grow in the Earth environment. If it can grow, what impact might such an organism have on Earth ecosystems?

The data hopefully provided by a successful Viking program will form a useful basis for assessment of these unknowns. However, the Viking information alone will probably be insufficient to allow meaningful quarantine decisions to be made during the Planetary Return Sample Mission.

The subject of biohazard assessment and control through inhibitory actions is of such complexity as to warrant separate treatment from the overall quarantine problem. However, the Viking information which might be available for the Planetary

Return Sample Mission is reproduced as Table 1 (5) to form a basis for estimating the level of quarantine protocol likely to be required as a function of various Viking results.

An examination of the Viking data possibilities reveals that only for the two cases of positive biology and no inhibition do the Viking data give a meaningful indication of the probable quarantine decision. For these cases, the most probable decision is that the risk associated with a return sample is too high to be acceptable. Therefore, while the Viking data may alter the a priori probability functions for back contamination, the Planetary Return Sample Mission will need to generate most of the required input for quarantine decisions.

In any case, preparation of a suitable quarantine protocol must consider the probability for life and the biohazard risk which will be accepted without aborting the mission prior to return of the sample. We assume that the only a priori condition which would absolutely preclude the return of a sample would be the known existence of life and the known ineffectiveness of selected inhibitory techniques. The probabilities for the existance of Martian life and for its growth on Earth are unknown. A prudent quarantine protocol, therefore, must be able to cope with high probabilities of both. Thus, a major burden is placed on the plan

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Table 1

Risk Factors

Viking '75 Results			Biohazard Risk			Site	
Life Present	Organics Present	Heat Effect	Very High	High	Mild	Selection Risk High	Mild
+	+	None	x				x
+	+	Inhibits		x			x
+	-	None	x			x	
+	-	Inhibits		x		x	
-	+	-			x	x	
-	-	-			x	x	

to maintain low probabilities for contamination of the returning equipment and for accidental release of the return sample. This situation is illustrated by the following equation which gives a qualitative picture of the quarantine problem:

$$P \cong P_l P_g [P_C P_{S1} P_D + P_{CL} P_{S2} P_R] \leq 10^{-6} \text{ to } -? \quad \dagger$$

Where P is the total probability of Earth becoming contaminated by a viable Martian organism

P_l is the probability of a Martian organism existing at the landing site

P_g is the probability that such an organism could survive and grow in the Earth environment

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† For detailed discussion of contamination statistics see Judd, North and Pezier, 'Assessment of Probability of Contaminating Mars,'(9) and Schalkowsky and Kline, 'Analytical Basis for Planetary Quarantine.' (10)

P_C is the probability of contaminating the returning equipment

P_{S1} is the probability that such contaminating organisms could survive the return trip

P_D is the probability of delivery of such organisms into the terrestrial environment

P_{CL} is the probability of collecting a viable sample

P_{S2} is the probability of survival for organisms in the sample

P_R is the probability of accidental release of an organism in the sample

An examination of the above equation shows the following types of information necessary for meaningful quarantine decisions:

- What is the probability that the sample contains or is contaminated by organisms which will grow in an Earth environment? This data must be acquired directly by the Planetary Return Sample Mission experiments.

- What is the probability that any organisms present could survive a range of environments to be encountered as a result of sterilization attempts, life support attempts and, naturally occurring conditions during return and reentry? Again, this data must be directly acquired by the Planetary Return Sample Mission experiments.

In addition to the probability of back contamination, the quarantine protocol will be influenced significantly by the risk assessment associated with such contamination. For example, if it were

known that inhibition by naturally occurring factors in the Earth environment were negligible, the quarantine decision at a given level of probability of contamination would differ from that if natural inhibition were high. Similarly, if the Martian organism were known to have an adverse impact on typical Earth ecosystems, the quarantine decision would be greatly influenced.

The quarantine related problem can, therefore, be divided into two broad categories: (1) biohazard control and assessment techniques which are required to mechanize reasonable quarantine protocol decisions and, (2) physical mechanisms and techniques for maintaining the probabilities of contamination and accidental release within acceptable bounds. The biohazard assessment and control problems are considered separately. The physical mechanisms and techniques for controlling contamination and release of the sample are discussed as follows.

The Lunar Receiving Laboratory experience (11,12) provides important background for defining the physical containment and quarantine problems. A brief description of the Lunar Receiving Laboratory (13) techniques and accepted evaluations of their efficacy

are given here to form a basis for discussing similar concepts for Planetary Return Sample Missions.

The basic strategy for the Lunar Receiving Laboratory involved vacuum sealing the lunar sample containers on the moon, cleaning the exterior of these containers during the return flight and opening these containers in large biological containment systems in the Lunar Receiving Laboratory for scientific investigation. These biological containment systems consisted of large stainless steel glove boxes purged with nitrogen at less than atmospheric pressure with the exhaust gasses passing through an incinerator for sterilization. These containment systems were later changed to a positive pressure system when it was determined that the major contamination concern was from the Earth environment to the sample. The system was regarded to be marginally satisfactory for lunar materials and completely unsatisfactory for a Planetary Return Sample Mission where significantly higher probabilities of life exist. Complaints against the biological containment systems fell into the categories of biobarrier failure and contamination and into

difficulty in using some instrumentation and operating through the gloves of the system. The general consensus of the evaluations of Lunar Receiving Laboratory for possible use for Planetary Return Sample Missions are:

- The biological containment systems are inadequate (11,12).
- Much of the physical instrumentation is not compatible with biological barrier concepts in use (11,12).
- Better quarantine protocols and experiment design are needed to maximize the use of the return sample. In particular, specialized equipments requiring small samples and compatible with quarantine requirements are needed (12).
- Use of small, resealable containers which can be easily sterilized offered major advantages over the glove box systems (12).
- Much of the quarantine protocol was poorly defined. For example, it was said to be harder to get material from the primary storage chamber to an analytical instrument inside the Lunar Receiving Laboratory than it was to take this same material outside to a separate facility (12).

This experience has served as guidelines for our consideration of the Planetary Return Sample Mission quarantine requirements. Detailed discussion of the physical containment and quarantine protocol are contained elsewhere in this report.

3.2 Life Support

The life support problem may well be the most difficult technical problem to be solved for the Planetary Return Sample Mission. The problem is maintaining a suitable environment for an unknown organism or group of organisms with unknown nutrient requirements, unknown self-generated or interspecies generated toxins, and unknown growth and survival mechanisms. The Viking data may provide some useful information but, because of the limited tests to be undertaken and the limited time span of the experiments, these data will not be sufficient to design the system needed to support Martian microorganisms during the return trip. For this reason, as well as for quarantine protocol reasons, it is imperative that as much biological information as practical be obtained as early as practical in the mission. In fact, it may be possible to use much of this early information to provide data for an adaptive life support system in the return sample container.

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Two basic approaches to the life support problem have been suggested. The first approach involves the use of hypothermia, thereby reducing the life support requirements drastically. The second approach involves measuring the properties of the environment in situ at the sampling site and duplicating and maintaining this environment throughout the return voyage. This approach may require that seasonal variations in the Martian environment at the sampling site be estimated and simulated on the return flight.

On the basis of available information, it seems unlikely that the low temperature approach can satisfy the total mission requirements and that some active environmental control would be required. Two major considerations point in this direction: (1) the low temperatures regimen imposed may cause damage to the organisms, and (2) the data required for quarantine protocol decisions could not be obtained during cruise at the low metabolic rates induced. The life support problem will continue after the sample has reached Earth and been placed in a receiving laboratory for analysis. The strict quarantine protocol likely to be imposed will significantly complicate the Earth maintenance life support functions over that for terrestrial microorganisms.

For these reasons, we assume that an active life support system will be required for a Planetary Return Sample Mission.

An active life support system must include:

1) Some method for measuring the composition of the atmosphere at the sampling site to provide a baseline gaseous constituent profile.

2) A method for monitoring the head space gaseous composition in the sample return container.

3) A supply of likely atmospheric constituent gasses and a method of regulating the supply to the sample, including a method of maintaining the partial pressures of the individual components and the overall total pressure of the head space at Mars ambient conditions.

4) A method of scrubbing out the metabolite gasses.

5) Methods for sensing and maintaining the desired temperature profile of the sample.

6) A supply of essential substrates and nutrients and a method for maintaining appropriate levels in the sample.

7) A method for controlling or scrubbing out metabolite toxins.

8) A method for simulating the natural radiation at the sampling site.

This list of life support requirements is formidable when it is understood that the measurements and control must take place

in a remote manner and when interaction with the system by project scientists must take place through limited communication and command channels. It is even more formidable when one considers that the system must function under a very strict quarantine protocol.

The general subject of life support for a return sample has received very little treatment to date. The results from the Viking program should provide a major improvement in our understanding of the environmental parameters at a typical landing site. A successful Viking program should, as a minimum, provide baseline data for the atmospheric constituents, the soil composition, physical parameters such as temperature, pressure and radiation input, and, if the biology experiments detect life, a first approximation to the nutrient requirements and metabolites of Martial life forms. The Viking data could remove many of the uncertainties as to the requirements of the life support system for a return mission. The technical problems for implementing such a life support system remain and some of the specific technical difficulties will be further explored in subsequent sections of the report.

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3.3 Biohazard Assessment and Control

The subject of biohazard assessment and control is the third major area where a primary technological deficiency exists, and this gap represents the most significant technical threat to a potential Planetary Return Sample Mission. While the technology for solving these problems is lagging, the scientific concern for their solution prior to a return sample mission to any of the planets is not. In addition, this subject is certain to elicit considerable public opinion and reaction in the future.

The overall subject can be broken down into the following categories for further consideration:

1) Life detection methods including assessments of the reliability of these methods for detecting exotic life forms.

2) Survival, metabolic mechanism, and adaptability assessment methods including reliability estimates for exotic life forms.

3) Methods for measuring and predicting interaction of foreign microorganisms with the terrestrial environment, and in particular, terrestrial ecosystems.

4) Methods for sterilization and growth inhibition of foreign organisms including exotic forms.

Satisfactory solutions to each of these classes of problems in probabilistic terms must be obtained prior to the return of a sample from the planets. The degree of technical competence in each of these areas and the confidence in the reliability will have a major impact on the viability of a Planetary Return Sample Mission and the quarantine protocol to be employed.

The rationale behind the biohazard data requirements as a function of the mission phase for a Planetary Return Sample Mission is discussed below.

3.3.1 Data to be Acquired at the Surface of Mars

It is likely that the experimentation to be carried out at the Mars surface will follow the general line of the Viking Mission though in a more advanced form. Two conflicting factors will determine the level of experimentation to be conducted at the surface. On the one hand, the naturally increasing probability for failure which occurs as the mission progresses acts as a strong incentive to acquire as much data as early in the mission as practical. On the other hand, the weight and physical parameter constraints for the lander, and particularly, for the ascent portion of the lander,

act as major deterrents for complicated surface experimentation. In addition, the desire to protect Mars from contamination by live Earth microorganisms may limit or preclude certain kinds of experiments, particularly studies of the interaction of Mars biota with terrestrial ecosystems or life forms.

3.3.2 Data to be Acquired in Mars Orbit

After the sample has reached a Mars orbit, many of the weight and physical parameter constraints of experimental apparatus will be significantly relaxed. As a matter of fact, the weight penality is smallest in the Mars orbit portion of the mission. In addition, this portion of the mission is the least restrictive portion of the mission from a quarantine standpoint. These factors, in addition to the desire for early information and the requirement for data for quarantine protocol decisions, will combine to stimulate strong interest in performing a rather detailed battery of tests on the sample before the risk of the return voyage is committed. This risk is significant and is comprised of two distinct aspects. The first aspect of the risk involved in injecting the sample into a return orbit is back contamination of the Earth considerations. Hoffman, et al (7) at JPL have performed an analysis on the probabilities for undesired Earth impact of a returning sample. In their opinion, the

total probability of impact on the Earth resulting from out-of-Mars orbit injection errors and concurrent inability to make a corrective maneuver will be about 10^{-4} for reasonable return trajectories. Clearly before such an impact risk were taken, considerable definition of the overall risk of back contaminating the Earth will be required. Even if a sterilization capability is incorporated into the sample return container, this information will still be required since there would be some probability that the sterilization system would fail. While this probability is a function of the design of the system and in particular a strong function of its failsafe configuration, it is not unreasonable to expect such a failure probability to be of the order of 10^{-2} to 10^{-4} and to be somewhat correlated to the guidance system failure modes. Taking a value of 10^{-3} as reasonable and combining this with the impact probability, we find a probability of the order of 10^{-7} that an unsterilized sample of Martian material will be deposited on Earth. Unless the sterilization system is effective over the entire spacecraft, any contamination on the spacecraft might still pose a serious problem. While it is recognized that the return capsule could readily be designed to reduce the risk of

actual contamination from this source, a significant concern can be expected to develop as to just what sort of risk we would be running as to the potential for undesirable effects on the Earth ecosystems from such accidental release.

Several possibilities exist for more accurately defining this latter risk. The first level of information which can be obtained using Viking-type technology (14) is an assessment for life. If experiments such as the multiple release of nutrients (5) are performed at least some information on the probable metabolic mechanisms of any life present and detected could be gained. Such information could be used to indicate the probable impact on Earth ecosystems which might be caused by an accidental release of unsterilized sample. Finally, a group of typical Earth ecosystems (15) could be exposed to the sample under a range of typical terrestrial environments and their reactions monitored. Such experiments, taken together, could provide at least a qualitative assessment of the biohazard represented by Mars sample material.

Experiments to determine the effects of various inhibitory techniques will probably also be required (5). Such experiments would shed considerable light on the probable seriousness of a

quarantine breach and provide information as to whether and how escaped organisms could be eliminated or controlled.

3.3.3 Data to be Acquired During the Return Voyage

During the return voyage more detailed information on probable metabolic mechanisms, growth rate under various conditions, and inhibition reactions can be obtained. In addition, long-term effects on Earth ecosystems can be evaluated. Such experiments can provide at least some information relative to the incubation periods for any interactions with the ecosystems tested and the long-term viability in typical terrestrial environments (15) of any Martian organisms present.

3.3.4 Data to be Acquired in a Space Station Laboratory

The subject of space station level tests for a return sample has been extensively discussed and documented in an AIBS study (15), mentioned earlier. The basic approach is similar to that discussed for the Mars orbit and return voyage with greatly increased detail and thoroughness and with the addition of visual and electron microscope examinations. The tests were estimated to require about 1,000 square feet of space laboratory,

a crew of five scientists and technicians, and a minimum flight period per man of one month. Much of the equipment needed to perform these tests in space must be developed.

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4.0 DISCUSSION OF CONCEPTS FOR KEY SUBSYSTEMS FOR PLANETARY RETURN SAMPLE MISSION

4.1 Essential Subsystems

The following five specific key subsystems are essential to a Planetary Return Sample Mission:

1) Sample collection capsule

2) Quarantine qualified docking mechanisms/ bioshield

3) Sample return container

4) Sample transfer subsystem

5) Analysis experiment containers for space or Earth-based quarantine examination

Concepts for implementing these key subsystems are discussed in the following section in terms of the quarantine, biohazard assessment and control, and life support considerations developed in the first two sections of this report.

The first problem we considered was that of getting the sample into a quarantined environment. Since the probability of the returning spacecraft impacting the Earth accidentally is unacceptably large (7) it becomes necessary to keep the probability of contaminating the spacecraft very small. Furthermore, it is highly desirable for quarantine protocol decisions that some means of verifying the quarantine status of the exterior of the return spacecraft be provided.

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In order to understand the conditions governing the sample collection capsule, sample return container and quarantine qualified docking, we will examine the events leading to docking of the ascent stage with the orbiting return spacecraft. As stated earlier, the ascent stage would be contaminated. We will now consider how this contamination is likely to arise and mechanisms by which it might be transferred to the exterior of the sample return container and the return spacecraft.

The major potential source of dust is that raised by the retro-rocket firing on landing. This is likely to stir up a considerable cloud of dust particles of sufficient size to harbor microorganisms. In addition, the impact of the spacecraft on landing and naturally occurring fallout from the atmosphere, frequently supporting dense clouds of dust, will further contribute to potential contamination of the exterior of the ascent stage. Finally, of course, the act of sampling, itself, will contaminate the sampling mechanism and probably the ascent stage.

Faced with this situation, our first inclination was to employ a discardable biobarrier shield to protect the ascent vehicle from contamination. The bioshield would be

jettisioned during the ascent at high altitude, with the spacecraft spinning and with a slight positive pressure within the bioshield. This technique could significantly reduce the potential bioload on the exterior of the ascent stage.

Several apparent problems must be considered in conjunction with this approach. The first problem arises in connection with maintaining and verifying the integrity of the bioshield over critical portions of the mission. The bioshield integrity could be compromised by penetration by a micrometeorite during the Earth-Mars portion of the flight. It might be damaged by a mission malfunction or structural stress during Earth launch, separation from the orbiter, landing, separation from the lander and ascent. Damage may also occur by unintended contact with a deploying mechanism such as an antenna or sample collection boom. If a source of pressurizing gas or biobarrier filtered pressure equilization ports are not used, any loss of integrity of the bioshield would result in a relatively high probability for contamination of the ascent vehicle. Since the weight constraints for the lander and, in particular, the ascent vehicle are likely to be very restrictive, any biobarrier must be very light and, therefore, fragile.

If a small container of gas were used to create a slight positive pressure, the possibility for contamination resulting from a minor break in the bioshield could be reduced considerably and crude verification of the biobarrier integrity could be derived from differential pressure measurements and/or gas flows. However, if the hole were large enough to provide a significant path for contaminants, the gas supply would soon be exhausted. The weight constraints again tend to reduce the attractiveness of such a system.

Finally, the perturbation constraints imposed by the capability of the ascent control system may preclude jettisoning the bioshield during the ascent at high altitude. Therefore, while the use of a bioshield is attractive from a quarantine standpoint, it may not be practical from a spacecraft design standpoint. In the interest of responding to this possibility, we have considered what might be done should it be impractical to use a bioshield on the ascent vehicle.

If no bioshield is employed, it must be presumed that the ascent vehicle surfaces are contaminated. Several mechanisms could result in contamination of the return spacecraft during docking for sample transfer. Since the ascent vehicle would have been exposed to Martian atmospheric pressure, the openings between mated surfaces, along screw threads and the like will be pressurized. In

orbit, this pressure will be relieved and will provide a source of energy to dislodge particulate matter from the spacecraft. In addition, the mechanical shock during docking and operation of moving parts in the ascent stage or orbiter could further contribute to loosening dust. It is likely that these particulates and the spacecraft will have electric charges caused by interaction with the atmosphere during the launch phase. Therefore, it must be assumed that the ascent vehicle is surrounded by a cloud of contamination at docking.

The problem then becomes one of docking the return spacecraft to the ascent vehicle surrounded by a cloud of contamination without contaminating the return spacecraft. Our first consideration was one of simply "waiting for the dust to settle." Certainly one would expect that the amount of contamination being evolved would be a strong function of time and further that the evolved contamination would tend to disperse or be recaptured by the ascent stage with time. Such a tactic does not, however, eliminate the shock at docking or the possibility that a difference in electric potential would exist between the ascent stage and the return spacecraft. Therefore, while the policy of waiting would certainly reduce the bioload which might be transferred to the return spacecraft, it cannot be relied upon to achieve acceptable levels.

A second possibility for reducing the contamination transfer is the use of a discardable bioshield on the return spacecraft. The weight constraints for the return spacecraft are much less stringent than for the lander/ascent stages. In addition, the orbiter will be thoroughly outgassed, thus removing one of the major sources of energy for uncontrolled particle migration.

Finally, an electrostatic precipitator could be incorporated into the docking mechanism to further reduce the bioload transferred to the bioshield protecting the return spacecraft. The precipitator might consist of a light-weight shield such as metalized mylar connected in electrical opposition to a ring on the docking adaptor. Prior to docking, the shield, which would extend back over the bioshield, could be polarized with a charge relative to the docking adaptor and also with respect to the ascent vehicle after docking. The bioshield could also be polarized with a like charge with respect to the precipitator shield. By monitoring the current between the precipitator shield and the docking ring/ascent stage , one might obtain an estimate of the total contamination. Monitoring of the current between the bioshield and precipitator shield might provide an estimate of the load transferred to the bioshield.

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Figure 2 illustrates a possible configuration of the spacecraft at docking. In order for an electrostatic precipitator to be effective in preventing the particulates from reaching the bioshield, the polarity of the charge on the acquired particulates must be known. The Viking program may provide data on the induced polarity for a Mars launch.

The major problem associated with employing a bioshield on the return spacecraft is designing the spacecraft and bioshield so that the solar panels, high gain antenna, and control jet nozzles are not required to penetrate the bioshield for their operation at the time of docking. If a two-stage return vehicle is employed, as now seems likely, this problem is somewhat reduced (3). In the following analysis, we assume a two-stage return vehicle.

The solar panels will be required to provide power for the return mission since the undesirability of exposing the sample to radiation weighs heavily against the use of an RTG power supply (1). The physical dimensions of the solar panels in the deployed configuration will be relatively large and the panels must be exposed to sunlight during the major portion of the mission. One could perhaps envision a large transparent bioshield, such as a plastic bag which could be deployed prior to erection of the panels. However, such a shield would be highly susceptible to damage. A second

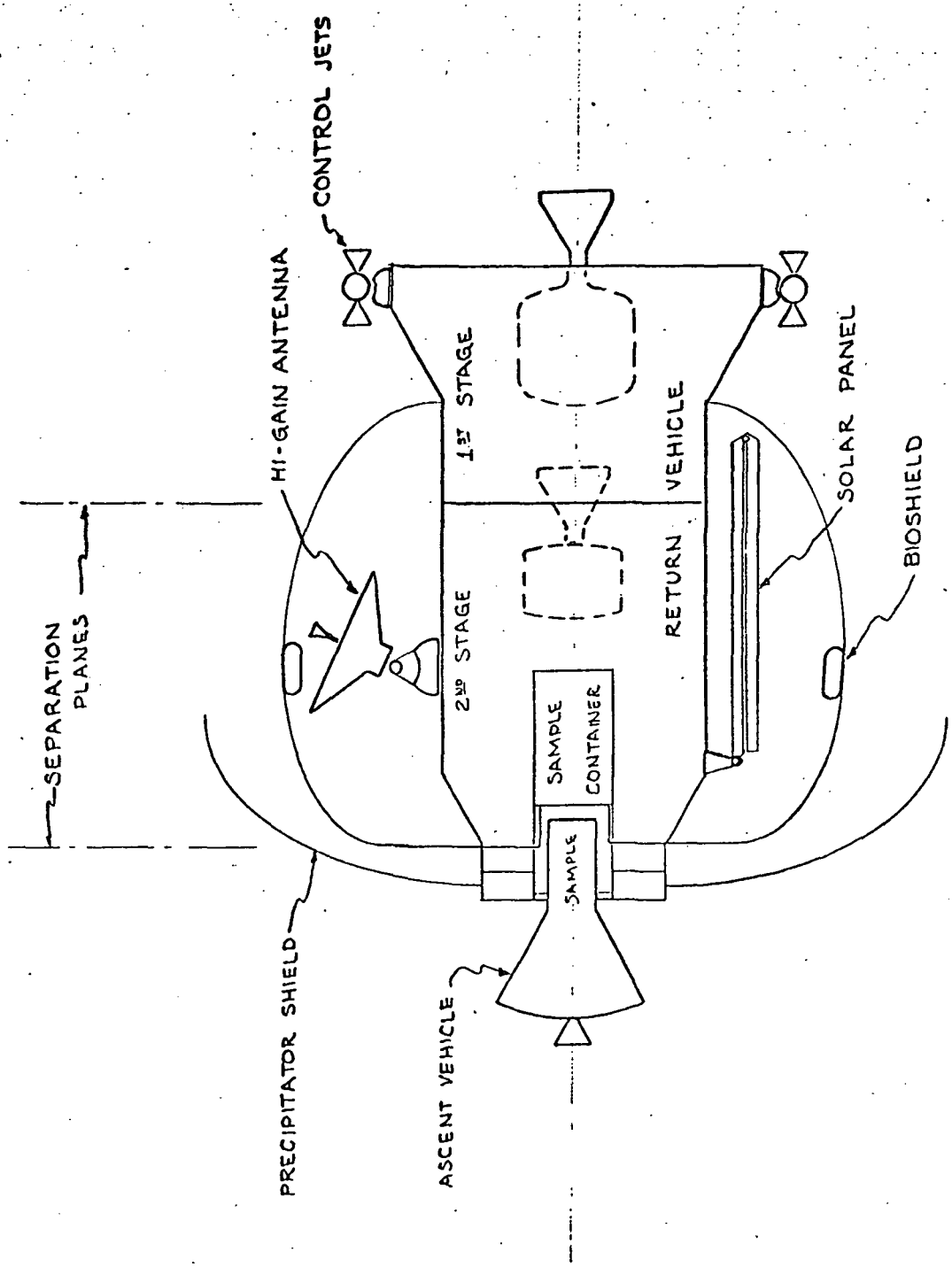

FIG 2 SPACECRAFT CONFIGURATION AT DOCKING IN MARS ORBIT

approach would be to use a bioshield which is deployed immediately prior to docking. The solar panels could be retracted for the duration of the docking. This may be desirable to prevent damage to the panels during docking in any case. The approach has the further advantage that the bioshield could be made of a light-weight flexible material since it would be protected from micrometeoroid and accidental damage through the majority of the flight.

A similar approach could be used to accommodate the high gain antenna. However, the use of this antenna is likely to be required during docking to receive commands and to transmit information regarding the spacecraft status including quarantine-related information, Fortunately, the antenna is relatively small so that it could be enclosed by the bioshield during docking provided the bioshield were made of radio-transparent material.

The control jet problem is not amenable to this type of solution. Since the gases must be expelled to permit the required reaction, the nozzles must have an unobstructed discharge path. Two basic approaches to the solution of the jet nozzle location problem were considered. The first possibility is to let the jets protrude through the bioshield and to perform a sterilization

procedure on the nozzles at a point in the journey when the contamination risk becomes low. This raises the possibility of leaks at the nozzle/bioshield interface and requires the development of a suitable sterilization procedure. A second and, in our view, more attractive approach is to locate the jets on a portion of the spacecraft which remains in Mars orbit. This second possibility is examined in more detail.

Because of weight restrictions on the ascent vehicle, we assume that the major burden of maneuverability will be placed on the orbiting spacecraft during docking and separation. Control jets will be required for all three axes of motion and a larger motor will be required to provide orbit correction for docking. Similar capabilities will also be required on separation in order to reorient the return vehicle prior to injection into a return orbit. If the control jet nozzles were located on the first stage of the return vehicle, this stage would not require bioshield protection since it would not reach Mars escape velocity. A second set of control nozzles would be required for the second stage return vehicle for midcourse correction and for maintenance of orientation during the return cruise. Since these nozzles need not be used during the docking procedure, they could be protected by the bioshield during docking. The bioshield would

then be jettisoned with the first stage of the return vehicle during injection into the return orbit but before Mars escape velocity had been achieved.

The bioshield configurations at various important times in the sample transfer process are illustrated in Figures 3 and 4. The bioshield can be of light-weight plastic or plastic impregnated fabric which is erected by inflating self-contained structural tubes. The bioshield can be designed to unfurl so as to move over the antenna without touching it. The seal at the second stage can be effected by inflating a circumferential tube on the aft portion of the bioshield. During injection, a similar circumferential tube at the sample return capsule end of the bioshield could be inflated to further unfurl this end of the bioshield to establish the jettison configuration. A slight positive pressure can be applied to the interior of the bioshield after it is erected to minimize the effects of small leaks and as backup insurance that the bioshield is not fouled on a spacecraft protuberance. Monitoring the gas flow required to establish this internal pressure could provide a measure of the bioshield integrity. Since the system is operating in a vacuum, the gas requirements for erection and pressurization will be small. During jettison, the internal pressure

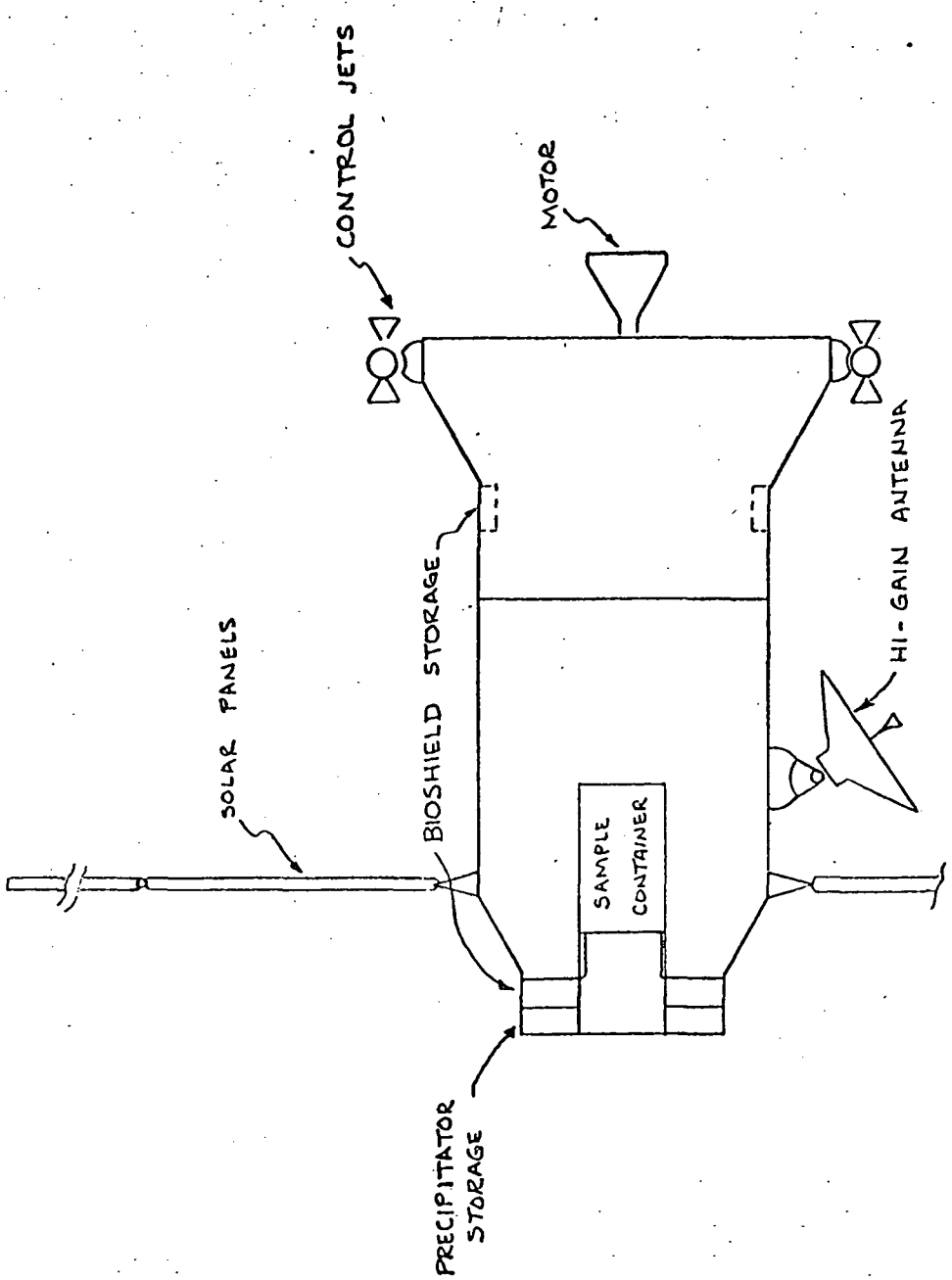

FIG. 3 RETURN SPACECRAFT CONFIGURATION PRIOR TO DOCKING

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FIG 4 BIOSHIELD CONFIGURATIONS

release would further act to prevent contamination transfer from the bioshield exterior to the return spacecraft.

