Planetary Protection Issues for the MESUR Mission: Probability of Growth (Pg)

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INTRODUCTION

A Workshop, convened under the auspices of the NASA Ames Research Center, was held in Palo Alto, California on June 3 and 4, 1991. The meeting was requested at this time in order to give some guidance on possible approaches to Planetary Protection to planners of the Mars Environmental Survey (MESUR) mission at Ames. The panel of invited participants (see attachment 9) were primarily microbiologists and ecological biologists with extensive experience in soil and marine biology and were gathered to consider the question of the probability for the growth (P_g) of terrestrial organisms on Mars. P_g is a crucial parameter in the calculations that lead to Planetary Protection requirements for planetary missions. In addition, several other participants were invited to provide background support for the Workshop (see attachment 9). Finally, a small number of invitees were unable to attend, but submitted written evaluations, which are included following the panelists' individual assessments of the value for P_g reported by the 1978 Space Studies Board (SSB).

The agenda for the meeting (see attachment 10) began with a series of tutorials by specialists on the current environment of Mars, after which open discussion followed centering around the issue of P_g. At the conclusion of these discussions, there was considerable agreement on the assessment of P_g, and the panelists were asked to submit individual written statements including recommendations for potential future research on this problem.

BACKGROUND BRIEFINGS

D.L. DeVincenzi briefly summarized the overall characteristics of the MESUR mission (see attachment 1), indicating the global distribution of the proposed MESUR landers. He emphasized the need for an early assessment of P_g, since requirements for Planetary Protection could potentially have significant engineering and cost impacts on the mission. This information was timely since planning for the MESUR mission had reached an advanced stage. He also briefly reviewed the history of the development of NASA's Planetary Protection policies (see attachment 2). Under current policy, only general guidelines are available for a mission such as the MESUR mission. Specific requirements have yet to be developed either by NASA or by the NRC's Space Studies Board.

H. Klein reviewed the history of previous assessments of P_g (see attachment 3), beginning with an initial "worst case" assessment of $P_g = 1$, at the first international conference devoted to Planetary Protection in space missions, sponsored by the Committee for Space Research (COSPAR) in 1964.

At a subsequent meeting, in 1967, this value for P_g was refined by further statistical analysis, and a value of $P_g = 10^{-3}$ was recommended for use by member states of COSPAR. In a 1970 study the Space Science Board considered what was known or inferred about Mars at that time and also what was known about the "hardiest" terrestrial organisms and their environments, including a consideration of such factors as temperature, water activity, UV flux, nutrients, and the presence of possible inhibitory substances. On the basis of these deliberations, they concluded that P_g was 3×10^{-9} or less, and that the chances were less than 1 in a thousand that P_g was greater than 10^{-4}. In summary, they recommended that NASA use a value of 10^{-4} for Mars. Nevertheless, NASA revised this figure downward, and used a value for P_g of 10^{-6} in planning for the Viking mission.

Following the analysis of the Viking results, the Space Science Board, in 1978, issued new guidelines for P_g based on two new findings; these were the absence of any organic compounds and the presence of strong oxidants at the Viking sites. On these grounds their revised estimates for P_g were $<10^{-10}$ for surface samples in subpolar regions, $<10^{-8}$ for subsurface samples from these regions, and $<10^{-7}$ for samples from polar regions.

For the purposes of this workshop, the participants were asked to consider these 1978 Space Science Board values for P_g as the most recent guidelines available to NASA, and to assess their validity for the MESUR mission, in the light of their own background and experience.

L. Daspit reviewed the various procedures that were used in the implementation of Planetary Protection measures on the Viking mission (see attachment 4). Based on the COSPAR guideline that the probability of contaminating Mars (P_c) be no greater than 1×10^{-3}, the "allocated" probability of contaminating Mars by the Viking mission (2×10^{-4}) required varied and extensive techniques to eliminate or reduce sources of potential contamination from large "impactable" spacecraft items, from ejecta efflux, and from the two Viking landers. The likelihood of contaminating Mars was treated probabilistically. The initial biological load on the spacecraft (N) was determined and then separate probabilities were estimated for: 1) the release of organisms from the spacecraft (P_r); 2) the survival of terrestrial organisms in interplanetary vacuum and temperatures (P_{vt}); 3) survival to UV radiation and to heating

during entry (P_{uv}); and, 4) the probability of growth and proliferation of organisms on Mars (P_g). Using values for these probabilities, assigned by NASA headquarters, the total surface, mated surface, and buried microbial loads of the Viking landers were reduced principally by a terminal heat "sterilization" of the Viking Landers. In turn, this required a rigorous program of component heat compatibility and flight acceptance testing.