A scheme has thus been devised for protecting the exterior surfaces of the return vehicle from contamination. It remains to formulate a method of getting the sample sealed and into the return spacecraft without contaminating the spacecraft. Jaffe et al (1) considered this problem in a JPL study for a Mars sample return. They propose a solution based on the use of a double seal and sterilization of the space between the two seals in the area of the entrance port. Figure 5 is from this report and illustrates the procedure.

A major problem with this technique is that it requires in-flight sterilization. Aside from the technical problems associated with implementing in-flight sterilization, there is the concern that such a sterilization technique may not really be effective since it would not have been thoroughly tested against Martian life. A primary objective of our study was to eliminate this requirement for in-flight sterilization during sample transfer from the ascent vehicle to the return spacecraft.

We have defined a transfer concept based on an adaptation of a technique described by McDade(10)which we feel offers the potential of an aseptic transfer and which does not rely on in-flight sterilization. This technique is illustrated in Figures 6 and 7, and described below.

PROCEDURE FOR PROVIDING EXTERNALLY-STERILE RETURN CAPSULE OR VEHICLE

(Dots indicate contamination)

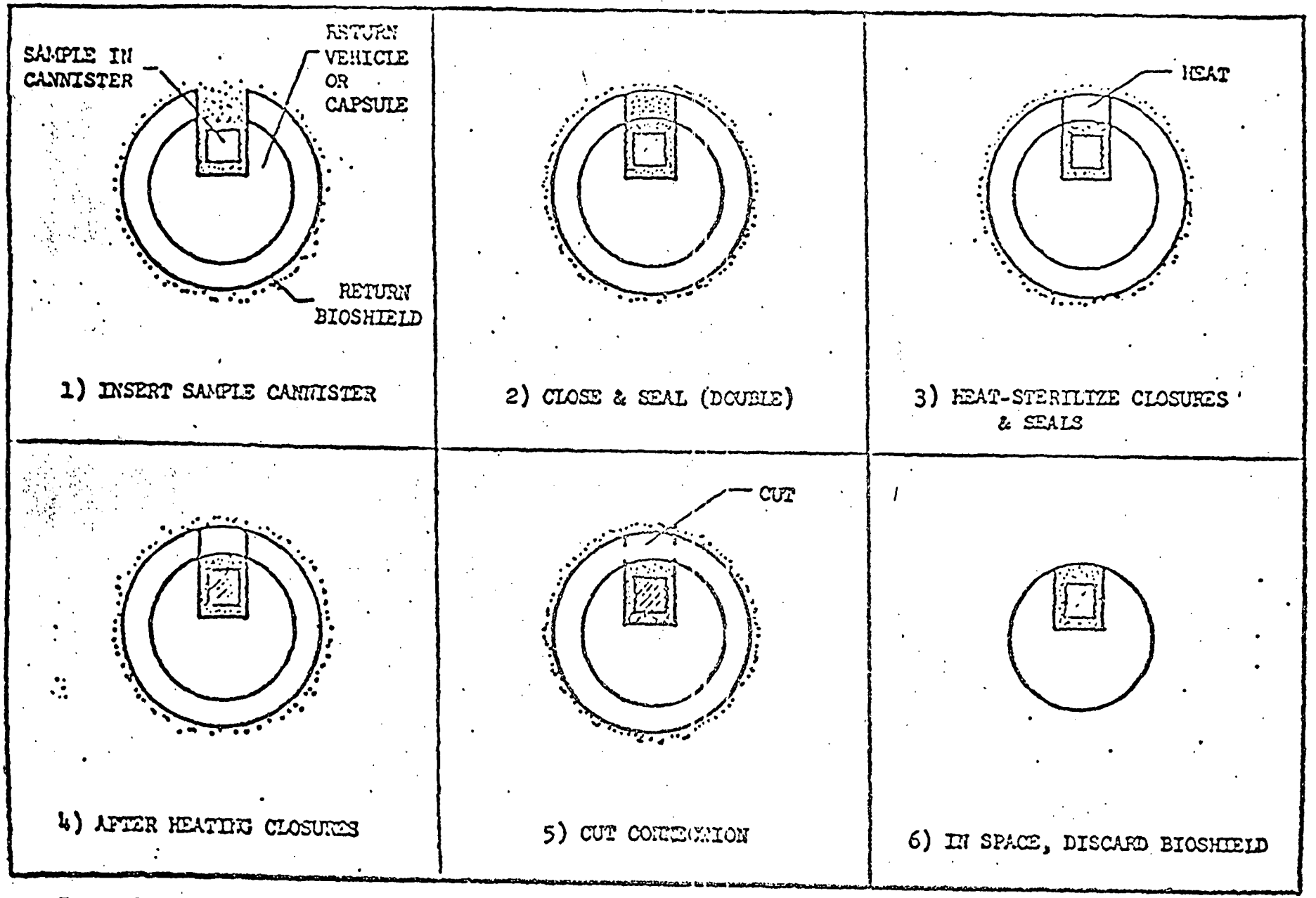

Figure 5

Reproduced from: Jaffe, L. D., et al, "Mars Surface Sample Return, Problems of Back Contamination," (Revision 2), Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif., June 1973.

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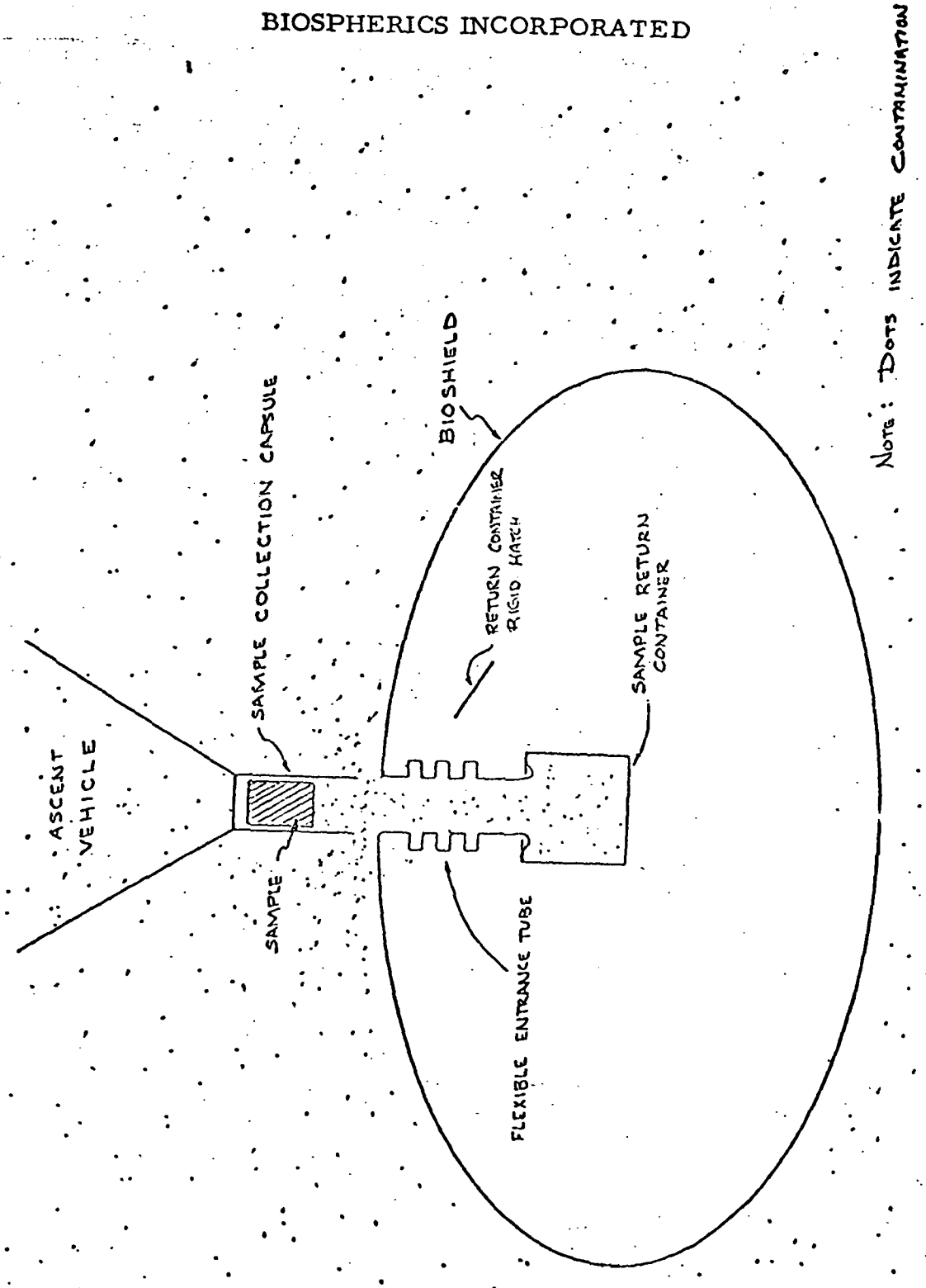

FIG 6 CONTAMINATION PROFILE AT DOCKING

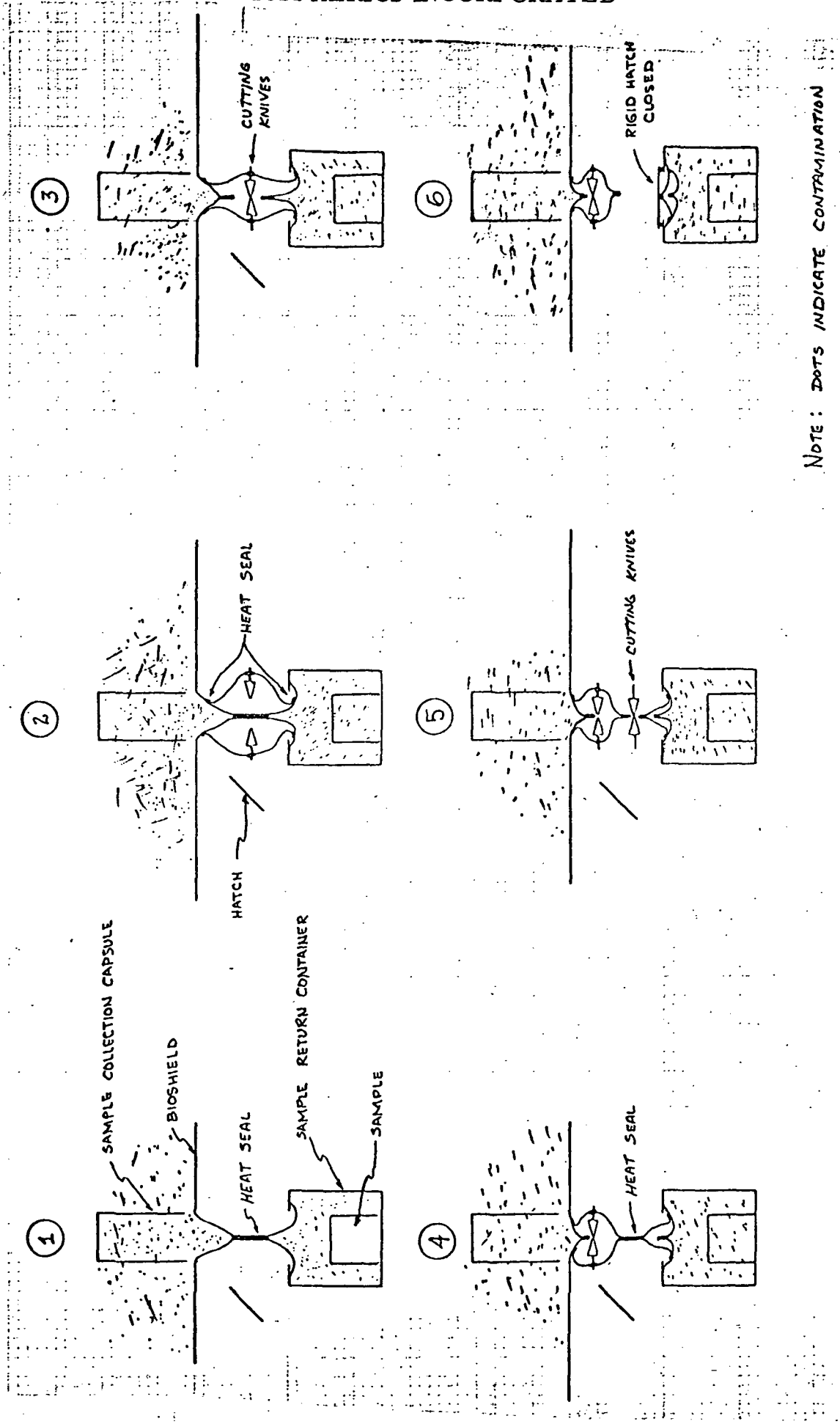

FIG 7 SAMPLE TRANSFER CONCEPT

Figure 6 illustrates the condition at docking. The sample is contained in a transferable capsule for this discussion. While this is not necessary for the described scheme, it will likely be the case since many of the scientists desire that the sample be sealed on Mars to protect its integrity. A flexible biobarrier is incorporated as the connection between the bioshield and the throat of the sample return container. Note that the sample return container is also provided with a rigid hatch which is protected from contamination by the bioshield.

The first stage in the transfer is comprised of physically moving the sample from the collection capsule in the ascent vehicle into the sample return container and heat sealing the flexible biobarrier entrance tube (Figure 7-1). The sample is isolated from the exterior of the spacecraft. One might simply cut the seal in two parts thus effecting the transfer, however, some concern would remain that microorganisms trapped in the heat seal might escape. This concern can be greatly reduced by proceeding through a second stage of isolation.

To affect this additional isolation a secondary barrier is heat sealed in place around the first seal (Figure 7-2). This barrier contains the separation knives to cut the first seal. The first seal is then

cut (Figure 7-3). The secondary barrier is then sealed (Figure 7-4) to form two compartments around the exposed ends of the first seal. The secondary heat seal is then cut (Figure 7-5). Finally, the rigid hatch of the sample return capsule is closed and sealed (Figure 7-6).

We believe that the above procedure could be implemented within the constraints of a Mars mission and, by eliminating the requirement for sterilization in-flight, offers significant advantages over the JPL technique. Even if surface sterilization is deemed necessary as an additional safeguard, the low-heat capacity of this type of bioshield would offer major advantages over typical metal structures. The concept is compatible with most sterilization concepts including:

- Heat sterilization of the biobarrier
- Heat sterilization of the spacecraft exterior
- Gaseous decontamination agents deployed between the bioshield and spacecraft.

4.2 Summary of the Sample Transfer at Docking in Mars Orbit

1. The sample has been placed in the sample collection capsule and sealed in a container.
2. A flexible bioshield is deployed around the second stage of the return vehicle prior to docking.

3. An electrostatic precipitator is used to minimize the bioload transfer from the ascent vehicle to the bioshield at docking.

4. The sample is transferred to the sample return container using flexible biobarrier and heat sealing techniques, thus effecting aseptic transfer without in-flight sterilization.

5. The electrostatic precipitator and its collected contamination are jettisoned with the ascent vehicle at the termination of docking.

6. The biobarrier is jettisoned with the first stage of the return vehicle during the initial phase of the return orbit injection maneuver.

4.3 Discussion of Sample Containment

In this section we will consider the problems of sample containment We have broken the problem down into the following subtopics for discussion.

- Size of the sample(s)
- Contamination of the sample(s)

The objectives of the presentation in this section are to define the problems, point out the implications for Planetary Return Missions, and summarize the known information relative to these problems.

Concepts for solving these problems and definition of areas requiring research and development are given.

4.3.1 Size of the Sample(s)

Jaffe et al at JPL (1) concluded that the minimum sample size required for current technology is 50 grams; that a 200 gram sample was highly desirable and caused negligible impact on the spacecraft parameters; and that biological and geological measurements on the same sample are not feasible. Table 2, which is reproduced from the JPL report, summarizes the sample size requirements as a function of the science to be performed.

Table 2. Minimum Sample Required[+]

Field of Interest	Determination	Minimum Sample Kind	Minimum Sample Mass, g	Reference Appendix
Biology	Evidence of life	2 mm size fraction	10	A
Biochemistry	Bio-organic compounds	2 mm size fraction	5	B
Geochemistry	Adsorbed gases, ices, sedimentary petrology	2 mm size fraction	10	C
Geochemistry	Geochronology	3-5 rock chips, 0.5 g each	2.5	C
Petrology	Igneous petrology	3-5 rock chips, 0.5 g each	2.5	C
Subtotal for 1 series of tests			30	
For follow-up tests and later investigations			20	
TOTAL			50	

[+] from Jaffe et al (1)

A one liter volume of atmosphere is also very desirable for the purpose of analyzing the isotopic composition of low-concentration gases. Reduction of the atmospheric sample size by compression, cooling, or adsorption in zeolite is said to be acceptable (1).

4.3.2 Contamination and Preservation of the sample(s). - Background Data

The JPL study (1) and a study conducted at Johnson Space Center (16) also considered in detail the level of contamination of the sample which could be tolerated without significant impact on the scientific results. The following material is reproduced from the JPL study in accordance with our desire to provide a self-contained summary of the information relevant to preservation of a Planetary Return Sample (PRS).

Sample Handling and Preservation

1. Contamination of sample. The lander propellants should not include any carbon compounds. Hydrazine, if used, should be purified to remove carbon. As a design goal, there should be no leakage or venting of propellants or stored gases on the surface of Mars until after the sample is sealed. Continued leakage is of great concern; it might be better to flush out lines quickly than to allow slow leakage. Undissociated hydrazine and its compounds are of greater concern than ammonia. One suggestion is to label nitrogen compounds in the propellants with a few percent of N^{15}, so nitrogen in the sample could be identified if it came from the propellant.

   There should be no outgassing of volatiles from spacecraft electrical or other components on the surface of Mars.

   Materials that contact the sample should be of high-purity metal. For biology and organic analysis, materials that are particularly undesirable and should not be allowed to touch the sample include organics and water-soluble compounds of the heavy metals. For geochemical examination, the containers (or its lining) should provide minimum interaction

with the Martian gas, including catalysis of gas reaction, and minimum transmission of gases, including hydrogen, by diffusion. (The surface should not be activated during manufacture.) The hydrogen loss, at partial pressures of 10^{-1} to 10^{-4} torr of free H_2, should not exceed 5% in two years. The container lining, scoop, and other sample-handling equipment should provide minimum chemical contamination of the sample, meeting the limits shown in Table 3. These limits may be waived for 1 or 2 elements constituting the major elements of the container lining, but in any case not for Pb. The isotopic composition of materials that may contact the sample should be known for the following elements: C, N, O, P, S, Si. The material touching the sample should be resistant to abrasion.

Table 3. Limits on Contamination of the sample (based on a worst-case low-silica sample)

Element	Contamination Limit
Si	10^{-3} g/g of sample:
Al, Ca, Fe, Ti	10^{-4} g/g of sample:
C, N, Na, Mg, S	10^{-5} g/g of sample:
Ag, As, Ba, Bi, Co, Cr, Cu, F, Hg, K, Li, Mn, Mo, Nb, Ni, P, Sn, Y, Zr	10^{-6} g/g of sample:
Rb, Sr	10^{-7} g/g of sample:
Pb, Th, U	10^{-9} g/g of sample:
Ar, He	10^{-8} cm^3STP/g of sample:
Kr, Xe	10^{-11} cm^3STP/g of sample:

2. Sealing. An extremely reliable vacuum-tight seal is essential. The maximum leak rate shall be equivalent to 10^{-10} cm^3/s STP of He under a pressure differential of 1 bar.

3. Temperature of sample. A goal should be to always keep the sample temperature below -30°C. This is based on the terrestial analogy that Antarctic microorganisms die if stored at -5°C for several months, but survive at -30°C. (Additional work on this question using Antarctic or similar microorganisms, is needed.)

   It is recognized that maintaining this temperature may be difficult. Accordingly, the following limits are proposed as requirements:

   (a) On Mars: at or below ambient temperature. This necessitates that sample acquisition and handling equipment be cooled to local ambient at the time the unsealed sample is handled. The sample should not be allowed to warm above the collection temperature until it is sealed.

   (b) In flight: below -30°C.

   (c) During Earth entry and recovery:

Required:	not to exceed +20°C
Highly desirable:	not to exceed 0°C
Desirable:	not to exceed -30°C

   In any case, the time above -30°C must not exceed a few hours.

   If the aim of preserving biological information is deleted, then the temperature is not to exceed +100°C, to prevent changes in hydrated minerals and organics. Except for short periods, the temperatures should not exceed +20°C.

4. Radiation at sample. As a design goal, the sample should not be exposed to more than 10^2 rem. In general, minimal radiation exposure is desired. A radio-isotope thermoelectric generator on the return vehicle is highly undesirable. Otherwise, no shielding is required.

5. Magnetic fields at sample. These should not exceed the Earth's field.

6. Vibration and mechanical preservation. Sample particles should be kept from rubbing against each other and against the container. A plug, perhaps spring-loaded, may be used to maintain a small compressive load. If a core is taken ("Enhancement", below), its stratigraphy should be preserved. If two samples are taken (below), they should be kept separate and identified.

7. Monitoring of sample during return. At the minimum, conditions of the sample during its return should be monitored in the following ways:

Temperature: A thermal sensor on the outside of the sample container, and a sensor recording the maximum temperature attained on the inside of the sample container during the time that the sample is within it.

Radiation: Undeveloped film ("film badge") to record the integrated flux received by the sample after acquisition.

Pressure monitoring of sample container(s) for leaks may be in handling problems of back-contamination and of opening the containers after return. Such monitoring would not need to be continuous.

4.3.3 Discussion of the Implications of the Sample Contamination and Preservation Criteria.

In this subsection we will consider the implications for the sample container of the contamination and sample preservation criteria.

4.3.3.1 Initial Container Cleaning and Sterilization:

The problems of initial cleaning and sterlization of spacecraft components have received extensive treatment in various NASA programs. Life detection apparatus has been addressed in the Viking program. While there is some disagreement about the efficacy of the techniques against all Earth life forms, we assume that these techniques and logical extensions to be developed in the period prior to a PRS mission are adequate to meet the needs of the PRS programs.

The primary implications for the PRS containers are:

(1) the material and design should be compatible with heat sterilization to 125°C (Possibly as high as 250°C if sterilization of the return sample is required)

(2) the materials should have low reactivity to the common chemical and ultrasonic cleaning methods.

(3) the surface finishes of the materials should be very smooth and the design should minimize small cavities which are difficult to clean.

It is probable that a long duration high temperature-high vacuum desorption procedure will be required to meet the contamination constraints. A convenient reference for decontamination and cleaning is provided by NASA's Contamination Control Handbook (17).

4.3.3.2 Permeation of the Sample Container by Gases.

In order to meet the desired hydrogen leak rate and the contamination specifications for the rare gases, Ar, He, Kr, and Xe, the sample container must be designed for low permeability and low adsorption of these gases. Three separate and distinct aspects of the problem must be considered.

(1) contamination of the sample by gases of the Earth's atmosphere permeating the walls of the container.

(2) contamination of the sample by desorption of terrestial gases stored in solution or adsorbed on the surfaces of the walls of the sample container.

(3) the escape or adsorption of the sample through or into the walls of the container.

The subjects of gas permeation and adsorption and desorption have been extensively investigated by technologists in the field of high vacuum because these phenomena usually limit the quality of vacuum attainable. The basic process of permeation which includes adsorption, diffusion, and desorption of a gas in and on a container wall is illustrated in Figure 8. A gas molecule, initially free in the left half of the figure, is adsorbed on the surface of the container wall. It enters into solution in the wall and diffuses through the wall to the other side where it is desorbed. Dushman (18) and Barrer (19) treat the process

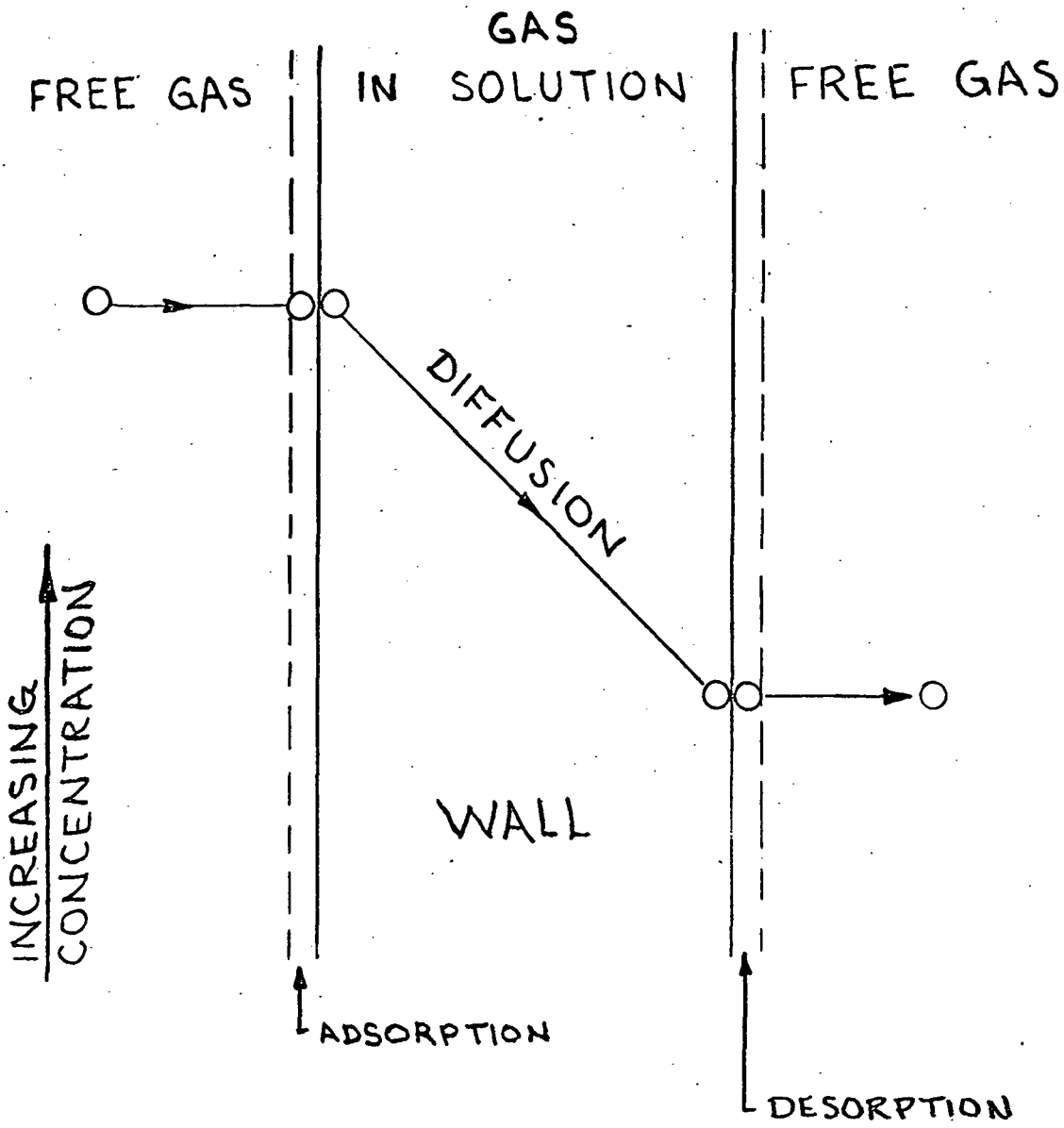

FIG 8. THE GASEOUS PERMEATION PROCESS

in detail giving the theory and specific data for many materials of interest. Norton (20) summarizes the important results. It is our purpose here to interpret the basic data in terms of the implication for suitable materials and thickness for the PRS container.

The first problem we will consider is that of contamination of the sample by gases of the Earth's atmosphere permeating the walls of the sample container. This category of the total contamination problem is of significance to the PRS technology because:

1. It may be desirable to store the sample for long periods once it has been brought to Earth.
2. Through a non-nominal recovery, the sample might be lost and later recovered thus inadvertently subjecting the sample to long periods of storage.
3. In order to design the sample handling and storage procedures it is necessary to have detailed knowledge of the effect of various ambient conditions on the container and the ultimate sample integrity.

Table 4 from Norton (20) gives the qualitative assessment of gaseous permeation through various materials.

Table 4

Gas Permeation Through

(In all, rate an exponential function of temperature for true permeation)

Glasses	Metals	Semi-conductors	Polymers
He, H_2, D_2, Ne, Ar, O_2 measurable through SiO_2	No rare gas through any metal	He and H_2 through Ge and Si.	All gases permeate all polymers.
	H_2 permeates most, especially Fe.	Ne, Ar not measurable	Water rate apt to be high
Vitreous silica fastest	O_2 permeates Ag.		Many specificities
	H_2 through Fe by corrosion, electrolysis, etc.		
All rates vary as pressure directly	Rates vary as $\sqrt{}$ (pressure)	H_2 rate varies as $\sqrt{}$(pressure)	All rates vary as pressure

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Norton also considers in detail the gaseous accumulation in a silica bulb of about the same size as our expected sample container. Silica will be shown to be one of the important materials for the sample container since it transmits ultra violet light. This data is useful since it illustrates the process and provides a reference for other materials. The atmosphere constituents and abundances in the standard Earth atmosphere are summarized in Table 5.

Table 5
Atmospheric Abundances+

	% by volume	Partial pressure (in mm)
N_2	78.08	5.95×10^{2}
O_2	20.95	1.59×10^{2}
Ar	0.93	7.05
CO_2	0.033	2.5×10^{-1}
Ne	1.8×10^{-3}	1.4×10^{-2}
He	5.24×10^{-4}	4.0×10^{-3}
Kr	1.1×10^{-4}	8.4×10^{-4}
H_2	5.0×10^{-5}	3.8×10^{-4}
Xe	8.7×10^{-6}	6.6×10^{-5}
H_2O (50%RH, 25°C)	1.57	$1.19 \times 10^{+1}$
CH_4	2×10^{-4}	1.5×10^{-3}
O_3	7×10^{-6}	5.3×10^{-5}
N_2O	5×10^{-5}	3.8×10^{-4}

+ Data from Norton (20)

These atmospheric parameters in combination with the specific permeation rates are used to calculate the order of flow of the gaseous constituents into an evacuated silica bulb. The flow rates per unit area are summarized in Table 6., and the total accumulation as a function of time is illustrated in Figures 9 and 10.

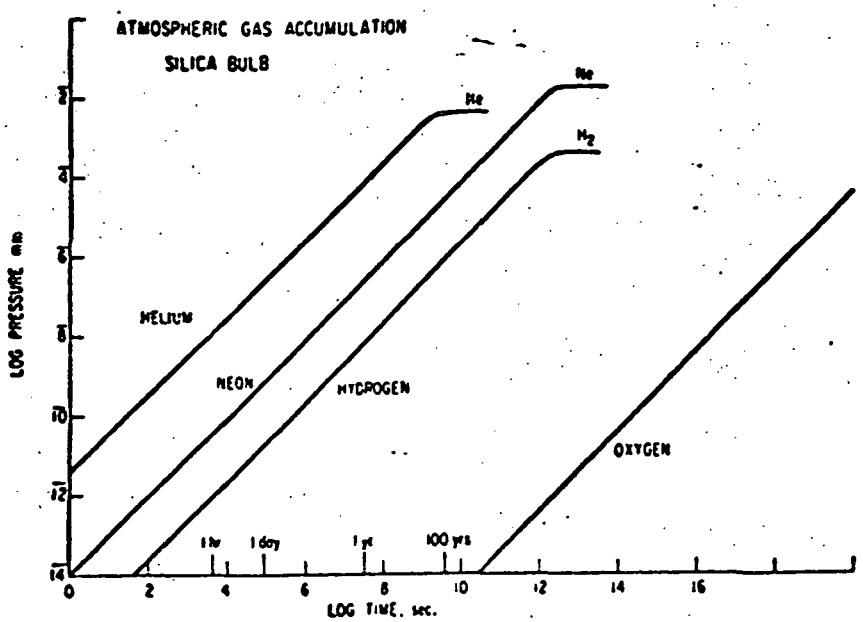
We can convert the desired maximum contamination levels specified in Table 3 to a form compatible with the data in Figure 9 to derive a basis of comparison. If we assume a 200 gram sample and a container roughly the size used in Figure 9, the specifications become:

Ar, He: 10^{-8} cm^3 STP/g → 4.6×10^{-6} mm partial pressure,

Kr, X: 10^{-11} cm^3 STP/g → 4.6×10^{-9} mm partial pressure.

Referring back to the data in Figure 9, we find that, if the container were made of one mm thick silica, the contamination level of helium would exceed the desired value in about one month of exposure to the Earth's atmosphere. The permissible exposure to an atmosphere containing a high concentration of helium such as might be used for leak detection or in conjunction with cryogenic equipment, would be very short.

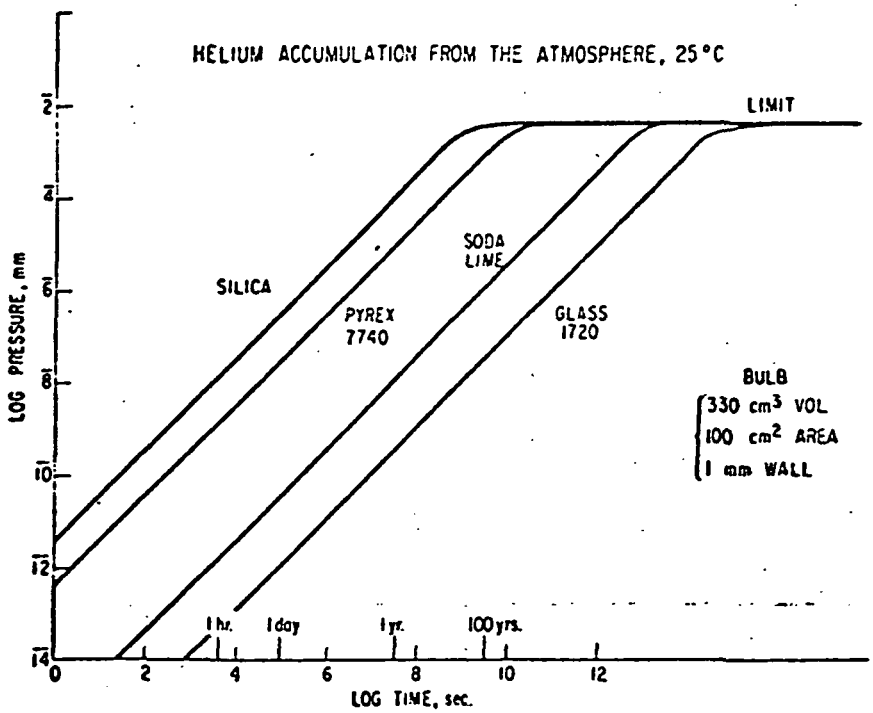
The above analysis indicated that if silica is used in the sample container construction, it should be held to a relatively low surface area and be several mm thick to provide a sufficiently low helium permeation rate to meet the desired contamination levels. Further, if silica is used, care must be taken to insure that the sample container is not exposed to a high helium concentration even for a short time.



Atmospheric gas accumulation, 25°C, in a silica bulb, 330 cm^3 vol, 100 cm^2 area, 1 mm wall thickness. Log_{10} pressure (in mm) vs. log_{10} time (sec).

Figure 9+

Gas Permeation through the Vacuum Envelope



Helium accumulation from the atmosphere in bulbs of different glasses, 25°C. Log_{10} pressure (mm) vs. log_{10} time (sec).

Figure 10+

+ Data reproduced from Norton (20)

Table 6[+]

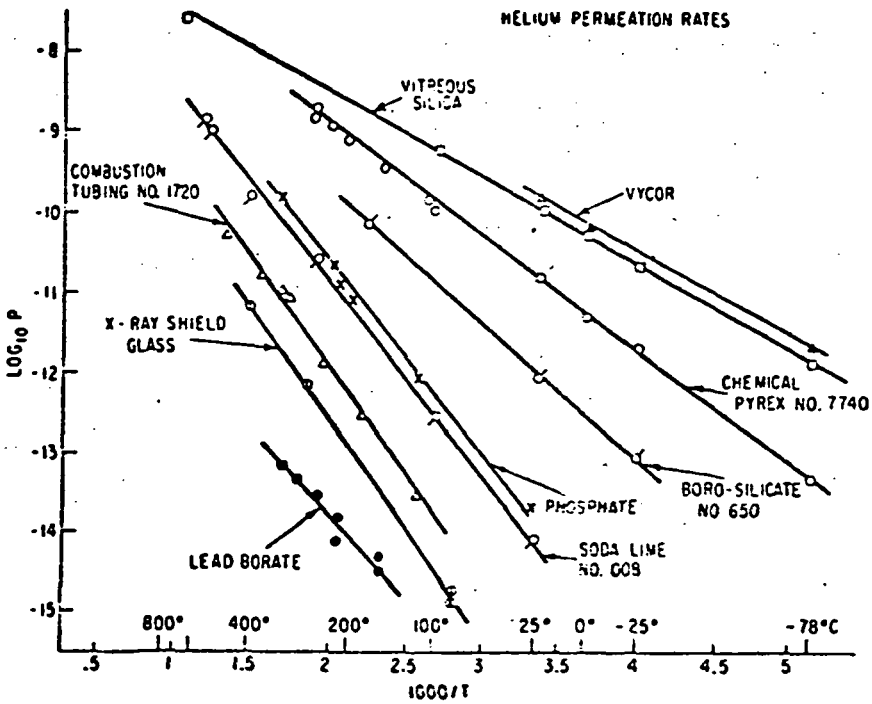
Order of Flow of Atmosphere into Evacuated SiO_2 Bulb at 25C°
(for 1 mm thick, 1 cm^2 area)

	Atmospheric abundance, C cm partial pressure	Permeation rate, P	CxP= inflow (cm^3/sec)	Order of inflow	Atoms per sec
N_2	5.95×10^{1}	2.0×10^{-29}	1.2×10^{-27}	5	
O_2	1.59×10^{1}	1.0×10^{-28}	1.6×10^{-27}	4	
Ar	7.05×10^{-1}	2.0×10^{-29}	1.4×10^{-29}	6	
Ne	1.8×10^{-2}	2.0×10^{-15}	3.6×10^{-17}	2	900
He	4.0×10^{-4}	5.0×10^{-11}	2.0×10^{-14}	1	500,000
H_2	3.8×10^{-5}	2.8×10^{-14}	1.0×10^{-18}	3	25

[+]Data from Norton (20)

Metals are not permeable to any of the rare gases He, Ar, Ne, Kr, Xe so that in terms of contamination by these gases, metals offer the best protection.

Helium permeation rates for other glasses are illustrated in Figure 11 from Norton (20). While almost all glasses have lower permeation rates than fused silica, they do not transmit as much ultraviolet light and they are in general more sensitive to chemical attack and leaching of metal ions. This subject will be more fully discussed in the section on chemical reactivity.



Helium permeation rate P through various glasses. Units of P: cm³ gas (STP) per sec for 1 mm thick per cm² area per cm gas pressure difference. Plot is $\log_{10}$ vs. $1000/T$.

Figure 11+

+ Data reproduced from Norton (20)

The next problem we will consider is the escape or adsorption of the sample through or into the walls of the container. If we assume the container walls are either a metal or glass the major problem is to prevent hydrogen from escaping or being adsorbed. Table 7 from Barrer (19) summarizes the reactivity of metals towards gases. We note from this table that the noble gases are not soluble in any metal.

In Appendix A, we show that the hydrogen leak criteria of not more than 5% at partial pressures from 10^{-1} to 10^{-4} torr is equivalent to the approximate permeation rates shown in Table 8 for sample containers of interest to PRS technology.

The data in the table are computed on the assumption of a 1 mm thick wall. The permeation is inversely proportional to thickness.

The permeation criteria in Table 8 are given in the various units commonly in use. Note that the pressure differential under which the measurement is made is important and that metals have permeabity which is a function of the square root of the pressure differential while the permeability of glasses varies directly with the pressure.

We have computed the permeation constant for a number of representative materials from data given in Dushman (18). Table 9 summarizes these data at three temperatures. Typical storage temperatures of -30°C and +25°C are considered and a sterilization or non-nominal temperature of 125° C is also considered.

Table 7

Summary of the reactivity of metals[+] towards gases

Gas	Group	Metals which dissolve gas	Group	Metals which do not dissolve gas
H_2	IA	Hydrogen gives salt-like hydrides	IB	Au
			IIB	Zn, Cd
	IB	Cu, Ag (slight)	IIIB	In, Tl
	IIA	Hydrogen gives salt-like hydrides	IVB	Ge, Sn, Pb (but give covalent hydrides)
	IIIA	Al. Rare earths Ce, La, Nd, Pr	VB	As, Sb, Bi (but give covalent hydrides)
	IVA	Ti, Zr, Hf, Th	VIB	Se. Te give covalent hydrides
	VA	V, Nb, Ta		
	VIA	Cr, Mo, W	VIII	Rh
	VIIA	(Mn)		
	VIII	Fe, Co, Ni, Pt, Pd		
O_2	IB	Cu, Ag		
	lVA	Zr		
	VIII	Fe, Co, (Ni)		
N_2	IIIA	Al (molten)	IB	Cu, Ag, Au
	IVA	Zr	IIB	Cd
	VA	Ta (nitrides)	IIIB	Tl
	VIA	Mo (nitrides only), W (nitride)	IVB	Sn, Pb
			VB	Sb, Bi
	VIIA	Mn (various nitrides)	VIII	Rh
	VIII	Fe (various nitrides		
CO	VIII	Ni, Fe (above 1000°C.)	lB	Cu
SO_2	lB	Cu (liquid), Au (liquid)	VIII	Pt
He				Do not dissolve in any metal so far studied either when liquid or solid
Ne				
Ar				
Kr				
Xe				
CO_2	VIII	Fe	VIII	Rh, Pt

[+]Data from Barrier (19)

Table 8. Maximum Permissible Permeation for 1mm wall thickness

UNITS	$\frac{\text{atm-cc}}{\text{cm}^2 \text{ sec}}$	$\frac{\text{atm-cc}}{\text{cm}^2 \text{ sec}}$	$\frac{\text{atm-cc}}{\text{cm}^2 \text{ min}}$	$\frac{\text{micron-liter}}{\text{cm}^2 \text{ sec}}$	$\frac{\text{micron-liter}}{\text{cm}^2 \text{ min}}$
Differential Pressure	1 cm	1 atm	1 atm	1 atm	1 atm
Log_{10} Permeation (metals)	-13.6	-12.6	-10.9	-9.7	-8.0
Log_{10} Permeation (glasses)	-11.1	-9.2	-7.4	-6.3	-4.5

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Table 9. Hydrogen Permeability of Materials +

Material	Permeability: Log base 10 micron-liter / cm^2 min P = 1 atm, 1mm thickness, 0°C		
	T = -30°C	T = +25°C	T = +125°C
SiO_2	-7.8	-6.3	-4.8
Ni	-7.9	-5.7	-3.2
Pt	-12.0	-9.0	-5.7
Pd	-3.8	-2.0	0
Cu	-11.5	-8.7	-5.7
Fe	-5.3	-3.7	-2.0
Al	-22.0	-16.9	-11.2
Mo	-14.1	-10.8	-7.0
Au, Zn, Cd, In, Tl, Rh	Do not dissolve hydrogen No Permeation		
As, Sb, Bi, Se, Te	Do not dissolve hydrogen but form covalent hydrides		

+ Computed from data in Dushman (18)
Permeating gas volume at 0°C.

The values of permeability listed in Table 9 show that a large fraction of the candidate materials for the sample container must be eliminated on the basis of excessive permeation for hydrogen. We have used these data in conjunction with other relevant data (18, 19, 21) with respect to these representative materials to prepare an elimination chart. The chart, in the form of a periodic table of elements, is presented as Figure 12. A single line through the element indicates that the material is unsuitable on the basis of poor high temperature properties. A cross through the element indicates poor properties at storage temperature. Two vertical bars plus one horizontal bar indicate that the material

reacts with hydrogen to form hydrides. A crosshatch symbol indicates the formation of salt-like hydrides. An "E" in the upper right hand corner indicates a material with particularly good properties. The gaseous elements are indicated by a diagonal bar.

On the basis of the preceding analysis, we are left with a number of materials which are known to have good properties with respect to reaction and permeability of hydrogen; another group with less desirable, but satisfactory, properties, and a final group with unknown but perhaps useful properties. These materials are summarized in Table 10.

Table 10

Summary of Materials With Respect
to Hydrogen Reactivity and Permeation Criteria

Materials with known good properties	Au, Zn, Cd, In, Te, Rh
Materials with known fair properties	Ag, Al
Materials with unknown properties but which may be satisfactory	Ga, Hg, W, Re,

4.3.3.3 Chemical and Biological Reactivity

In our examination of the potential usefulness of materials for PRS we compared the properties of the elements against the following criteria:

1. The element must be inert under the range of electrochemical conditions expected to exist within the sample container.

2. The element must be available in pure form.

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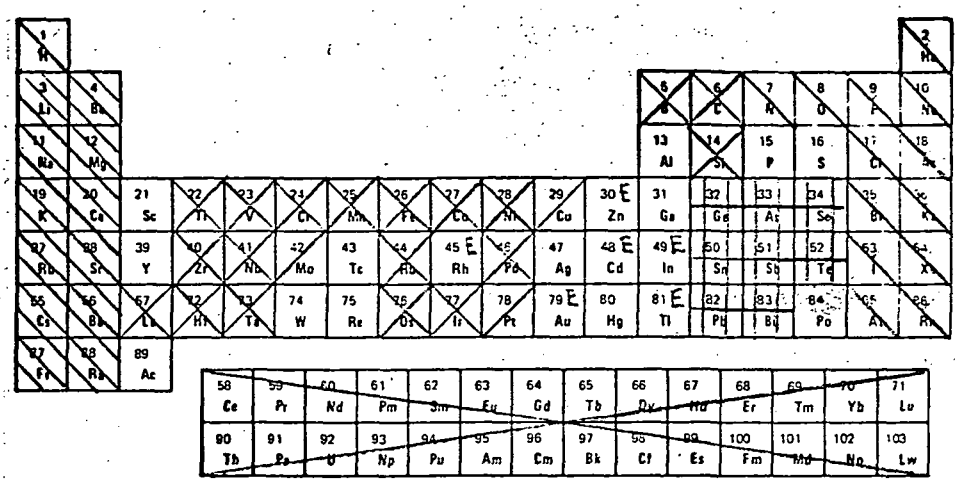

Figure 12. Rejection Criteria:
Reaction to hydrogen

Legend:

Forms salt-like hydrides

High permeation - all temperatures

Poor high temperature properties

Forms hydrides

Excellent properties

Gaseous element

3. The element must not be radioactive.

4. The element must not act as a catalyst.

5. The element must have low toxicity to earth life forms.

We conducted our analysis by a process of elimination in stages beginning with the obviously unsuitable elements and progressing to more detailed analysis for each stage in the elimination process. A periodic chart of the elements, illustrated in Figure 13, formed the basis for discussion of the interesting properties.

We were able to eliminate groups VIIb and O and the elements N and O on the basis of their gaseous state at applicable temperatures. The elements in groups Ia, IIa, and IIIa were eliminated because of their very high chemical reactivity. The elements Fr, Ra, and Ac are also radioactive. The Lanthanide series, 4f, was eliminated because of poor chemical stability and/or lack of availability of the elements in pure form. The Actinide series, 5f, and the elements Po, Tc were eliminated since the elements are radioactive. Fig. 13 illustrates the elements eliminated on the basis of this preliminary screening.

The next stage of the elimination process consisted of considering in more detail the chemical reactivity and known toxicity of the elements (22, 23, 24). The entire question of toxicity is a very broad and difficult one since the toxic actions are diverse and dependent on concentration in many cases. Brookes (23) and Bowen (24) have reviewed

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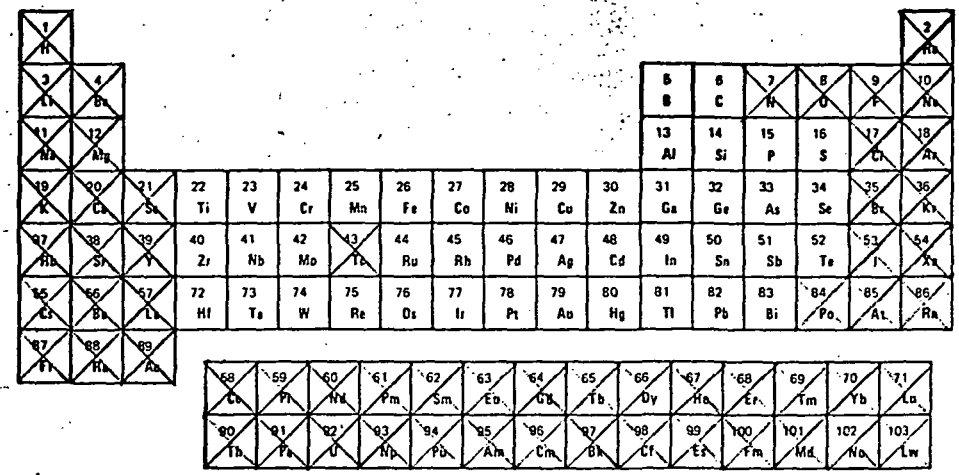

Figure 13. Stage I Preliminary Screening
Radioactivity, Chemical Reactivity, Physical

Indicates element eliminated from further consideration

the toxicity problem and give qualitative data relative to known toxicity. We have listed an element as being potentially toxic if we found evidence of toxicity for any life form. Figure 14 illustrates the elements eliminated on the basis of this more detailed screening.

The elements Ni, Pd, Pt, Rh, Ru, Re, Fe, and Cr are known to be active catalysts and were eliminated on this basis.

In the next stage of our elimination process, we considered the corrosion properties of the surviving elements from the standpoint of their Pourbaix diagrams (25). The Pourbaix diagram is a graphical representation of the reactions possible in a given system as a function of the pH of the solution and electrode potential. The two sloping dashed lines in the diagrams represent the upper and lower bounds of the central region in which water is thermodynamically stable and cannot be electrolyzed into hydrogen and oxygen. The Pourbaix diagrams for the elements under consideration are reproduced (25) here for convenience.

We are interested in the electrode potential since a potential difference between materials used in the container could arise from differences in work function of the materials. Table 11 lists the work functions (22) for the elements of interest.

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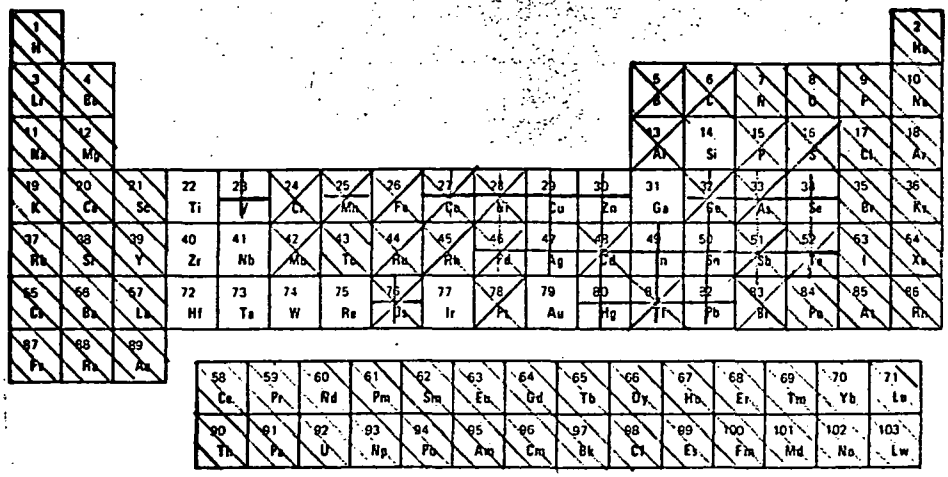

Figure 14. Stage II Rejection

Legend: Eliminated on basis of:

Chemical reactivity or catalyst

Biological toxicity

Both

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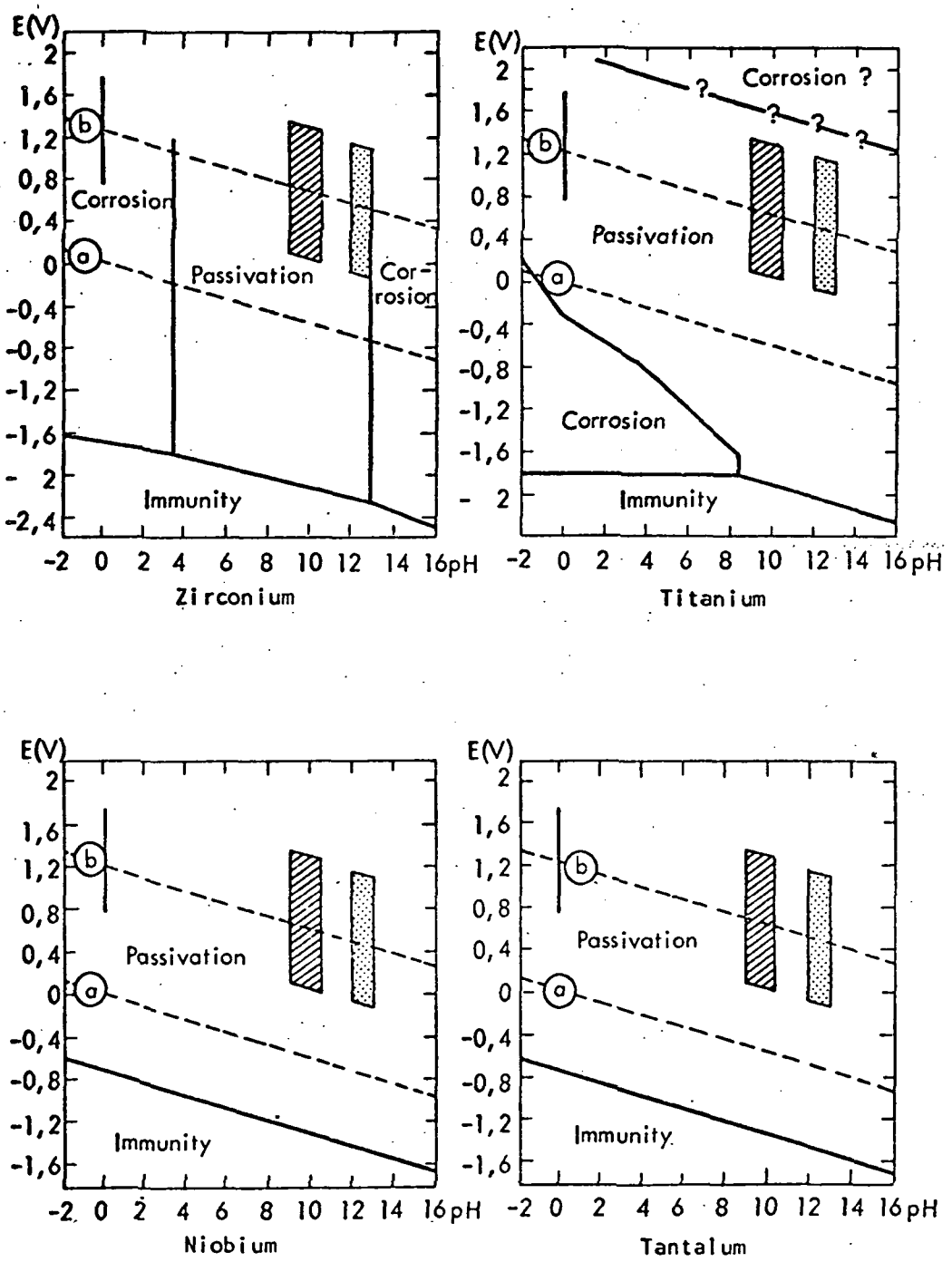
POURBAIX DIAGRAMS



POURBAIX DIAGRAMS - ZIRCONIUM, TITANIUM, NIOBIUM, TANTALUM

Figure 15

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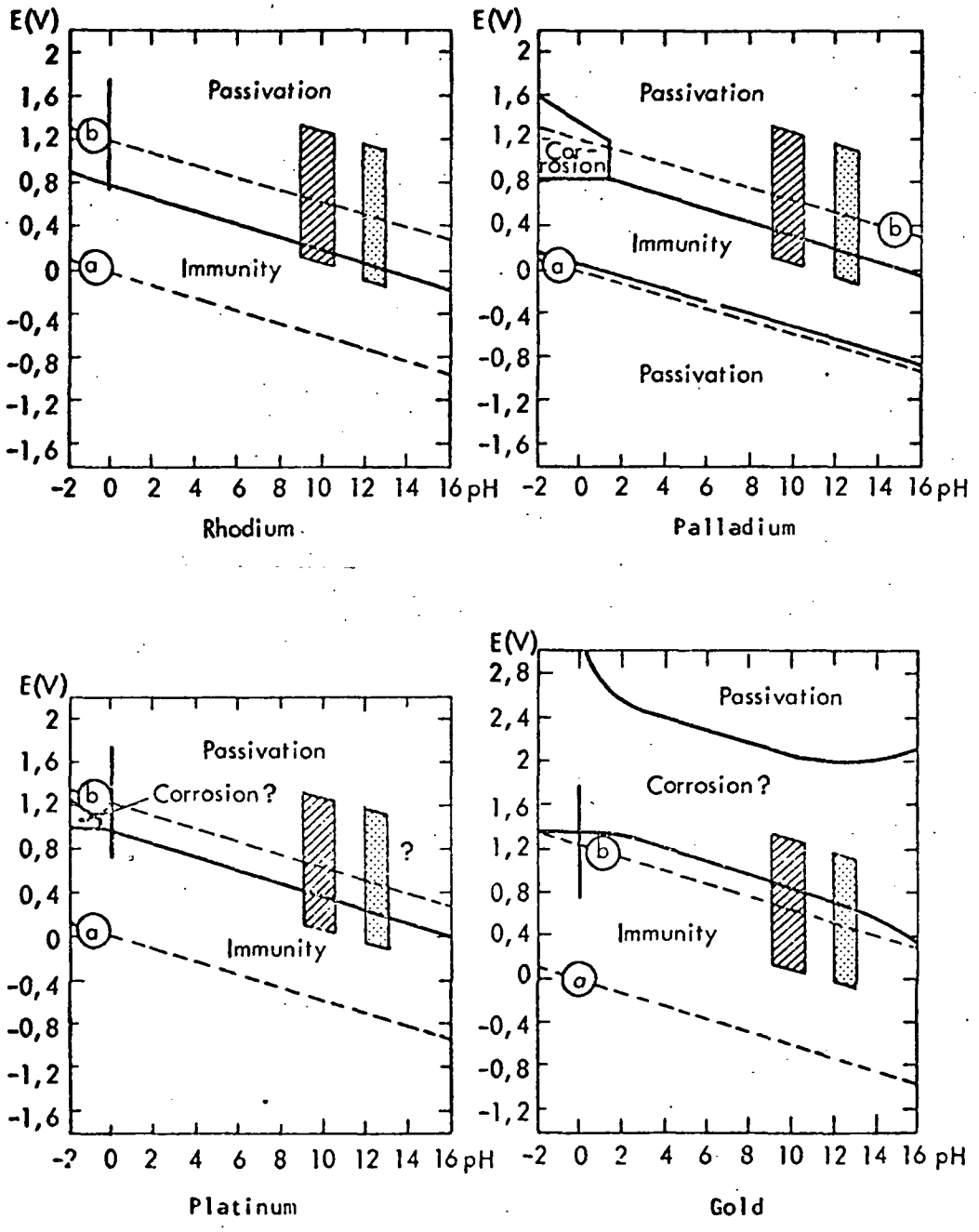
POURBAIX DIAGRAMS



POURBAIX DIAGRAMS - RHODIUM, PALLADIUM, PLATINUM, GOLD

Figure 16

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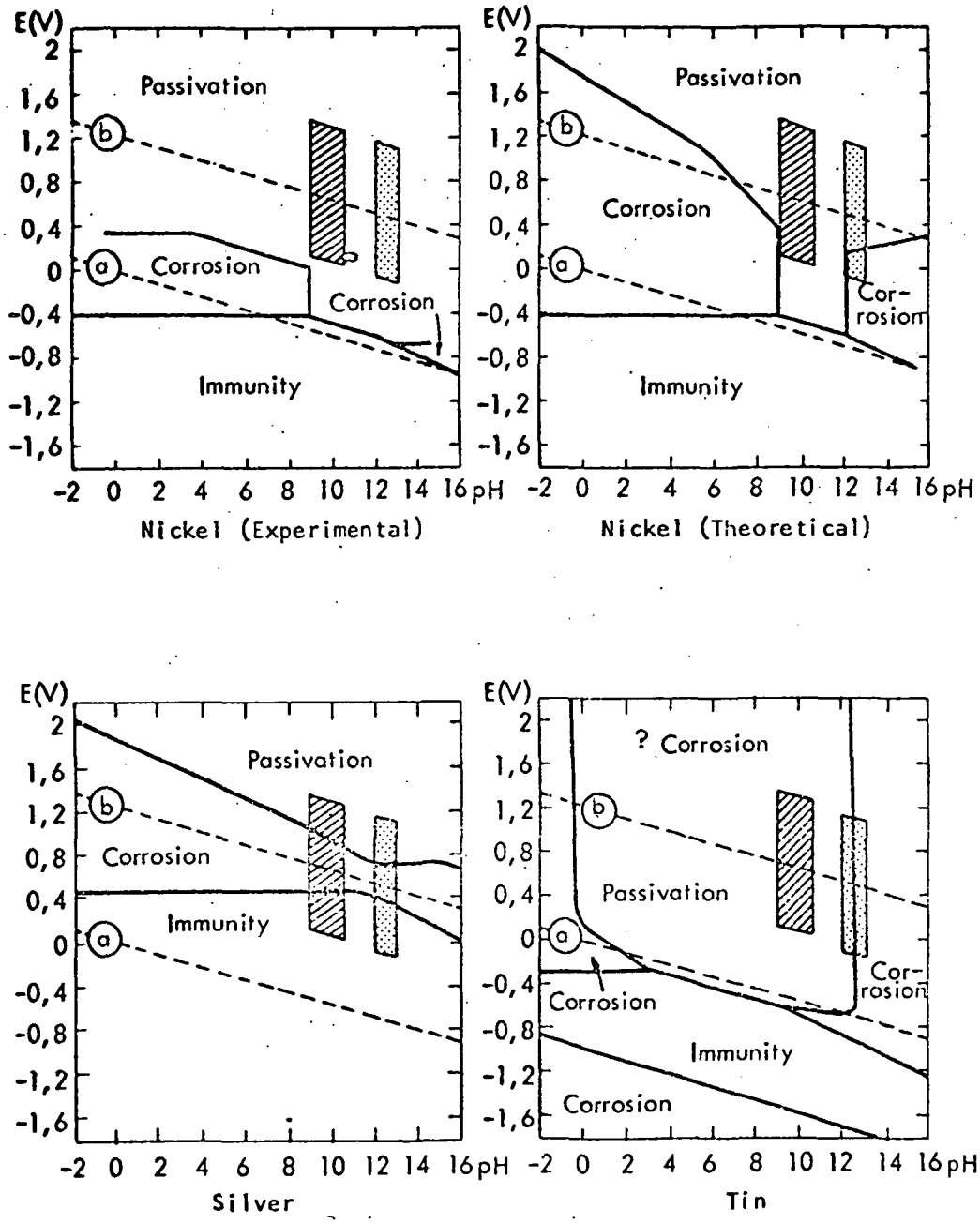
POURBAIX DIAGRAMS