R. Haberle reviewed the current information regarding the basic physical properties of Mars (see attachment 5). Because of the nature of the workshop, particular attention was paid to temperature variations on the planet, its atmospheric composition, and the radiation flux at the surface. Considerable discussion ensued regarding whether or not local "hot spots" might exist on Mars and also about uncertainties in estimates of the flux of UV radiation that reaches the surface. On both counts, it was clear that resolution of these issues will require future direct measurements on Mars.

B. Clark presented a brief review of the status of information on the composition of the Martian surface material (see attachment 6). From the Viking X-ray fluorescence experiments at the two sites on Mars, the data revealed a remarkable similarity in the elemental composition of the loose surface matter that covered these regions. In addition to silicon, iron, aluminum, calcium, and titanium, surprisingly high values were obtained for sulfur and chlorine. The data are interpreted as indicative of three components: a rocky component, a salt component and an iron mineral phase. Sulfur is presumed to be present largely as sulfate. No sulfur-containing gases were detected in the Martian atmosphere by the Viking experiments. It is hypothesized, therefore, that chlorine and sulfur-containing materials were outgassed from volcanoes and then rapidly reacted with the surface to form salts. Other outgassed material may also have contained fairly high concentrations of heavy metals, and whether these (if present) might prove to be inhibitory to terrestrial contaminating microbes is a matter of conjecture. On balance, the overall composition of the "soil" as inferred from the X-ray fluorescence data could be either advantageous or deleterious to terrestrial organisms. The data suggest that about 80% of the soil is in the form of some type of clay, about 13% as magnesium sulfate, and about 7% as calcium carbonate and chloride. Since the data suggest high salt concentrations on Mars, it is probable that significant amounts of water are tied up both in the clay and salt phases of the material.

Discussion was heated about the possibility of forming brines from the presumed soluble salts, but Clark stated that the inferred concentrations and nature of the salts would not depress the freezing point of water sufficiently to provide brines that could exist on Mars. Fanale, however,

pointed out that this conclusion was true only if it is presumed that the surface temperatures do not rise, even occasionally, to relatively high temperatures on Mars. In his view, brief excursions of temperature could then provide intermittent liquid environments.

The findings regarding the lack of organic compounds and the presence of oxidants on Mars were also discussed.

F. Fanale discussed the presence of water on Mars, and presented a model of Mars as a planet with large amounts of water ice on and beneath the surface (see attachment 7). Morphological evidence for this view comes from estimates of water in the pole caps (around 10 meters); many features seen in Viking data indicative of ground ice either now or in the past; pictures showing layered terrain; and ejecta patterns around many craters (so-called "splosh" craters). These all are interpreted to mean that perhaps several hundred meters of water as water ice are locked up on Mars. At equatorial latitudes (between about 45°N and and 45°S) such ice cannot exist at any depths according to this model unless the region is out of equilibrium with the "mega-environment" of the planet. At the pole caps, ice layers to depths of 1 kilometer are possible. The presence and extent of ice layers are also heavily dependent upon the surface composition. His studies predict that pole-ward of ±45° ice can exist in equilibrium with the polar caps at depths from 4 meters to less than 2 meters, depending on the latitude and local mineralogy (e.g. clay versus igneous material).

Whether periodic brines are possible requires that such zones be out of equilibrium with the overall ambient Mars environment. The models show that at equilibrium, many places on Mars contain water ice in equilibrium with the polar caps; also, many places could occasionally reach temperatures that could provide liquid water at depths. However, according to this model, there are no sites that get warm enough and at the same time still retain water ice. On the other hand, brines could exist, in principle, provided that the sites are out of equilibrium with the ambient environment. For example, regions with a different albedo, or covered by a cohesive duracrust layer, could prevent water (that is coming up towards the surface from the vast reservoir of ice beneath) from escaping rapidly into the atmosphere, and thus provide areas for intermittently sustained brines.

DISCUSSION OF P_g VALUE

Following the briefings on the current Mars environment, the panelists were each afforded an opportunity to put forth their own estimates of P_g, using as a standard the most recent (1978) Space Science Board (SSB) values, as noted above. The panelists' individual assessments, together with their reasoning, are given in a later section. What follows is an overall summary as gleaned from the discussions and the individual statements.