POURBAIX DIAGRAMS - NICKEL, SILVER, TIN

Figure 17

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POURBAIX DIAGRAMS

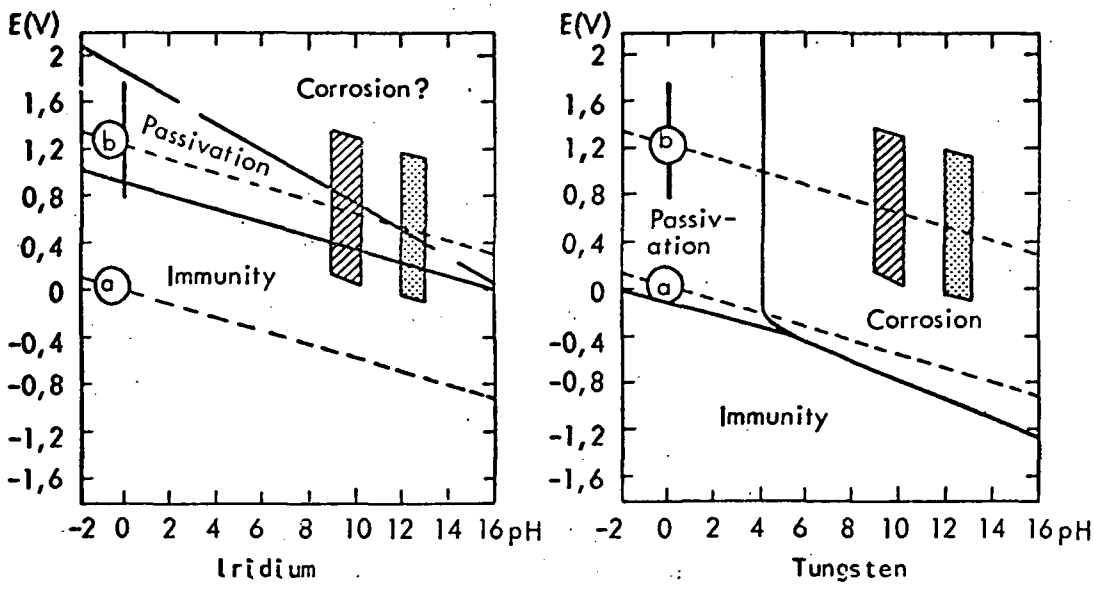

Figure 18

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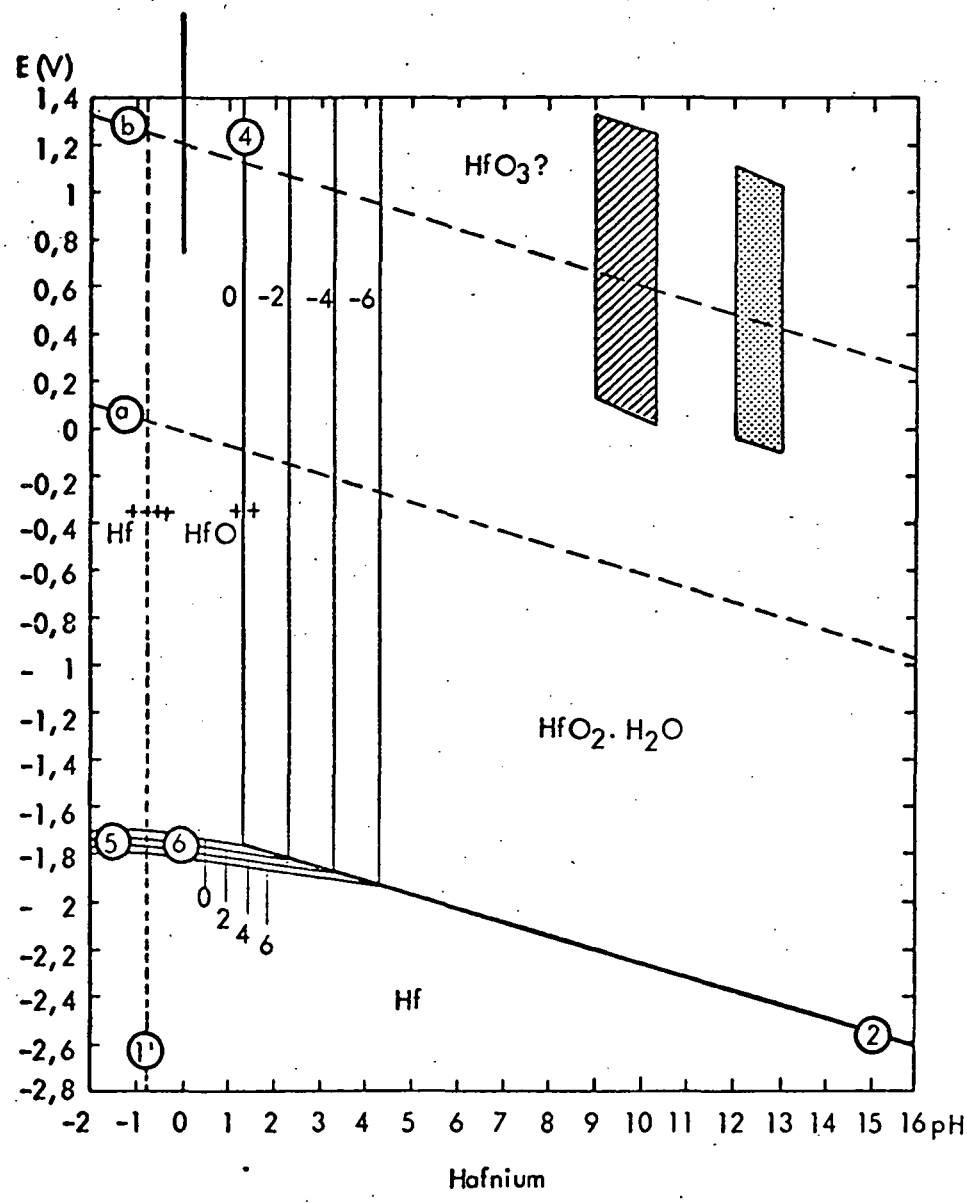
POURBAIX DIAGRAM



POURBAIX DIAGRAM - HAFNIUM

Figure 19

Table 11. Work Functions of Candidate Elements

Element	Work Function[+] (eV)
Au	4.46
Ga	3.80
Hf	3.53
Ir	4.57
Mo	4.08 - 4.48
Re	4.74 - 5.1
Si	4.2
Ta	3.96 - 4.25
Ti	4.14
W	4.38
Zr	3.60

[+]Data from (22)

An examination of the Pourbaix diagrams reveals that many of the elements noted for corrosion resistance are dependent on passivation for their properties. The most common cause of passivation is the formation of a stable oxide coating on the metal surface. This phenomenon is exhibited by Ti, Zr, Nb, Ta, Sn, and Hf which are really highly reactive metals protected by an oxide film. If for any reason the protecting oxide film breaks down, for example due to mechanical scraping, the bare metal would enter into a reaction with the sample. In an oxygen rich environment the protective film would quickly reform and heal itself. However, in a planetary atmosphere lean in free oxygen, the reaction might continue or other oxides might be reduced in the process of healing.

Since gold and iridium have a much larger range of true immunity against reactivity and exhibit lower toxicity than the other surviving elements, we believe they are better choices for the sample container. Table 12 summarizes the suitability of the elements on the basis of chemical and toxicity criteria.

Table 12. Suitability of Elements
Based on Chemical and Toxicity Criteria

Properties	Elements
Excellent	Au, Ir
Good (if passivated)	Ti, Zr, Nb, Ta, Hf
Fair	W

Brookes (23) gives a detailed discussion of the chemical and biological properties of the glasses. He finds the glasses to be satisfactory materials for biological applications. Glasses are relatively stable materials except under strong alkali action. Fused quartz is available with very low impurity levels and for this reason, and its higher ultraviolet transmission, we feel fused quartz has advantages over the common glasses. Brookes notes that boundary surface effects do occur in which some cations (H+) are removed from the silicic acid of the glass and enter solution. This causes the glass surface to acquire a negative charge with a diffuse region of mobile cations in proximity to the surface. This then promotes an enhanced concentration near the walls of specific ions from the bulk of the solution. As a consequence, there is a propensity for life forms to migrate or grow into these enriched areas and attach themselves to the walls.

4.3.3.4 Summary of isotopes of potentially useful elements.

Table 13 summarizes the naturally occurring isotopes for those elements which are potentially useful in the construction of a planetary return sample container. We note that gold has only one naturally occuring isotope. The requirements to know the isotopic composition of any Si and O touching the sample could raise objections to the use of fused silica or glass in the sample container since both oxygen and silicon have three naturally occurring isotopes.

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Table 13. Naturally Occurring Isotopes of Candidate Elements

Element	Isotope	Natural Abundance (%)
Si	$_{14}Si^{28}$	92.21
	$_{14}Si^{29}$	4.70
	$_{14}Si^{30}$	3.09
O	$_{8}O^{16}$	99.759
	$_{8}O^{17}$	0.037
	$_{8}O^{18}$	0.204
Au	$_{79}Au^{197}$	100
Ga	$_{31}Ga^{69}$	60.4
	$_{31}Ga^{71}$	39.6
In	$_{49}In^{113}$	4.28
	$_{49}In^{115}$	95.72

4.3.3.5 Summary of Material Selection Criteria.

Table 14 summarizes the properties of the elements, fused quartz, and borosilicate crown glass with respect to the various selection criteria.

4.3.3.6 Conclusions on Materials Suitability.

An examination of Table 14 reveals that only gold satisfies all our material selection criteria. If we delete or relax the gaseous permeation requirement, iridium can be considered. The use of fused quartz and glasses requires a relaxed helium permeation criteria and either assay of the isotopic composition or relaxation of this specification. Plastics and other hydrocarbons are eliminated since organic contamination of the sample is very undesirable; other inorganic compounds were eliminated because of the possibility that the compounds would breakdown under extreme conditions and the difficulty of assuring high purity and isotopic composition.

In contrast to these conclusions the Apollo program used teflon bags for sample containment and aluminum and stainless steel for the return container (26). The choice of materials was based on the easy identification of teflon contamination and the desire to minimize gold contamination to satisfy one of the experiment objectives.

4.3.4 Discussion of the Sealing Problem for the Sample Container.

The maximum leak rate of the seal has been tentatively set at 10^{-10} cm^3 per second, STP, of helium under a differential pressure of one bar.

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Table 14

Summary of Material Properties

Key:
X Eliminated
F Marginal
E Excellent
G/P Good if Passive

Material	Symbol	Physical	H_2 Permeation	He Permeation	Chemical Stability	Toxicity	Radioactive	Catalyst	Composite
Fused Quartz	SiO_2	G	F	P	G	G	-	-	F
Borosilicate Glass	$SiO_2+B_2O_5+Al_2O_3+Na_2O+K_2O$	G	F	F	F	G	-	-	F
Actinium	Ac						X		X
Aluminum	Al				X		-		X
Americium	Am						X		X
Antimony	Sb				X	X	-		X
Argon	Ar	X					-		X
Arsenic	As	X			X	X	-		X
Astatine	At	X				X	-		X
Barium	Ba				X	X	-		X
Berkelium	Bk						X		X
Beryllium	Be				X	X	-		X
Bismuth	Bi				X		-		X
Boron	B				X	?	-		X
Bromine	Br				X		-		X
Cadmium	Cd		E		X	X	-		X
Calcium	Ca				X		-		X
Californium	Cf						X		X
Carbon	C	X			X				X
Cerium	Ce				X				X
Cesium	Cs				X				X

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Table 14 (continued)

Key:
X Eliminated
F Marginal
E Excellent
G/P Good if Passive

Material	Symbol	Physical	H_2 Permeation	He Permeation	Chemical Stability	Toxicity	Radioactivity	Catalyst	Composite
Chlorine	Cl	X			X				X
Chronium	Cr		X					X	X
Cobalt	Co		X		X	X			X
Copper	Cu		P			X			X
Curium	Cm						X		X
Dysprosium	Dy				X				X
Einsteinium	Es						X		X
Erbium	Er				X				X
Europium	Eu				X				X
Fermium	Fm						X		X
Flourine	Fl	X			X	X			X
Francium	Fr						X		X
Gallium	Ga				F	?			?
Germanium	Ge				X	X			X
Gold	Au		E	E	E	E	-		E
Hafnium	Af		X						X
Helium	He	X							X
Holium	Ho				X				X
Hydrogen	H	X			X				X
Indium	In		E		F	?			?
Iodine	I	X				X			X

Key:
X Eliminated
F Marginal
E Excellent
G/P Good if Passive

Material	Symbol	Physical	H_2 Permeation	He Permeation	Chemical Stability	Toxicity	Radioactive	Catalyst	Composite
Iridium	Ir		X						X
Iron	Fe		X		X				X
Krypton	Kr	X							X
Lanthanium	La		X		X				X
Lawrencium	Lr							X	X
Lead	Pb					X			X
Lithium	Li				X				X
Lutetium	Lu				X				X
Magnesium	Mg				X				X
Manganese	Mn		X		X	X			X
Mendelevium	Md						X		X
Mercury	Hg	X				X			X
Molybdenum	Mo		P		F	?			P
Neodymium	Nd				X				X
Neon	Ne	X							X
Neptunium	Np						X		X
Nickel	Ni		X			X		X	X
Niobium	Nb		X		F				X
Nitrogen	N	X							X
Osmium	Os	X	X		X	X			X
Oxygen	O	X							X
Palladium	Pd		X					X	X

Key:
X Eliminated
F Marginal
E Excellent
G/P Good if Passive

Material	Symbol	Physical	H_2 Permeation	He Permeation	Chemical Stability	Toxicity	Radioactive	Catalyst	Composite
Phosphorus	P				X				X
Platinum	Pt		P					X	X
Plutonium	Pu						X		X
Polonium	Po						X		X
Potasium	K				X				X
Praseodymium	Pr				X				X
Promethium	Pm				X		X		X
Protactinium	Pa						X		X
Radium	Ra				X		X		X
Radon	Rn	X					X		X
Rhenium	Re							X	X
Rhodium	Rh		E					X	X
Rubidium	Rb				X				X
Ruthenium	Ru		X					X	X
Samarium	Sm				X				X
Scandium	Sc				X				X
Selenium	Se				X	X			X
Silicon	Si		X	X	X				X
Silver	Ag				F	X			X
Sodium	Na				X				X
Strontium	Sr				X				X
Sulfur	S				X				X

Key:
X Eliminated
P Marginal
E Excellent
G/P Good if Passive

Material	Symbol	Physical	H_2 Permeation	He Permeation	Chemical Stability	Toxicity	Radioactive	Catalyst	Composite
Tantalum	Ta		X		G/P				X
Technetium	Tc						X		X
Tellurium	Te	X			X	X			X
Terbium	Tb				X				X
Thallium	Tl		E		X	X			X
Thorium	Th						X		X
Thulium	Tm				X				X
Tin	Sn				F	X			X
Titanium	Ti		X		G/P				X
Tungsten	W	P			F				P
Uranium	U						X		X
Vanadium	V		X			X			X
Xenon	Xe	X							X
Ytterbium	Yb				X				X
Yttrium	Y				X				X
Zinc	Zn		E			X			X
Zirconium	Zr		X						X

Again, the field of high vacuum provides a technological base for consideration of the problem. The state-of-the-art in ultrahigh vacuum system seals is reviewed by Dushman (18), Wishart (2) and Hees (27). In basic concept only two sealing techniques are used for the range of leak rates of interest here.

The first (and most common) sealing concept involves pressing two metal surfaces into intimate contact. Generally one of the metal pieces is in the form of a knife-edge and the other a flat gasket. The knife-edge is usually harder and deforms the softer flat piece to cause a very tight, nonleaking joint. Leak rates as low as 10^{-12} atm cm^3/sec have been reported (27). Figure 20 illustrates a typical configuration for the knife edge/gasket seal. Figure 21 illustrates a sealing configuration described by Wishart and Bancroft (2). This seal makes use of the increase in diameter of the cup as it is deformed to create a knife-edge seal against the inside diameter of the tube. Leak rates less than 10^{-12} atm cm^3/sec. are claimed.

The other sealing concept in ultra-high vacuum use is the low melting point metal seal. The seal is formed by the low melting point material contained within the junction between the two pieces to be joined. Figure 22 illustrates the basic concept. Several variations on the general theme have been used. Milleron (28) describes a seal of this type in which the sealing metal is maintained in the liquid state. The surface tension of the liquid metal is sufficient to withstand full atmospheric pressure across a gap as large as 10^{-3} cm. Two variations are described in NASA's compilation of seals and sealing techniques (29)

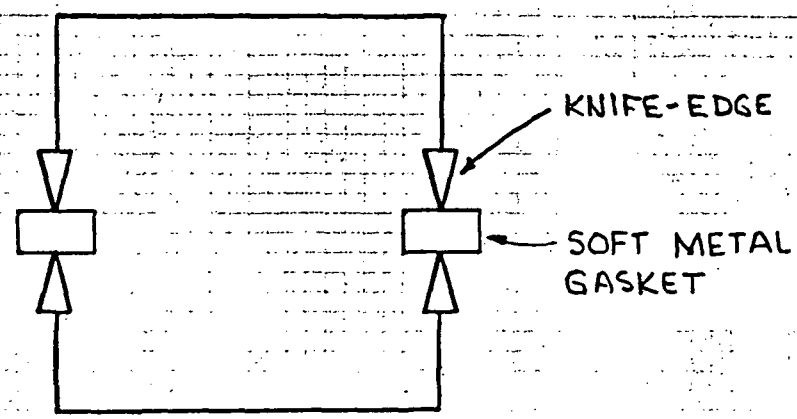

FIG 20 KNIFE-EDGE SEAL

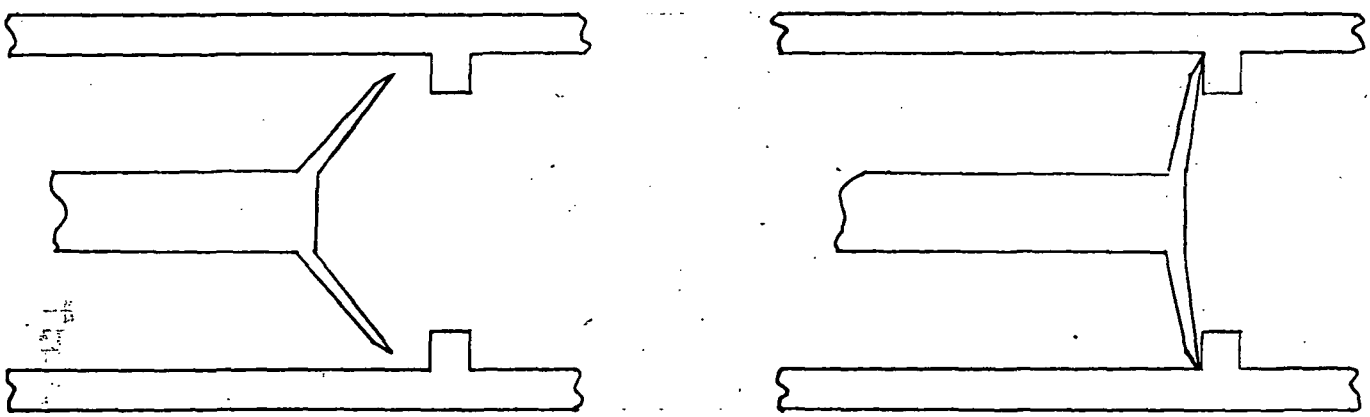

FIG 21 WISHART & BANCROFT HIGH VACUUM SEAL

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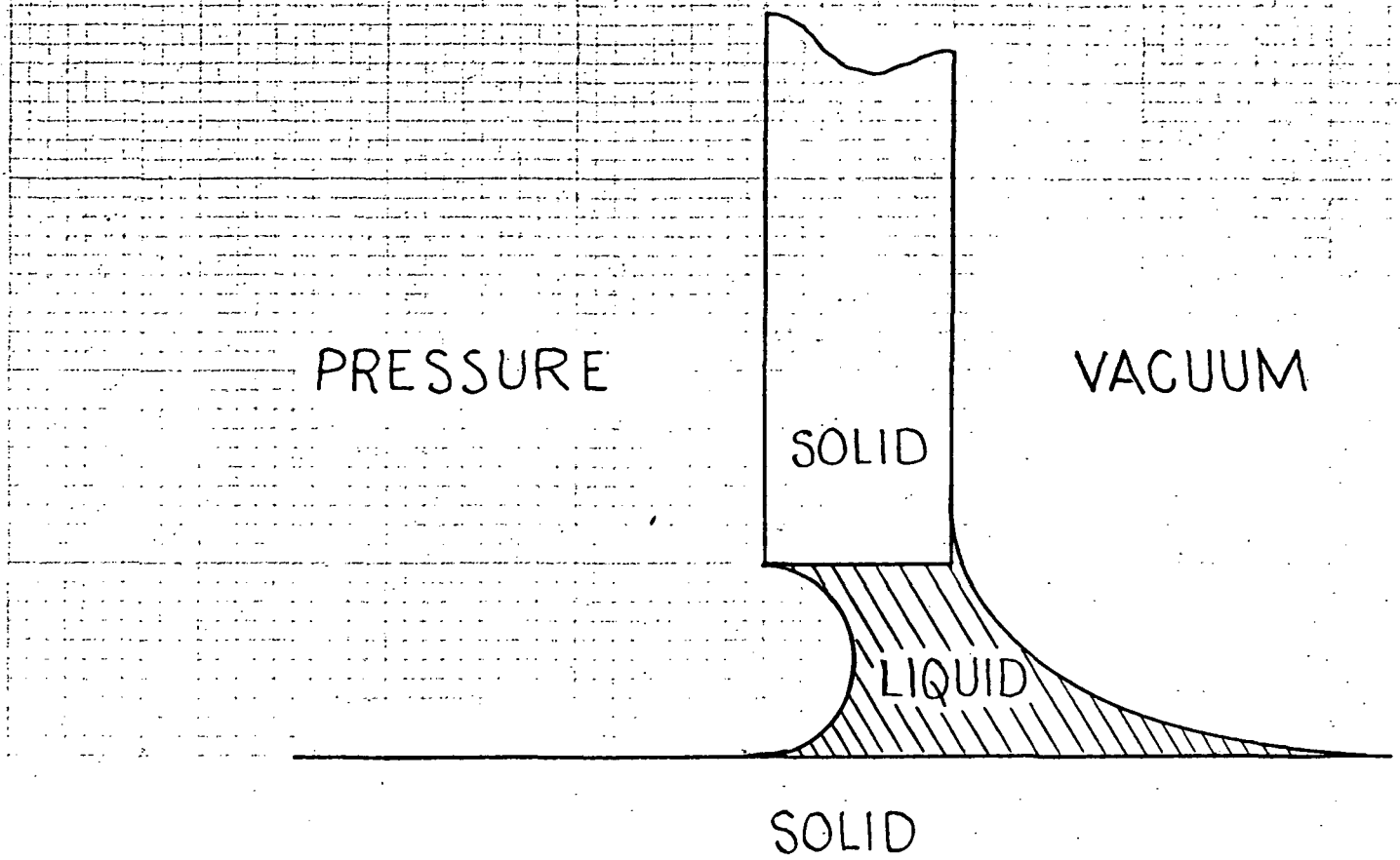

FIG 22† SURFACE TENSION LIQUID METAL SEAL

† FROM MILLERON (28)

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List of Low-Melting-Point Alloys Suitable for Use as Liquid-Metal High-Vacuum Seals
(Numbers in parentheses are references)

I Metal or per cent composition by weight of alloy	II Melting point or range °C	III Vapor pressure mm Hg	III °C	IV Surface tension dyn/cm	IV °C
Gallium	29.9	$<10^{-8}$(2)	500	735(2)	30–40
Indium	156.4	$<10^{-8}$(2)	500	340(2)	170–250
Tin	231.9	$<10^{-8}$(2)	500	526(2)	300
				510(2)	500
Bismuth	271.0	$<10^{-8}$(2)	300	376(2)	300
				363(2)	500
Lead	327.4	$<10^{-8}$(2)	350	422(2)	350
				431(2)	500
62.5 Ga, 21.5 In, 16 Sn(1)	10.7(1)	$<10^{-8}$*	500	>500*	500
62 Ga, 25 In, 13 Sn(5)	~5 (5)				
69.8 Ga, 17.6 In, 12.5 Sn (2)	10.8(2)				
76 Ga, 24 In(1)	15.7(1)				
92 Ga, 8 Sn(2)	~20 (2)				
~70 Ga, ~30 Sn(2)	~60 (2)				
49 Bi, 18 Pb, 12 Sn and 21 In (4)	57.8(4)				
49 Bi, 18 Pb, 15 Sn and 18 In (4)	57.8–69 (4)				
32.7 Bi, 7.5 Pb, 16.7 Sn and 43.1 In(2)	58.8(2)				
49.5 Bi, 17.6 Pb, 11.6 Sn and 21.3 In(2)	58.2(2)				

* Experimental.

[1] J. H. Hamilton, J. R. Lewis and John P. Denny; Final Technical Report, Physical Chemistry of Gallium–Indium Alloys, NRO-42109.
[2] *Liquid Metals Handbook* (2nd ed.), NAVEXOS P-733 (Rev.).
[3] R. L. Loftness; A Vapor Pressure Chart for Metals, NAAISA-132, 1952.
[4] W. H. Kohl; *Materials Technology for Electron Tubes*, 1951.
[5] H. Spengler; *Z. Metalkunde* 46, 464–467 (1955).

Table 15+

+ Data from Milleron (28)

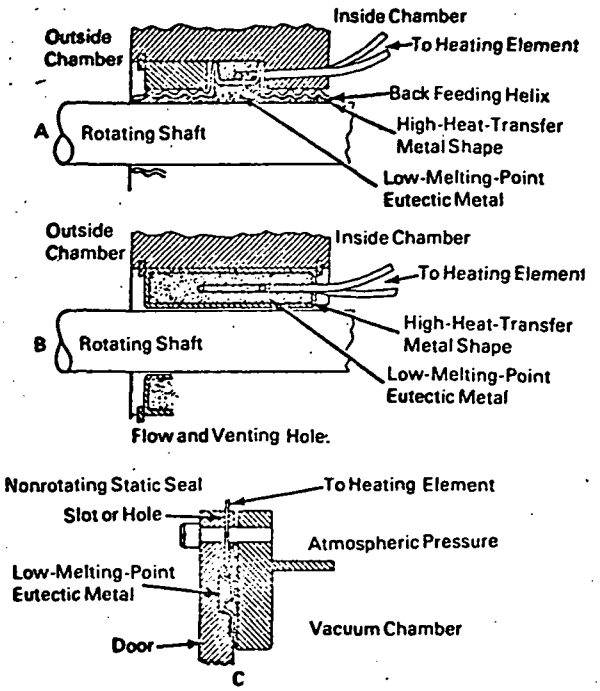

Figure 23. Imus Vacuum Seal+

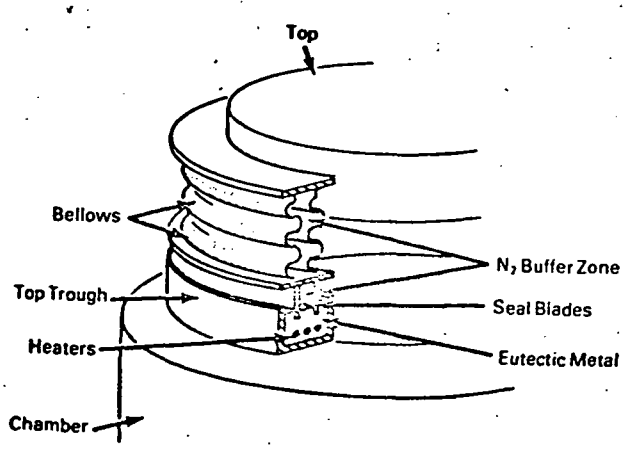

Figure 24. Halpert et al Vacuum Seal

+ Source: Seals and Sealing Techniques - A Compilation NASA SP-5905 (02), Wash. D.C. 1970

in which the sealing metals are heated to a liquid state by a resistance heater when the joint is to be made up or dissassembled; otherwise the sealing metal is allowed to solidify. Milleron (28) lists the properties of the potentially useful metals and Table 15, reproduced from his paper, summarizes the important parameters. Figures 23 and 24 reproduced from (29) illustrate the two NASA techniques.

4.4 Life Support - A Set of Alternate Strategies

In studying the life support problem for a Planetary Return Sample Mission, we were quickly forced to the conclusion that a range of alternatives must be considered. Three major factors contributed to this conclusion. First, there is the obvious relationship between mission and spacecraft complexity and the degree of sophistication possible in the life support system. Second, all requisite information for designing a comprehensive life support system is not currently available. And finally, interaction between the life support system and the sample may contribute a degree of uncertainty in the representativeness of the sample after prolonged exposure which could alter the confidence in experimental results.

In the following material, we have presented a general analysis of the problem and considered a set of likely alternate stratagies which could be employed.

4.4.1 Life Support - A Generalized Analysis

An ideal life support system would accurately maintain or simulate the total indigenous condition of the sample including all interactions between the sample and its external environment. The physical configuration of the sample would be preserved and a set of interface conditions

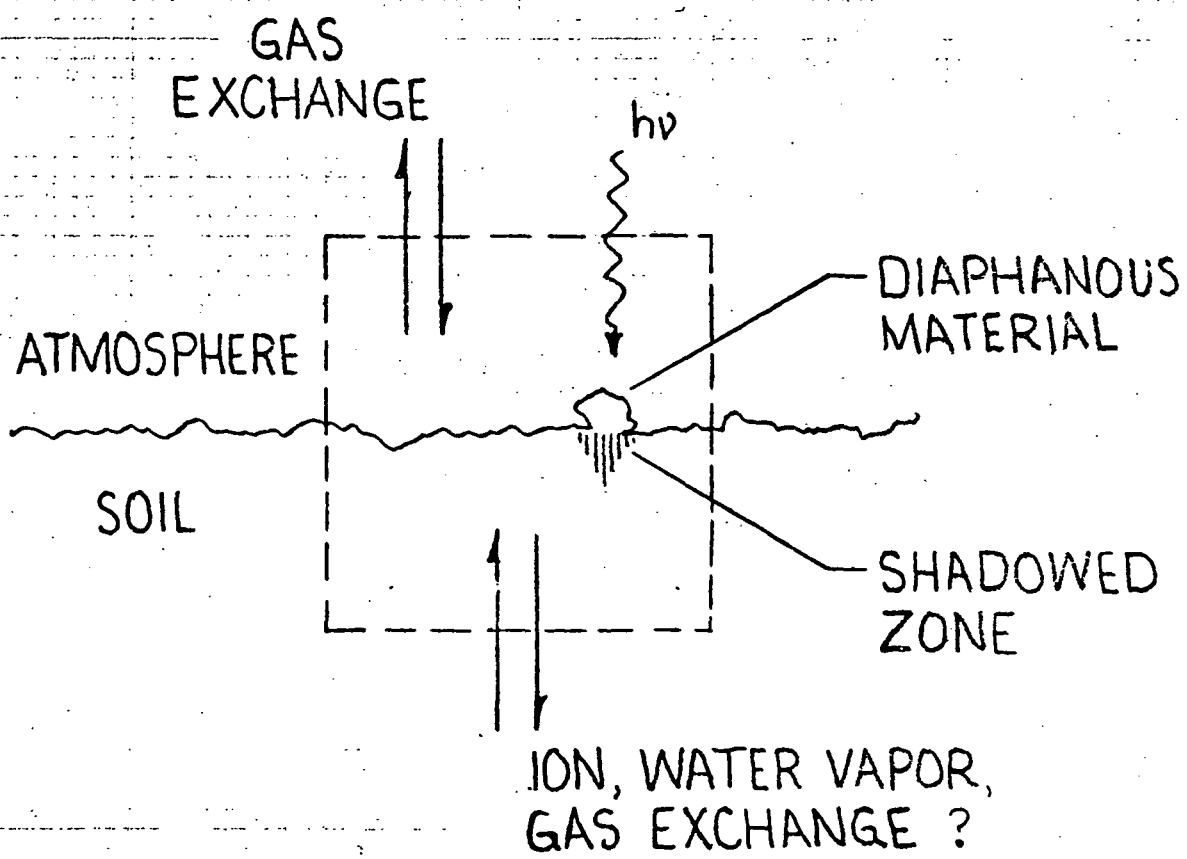

FIG. 25 INTERACTIONS AT THE SAMPLE BOUNDARIES

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and response dynamics would be constructed at the boundaries of the sample accurately representing those which the sample would have experienced had it remained in situ. Figure 25 illustrates the problem. The sample is considered to be a "black box" and the interactions are grouped into those with the atmosphere, those with the planet's crust and radiation.

The first problem we will consider is the need to preserve the physical configuration of the sample, that is, the strata and surface features such as small rocks, cavities, etc. should be maintained. In an ecosystem occurring at the boundary between atmosphere and soil, biological stratification is likely since a large gradient in conditions occurs in the physical environment. For example, on Earth, aerobes occur near the surface and the microbial population shifts in favor of anaerobes with increasing depth in some soils. The forcing factor on Earth is the drop in free oxygen content with increasing depth (30). On Mars a similar gradient in carbon monoxide concentration[+] could result in a similar population gradient. Phototrophs also decrease in population with increasing depth and consequent reduced light levels. Disruption of the natural gradient in population distribution could significantly impact the balance of the ecosystem. A similar phenomenon is known to occur in the case of tilling the soil for agriculture on Earth.

A further argument for the necessity to preserve surface features is provided by the diaphanous substrate phenomenon observed to play a significant role in the ecology of desert soils. Cameron and Blank (31)

[+] Wolfgang (3), Horowitz, Hubbard, and Hobby (4) have proposed CO as a potential substitute for oxygen in Martian biology activity.

describe the phenomenon in detail. Essentially two important factors occur in conjunction with diaphanous, or light-transmitting, materials. The first is the effect on the spectral distribution and intensity. These transparent and translucent materials provide habitats or micro-environments for organisms which otherwise could not tolerate the full spectrum or intensity of the radiation flux arriving at the surface. Since Mars is believed to have an atmosphere which is transparent in the ultraviolet, these microenvironments may play an even more important role on Mars than the quite significant role they are known to play in Earth deserts. The second factor associated with these materials is a modified physical-chemical environment. For example, quartz stones in Earth deserts have been found to act as a moisture gathering mechanism (31). Changes in temperature and insolation have also been found to be associated with diaphanous substrata (31). Finally, since these micro-environments are favorable for certain species, organic matter tends to accumulate there. This material enhances the favorable attributes of the habitat by providing food, insolation, a higher moisture content, and an increased ion exchange capacity for still other species (31).

We will now consider the necessity of simulating the radiation input. The role of radiation from the sun in the photosythetic process on Earth is well known. Wolfgang (3) and Horowitz et al (4) have proposed a hypothetical Martian CO-CO_2 cycle which also depends on solar radiation as the energy source:

Photochemical:

$$CO_2 \xrightarrow{h\nu} CO+O \qquad \text{eq 1}$$

Biological:

$$2CO+H_2O \rightarrow (CH_2O) + CO_2 \qquad \text{eq 2}$$

In this hypothetical life giving cycle, the atmospheric carbon dioxide is reduced to carbon monoxide by ultraviolet photolysis. If we elect to screen out the radiation flux necessary to carry out the first reaction, the carbon monoxide would be depleted by the ongoing biological reaction. Of course, the question arises - when? And, unfortunately, the answer is - we don't know. It depends on the rate of the second reaction. Since reaction rates are temperature dependent, hypothermia has been proposed to reduce the rate to such a low value that the biological population in the sample would remain unaltered during the return trip and no essential ingredients would be exhausted. The problem with this approach is that we don't know how low the temperature must be to insure a low metabolic rate in all species in the sample, and we don't know the impact of hypothermia on the subsequent viability of the sample. A storage temperature of -30°C has been proposed in a JPL study (1). However, algae, lichens, and conifers are known to carry out photosynthesis at this temperature, and mold spores germinate at temperatures as low as -44°C (32). The Viking experiments may provide a rough estimate of the metabolic rate and process over a limited time span. However, seasonal factors and altered environmental conditions will not be tested, and the Viking data will probably not be sufficient to answer the questions.

If the photolysis step of photosynthesis occurs in the body of the atmosphere, as opposed to the boundary layer near the surface, even the inclusion of simulated radiation may be inadequate since it is not

practical to simulate the depth of the atmosphere in the return sample container. An equivalent depth of atmosphere might be simulated in the return container by increasing the pressure appropriately; however, in doing so, we would run considerable risk that the abnormally high partial pressures of the gasses might be toxic to life forms or substantially alter the balance of ongoing reactions in the sample.

On the other hand, if the photosynthetic process occurs within organisms in the sample as it does on Earth, the inclusion of simulated radiation might be necessary to maintain the balance of the life cycle.

Another possibility is that the photosynthetic process occurs in abiotic materials near the surface, in which case the simulated radiation would also be necessary. In either case, the actual Martian spectrum and flux cannot be simulated and leaves considerable doubt as to the effectiveness of the simulator.

In summary, we are faced with three distinct possibilities for the photosynthetic portion of the food cycle. Their implications for a sample return mission are summarized in Table 16. One, two or all of these possibilities may exist on the planet.

Table 16

Photosynthesis (or Photolytic step) Possibilities

Occurs in	Requirements for Sample Return
1) biota in sample	simulate radiation input
2) abiotic material in sample	simulate radiation input
3) body of planetary atmosphere	monitor and replenish essential gasses, e.g. CO and CO_2

We now turn our attention to interactions across the sample/atmosphere and sample/soil boundaries. In addition to the CO-CO_2 gas exchange considered above, it seems likely, on the basis of present information, that water vapor is given up to the atmosphere and replenished from underlying permafrost or juvenile sources. If this process exists, it could be an important mechanism for ion exchange as well as a source of water for biological activity. The question of water availability has sparked considerable controversy and remains as perhaps the largest single factor in arguments against the likelihood of Martian life. Recent experimental results from Vishniac and Hempfling (33) have pointed out that life can and does exist and grow on Earth in areas previously reported to be unable to support life because of lack of available water.

If the upwelling of water or water vapor from deeply buried permafrost occurs on the planet, and if this phenomenon is important to the life forms there, it would be essential to simulate this phenomenon in the sample during the return trip. In addition to water and water vapor, the possibility of other chemicals diffusing through the soil from underlying reservoirs and subsequently reduced within the biota can not be excluded. Kuzyurina and Yakshina (34) find the possiblity of "osmophilic life forms" within the bounds of reason and the available information.

In summary, one can easily imagine biologically important transactions occurring across the boundaries between the sample, the atmosphere and underlying soil. Unfortunately, we have no significant information

about the nature of such interactions at present. Further, while we can expect some elucidation of these points from Viking data, it is likely that much of the mystery will remain at the time the first sample is collected for return to Earth.

Finally, we will consider the physical/chemical parameters within the sample volume. These include temperature, pH, Eh, and metabolite concentrations. Temperature and temperature gradients are known to play a role in desert biota. For example, at night-fall the relative humidity in the desert air increases dramatically. A corresponding decrease in the planetary atmosphere's "thirst for water" might be important to the life processes going on there. For example, the biota may carry out certain processes which involve the risk of losing water to the environment at these times. Differences in heat conductivity and heat capacity of the sample container from those of the natural environment make simulation of the thermal pattern very difficult. It seems likely that, while the average temperature pattern could be simulated in the return capsule, the gradients, profile across the sample, and dynamics will depart significantly from the in situ situation.

The pH, Eh, and metabolite concentrations in the sample may also be difficult to simulate. Naturally occurring factors such as soil percolation, evaporation, wind blown removal and deposition of the surface layer, and ion exchange will not be adequately simulated in practical sample return systems. One can imagine at least some of these parameters being monitored and the balance within the sample corrected at least on

an average volumetric basis. However, when the quarantine constraints and the desire to maintain the sample in a pristine state are considered, the practicality of adjusting these parameters in flight becomes questionable.

4.4.2. Life Support - Alternate Strategies

As we have seen, an "ideal" live support system would control many parameters, of which a number are yet to be identified, and those identified are not fully understood. Extensive monitoring and corrective instrumentation and mechanisms would be required. The inclusion of some of these control systems requires interaction with the sample in ways which involve a risk that the sample would be contaminated or altered as a result of addition of nutrients, removal of metabolites, and the like. Further, because of inaccurate or inadequate information, the life support system could kill all or a portion of the biota present, or alter the balance of life forms, in ways which could be very confusing to scientists in their attempts to reconstruct the orginal situation.

The conflict between the requirements and risks associated with a life support system is, perhaps, most evident when the organic chemistry of the sample is considered. Viewed from an organic chemist's eyes, the life support function is primarily a risk, a risk that the sample will be altered or contaminated, which must be weighed against relatively low probability benefits. From a biologist's viewpoint, however, the life support function is paramount.

It is important that these rather basic differences in risk-reward functions for the various sciences be reflected in the life support

strategy adopted for the sample return. In the following material, we will consider a number of alternate strategies ranging from a simple gas tight cannister with spacecraft ambient temperature control to quite sophisticated life support systems. It is our view that the overall mission strategy will encompass a divided sample concept with different life support strategies employed as a function of the intended use of each sample portion.

4.4.2.1 Strategy A - Containment

This strategy is one of simple containment. The sample, either in the form of loose fines, as recommended in the JPL study referenced earlier (1), or in the form of a core sample with strata preserved, is loaded into the container. The container is then sealed, transferred to the return sample quarantine capsule in the orbiting spacecraft and returned to Earth. The temperature profile of the sample during the return trip is determined by the spacecraft ambient conditions.

The basic goals of this strategy are:

(1) to prevent contamination of the sample.

(2) to preserve or confine all of the sample constituents to the sample container.

Such a strategy must be recognized to have the following explicit limitations:

(1) Life forms may autosterilize or species populations may be altered due to exhaustion of substrates and nutrients or due to changes in critical environmental factors such as radiation input, temperature, diurnal cycling of various parameters and the like.

(2) The organic chemistry of the sample may be altered by an induced change in a biological component, or lack of a critical factor such as radiation input or ion exchange with the atmosphere or underlying soil.

(3) The organic and inorganic chemistry of the sample may be altered due to major departures from the nominal in situ temperature/humidity profile.

To implement this strategy, the sample container must also satisfy certain mission and spacecraft design constraints. Among these are:

(1) The sample container design must be compatible with remote loading and sealing of the sample in the container.

(2) The design and its associated loading and sealing mechanisms must result in minimum weight and power requirements particularly with respect to the return planetary lift-off weight.

(3) The design must be compatible with the quarantine and biohazard control strategy adopted for the mission.

We note that this sample containment strategy places certain limitations on the biohazard control strategy in that no monitoring of the sample or biohazard assessment measurements are included. In short, this strategy represents the absolute minimum approach which might be compatible with any reasonable quarantine and sample preservation program.

Figure 26 illustrates a design concept which we believe would satisfy the requirements of this sample containment strategy. All components of the container are pure gold except the outer sealing ring which has an alloyed edge for better sealing. During the loading process, a loading chute, or funnel, is envisioned to prevent dust particles from settling on the sealing areas of the cup. The lid portion of the container would be protected during the loading process. The seals are knife-edge type

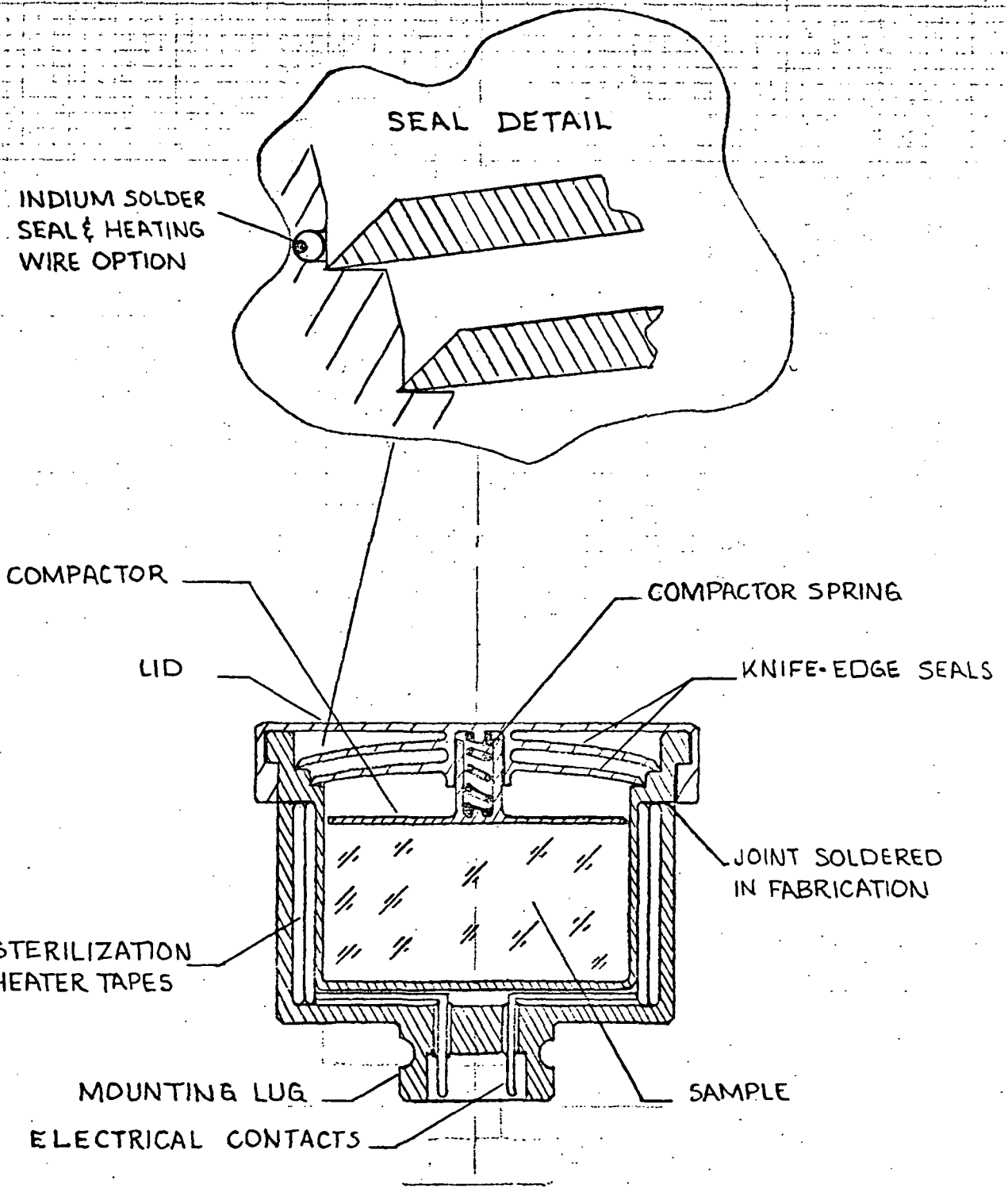

FIG 26 50 GRAM SAMPLE CONTAINER FULL SCALE

MAT'L: GOLD

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seals as described by Wishart and Bancroft (2). A double seal is used for improved reliability. The lid is held to the cup by a simple breach block thread requiring only a few degrees rotation for setting. A spring loaded pin, or other mechanism, can be employed to provide a positive lock when the cap is installed. The container cup includes a spring loaded compaction plate to prevent the sample from self comminution during the return trip and reentry. The outer seal could be soldered using a low melting point alloy such as indium, however, the advantages to be gained are probably more than offset by the complexity of the soldering operation, the thermal stress imposed on the sample, and the problems such a system might cause during the spacecraft sterilization procedure prior to Earth launch.

4.4.2.2. Strategy B - Simple Containment Plus Hypothermia

This strategy represents an extension of STRATEGY A to include hypothermia to retard chemical reaction rates and biological metabolism during the return voyage. The goals of the strategy are:

(1) to prevent contamination of the sample.

(2) to preserve the contents of the sample.

(3) to preserve the chemical, biological, and physical status of the sample by retarding the on-going processes through the imposition of a low temperature regimen.

The strategy must be recognized to have the following explicit limitations;

(1) Although the probability would be significantly reduced in the low temperature environment, life forms may autosterilize and species populations may be altered because of exhaustion of substrates and nutrients or the absence of a critical environmental factor such as radiation input, temperature cycle, etc.

(2) The organic chemistry of the sample may be altered due to an altered biological component or environmental factor such as radiation input or ion exchange.

In addition to the above life support limitations, the strategy does not provide for monitoring or biohazard assessment measurements on the sample. The strategy retains the ease of remote loading and sealing of STRATEGY A, but requires additional weight and power for the thermal control systems.

Figure 27 illustrates a design concept which we believe would satisfy the requirements of this sample containment strategy. The sample cannister is identical to that depicted in Fig. 26. Thermal control is provided by a thermoelectric cooler which serves as a mount to hold the sample cannister inside the return quarantine capsule. While definition of the exact mechanism for providing the heat pump is not critical, we have illustrated a thermoelectric unit after considering alternatives such as Joule-Thompson coolers, refrigeration units, and passive radiators to deep space. The passive radiation technique has been employed with fair success in previous military space missions, however, it is felt that the design of a system which would meet the quarantine and weight restrictions for a planetary return mission would be very difficult. The Joule-Thompson cooler requires storage of an unreasonable amount of gas with attendant weight problems. The thermoelectric cooler has weight and reliability advantages over a conventional refrigeration unit. We estimate the cooling capacity required for the illustrated design to be about 0.5 to 1 watt against a temperature difference of 50° to 70°C. We note that this heat load is near the current state-of-the-art for thermoelectric coolers.

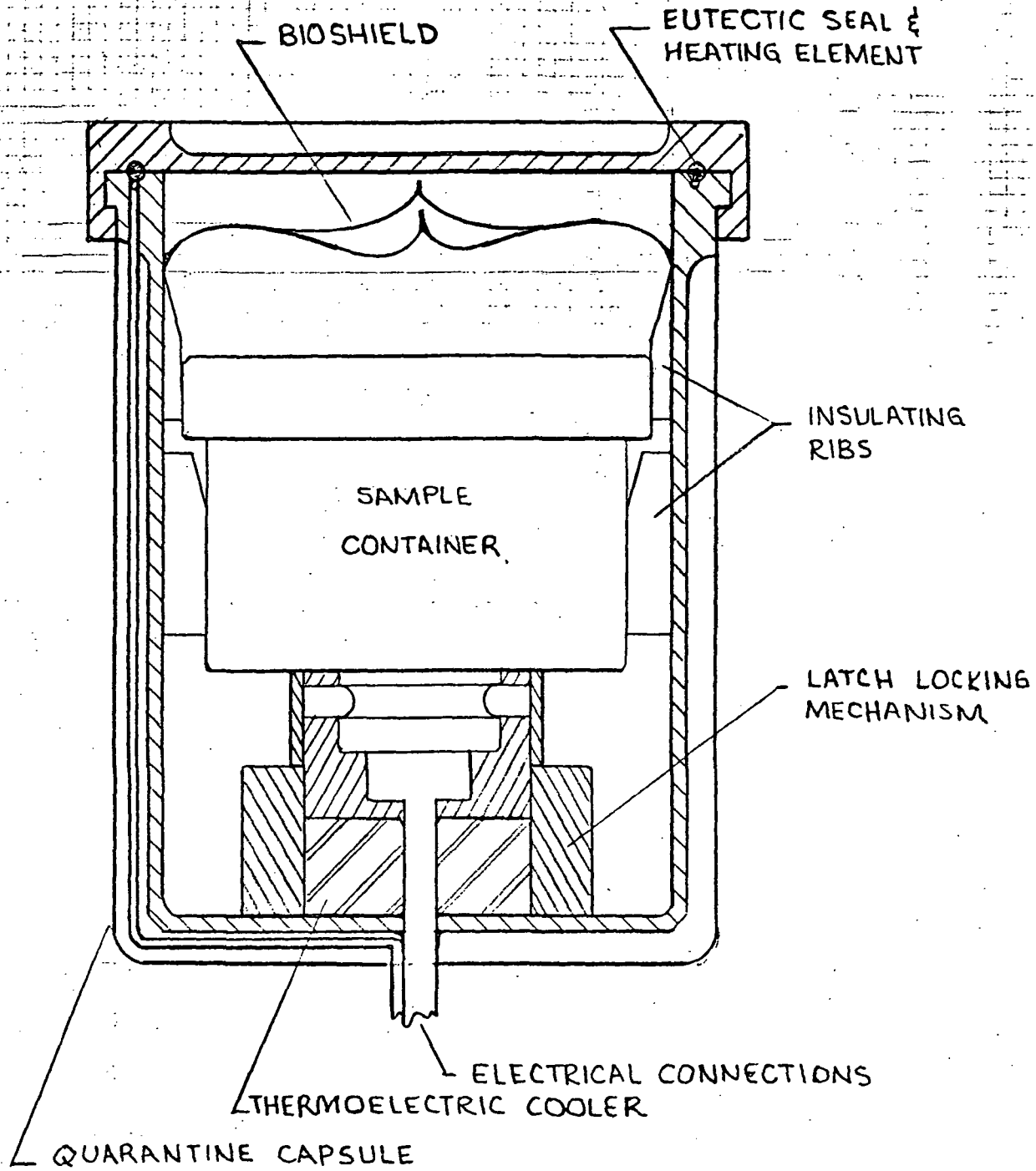

FIG 27 CONTAINMENT WITH HYPOTHERMIA

BIOSPHERICS

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4.4.2.3. Strategy C - Containment with Temperature Control and Simulated Radiation

This strategy represents the first step toward an active life support system. The goals of the strategy are:

(1) to prevent contamination of the sample.

(2) to preserve the sample constituents.

(3) to maintain any biological activity by simulating the thermal pattern and radiation flux of the habitat.

The strategy has the following explicit limitations:

(1) If the photosynthetic component of the life cycle occurs in the bulk of the atmosphere, the radiation input provided would not adequately simulate in situ conditions since an equivalent atmospheric depth cannot be provided. In this case, the biological component could be adversely affected by exposure to the nominal thermal cycle without regen eration of nutrients.

(2) The organic chemistry of the sample may be altered by a changing biological component or lack of a critical environmental factor such as ion or water exchange with the atmosphere and underlying soil.

(3) Biological activity may be modified by lack of a critical factor related to interactions with the underlying soil or bulk of the atmosphere.

(4) An increased container complexity and materials thermal coefficient matching problems introduce greater uncertainty in our ability to prevent contamination or escape of the sample through gaseous diffusion and small leaks. These leak possibilities are not believed to be significant from a quarantine standpoint since the sample cannister will be enclosed in an isolation capsule which will provide the quarantine barrier in any case.

The incorporation of a light source in the sample cannister design problem gives rise to a number of difficulties. Figure 28 illustrates schematically what we would like to be able to do. Unfortunately two complications must be resolved:

BIOSPHERICS

PROBLEMS:

(1) NO GRAVITY - SAMPLE DISPERSES IN CONTAINER

(2) THERMAL COEFFICIET MISMATCH WINDOW/TOP WINDOW MOUNT AND SEALING

(3) H AND He DIFFUSION THROUGH WINDOW

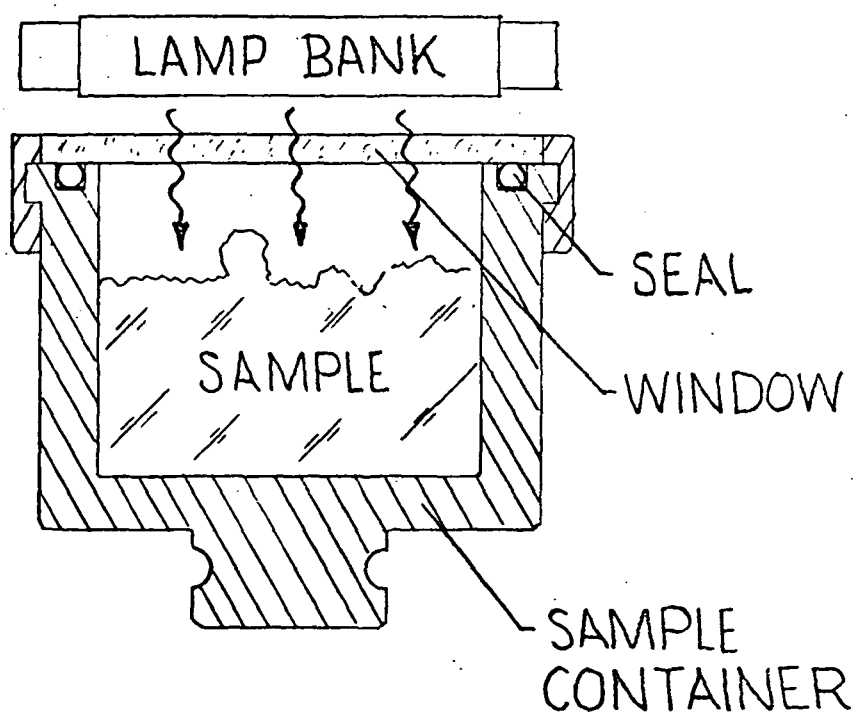

FIG 28 DESIRED CONFIGURATION

(1) The lack of gravity would result in the sample being dispersed in a more or less uniform manner inside the container.

(2) The wide temperature range necessitated by the spacecraft sterilization procedure and simulation of planetary night time conditions (250 to -60°C approximately) coupled with a mismatch in thermal coefficients of expansion between the container walls and the window material results in a very difficult sealing problem.

The first complication can be resolved more or less satisfactorily by placing the window against the top of the sample and relying on gaseous diffusion through the soil for circulation. Opaque spots in the window could provide shadowed habitats in the sample. The diaphanous action of the larger particles and pebbles would remain unimpeded.

The problem caused by the thermal coefficient mismatch between the container and window is not so easily solved. Mounting the sample on a substrate which is used to cycle the temperature of the sample during the return voyage, while having the cannister and window at spacecraft ambient temperature, would significantly reduce this aspect of the problem, but the spacecraft sterilization temperature excursions would remain. The window could be held loosely in a circumferential slot in the cannister wall but this would result in an unacceptable "seal". Finally, this later approach could be combined with the inclusion of the lamp within the sample cannister as illustrated in Figure 29. We are still left with the problem of getting electrical connection to the lamp. The problem then becomes one of designing an adequate electrical feed through.

Figure 29 illustrates a design concept which at least in theory provides a mechanical solution. The leads are kovar and are bonded to the sealing cup by glass insulators. The kovar cup is sealed to the container by a knife-edge type seal which can accomodate differential changes in diameter by springing the cup similar to the action of the Wishart and Bancroft (2) seal. Note, however, that we have been forced to use materials which do not satisfy the requirements of low gas permeability and chemical inertness. Since the kovar is separated from the sample by the window, bulk reactions with the sample will not occur. Some interaction with the atmosphere is possible, however. Hydrogen permeation could perhaps be reduced to an acceptable value by gold plating the kovar cup and keeping its area small.

An alternate design approach which deserves consideration, if the hydrogen permeation specification can be relaxed for the biological portion of the sample and if the Viking data or other results indicate that kovar, etc. would not cause significant catalysis or react with the atmosphere, is to make the container out of, say, kovar and protect the bulk of the sample by placing it in a gold cup pressed against the window.

In either case, it is evident that a substantially greater risk of contaminating or allowing portions of the sample to escape is associated with this strategy as opposed to STRATEGIES A or B. For this reason we rate this strategy of low value for the portions of the sample destined for use in inorganic, isotopic, atmospheric and possibly organic analysis. The strategy does deserve serious consideration for the biological portion of the return sample.

FEED THROUGH DETAIL

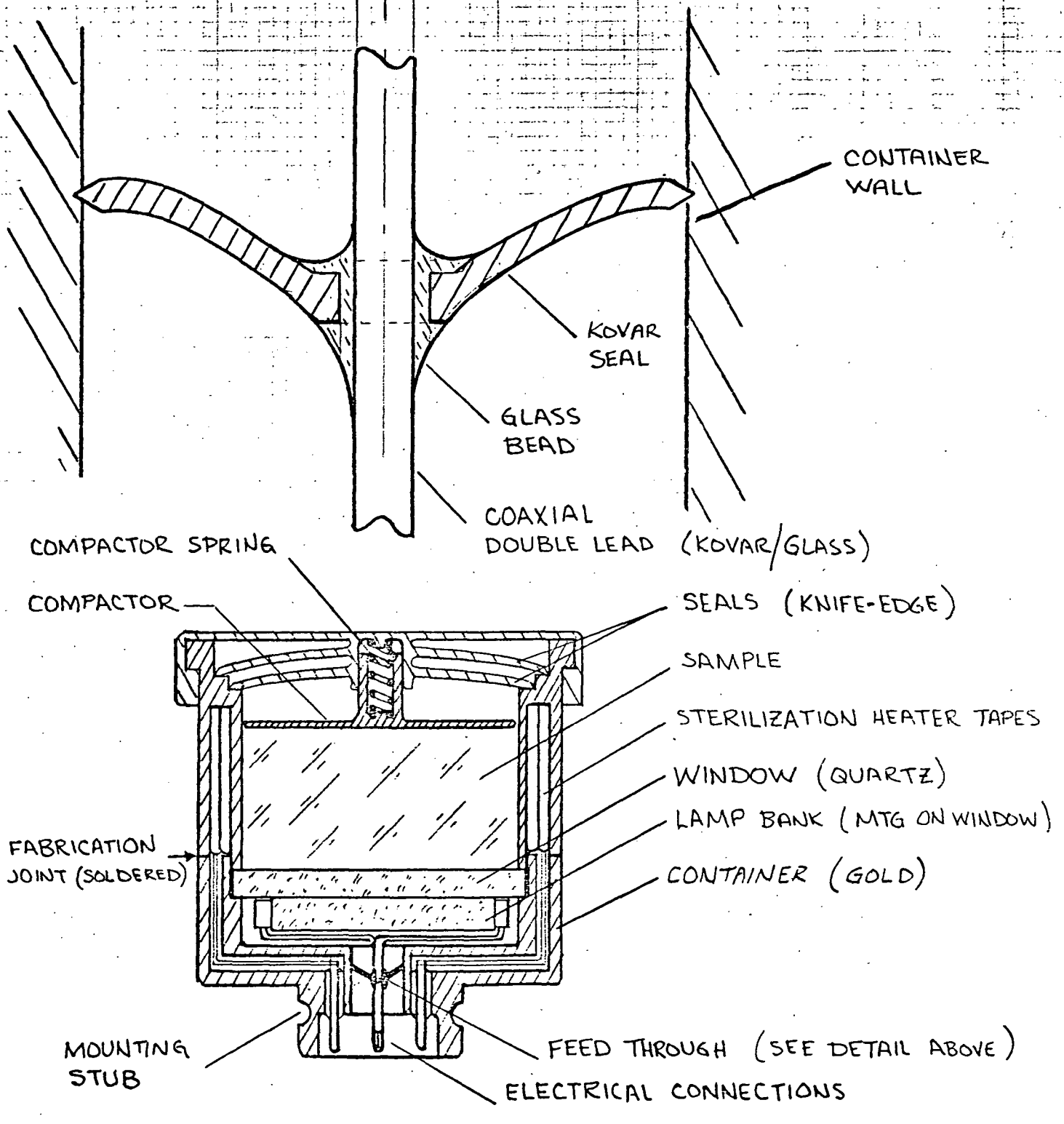

FIG 29 CONTAINER WITH SIMULATED RADIATION

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4.4.2.4 Sample Headspace Gas Exchange

On the basis of our present knowledge, it seems likely that gas exchange between Martian biota (if extant) and the Martian atmosphere would be important to the life process. It is generally assumed that the elements carbon, oxygen, nitrogen and hydrogen play essential roles in likely forms of Martian biology. On Earth, gas exchange with the atmosphere is involved in the utilization cycles for each of these elements. Unfortunately, our very limited knowledge of Martian conditions and biota (if present) restricts us to speculation as to the detailed mechanisms such gas exchange would take on Mars. However, in keeping with our desire to provide a link between exobiologists and spacecraft engineers involved in TPR, we will give a brief description of what is known to happen on Earth and a few speculations about what might be going on in a Martian environment.