All of the participants agreed that, at our present level of understanding of Mars, there was at least some chance that some highly specialized terrestrial organisms might conceivably be able to grow somewhere on Mars. However there was almost uniform agreement that the probabilities involved were exceedingly small. Of the eleven panelists, three felt that the SSB's values were reasonable; five specifically said that the Board's estimates were too high; two did not relate their estimates to the Board's figures, but implied that their estimates would put the value of P_g even closer to zero; and one stated that his estimate for P_g was less than 10^{-6}. Below are excerpts from each of the panelists' statements:

MARY LYNNE PERILLE COLLINS: "The most significant factor affecting P_g is the lack of water; as a result of this, P_g approaches zero. Growth would only be possible should there be oases due to geothermal activity. P_g should be adjusted down to account for the inability of Earth organisms to grow outside of such putative oases."

DIANA FRECKMAN: "The estimates by the SSB, of P_g from 10^{-7} to 10^{-10}, depending on the region of Mars and its environment at that region, are too high in my opinion. I think, based on current evidence and knowledge of the Mars environment, that the P_g is very remote and should be much lower than the Board's P_g value, perhaps 10^{-30}."

IMRE FRIEDMANN: "In my opinion, the P_g values for growth of terrestrial organisms on Mars ($<10^{-10}$, 10^{-8}, 10^{-7}) are too high and should be substantially revised downward."

RICHARD HANSON: "I believe the value of P_g for subpolar regions is very small. I believe a value of 10^{-10} is high, and is a number that has real meaning to many microbiologists who examine microbial survival in food products, pharmaceuticals, etc. Therefore I would use a

value less than 10^{-10} for subpolar regions. I intuitively find it unlikely that a microbe would survive and grow at the poles . . . I believe a value of 10^{-7} is acceptable."

LAWRENCE HOCHSTEIN: "The question of P_g is related to the presence of liquid H_2O. That is, the limiting factor for determining a value for P_g is evidence for the presence of H_2O, since there is no evidence that terrestrial organisms can grow in the absence of H_2O. The temperature and pressure values for Mars do not allow for the presence of liquid H_2O on the surface of Mars. Therefore, P_g approaches zero (i.e., the Space Science Board values are too high)." '

HOLGER JANNASCH: " . . . in light of the reports presented at this meeting, I believe in the differentiation of P_g into the three categories: $P_g = 10^{-10}$ for subpolar surface areas, $P_g = 10^{-8}$ for subpolar subsurface areas, and $P_g = 10^{-7}$ for polar areas are important. I also believe that their actual values are reasonable and not too low."

JOHN INGRAHAM: "Taken together, the chances of a terrestrial bacterium growing on Mars must be very small indeed. But how does one estimate the probability? I guess the hypothetical water site must cover less than 10^{-4} of the surface. I also guess that potential Mars-growing bacteria would constitute less than 10^{-9} of the Earth's bacterial population. In combination, the estimated P_g is considerably less than 10^{-10}."

HAROLD MOROWITZ: "Based on the evidence presented, the probability of any microorganisms, from a clean spacecraft, growing in a martian habitat is vanishingly small but not zero."

RONALD OREMLAND: "I feel that multiple factors assure that the value of P_g for a microorganism on the surface of Mars, introduced from a terrestrial source, would be so low as to render the P_c for the equation to be less than 10^{-3}; hence my subjective feeling is that P_g is less than 10^{-6}. I base this upon the fact that there are no evident sources of water, either in liquid form or at reasonably high humidity, comparable to that encountered even in the most hostile terrestrial environment. When other factors are considered which would also constrain P_g, such as lack of available electron donors for energy, temperature extremes, harmful soil oxidants, lethal UV exposure, this ensures a low value."

MARGARET RACE: "Nothing discussed during these two days would allow anyone to quantitatively adjust the 1978 Space Science Board estimates of P_g. In the absence of

additional data or information we are hard pressed to suggest other values, so I recommend that we accept these earlier figures as "operational" P_g's."