The carbon cycle provides a good illustration of the importance of gas exchange and lies at the heart of the life process. The carbon cycle is illustrated schematically in Figure 30. The atmosphere provides a reservoir of carbon in the form of carbon dioxide at relatively low concentration (about 0.03%). Green plants and algae fix the free CO_2 from the atmosphere according to the simplified reaction:

$$CO_2 + H_2O \xrightarrow{h\nu} (CH_2O) + O_2 \qquad \text{eq 3}$$

In addition, certain soil bacteria fix atmospheric CO_2 by an anaerobic reaction which does not result in the liberation of oxygen and which does not require water as the electron donor. These soil bacteria commonly use molecular hydrogen, reduced sulfur compounds, or organic compounds to play the role of water in the above reaction. A typical

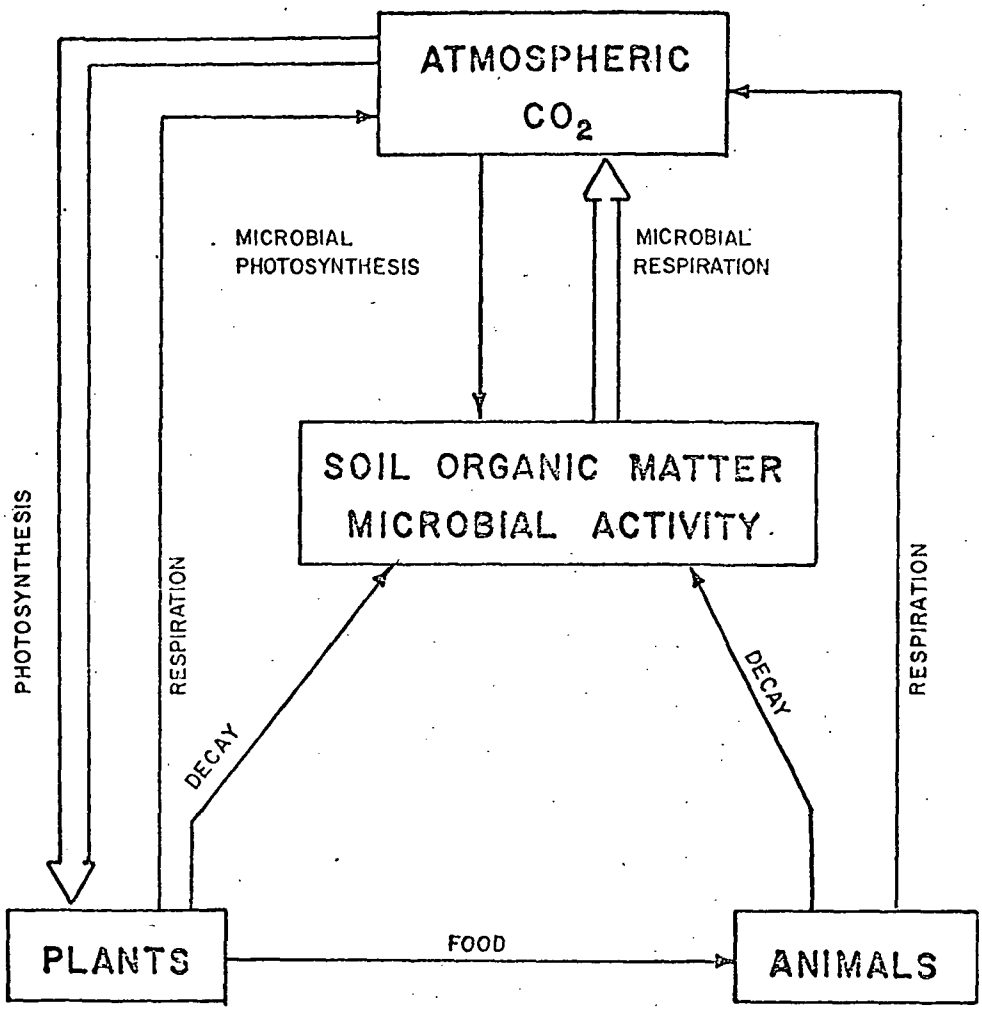

Figure 30

CARBON CYCLE

photosynthetic reaction is illustrated by the metabolism of the green sulfur bacteria as given by the following reaction (35):

$$CO_2 + 2H_2S \xrightarrow{h\nu} (CH_2O) + H_2O + 2S \qquad \text{eq 4}$$

Another interesting reaction exhibited by many purple bacteria is (35):

$$CO_2 + 2H_2 \xrightarrow{h\nu} (CH_2O) + H_2O \qquad \text{eq 5}$$

Reactions such as the two above are of significance since they at least partially circumvent one of the major arguments against the probability of life on Mars, that is, the lack of liquid water in the environment. One might imagine that Martian biota could manufacture the water which might be required as a solvent with the cell.

The other half of the carbon cycle involves degrading the organic matter back to carbon dioxide which is liberated to the atmosphere thereby completing the cycle. Higher animals, plants and many micro-organisms accomplish this through a process known as aerobic respiration. Free oxygen from the atmosphere reacts with organic matter according to the following simplified reaction:

$$O_2 + (CH_2O) \longrightarrow CO_2 + H_2O + \text{energy} \qquad \text{eq 6}$$

Which, in the case of glucose, is usually written:

$$6O_2 + C_6H_{12}O_6 \longrightarrow 6\,CO_2 + 6\,H_2O + \text{energy} \qquad \text{eq 7}$$

However, many soil microorganisms also exhibit anaerobic respiration, a process which does not require free oxygen from the atmosphere. A comparable anaerobic metabolism of glucose can be represented by the following reaction:

$$C_6H_{12}O_6 \longrightarrow 2CO_2 + 2\,C_2H_5OH + \text{energy} \qquad \text{eq 8}$$

On Earth, the photosynthesis provided by green plants and algae dominates due to their abundance and the reaction given in Equation 3 has progressed until the concentration of CO_2 in the atmosphere and the available light limit the process. Consequently, the balance of gas constituents in the atmosphere reflects a high proportion of oxygen and relatively low CO_2 concentration.

If we look more closely at the soil microorganisms on Earth, we find that organisms have developed which can live in our harshest environments and which show remarkable diversity in obtaining food. A large number of photosynthetic and chemosynthetic bacteria have been identified which can manufacture nutrients from inorganic compounds. Table 17 from (36), lists a number of autotrophic bacteria and gives data relative to their metabolisms. An even larger variety of heterotrophs are available for breaking down practically any organic molecule including many which are not found in nature. Lichens, a symbiotic relationship between algae and fungi, are a miniature ecosystem in themselves.

A number of investigators have studied the gas exchange occurring between Earth soil samples and a simulated Martian atmosphere. For purposes of our discussion, we will use data reported by Oyama (37) since the data to be obtained by Viking will be determined by this investigator using the methods reported. Table 18 lists a number of soil samples tested and the headspace gas changes in nanomoles for the constituents H_2, N_2, CH_4, CO_2 and N_2O. The gas data is for a 0.1 cc sample from the containers which had a headspace volume of 8 cc and contained 1 cc of soil suspension. The initial atmosphere was composed

Table 17

Autotrophic bacteria

Photosynthetic types:

1. Purple, sulfur bacteria (*Thiorhodaceae*, Molisch) anaerobic, develop readily in H_2S media, and oxidize inorganic sulfur compounds to sulfate with reduction of CO_2. H_2S can be replaced by certain hydrogen donators, *e.g.*, lower fatty acids, dibasic acids or molecular hydrogen. Growth factors not required.

2. Purple, non-sulfur bacteria (*Athiorhodaceae*, Molisch). Organic substances and molecular hydrogen serve as H_2-donators; CO_2 reduced. Growth factors required. Certain species oxidize inorganic sulfur compounds..

3. Green bacteria (*Chlorobacteriaceae*, Geitler and Pascher). Occur in H_2S media. CO_2 reduced, H_2S being oxidized to free S which is usually deposited outside the organisms. Growth factors not required.

Chemosynthetic types:

NAME	N SOURCE	C SOURCE	ENERGY SOURCE		AUTOTROPHISM	O_2-RELATIONSHIP
			Oxidation of	Reduction of		
Nitrosomonas, Nitrosococcus	NH_4^+	CO_2	NH_4^+	CO_2, O_2	Obligate	Aerobic
Nitrobacter	NO_2^-	CO_2	NO_2^-	CO_2, O_2	Obligate	Aerobic
Beggiatoa, Thiothrix, Thioploca	NH_4^+	CO_2	H_2S	CO_2, O_2	Obligate (Facultative?)	
Thiobacillus thioparus	NH_4^+, NO_3^-	CO_2	H_2S, $S_2O_3^-$, S	CO_2, O_2	Obligate	
Thiobacillus novellus	NH_4^+	CO_2	$S_2O_3^-$	CO_2, O_2	Facultative	Aerobic facul.
Thiobacillus thiooxidans	NH_4^+	CO_2	S, $S_2O_3^-$	CO_2, O_2	Obligate	Aerobic
Thiobacillus denitrificans	NH_4^+	CO_2	S	CO_2, NO_3^-	Obligate	Anaerobic facul.
Thiobacillus ferrooxidans	NH_4^+, NO_3^-	CO_2	Fe^{++}, $S_2O_3^-$	CO_2, O_2	Obligate	Aerobic
Hydrogenomonas	NH_4^+	CO_2	H_2	CO_2, O_2	Facultative	Aerobic
*Carboxydomonas oligocarbophila**	NH_4^+	CO	H_2, CO	CO_2, O_2	Facultative	
Methanomonas methanica†	NH_4^+	CO_2	CH_4	CO_2, O_2	Facultative	Aerobic
Didymohelix‡, *Sideronomas, Leptothrix, Crenothrix*	NH_4^+	CO_2	Fe^{++}, Mn^{++}	CO_2	Facultative and obligate	

* Has also been called *Actinomyces oligocarbophila*.

† Change of name to *Pseudomonas methanica* has been suggested.

‡ *Didymohelix* is now the genus *Gallionella* in *Bergey's* seventh edition.

(Adapted from Werkman and Wood, 1942)

Reproduced from (36)

Table 18

GAS COMPOSITIONAL CHANGES IN THE ATMOSPHERE OVER SOIL WITH BASIC COMPLEX MEDIUM[a]

		Cycle 1					Cycle 2					Cycle 3				
			Gas (max)			Gas (end)		Gas (max)			Gas (end)		Gas (max)			Gas (end)
Soil	Gas	I.T.	L.T.	N.	T.	N.	I.T.	L.T.	N.	T.	N.	I.T.	L.T.	N.	T.	N.
Antarctica 500	H_2	5		0		0	15		0		0	15		0		0
	N_2		0	−1.01	5	−10.1		0	−1.33	15	−1.33		0	−1.81	15	−1.81
	CH_4			0		0			0		0			0		8
	CO_2		1	+3.02	5	+3.02		1	+2.38	15	+2.38		1	−18.5	15	−18.5
	N_2O			0		0			0		0			0		0
DV 1S	H_2	10		0		0						15		0		0
	N_2		0	+77.6	10	+77.6							1	−8.95	13	−8.95
	CH_4			0		0								0		0
	CO_2		4	−2.0	10	−2.0							3	+160	15	+160
	N_2O			0		0								0		0
DV 2S/1	H_2	15		0		0	7		0		0	7	6	−14.1	7	−14.1
	N_2		0	+50.0	15	+50.0		0	+67.5	7	+67.5		0	+501	7	+501
	CH_4			0		0			0		0			0		0
	CO_2		2	+4.26	15	+426		0	+382	7	+382		0	+279	7	+279
	N_2O		7	+2.72	15	+2.72		4	+25.5	7	+25.5		4	+4.09	4	0
Geyserville # 6	H_2	15		0		0	16		0		0					
	N_2		0	+22.7	15	+22.7		0	−26.6	16	−26.6					
	CH_4			0		0			0		0					
	CO_2		1	+25.8	15	+25.8		0	+19.8	16	+19.8					
	N_2O			0		0			0		0					
Aiken	H_2	10	5	+55.1	10	+55.1	3	0	+76.6	3	+76.6	4	1	+4.13	4	+4.13
	N_2		0	+340	9	+333		0	+117	3	+117		0	+216	4	+216
	CH_4			0		0			0		0			0		0
	CO_2		1	+1577	10	+1572		0	+166	3	+166		0	+429	4	+429
	N_2O		2	+26.9	6	0		0	+1.58	1	0			+0.462	4	+0.462
Bowers Clay # 4	H_2	8	1	+295	5	+148	7	2	+12.9	6	+12.7	7	1	+3.52	7	+3.52
	N_2		3	+116	8	+116		0	+38.8	7	+36.8		0	+2.93	7	+29.3
	CH_4			0		0			0		0			0		0
	CO_2		1	+1102	8	+1102		0	+247	7	+247		0	+66.9	7	+66.9
	N_2O			+2.20	2	0		1	+51.9	7	+51.9		0	+0.947	5	+0.928
Hesperia	H_2	8		0		0	5	1	+80.4	5	+80.4	5	1	+12.0	5	+12.0
	N_2		0	+825	8	+825		0	+65.9	5	+65.9		0	+194	5	+194
	CH_4			0		0			0		0			0		0
	CO_2		0	+566	8	+566		0	+612	5	+612		0	+374	5	+374
	N_2O		0	+38.3	5	+0.278			+14.6	5	+14.6		0	+3.91	2	0
Holtville	H_2	10		0		0	7		0		0	7		0		0
	N_2		0	+1030	10	+1030		1	+91.0	7	+91.0		0	+20.4	7	+20.4
	CH_4			0		0			0		0			0		0
	CO_2		1	+890	10	+890		0	+136	7	+136		0	+75.3	7	+75.3
	N_2O		0	+1.68	6	0		0	+11.0	7	+11.0		1	+1.30	7	+1.30
Panoche	H_2	8	4	+35.0	8	+35.0	4		+1.48	2	0	5	2	+16.5	5	+16.5
	N_2		2	+515	8	+515		9	+23.7	4	+23.9		2	+7.89	5	+7.89
	CH_4			0		0			0		0			0		0
	CO_2		2	+2510	8	+2510		0	+1060	4	+1060		0	+1190	5	+1190
	N_2O		3	+15.5	5	+0.857		2	+147	4	+147		2	+30.1	5	+30.1
Ramona	H_2	10	6	+785	10	+785	8		0		0	8	8	+23.1	8	+23.1
	N_2		4	+817	10	+817		5	+165	8	+165		4	+31.0	8	+31.0
	CH_4			0		0			0		0			0		0
	CO_2		2	+2410	10	+2410		0	+521	8	+521		4	+578	8	+578
	N_2O			+31.4	5	0			+27.6	5	0		5	+3.86	8	+3.86
Salinas Loam	H_2	8		+93.7	5	+17.5	3	1	+111	3	+111	4	2	+15.9	4	+15.9
	N_2		1	+510	8	+510		0	+131	3	+131		2	+81.0	4	+81.0
	CH_4			+0.285	8	+0.285			0		0			0		0
	CO_2		1	+2370	8	+2370		0	+432	3	+432		0	+357	4	+357
	N_2O			+0.389	1	0			+1.08	2	0		1	+80.0	4	+80.0
Siskiyou	H_2	8		+231	8	+231	9	4	+143	9	+143	9		0		0
	N_2		4	+132	8	+132		3	+86.4		+86.4		2	+78.8	9	+78.8
	CH_4			0		0			0		0			0		0
	CO_2		2	+2130	8	+2130		1	+1360	9	+1360		1	+496	9	+496
	N_2O			+23.7	6	+12.5		1	30.0	9	30.0		1	+10.2	9	+10.2
Yolo	H_2	8	2	+27.4	6	+22.9	5	0	+162	4	+122	5	1	+67.3	5	+67.3
	N_2		0	+438	8	+438		0	+133	4	+133		0	+48.2	5	+48.2
	CH_4			0		0			0		0			0		0
	CO_2		0	+1450	8	+1450		0	+724	5	+724		0	+210	5	+210
	N_2O			0		0			0		0		1	+35.5	5	+35.5
Staten Island Peatty Muck	H_2	8	2	+297	5	+72.2	9	0	+24.0	4	+6.51	9	1	+167	3	+11.4
	N_2		0	+566	8	+566		0	+181	9	+181		0	+161	8	+154
	CH_4		2	+7.86	8	+7.86		7	+0.678	9	+0.678			0		0
	CO_2		0	+2356	8	+2356		0	+1495	9	+1495		0	+2234	9	+2234
	N_2O		0	+44.3	2	0		0	+7.47	2	0		0	+25.3	3	0
Tule Lake	H_2	8	3	+416	6	+114	9	0	+28.2	9	+28.2	9	0	+33.4	7	+10.1
	N_2		0	+1249	7	+1249		0	+124	7	+114		0	+6.12	8	+5.46
	CH_4			0		0			0		0			0		0
	CO_2		1	+3433	8	+3433		0	+1280	9	+1280		0	+1552	9	+1552
	N_2O		0	+0.593	2	0		0	+15.4	9	+15.4		0	+65.0	9	+65.0
Waukena	H_2	3		0		0	9	0	+30.6	9	+30.6	5	0	+27.2	5	+27.2
	N_2		0	+1.39	3	+1.39		0	+87.3	9	+87.3		0	+0.885	5	+0.885
	CH_4			0		0			0		0		4	+0.144	5	+0.144
	CO_2			+0.904	3	+0.904		0	+2488	9	+2488		0	+310.6	5	+310.6
	N_2O			0		0		2	+3.19	6	+1.87			0		0

[a] Abbreviations: "I.T.," Incubation time (days) for cycle indicated; "L.T.," lag time (days), defined as time interval from start of cycle to when gas increased or appeared; "N," nanomoles, cumulative; "T," (days), time; "Gas (max)," maximum cumulative gas; "Gas (end)," gas at end of cycle.

of CO_2 1.39 vol.%, Kr 1.37 vol.% and balance He. The total pressure was 1 atm (760 mm of Hg). The initial atmosphere contained less than 25 ppm of O_2 and N_2. The numbers of viable organisms as determined by plate counts for the various soils listed are summarized in Table 19. A nutrient media was added at the beginning of each cycle and incubation was at 20 ± 2 °C under dark conditions.

An inspection of the above data reveals that under these anaerobic conditions with nutrients provided, the soil organisms produced between 10^{-4} and 10^{-7} nanomoles of CO_2 per organism per day. Most of the soils produced about 10 micromoles of CO_2 per day per cc of soil.

We would like to use data like this and, in particular, data to be obtained by Viking on Mars for estimating what the magnitude of head-space gas exchange is likely to be in a Mars Return Sample for purposes of designing the life support system. Unfortunately, the metabolism of the soil microorganisms is known to be highly sensitive to nutrient concentration. Figure 31 illustrates the effect of nutrient additions on metabolic rate. Note that in this particular case, the availability of a nutrient increased the metabolism by a factor of 6 to 8 over the endogenous level.

Figures 32A and 32B from (38), illustrate the effect of adding nutrients to a soil sample sealed in a gas-tight container. The log ratio of CO_2 to N_2 or Ar is plotted as a function of time for four soil samples. We note that in all of the soils, the biological activity was low enough (without nutrients added) so that the gas exchange was below detectable limits. The head space volume was about 8 cc. The sample

Table 19

APPROXIMATE VIABLE ORGANISMS AT TIMES INDICATED FOR TABLE 18 EXPERIMENT

Soil	At the end of last cycle before autoclaving		At the end of autoclave cycle	
	Aerobic[a]	Anaerobic[a]	Aerobic	Anaerobic
Antarctica 500	0	0	0	0
DV 1S	3×10^2	3×10^2	0	0
DV 3S/1	3×10^6	3×10^{10}	0	0
Geyserville	0	0	0	0
Aiken	3×10^4	3×10^8	0	0
Bowers Clay #4	3×10^4	3×10^6	0	0
Hesperia	3×10^9	3×10^9	0	0
Holtville	3×10^5	3×10^4	0	0
Panoche	3×10^8	3×10^8	0	0
Ramona	3×10^8	3×10^{10}	0	3×10^1
Salinas Loam	3×10^8	3×10^{10}	0	0
Siskiyou	3×10^6	3×10^7	0	3×10^1
Staten Island P.M.	3×10^7	3×10^9	0	3×10^2
Tule Lake	3×10^5	3×10^8	3×10^3	3×10^2
Waukena	3×10^7	3×10^7	0	0
Yolo	3×10^5	3×10^7	0	0

[a] Growth occurring in last serial 10-fold dilution of TSB (aerobic) and thioglycollate medium (anaerobic).

Reproduced from (4)

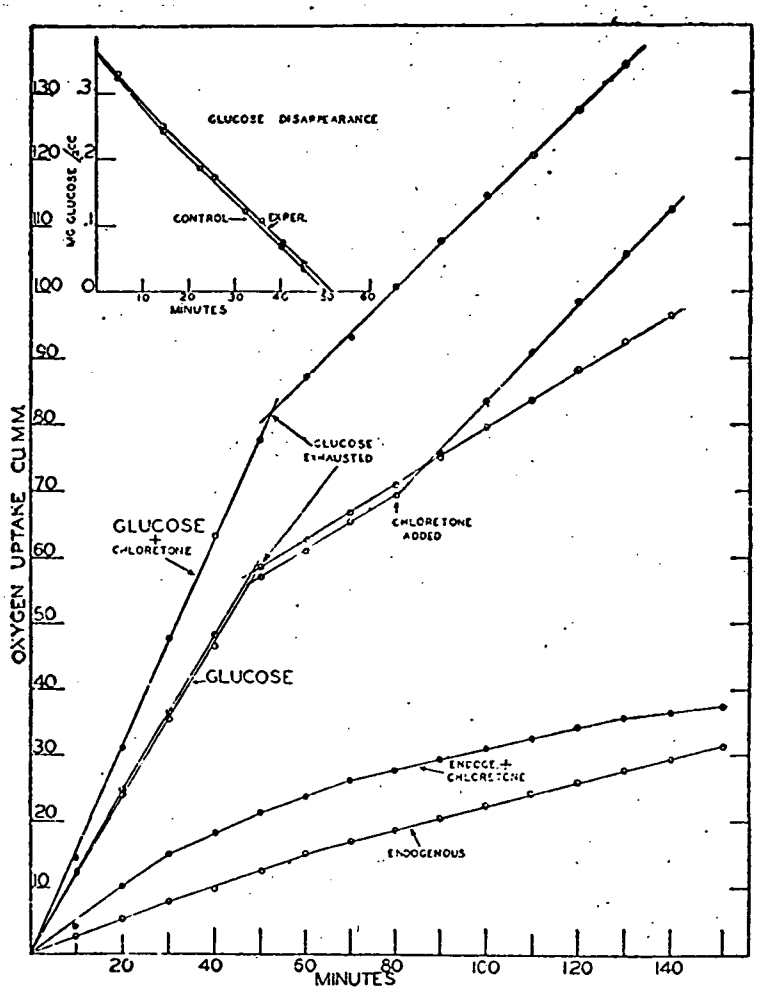

Figure 31. Oxygen Uptake of Achromobacter fisheri with and without glucose

Reproduced from (36)

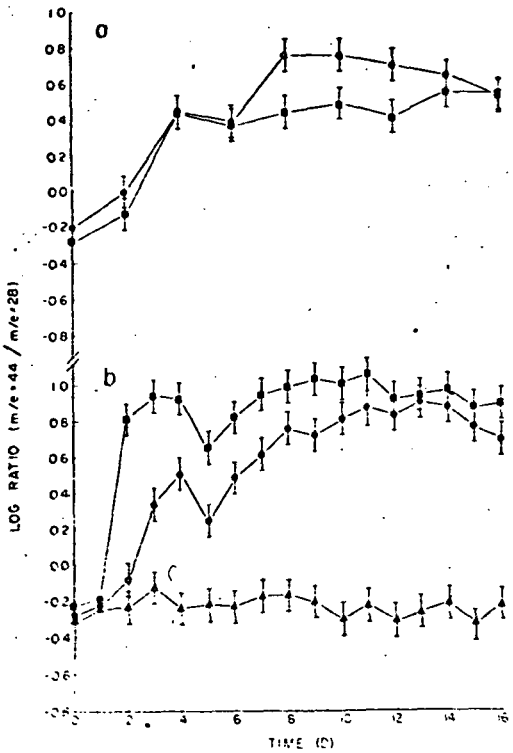

FIG. A *Gas disequilibrium in samples of Tucson, Ariz. soil mixtures during incubation in N_2 atmosphere at room temperature after addition of (a) isomers of a mixture of seven amino acids and (b) isomers of a mixture of five carbohydrates. Symbols: ■, D isomers; ●, L isomers; ▲, addition of water only. Vertical lines represent the 99% confidence limits of each mean ratio of experiments with duplicate samples. Vertical axis shows the log ratios of ion intensities.*

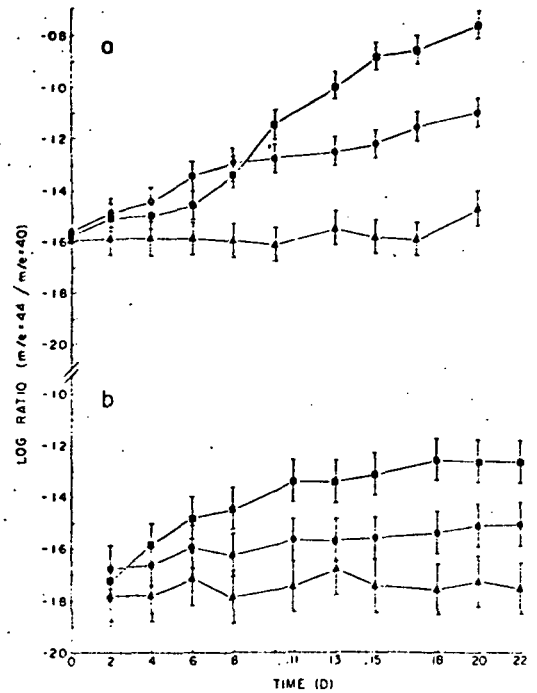

FIG. B *Gas disequilibrium in (a) clay loam soil (Silver Bell, Arizona; 91 to 97 cm depth) and (b) Antartic dry valley soil (no. 500) during incubation in Ar atmosphere at room temperature after addition of isomers of a mixture of five carbohydrates. Symbols: ■, D isomers; ●, L isomers; ▲, water controls. Vertical lines represent the 99% confidence limits of each mean ratio of experiments with triplicate samples with the carbohydrates and duplicate samples with the control. Vertical axis shows the log ratios of ion intensities.*

Figure 32

Reproduced from (38)

weighed 1 gram, and 1 ml of 50 μM nutrient solution comprised of five carbohydrates and seven amino acids in equimolar proportions was used. These data support the theory that the activity of soil biota is limited by the availability of nutritional sources. If we assume that the nutrient to be added is not toxic to Martian biota, we can at least obtain an upper limit for the gas exchange rates under dark conditions from the Viking experiments.

The dark conditions information is only half the story. We also need to know what happens under light conditions in order to decide what the net exchange rates will be between the soil sample and the headspace gas. The Viking pyrolytic analysis experiment data can give a partial answer to this question. In the pyrolytic experiment, a soil sample will be incubated under simulated radiation conditions in a labeled $^{14}CO_2$ atmosphere. After the incubation period, the fixed organic material is pyrolysed and the labeled CO_2 given off is detected. Thus, an estimate of the photosynthetic activity in the sample is derived. Unfortunately, for our purposes, the short wavelength ultraviolet is not simulated for the experiment since this radiation causes CO and H_2O to combine in an abiogenic synthesis of organic matter (4). While this process is undesirable from a life detection standpoint and is consequently avoided, if it occurs it might be an important life process. Finally, light reactions or biological activity involving gases other than those containing carbon will not be monitored by any of the Viking experiments. Table 20 (4) gives some typical results for soils using the Viking pyrolytic analysis experiment.

In summary, we find the following probable situation at the time when a planetary return mission is attempted:

(1) Atmospheric gas exchange is likely to be important to the life support function.

(2) We will have very incomplete information relative to the rates of gas exchange and atmospheric constituents involved.

In the absence of post-Viking missions comprised of experiments designed to provide better data relative to the gas exchange rates, the design of the life support system becomes one of solving a problem with a large number of unknowns.

In solving problems where large numbers of unknowns exist, the designer is usually forced into using a "brute force" technique. Two such possibilities exist for coping with the gas exchange problem. The first type of solution involves providing a large enough headspace volume so that the maximum gas exchange rates expected do not significantly change the composition of the headspace atmosphere during the return trip. We have given this concept the nomenclature, "Infinite Reservoir". The second approach involves analyzing the headspace gas on a periodic basis and adjusting its composition through a combination of scrubbers and makeup gas supplies.

4.4.2.4.1 Infinite Reservoir Concept for Gas Exchange

The most obvious approach to the "Infinite Reservoir" concept is simply to make the headspace volume physically large. Unfortunately, in an application where space and weight are at a premium, the disadvantages of this approach are equally obvious. We could increase the pressure of the headspace gas and achieve an effectively

Table 20

CO_2 Assimilation in Soils[a]

Soil	Amount of soil (mg)	Algae	Bacteria	Exposure conditions (hr)	Pyrolysis CO_2 (counts/min)	Trapped organics above background
Algal (sterilized)	15			Dark, 23	319	10
Algal	14	~10^5	4.9×10^5	Dark, 23	7,104	1,434
Algal	12	~10^5	4.2×10^5	Light, 23	106,588	107,399
Farm (sterilized)	15			Dark, 3	9,339	10
Farm	15		5.3×10^5	Dark, 3	13,799	110
Farm	15		5.3×10^5	Dark, 24	8,689	449
A609 (sterilized)	15			Light, 22	8,354	3
A609	15	30	300	Light, 22	7,023	165
A609	15	30	300	Dark, 22	16,832	78
A652 (sterilized)	15			Light, 22	20,413	19
A652	15	0	150	Light, 22	11,825	13
Siskiyou clay (sterilized)	15			Light, 24	112	1
Siskiyou clay	15	0	6×10^4	Light, 3	361	68
Siskiyou clay	15	0	6×10^4	Light, 24	1,070	272
Siskiyou clay	15	0	6×10^4	Light, 96	2,862	544
Barren topsoil (sterilized)	15			Light, 24	142,635	50
Barren topsoil	15	~100	1.2×10^6	Light, 3	171,829	1,072
Barren topsoil	15	~100	1.2×10^6	Light, 24	107,765	4,902
Barren topsoil	15	~100	1.2×10^6	Light, 96	192,767	28,385

[a] Approximately 300mg samples of soils were spread on sterile stainless steel planchets and moistened with 0.3ml of sterile distilled water and placed inside a Pyrex chamber having a capacity of approximately 40ml. The chamber had a pressure of 1 atm of air enriched with 0.04% excess $^{14}CO_2$ (final specific activity of $CO_2 \cong 15$ Ci/mole). For light exposure, the chambers were placed under fluorescent lights at approximately 600 ft-c light intensity. For dark-exposed samples, the chambers were wrapped with opaque cloth before the introduction of $^{14}CO_2$. After exposure, the samples were dried at 65°C and aliquots were taken for analysis. Sterile controls were prepared by dry-heat sterilization of soils overnight at 175°C and exposure as described above. Microbial counts refer to the quality of soil taken for pyrolysis (12–15mg).

Reproduced from (4)

larger volume in this way. However, the higher partial pressures of some of the constituent gases might be toxic to life forms or cause a shift in the balance of on-going chemical and biochemical reactions. A third possibility makes use of the sorption phenomena discussed earlier.

A number of finely divided materials have found use as sorbents. The most important of these materials are "active" charcoal, silica gel and the zeolites. Their use in the manufacture of gas masks and passive vacuum pumps has resulted in a large volume of experimental data on the sorption process although technologists have been unable to develop a fully satisfactory theory of the complex physical and chemical processes involved in sorption. Dushman (18) considers the phenomena in detail and provides an excellent summary of the theory and experimental results.

In general, it is found that the quantity of the sorbate gas is a function of the pressure and temperature as well as the physical state of the sorbent. Figures 33A and 33B from (18) illustrate sorption isotherms for carbon dioxide on wood charcoal. The quantity, Vo, is the volume of gas in cubic centimeters under STP (0°C, 760 mm) conditions. From Figure 33A, we see that at 0°C a change in Vo of 1 cc STP would cause only 1 mm change in pressure. As a comparison, the evolution of 1 cc, STP of CO_2 by the sample into the same headspace unit volume would raise the pressure in the headspace to at least 760 mm, depending on the starting pressure. Thus, the inclusion of the sorbent has the effect of greatly buffering the headspace against changes in gas composition.

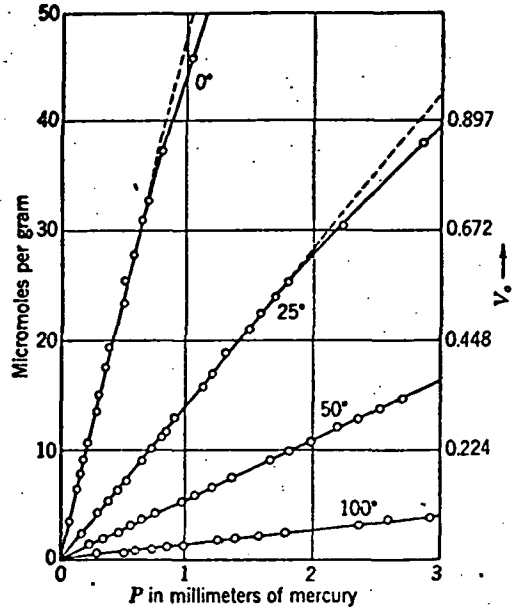

Fig. 33A* Isotherms of CO_2 on wood charcoal - low pressures

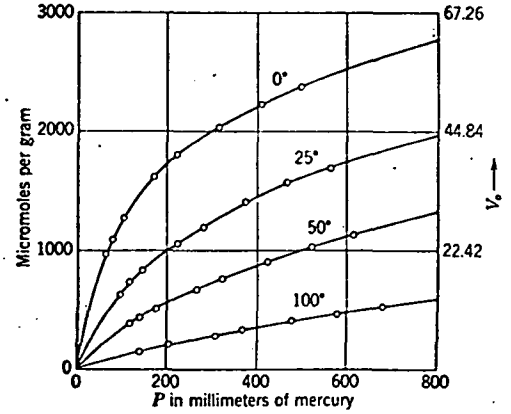

Fig. 33B* Isotherms of CO_2 on wood charcoal

* Reproduced from (18)

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The concept underlying the possible use of a sorbent material such as activated charcoal or a zeolite as a buffer involves exposing a fully degassed sorbent to the planetary atmosphere at the time the sample is collected. The sorbent comes to equilibrium with the atmosphere and is then sealed with the sample. Subsequent gas exchange between the sample and headspace is then buffered by sorbent equilibrium with the headspace gases so that a much higher gas exchange disequilibrium between the sample and headspace can be tolerated without significantly changing the balance of the headspace constituent gases.

It must be noted that the sorption equilibrium is temperature-dependent so that changes in the temperature of the sorbent during the return voyage would be reflected as significant variations in the headspace gas pressure. Temperature cycles on the order of those expected for the Martian diurnal cycle ($\sim$ 100°C) would result in very large headspace pressure changes and weigh heavily against the use of this technique if the diurnal cycle is to be simulated. It must also be noted that the soil in the sample itself will act as a sorbent for gases and thereby introduce headspace pressure fluctuations with temperature. The magnitude of these fluctuations would undoubtedly be considerably smaller than those for activated charcoal or a zeolite, but they would none-the-less, be significant over the temperature range of a Martian diurnal cycle.

Coupling of the headspace gas pressure with the sample temperature can be circumvented by maintaining the "Infinite Reservoir" at the collection temperature as the sample is cycled. This would buffer the

gas constituents and the headspace pressure over the diurnal cycle. And, in fact, by controlling the temperature of the sorbent as a function of headspace pressure, a means of total pressure compensation would be available. However, heat conduction between the sample and reservoir would require considerable extra power consumption for operating the thermal control system.

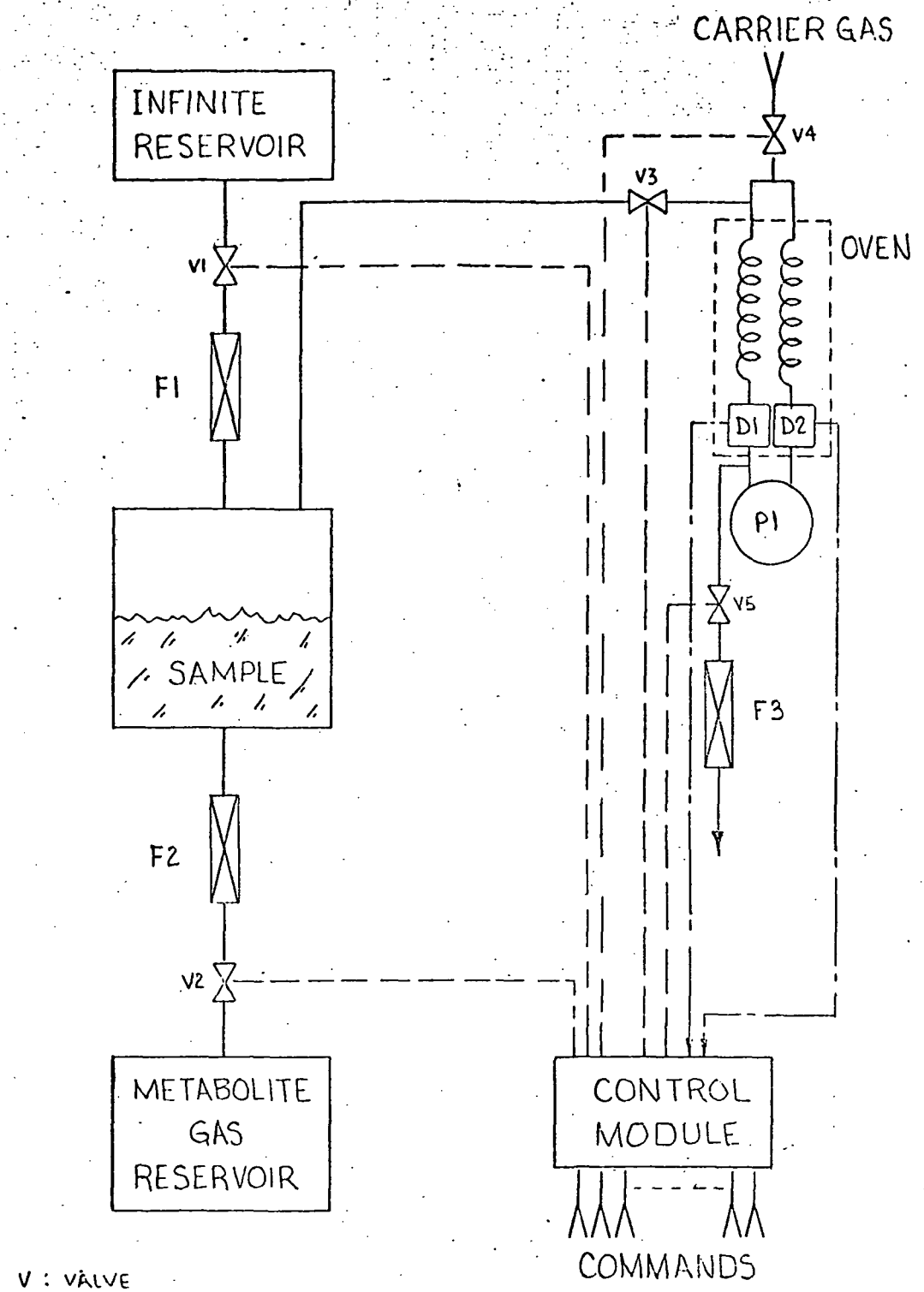
Furthermore, if the estimates of the Martian atmosphere are even nominally accurate, the very low atmospheric concentrations of CO in the case of a CO-CO_2 cycle or even lower free oxygen concentration for an O_2-CO_2 cycle would support only a very small disequilibrium in gas exchange rate over the duration of the return voyage. Inclusion of a sorbent would however, greatly reduce the chance of a toxic gas buildup. On the basis of the present level of information, the merits of inclusion of a simple integral sorbent probably do not balance the disadvantages. If it is determined by Viking or other means that a significant potential for toxic gas buildup exists, then the "Infinite Reservoir" concept would deserve serious consideration.

4.4.2.4.2 Headspace Atmosphere Analysis and Adjustment

The analysis and adjustment scheme for headspace gas constituent control can be made to overcome the basic difficulty of the passive "Infinite Reservoir" concept, that of very low atmospheric concentrations of one of the biologically active gases. A price must be paid, however, in added complexity and an increased thermal load on the sample cooling system.

The simplest mechanization of an active scheme in terms of hardware might comprise an "Infinite Reservoir" and another reservoir of the gases which are normally at low concentrations in the planetary atmosphere. The "Infinite Reservoir" would provide buffering and scrubbing action. As the low concentration metabolite gases were consumed they could be replenished from the second reservoir where they would be stored in high concentrations. Either a cyclic operation of the "Infinite Reservoir" or introduction of the makeup gases through the soil from the "bottom" of the sample could be used to minimize direct sorption of the metabolite gases by the "Infinite Reservoir," the soil in the sample acting as a buffer reservoir. Figure 34 illustrates the concept schematically.

Two techniques which could potentially be used to monitor the headspace gas composition are: gas chromatography and mass spectrometry. Each has advantages and undesirable features in the contemplated application. Both instruments have been developed for use in the Viking program and are therefore readily adaptable to the purpose at hand. The gas chromatograph has the advantage of good separation of CO and CO_2,



V : VALVE
F : FILTER
P : PLENUM
D : DETECTOR

FIG. 34

ACTIVE HEADSPACE ATMOSPHERE CONTROL

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whereas in the mass spectrometer, CO_2 can break down into CO^+ and O upon ionization. In this case, the atmospheric CO is indistinguishable from the CO_2 degradation product (39). In addition, N_2 (mass 28.006) and CO (mass 27.895) are confused in a mass spectrometer of resolution suitable for spaceflight. The N_2 and CO confusion is not likely to be a serious problem in the present application, but the CO_2 degradation to CO^+ is unacceptable if it is established that CO plays an important biological role. This latter problem might be allieviated by the use of a selective filter to remove the CO_2, but since the relative concentration of CO_2 is believed to be approximately 1,000 times that of CO, the design and development of such a filter would be both difficult and complicated. The mass spectrometer has one major practical advantage over the gas chromatograpic approach; it does not require a carrier gas. It does, however, require a good vacuum which in the case of the Viking instrument is provided by an ion pump.

Gas chromatography can provide good separation and identification of all the potentially biologically important metabolite gases. The Viking gas chromatographic unit (37) employs a Poropak Q column which cannot, however, adequately separate Argon, CO and O_2. If Argon is present on Mars in substantially higher concentrations than CO and O_2, a new column would be required. Heylmun (40) has reported separation of oxygen and Argon in a 99 percent Argon atmosphere using a molecular sieve column at 72°C. The major problems in employing a gas chromatograph for headpsace analysis arise because of the required carrier gas.

Although the sampled gas volume is very small (~0.1 cc), a relatively large volume of carrier gas is required for the measurement (~10 cc/min). Thus, a large supply of carrier gas would be required and some way to collect and dispose of the carrier gas after it passes through the detectors must also be devised.

The carrier gas supply problem is simply one of weight and size since the components have been developed for Viking. The problem of disposing of the used gas under the quarantine regime to be imposed on a return sample is much more difficult. Three approaches to this problem were considered:

(1) Collect and store the spent carrier gas in another container.

(2) Collect, purify and pump the carrier gas back into the supply bottle.

(3) Collect and allow the carrier gas to escape overboard through biologically secure filters.

The first approach, illustrated in Figure 35, results in even more size and weight since another storage container must be provided and, unless a pump is included to compress the gas into this container, it must be even larger than the supply bottle. When this situation is evaluated against the component sizes for Viking (a much shorter duration mission), it becomes clear that this approach has very undesirable weight and size characteristics.

In the second approach, a relatively small volume of carrier gas would be required, only enough to perform one measurement plus a reserve for leakage, pump inefficiency and adsorption by the sample and purifying

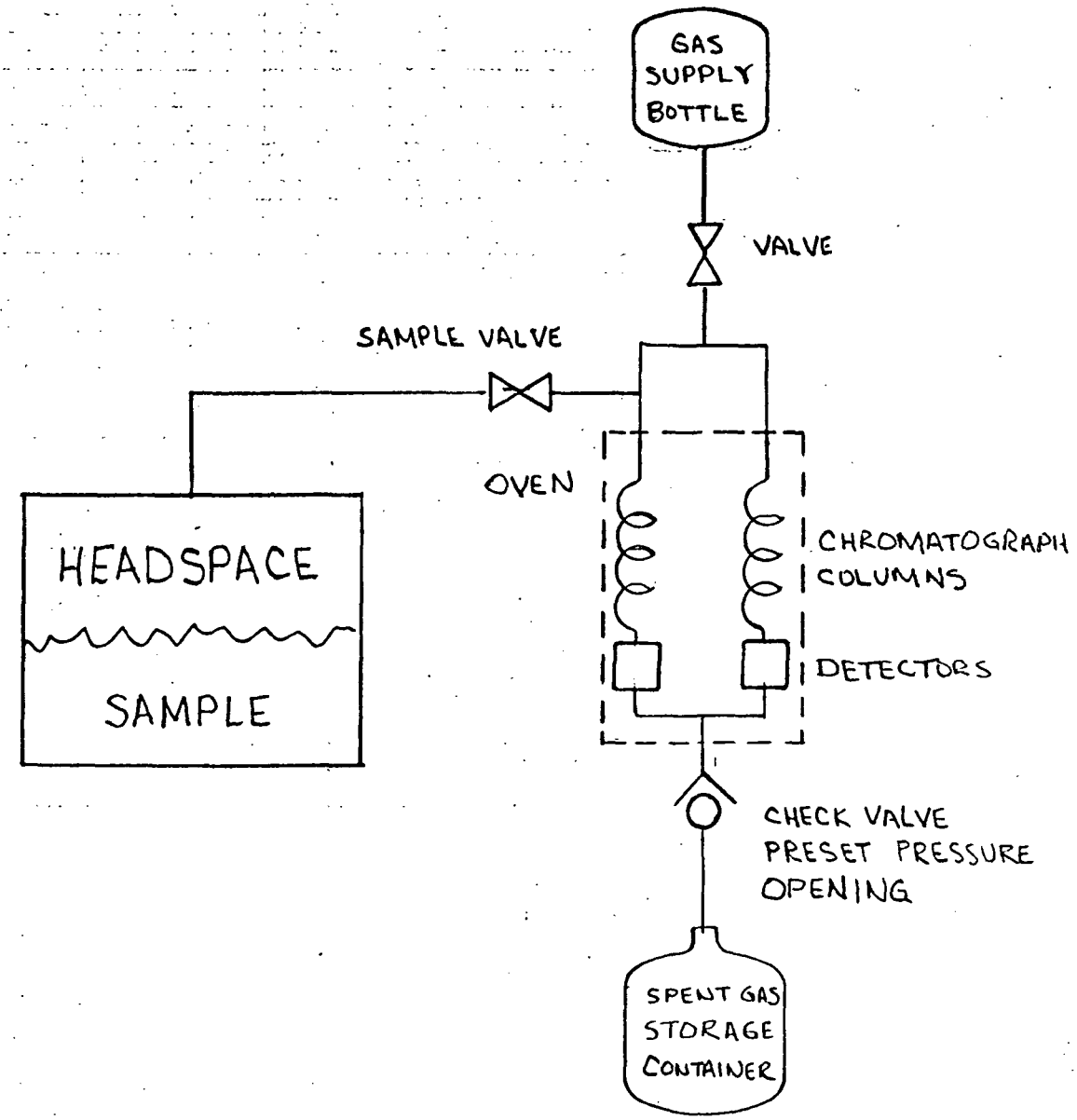

FIG. 35

CARRIER GAS STORAGE

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filter. Furthermore, the gas storage pressure could be relatively low and the space requirements would not be excessive. A pump development would be required. If the configuration illustrated in Figure 36 is used, the pump seals would not be particularly critical.

The third approach considered is illustrated in Figure 37. The carrier gas is accumulated in the temporary storage bottle and allowed to diffuse through the thin metal or glass membranes. (Depending on the specific carrier gas used). The membranes act as a biological barrier and the system is provided with backup filters as a failsafe precaution. The weight and size would be intermediate to the first two approaches. The approach has the obvious disadvantage of a potential quarantine breach.

On the basis of our preliminary evaluation, the second approach has the merits of minimum size and weight and the added advantage of total containment within the quarantine container. The pump is believed to be well within the state-of-the-art. Unless the pump development proves to be considerably more difficult than we imagine, the second approach is the method of choice. It appears to have very significant weight and size advantages over either of the other two considered.

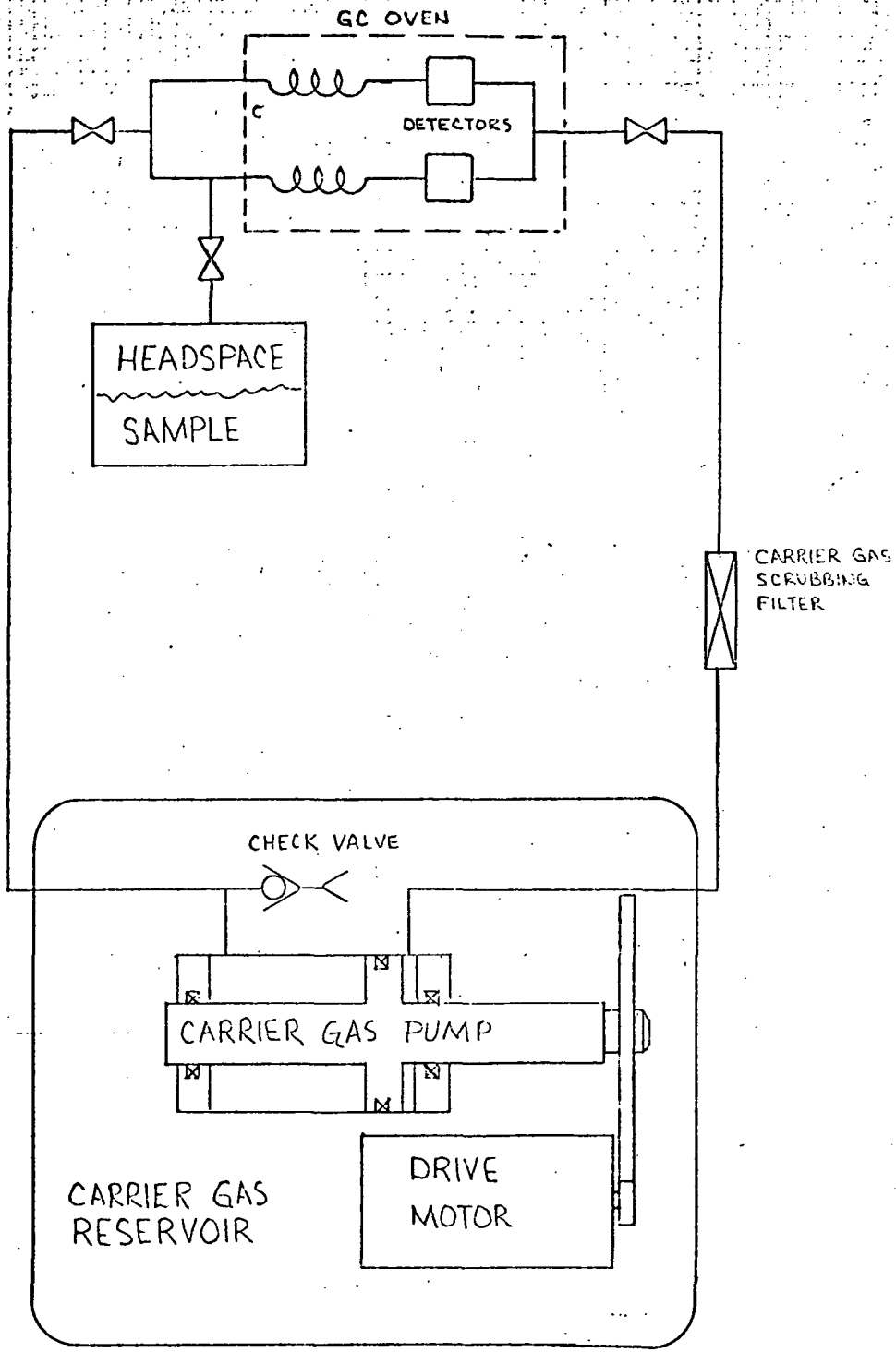

FIG. 36

CARRIER GAS PUMP

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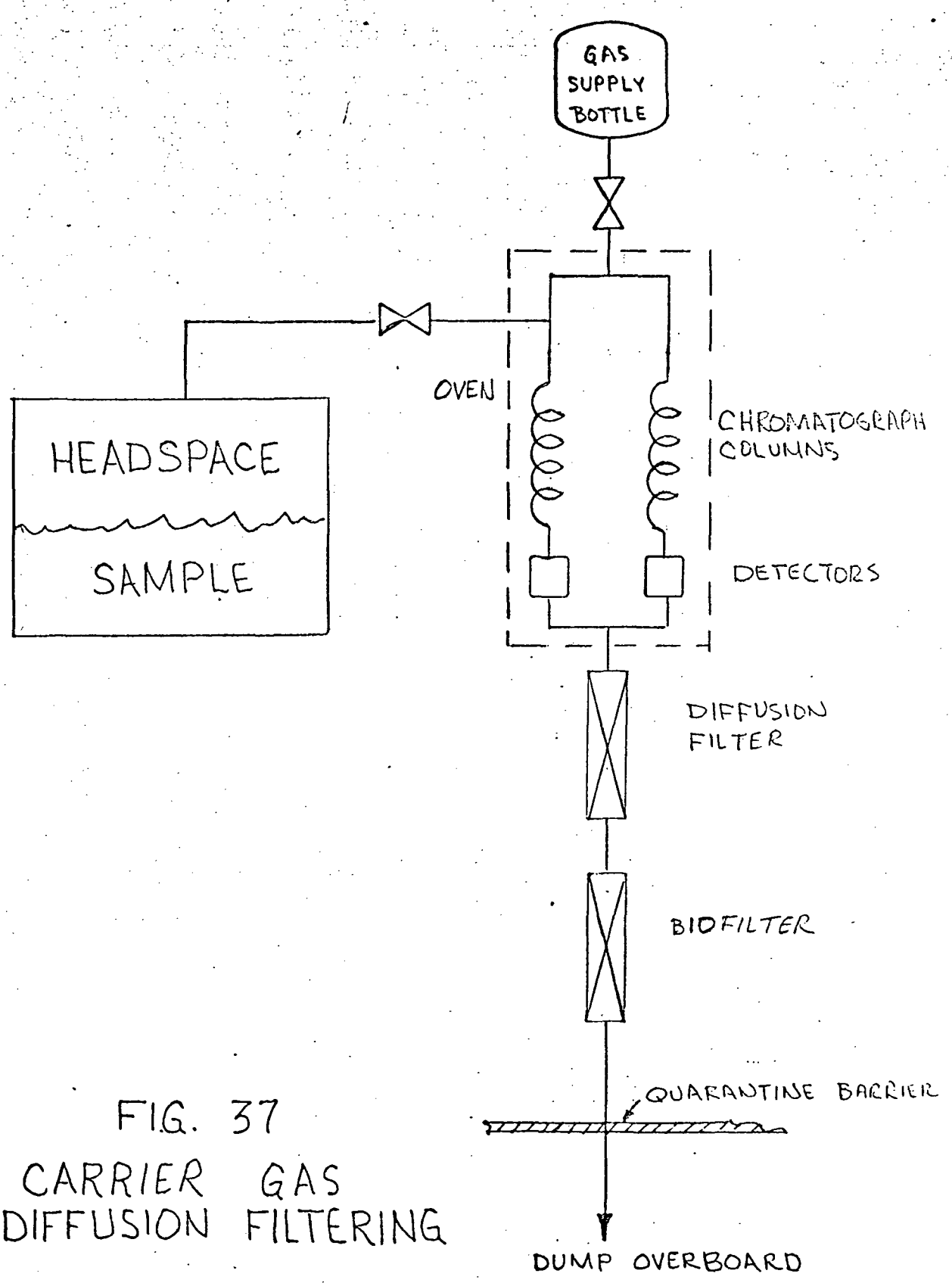

FIG. 37
CARRIER GAS DIFFUSION FILTERING

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4.4.2.5 Strategy D - Hypothermia Plus Infinite Reservoir

This strategy represents an extension of STRATEGY B to include a reservoir of atmosphere as a precaution against changes in the headspace gas composition due to metabolic activity or chemical instability in the sample. The goals of the strategy are:

(1) To prevent contamination of the sample

(2) To preserve the contents of the sample

(3) To preserve the chemical, biological and physical status of the sample by retarding the on-going processes through the imposition of a low temperature regimen.

(4) To provide a buffered headspace atmosphere as a precaution against toxic accumulation of gaseous metabolic products and/or chemical decay products.

The strategy must be recognized to have the following explicit limitations:

(1) Although the probability would be significantly reduced under the low temperature regimen and buffered atmosphere, life forms may autosterilize and species populations may be altered because of exhaustion of substrates and nutrients or the absence of a critical environmental factor such as radiation input, or temperature cycling.

(2) The organic chemistry of the sample may be altered due to an altered biological component or environmental factor such as radiation input or ion exchange.

(3) No provisions for monitoring or biohazard assessment measurements are included.

(4) The inclusion of an absorbent in the sample container results in increased probability of contaminating the sample both biologically and chemically.

A practical implementation of the concept can be based on the configuration shown in Figure 26. In this case, however, an absorbent, comprised of a zeolite, for example, would be included in the cap. The absorbent would be enclosed in a sealed compartment except for micropore filtered ports to allow gas exchange in a manner to preclude exchange of particulate matter. The micropore filters might consist of a stack of thin gold plates pierced by submicron holes. Laser drilling could be used to generate the small holes required.

4.4.2.6 Strategy E - Simulated Diurnal Cycle Plus Active Gas Exchange

This strategy represents an extension of STRATEGY C to include:

- A reservoir of atmosphere as a precaution against accumulation of gaseous metabolic or chemical decay products in the headspace of the sample container.
- A supply of biologically consumed gases which are normally present in low concentrations in the planetary atmosphere.
- Means for sensing and regulating the concentration of the headspace component gases.

The goals of the strategy are:

(1) To prevent contamination of the sample

(2) To preserve the sample constituents

(3) To maintain any biological activity by simulating the thermal pattern and radiation flux of the natural habitat.

(4) To provide a buffered headspace atmosphere as a precaution against toxic accumulation of gaseous metabolic or chemical decay products.

(5) To provide a supply of metabolite gases as a precaution against disequilibrium of ecosystem/atmospheric balance caused by inadequate simulation of the sample boundary conditions or the collection of an incomplete ecosystem.

Figure 38 illustrates the concept schematically. The sample container could be made similar to that shown in Figure 26, except that connections for the gas reservoirs, gas chromatograph and headspace pressure tranducer would be required. The gas reservoir could consist of containers filled with a zeolite and separated from the sample by a filter which would allow gas diffusion, but block particulate matter transfer. The gas chromatograph could be based on the configuration illustrated in Figure 34.

The strategy has the following explicit limitations:

(1) Increased container complexity and materials thermal coefficient matching problems introduce greater uncertainty in our ability to prevent contamination or escape of the sample through gaseous diffusion and small leaks. These leak possibilities are not believed to be significant from a quarantine standpoint since the sample cannister and associated equipment will be enclosed in an isolation capsule which will provide the quarantine barrier in any case.

(2) A significant possibility exists that the sample would be contaminated biologically or chemically by the zeolite material or entrained microorganisms in the gas reservoirs and gas chromatograph column.

(3) If the photosynthetic component of the life cycle occurs in the bulk of the atmosphere, the radiation input provided would not adequately simulate in situ conditions since an equivalent atmosphere depth cannot be provided. The metabolite gas reservoir can be sized to accommodate a nominal disequilibrium in the metabolite gas cycles, however, if the metabolic rate is higher than expected, changes in the headspace gas composition which could adversely affect the biological component might occur.

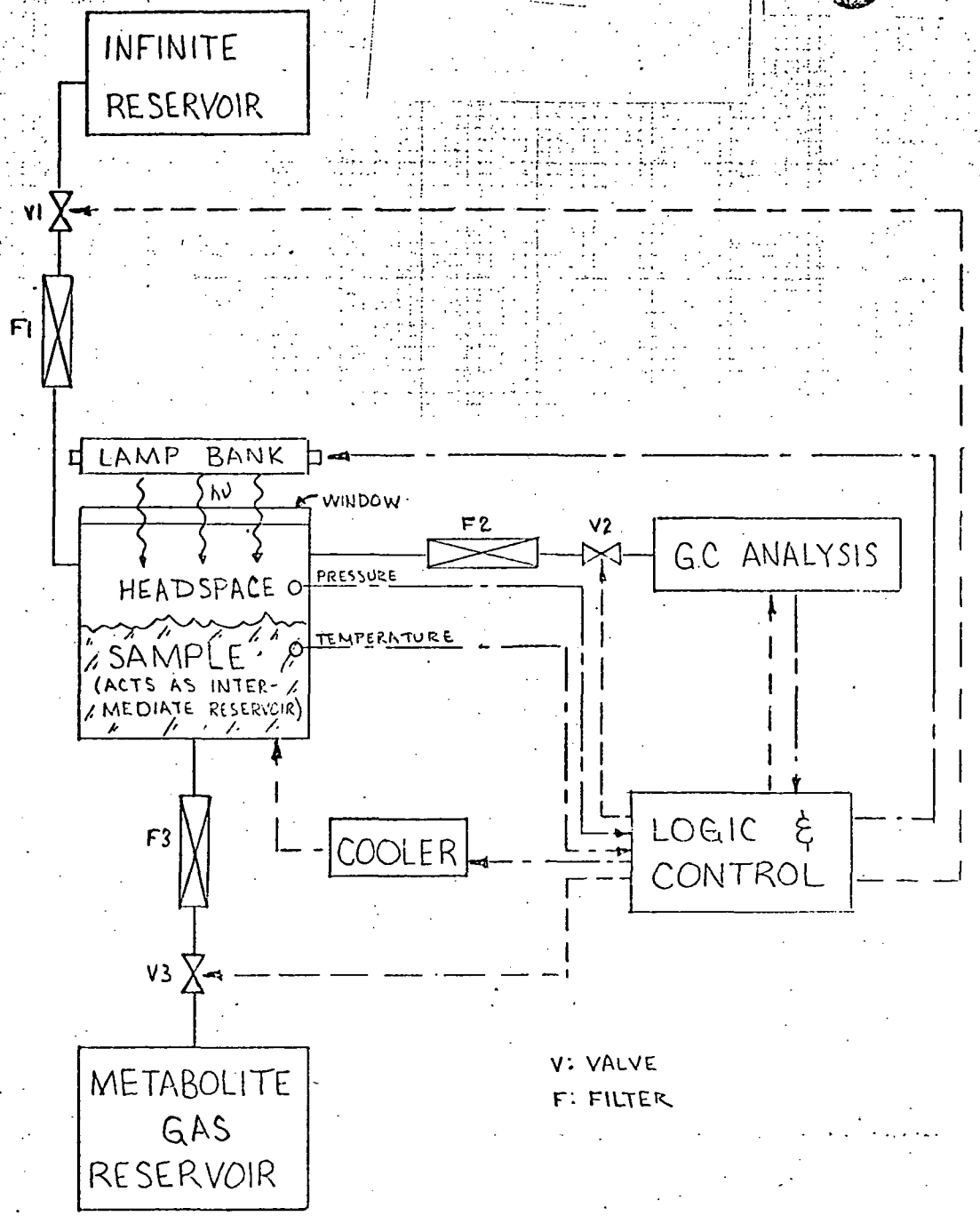

FIG. 38

STRATEGY E CONCEPT

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(4) The organic chemistry of the sample may be altered by a changing biological component or lack of a critical environmental factor such as ion or water exchange with the atmosphere and underlying soil.

(5) Biological activity may be modified by lack of a critical factor related to interactions with the underlying soil.

The inclusion of monitoring capability of the headspace gases results in the availability of a tool for use in assessing biological activity and quarantine implications.

4.4.2.7 Water, Nutrient, or Inorganic Matter Additions and/or Regulations

In addition to gas exchange, it is conceivable that exchange of water, nutrients and inorganic ions may be important to life processes in the sample. This would certainly be true in the case of an Earth sample. Unfortunately, we are very unlikely to have sufficient data on the metabolisms and life processes of Martian biota to be able to define a suitable program for supplementing or regulation of these exchangeable materials at the time of a return sample. And, with this requisite information lacking, it seems prudent to implement no supplemental program rather than risk the results of a poorly understood attempt.

The contamination of the sample from a chemical standpoint and the potential biological disequilibrium which might result from providing substrates, nutrients and even water, provide more potent arguments against supplemental programs than the uncertain benefits.

4.4.3 Life Support Monitoring

Some of the questions sure to arise in connection with a planetary return mission are: How do we know that the biota in the sample did not "die" or change population distribution during the long return voyage? How do we know the life support system worked? Even assuming that the biologists could reconstruct much of the information from a "dead" sample, a set of measurements characterizing the sample during the life and death phases would be an invaluable aid to this reconstruction process and advancement of the life support technology. For example, a history of the headspace gas component concentrations could provide a basis for estimating the metabolism rates, the order of death of various species, the representativeness of the biota left alive at the end of the voyage, the kinds of nutrients and substrates which limited life, and further life support requirements for subsequent missions.

If one carries this line of reasoning to its logical conclusion, a large number of physical parameters of the sample such as temperature, pH, Eh, relative humidity, headspace pressure and even specific ion concentrations could provide valuable information. Highly desirable measurements of biological activity such as might be provided by labeled carbon nutrient additions (5) would also be important. Unfortunately, the experiment would quickly get out of hand. The complexity of equipment which can perform remotely and in a quarantine compatible environment even the simplest measurements was demonstrated by Viking development experience to be formidable. A fully instrumented planetary return sample experiment with its life support

functions and monitoring could easily evolve into a development program which would be an order of magnitude more difficult than the Viking biological package.

The problem of instrumenting the return sample capsule becomes one of carefully balancing the desire for a record of what happened inside the sample during the return voyage against mission cost and development and operational complexity. These tradeoffs are difficult to make given the present level of uncertainty in the mission, planetary conditions, biological activity, etc. However, it is our opinion that the order of priority for records would be as follows:

1. Temperature
2. Headspace gas including water vapor, CO, CO_2 CH_4, H_2S, O_2, SO_x, NO_x, N_2, NH_3, formaldehyde, and ethylene.
3. Visual image of sample surface interface with headspace atmosphere
4. Response to selected nutrient additions
5. Other physical parameters

In addition to the constraints imposed by development complexity and cost considerations, the desire to maintain the sample in a pristine state is in conflict with the desire for historical records during the return voyage. The sample temperature can be readily measured within the constraints of sample quarantine and preservation criteria. Monitoring other parameters listed above would compromise to some extent the sample integrity. The headspace gas composition and visual observation can be accomplished if the gaseous contamination criteria are relaxed on this portion of the sample. Nutrient addition and

monitoring specific ion concentrations would also compromise the chemical and biological integrity of the sample.

The strategy to be adopted for a planetary return mission will be a function of the biohazard assessment approach taken for the mission. For example, if an extensive biohazard assessment program is followed, it is likely that much of the desired historical data to be derived from nutrient additions would be available from the biohazard assessment tests on a separate portion of the sample. In this case, emphasis should be on preserving the sample integrity and only those measurements which involve very low risk of contaminating the main sample should be undertaken.

4.5 Biohazard Assessment and Control Subsystem

In Section 3.3, we found that the incorporation of a comprehensive biohazard assessment and control subsystem (BAC) as an integral part of the return mission should be given high priority. The biohazard assessment and control function differs in a fundamental way from that of exobiology detection. In the latter case, we are primarily concerned with determining if life forms exist. And, it is generally agreed that the most probable environment for detecting exobiota is in its native environment or a close simulation of its native conditions. The BAC function, is on the other hand, interested in what would happen in terrestrial conditions. Would the exobiota grow? Would it be subject to inhibition by naturally occurring factors? Could inhibition be induced by practical "countermeasures" should a quarantine breach occur? What would be the effect on the terrestrial biosphere from exposure to the exobiota?

In the following material we discuss the implementation of what we believe to be a suitable approach to the BAC function for planetary return missions in the 1980's. We have defined, in preliminary form, an implementation scheme based on updated Viking technology, which we believe would meet minimum requirements within the cost and development constraints of a Mars Return Sample Mission.

4.5.1. Sterilization

A primary requirement for any BAC system is sterilization capability. At the present state of definition of a planetary return mission two basic situations are under consideration: (1) a priori sterilization of the return sample before committing to the return and, (2) contingency

sterilization of the sample during the mission at any time the mission is determined to become nonnominal. The general sterilization problem has received extensive treatment and coverage (10, 26, 41, 42) in connection with the on-going quarantine program. Two basic methods have demonstrated adequate performance on terrestrial organisms, heat and ionizing radiation.

The general consensus of the quarantine community is that these techniques can provide adequate protection against exobiota if small contingency factors are added to standard practice. Since exobiology is assumed to be based on carbon chemistry, it should be subject to the same chemical laws relative to bond strengths as terrestrial life. Sterilization of a planetary return sample has an additional consideration over ordinary sterilization practice: the desire to minimize chemical and structural damage to the sample.

In general, radiation sterilization procedures are thought to minimize damage to the sample and are, therefore, preferable to either dry or wet heat sterilization for return samples. However, exposure of the sample to radioactivity does cause some changes in the sample which are undesirable. It is difficult, within quarantine constraints, to design a spaceflight manageable, failsafe radiation sterilization scheme without significant radiation exposure of the sample even if the actual sterilization procedure is not used. The choice of a sterilization method for a return sample is not as obvious as the above considerations might indicate.

After weighing the relative advantages of heat and radiation sterilization against the mission constraints and, in particular, the design constraints for the quarantine barrier, we conclude that:

(1) If the decision to sterilize the sample is firm and made a priori, then radiation sterilization is marginally the best method.

(2) If a contingency sterilization strategy is adopted for the mission, then heat sterilization is preferred since, in the case where sterilization is not required (assumed to be the nominal mode), no exposure to adverse conditions is required.

4.5.2 Growth and Inhibition in Terrestrial Environment

The problem of characterizing the growth and inhibition of exobiota in terrestrial environments is complicated by a combination of three distinct difficulties:

1. The terrestrial environment cannot be characterized by a single set of parametric values such as temperature; water activity; oxygen, carbon dioxide and other gaseous constituent concentrations in the atmosphere; and nutrient availability. Instead, many widely different microenvironments exist.

2. It is likely that chemical reactions will be induced by the introduction of the planetary sample into a terrestrial environment. Depending on the detection methods used and the actual magnitude of these reactions, biological activity may be masked or "swamped out" by these chemical phenomena.

3. The reliability of the measurement techniques for exotic life forms and even for a significant number of terrestrial microorganisms is open to question.

In the face of these complicating factors, we have adopted a more or less serial approach beginning with conditions near those on Mars and changing toward terrestrial conditions of higher water activity and temperature. Even under this serial approach, four separate experimental chambers and samples will be required.

The sample experiments involve testing the planetary material under aerobic conditions in one chamber, in anaerobic conditions in another, and performing controls in the other two chambers using sterilized planetary material. The water activity would be low initially with the temperature near Mars median day temperature. A radiation source simulating sunlight at the Earth would be cycled on and off to test for phototrophic as well as heterotrophic activity. The water activity and temperature would be slowly increased to typical Earth tropical conditions. Water would then be added to form an aquatic environment. Thermal cycles could be incorporated at various points to test for temperature effects with the other parameters fixed. The measurement instrumentation could be based on updated Viking technology and is discussed in Section 4.5.4. Specific inhibition techniques other than nutrient limitation, water activity and temperature could be tested at the end of the experiment against the marine environment recognizing that the first successful test would terminate the experiment. Reference (5) gives a detailed discussion of multiple nutrient and inhibitor test sequences and rationale. The test sequence should be carried out on the planet surface prior to launching the return sample.

4.5.3 Interaction with Earth Ecosystems

The growth and inhibition experiments can provide important information on the environmental tolerance and nutrient requirements of exobiota. This data can, in turn, be used to predict the impact on the terrestrial biosphere of a quarantine breach. It must be noted, however, that this is not a direct measurement. It does not measure directly the ability of the exobiota to compete with native organisms in a terrestrial environment. In addition, there is a risk that the measurement methods may underestimate the level of activity or miss it entirely. After the sample has left the surface of the planet, but before it leaves planetary orbit, we have an opportunity to make more direct measurements, that is, expose a number of typical terrestrial ecosystems to the exobiota. In this case, we can monitor the activity of the terrestrial organisms selected to be representative of the most important life processes on Earth and for ease in establishing and monitoring species metabolism and ecosystem stability.

Fortunately, most of the basic life processes and nutrient cycles can be investigated through microecosystems based on a few species of microorganisms. Interactions of microorganisms at the base of the food chain can be studied at the metabolic level and, through the use of a camera, at the microscopic level. At the metabolic level processes which can be monitored include heterotrophic metabolism (fermentation, glycolysis, etc.), autotrophic metabolism (photosynthesis and chemosynthesis) and nitrogen and sulfur metabolism. In the following section, we outline a BAC mechanization based on updated Viking technology which attempts to provide reasonable protection within practical constraints for a 1980's Mars Return Sample Mission.

4.5.4 BAC Implementation Scheme Based on Updated Viking Technology

The BAC subsystem is comprised of two separate modules with the same basic design. One of the modules is intended for the growth and inhibition experiments on the planetary surface. The other module is to be used for the microecosystem insult tests in planetary orbit. Figure 39 illustrates the concept schematically. Each module is comprised of four experiment chambers, a thermal control subsystem, a lamp for simulating sunlight, a sample distribution subsystem and a battery of analytical instruments. The analytical instruments are based on those developed for the Viking program (Figures 40-43) and include a pyrolytic release or carbon assimilation unit (10), a multiple labeled release unit (10), a gas chromatograph unit (10), a light-scattering detector (10) and a camera. The module is designed so that each chamber can be rotated into the analysis station a number of times during the course of the experiment. An "Infinite Reservoir" scrubber system and a reservoir of metabolite gases similar to those described in Section 4.4.2.4 are included and can be valved to any of the four experiment chambers.

A summary of the BAC surface module function is given below:

Chamber Use:
1. Aerobic environments
2. Aerobic control
3. Anaerobic environments
4. Anaerobic control

Experiments: Growth-inhibition studied under programmed variation of environmental conditions

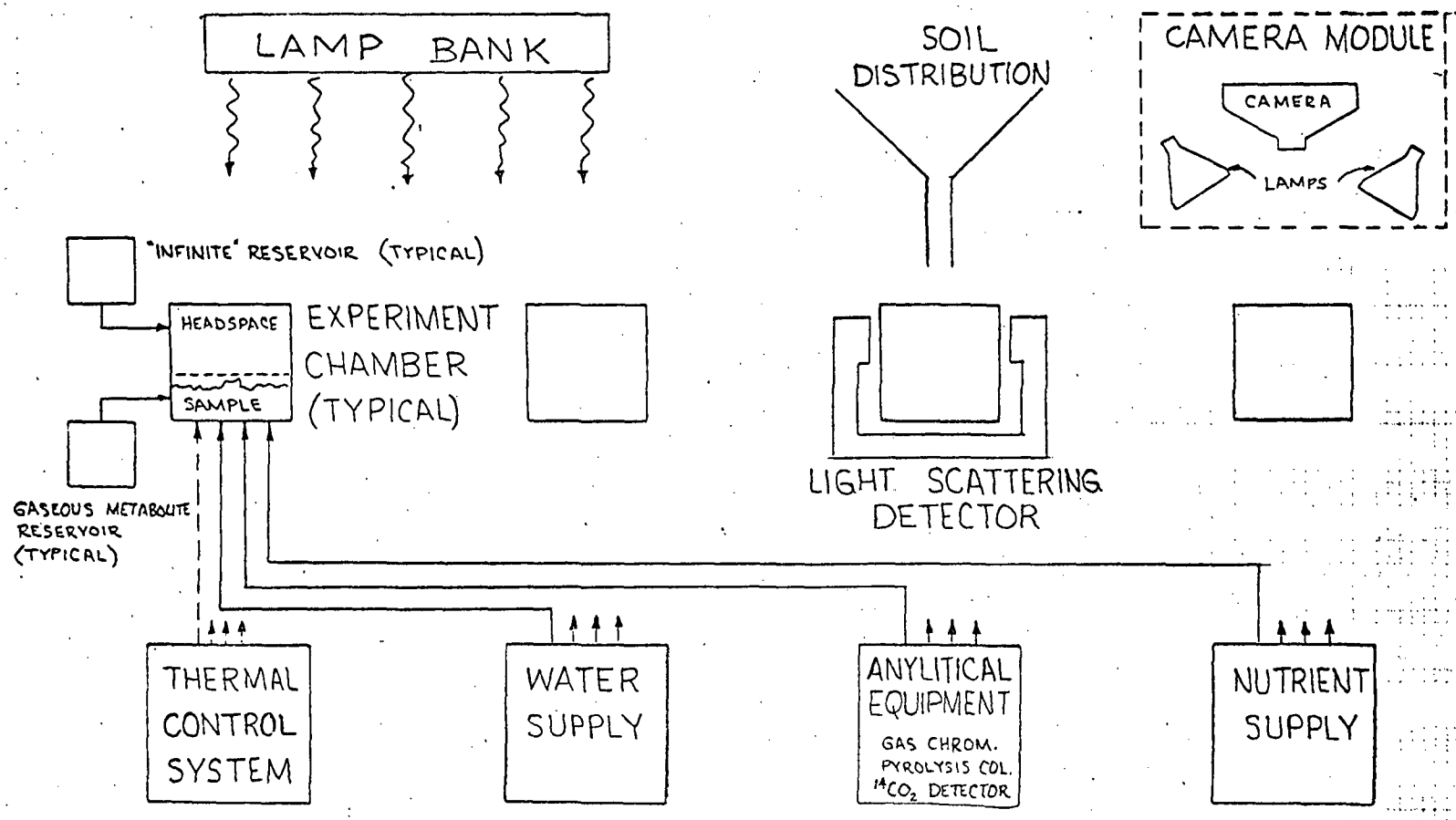

FIG. 39
B.A.C. CONCEPT

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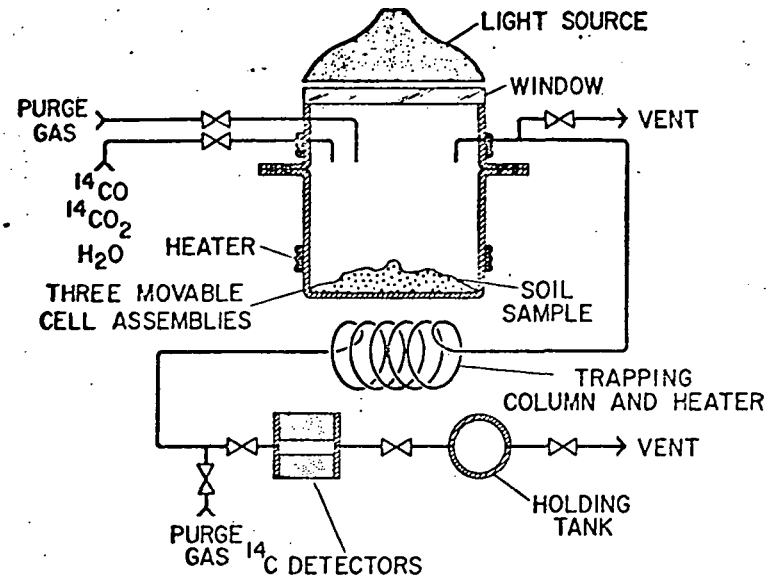

Figure 40

Carbon assimilation (Experiment I). The soil sample is placed in one of three movable incubation cells under an atmosphere containing labeled carbon dioxide and carbon monoxide (addition of water vapor is optional upon command). The samples are incubated for several days under light from a xenon lamp, filtered to remove energy below 310mm. At the end of the incubation, the headspace gases are flushed from the chamber and an acceptable background is counted by the detectors. The sample is then pyrolyzed to 600°C, and the evolved gases are swept onto the copper oxide trapping column held at 120°C. The carbon dioxide liberated in the pyrolysis passes through the column to both the detector and holding chamber for counting. The system is then purged, background counted, and the trapped organics are liberated from the column by heating the column to 700°C. During this process, the organics are oxidized and transferred to the detector chamber for counting.

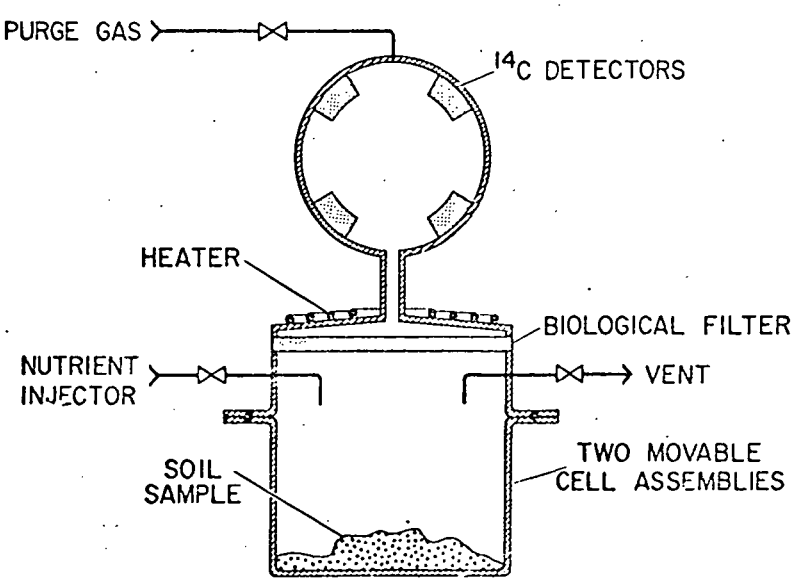

Figure 41

Label release (Experiment II). The soil sample is placed in one of two movable incubation chambers. The stored nutrient and the incubation chamber are both flushed, after which, the nutrient is injected onto the soil. The evolution of labeled gas is monitored in the detector chamber.

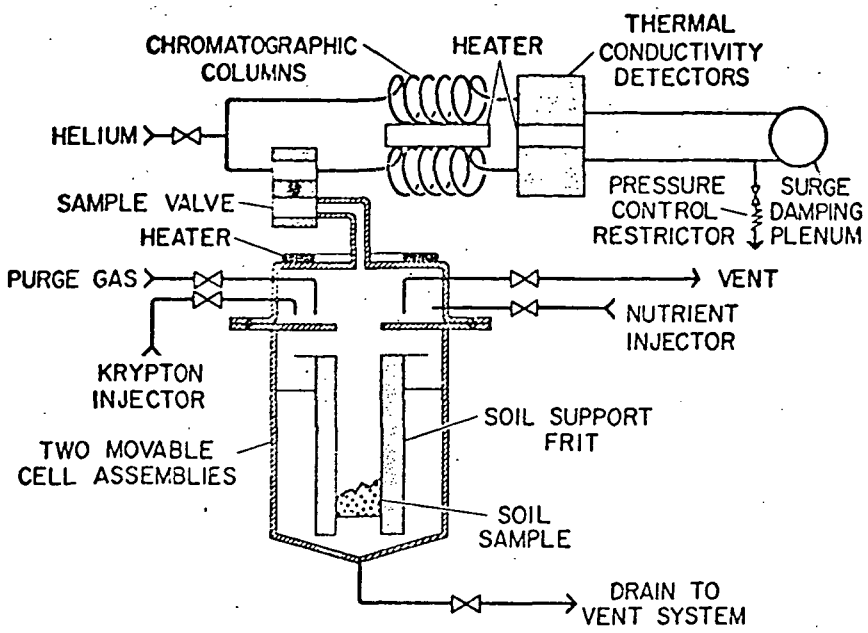

Figure 42

Gas exchange (Experiment III). The soil is placed in one of two movable incubation chambers. After purging of the system, the nutrient is added in a manner that does not submerge the entire soil sample. Krypton is added as an internal standard. Exchange of gas into the headspace is sampled by the gas sampling valve which removes a 100 μl sample and places it in the helium carrier stream. The gaseous components of the sample are resolved on the chromatograph column and, upon reaching the detector, yield a signal that when compared with the pure helium reference side is proportional to the gas concentration. The retention time of the various gaseous components is used to identify the various gases.

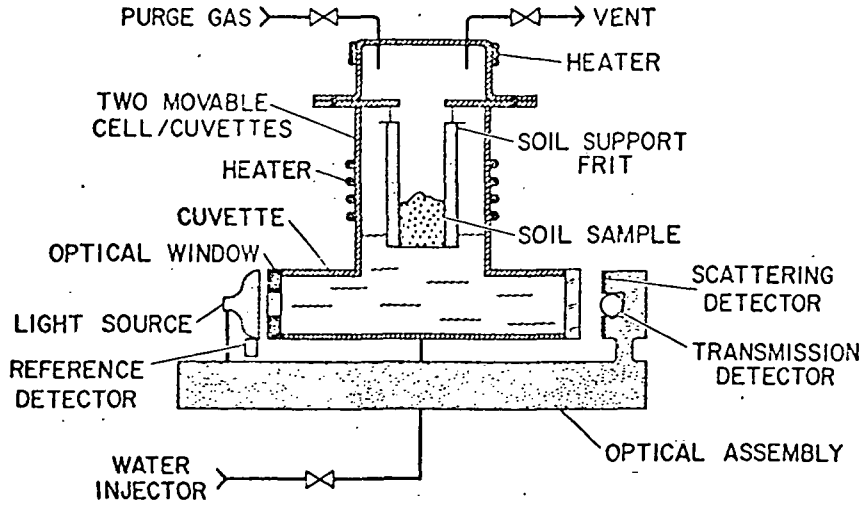

Figure 43

Light scattering (Experiment IV). The soil is placed in one of two incubation chambers into a porous frit cup. Water is then added to the chamber so as not to totally submerge the sample and is periodically monitored thereafter for changes in light scattering and light transmission through the optical cuvette portion of the chamber. The reference beam is also measured. The entire optical assembly can swing away to allow rotation of the incubation cells into position.

The BAC flight module will perform the following experiments:

Chamber Use:	1. 2. 3.	Earth microecosystem insult studies
	4.	Mars environment simulation for historical record during return trip
Experiments:		Insult monitoring using terrestrial microecosystems as sensor and long-term monitoring of return sample in simulated native environment.

4.6 Sample Transfer in Earth Orbit

Sample transfer from the return spacecraft to the shuttle in Earth orbit can be accomplished using the concepts developed for sample transfer in Mars orbit and described in Section 4.2. As a precaution against residual contamination of the exterior surfaces of the return spacecraft, a flexible bioshield could be deployed enclosing the return spacecraft prior to docking with the shuttle or a sample recovery module. Connection between the return sample quarantine container and reentry container can be made via a flexible tube similar to the concept illustrated in Figure 6. The sample quarantine container would be transferred to the reentry container and the connecting tube sealed in steps as illustrated in the concept shown in Figure 7. The reentry container would then be recovered by the shuttle for in orbit experimentation and subsequent return to Earth.

5.0 CONCLUSIONS AND RECOMMENDATIONS

In reviewing the technological requirements for a Planetary Return Sample Mission (PRSM), we found many specific engineering details which need to be addressed. Most are within the current state-of-the-art. However, technology transfer from the physical sciences and engineering to biological applications is involved in many instances. Because of the technology transfer aspects and unusual conditions such as preflight sterilization involved, development and testing lead times for planetary missions will be relatively long and expensive in comparison to non-biological space missions.

We found that for three technical problem areas the state-of-the-art must be advanced significantly to support a PRSM. These areas are:

1. Life support for the exobiota during the return trip and within the Planetary Receiving Laboratory (PRL).
2. Biohazard assessment and control technology.
3. Quarantine qualified handling and experimentation methods and equipment for studying the returned sample in the PRL.

We conclude that additional studies are urgently required in the later two areas since the viability of the PRSM concept is inextricably dependent upon achieving practicable and convincing solutions to these problems. We have included a suggested statement of work for these two studies in the following material. In addition,

we conclude that high priority be given to establish more accurately the life support information needed to define adequately a strategy and design parameters for this important function. We believe that the back-up Viking spacecraft with relatively minor modifications to the experiments could gather this information.

5.1 Suggested Work Statement for a Basic Warning System and a Preliminary Definition Study of the PRL

A. Purpose

The objective of this effort is to devise a program to define and establish the feasibility of a biohazard basic warning system using microecosystems incorporating the basic idea that by monitoring the interaction of extraterrestrial materials with a few selected microorganisms a first approximation to the biohazard represented by quarantine breakdown could be established.

B. Tasks

1. Conduct a Study to Select One or Two Candidate Basic Warning System Microecosystems for an Ultimate System Which Would Satisfy the Following:

   a. Be representative of the most important life processes

   b. Be compatible with spaceflight and quarantine requirements

   c. Be compatible with existing technology for monitoring perturbances on the ecosystem

   d. Conduct a literature review on research being done on Desert Biomes and Alpine Tundra

e. Interview leading scientific authorities on this research to establish candidate ecosystems for detailed investigation and analysis

2. Define a Basic Warning System Based on the Set of Microecosystems and Existing or Near-Term Technology for Evaluating the Effect of the Sample on the Microecosystems Developed Under (1).

   a. Review life detection and monitoring techniques for sensitivity

   b. Develop other methods beyond Viking Technology for assaying unknown life forms to include detection of perturbations to known organisms

   c. Develop techniques to differentiate between biological and other types of insults

3. Design Strategy and Methodology for Employing Basic Warning System in Quarantine Protocol for Planetary Return Technology

   a. Assess life support requirements of the ecosystems in relation to practical problems involved in employing the basic warning system

   b. Formulate qualitative assessment of biohazard implications of positive and negative responses

4. Design, Construct and Test a Feasibility Model Basic Warning System

   a. Construct and demonstrate laboratory breadboard system which will simulate storage and activation of component ecosystems utilizing selected assessment techniques

5. Justify Model Basic Warning System as a Suitable Approach to Minimizing Risks Associated with Interplanetary Biological Interaction

6. Conduct a Preliminary Definition Study of Planetary Receiving Laboratory to Provide NASA with Pertinent Information Before Extensive Programs are Planned and/or Conducted

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This study will collect and refine data on kinds of experiments which need to be performed, their scientific justification, availability of suitable techniques and equipment. This will include:

a. Survey of scientific communities and NASA centers

b. Compile survey data into a report to be circulated to participants for criticism

c. Examine experiments in terms of compatibility with quarantine restrictions, available instrumentation with quarantine systems and desired sensitivities

d. If new instrumentation is required, present a plan as to feasibility, time schedule and cost

e. Summarize in report form a test program, available instrumentation, specifications for new instrumentation if necessary

f. Conduct symposia to resolve criticisms from participants and/or scientific community

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Respectfully submitted,

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APPENDIX A

TRANSLATION OF THE HYDROGEN LOSS CRITERIA INTO A SPECIFICATION FOR HYDROGEN LEAK RATE

In their sample preservation study, Jaffe et al (1) determined that: "The hydrogen loss, at partial pressures of 10^{-1} to 10^{-4} torr of free H_2, should not exceed 5% in two years." If we define the total quantity of H_2 in the container as Q and the leak rate, q, measured in the same units as Q per second, we have:

$$\frac{qtA}{Q} \leq 0.05 \qquad \text{eq 1}$$

Where $t = 2$ years $= 6.3 \times 10^7$ seconds

A is the surface area of the container.

From Dushman (7) we find for metals:

$$q = \frac{k_o}{d} \sqrt{p}\, e^{-(b_o/T)} \qquad \text{eq 2}$$

$$Q = PV \qquad \text{eq 3}$$

Where k_o is the diffusion constant

d is the wall thickness in mm

p is the partial pressure

b_o is a constant

T is the absolute temperature

V is the container volume

Therefore the ratio of the leak rate due to diffusion to the total quantity of gas present in a metal container is proportional to the inverse of the square root of the partial pressure differential across the wall:

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APPENDIX A (continued)

$$\frac{q}{Q} \propto \frac{\sqrt{P}}{P} \propto \frac{1}{\sqrt{P}} \qquad \text{eq 4}$$

This shows that the most severe requirement on metalic wall material would occur at the lower partial pressure limit specified at 10^{-4} torr even though the actual leak rate is higher at the higher partial pressures.

The criteria for the wall material leak rate then becomes:

$$q \leq 8 \times 10^{-10} \times \frac{Q}{A} \qquad \text{eq 5}$$

at $P = 10^{-4}$ Torr

For a 50 cubic centimeter sample with 60 square centimeters of surface area we find:

$$q \leq 6.6 \times 10^{-14} \quad \frac{cc \cdot mm}{cm^2 \cdot sec}$$

$$= 8.7 \times 10^{-17} \quad \frac{atm \cdot cc}{cm^2 \cdot sec} \quad \text{at } \Delta P = 10^{-4} \text{ torr}$$

However the quantity, q, is usually specified as a permeation constant, s, in terms of 1 cm or 1 atm differential pressure. The valves of s corresponding to the above leak rate are:

$$s = 2.8 \times 10^{-14} \quad \frac{atm \cdot cc}{cm^2 \cdot sec} \quad @ \Delta P = 1 \text{ cm Hg}$$

$$= 2.4 \times 10^{-13} \quad \frac{atm \cdot cc}{cm^2 \cdot sec} \quad @ \Delta P = 1 \text{ atm}$$

$$= 1. \times 10^{-8} \quad \frac{\text{micron-liters}}{cm^2 \cdot min} \quad @ \Delta P = 1 \text{ atm}$$