DAVID WARD: "In my opinion our ability to estimate P_g is limited by the uncertainties in calculating the probability of suitable habitats. Intuitively, I agree that the probability of habitats with liquid water is likely to be low, but we should seek a more scientific approach to estimating the limits of this term. Realizing that the 1978 P_g estimates were made "reluctantly" with the caveat that we cannot absolutely rule out the existence of oases capable of supporting terrestrial life, I concur with the opinion that P_g is probably very low. The 1978 estimates of P_g are probably fair."

To complete the record of this aspect of the Workshop proceedings, it is also necessary to indicate the nature of comments received from the three invitees who were unable to attend, but who sent in letters containing their reactions to the issue at hand; the complete letters are to be found in a later section.

THOMAS BROCK: "Frankly, I do not think this is a scientific question, since it is not subject to testing or verification. I would not sterilize any probes, since I think it would be more trouble than it was worth."

NORMAN HOROWITZ: "I have been convinced for over 20 years that there is insufficient water on the planet Mars to support terrestrial life or anything like it."

NORMAN PACE: "My opinion as a microbial ecologist is that no known terrestrial organisms could grow on the surface of Mars. That hostile environment of low temperature, low atmospheric pressure, low water content, high UV flux and low reduced-carbon (based on Viking results) does not occur on Earth, so organisms cannot have been selected for those conditions. Terrestrial organisms are exquisitely molded to their particular environments."

SUGGESTIONS FOR FURTHER STUDY AND RESEARCH

Most panelists responded to a request to suggest additional studies or research relevant to the issue under consideration here. While no consensus was sought for any of the suggestions, some topics appeared to be of concern to several of the Workshop members and are listed below (all of the individual suggestions appear in the panelists' statements):

1. Foremost among the problems raised was a perceived need to obtain better information about the UV flux at the martian surface. UV data presented at the Workshop appeared to be inconsistent with previous estimates.

2. Also cited was a desire to establish a program of laboratory simulations, using the most recent available information about potential Mars surface environments, in order to subject terrestrial organisms, ranging from likely spacecraft contaminants to organisms known to inhabit (relevant) "exotic" microenvironments on Earth, to Mars-like conditions in order to test their survivability and growth.

3. Several panelists pointed to the critical need for additional information about martian surface properties, including better characterization of the postulated oxidants, searches for fixed nitrogen compounds, reducing gases, and organic matter. For the most part this data would become available only through spacecraft investigations.

4. There was much discussion of hypothetical geothermal activity on Mars and how information about this might be obtained. While it was conceded that some insights might be derived from the forthcoming Mars Observer and Mars '94 ('96) missions, it was suggested that theoretical studies of this topic might at least place limits on the areal extent of such putative habitats.

5. Laboratory studies were recommended that would be conducted on specific types of terrestrial organisms that might be relevant to the central question at hand. These include the study of organisms that might grow on brines other than NaCl brines, organisms that would be the most likely spacecraft contaminants, spore-forming organisms, and radiation and desiccation resistant organisms, including nematodes.

In addition, Ben Clark suggested a modelling approach to evaluate Planetary Protection compliance and also proposed a strawman strategy for the approach (see attachment 8).

PANELISTS' INDIVIDUAL ASSESSMENTS
OF P_g VALUE REPORTED BY THE 1978 SSB

MARY LYNNE PERILLE COLLINS

PP Policy

PP protocols for MESUR will be determined on the basis of several factors. In addition to P_c, other factors include:

1. Mission requirements

   a. Should life-detection experiments be included in the payload, more stringent PP requirements would be necessitated.

   b. Possible compromise of mission goals due to excessive PP requirements. Current estimates of P_g are based on and inferred from information obtained from Viking. Further studies in MESUR (possibly including geochemical, elemental, and organic analyses) should provide a better basis of information that will affect future estimates of P_g. This will be important in formulating future policy especially in the context of back contamination.

2. Other missions

   a. Contamination of Mars by Soviet missions or a manned mission will reduce the importance of PP in NASA's unmanned missions.

   b. New information may become available that will necessitate reevaluation of PP.

Probability of Contamination (P_c)

The current estimates of P_c are probably too high. Adjustment of P_c to lower values may be quantitatively justified by readjustment of N, P_g, and P_{uv}. The readjustment would be justified on the basis of information obtained from Viking.

Number of Organisms on the Spacecraft (N)

1. Only organisms which do not require the presence of organics, i.e. phototrophs and lithotrophs capable of growth at low temperature, should be considered as contributing to N.

2. The bio-burden on the lander could be lowered by cleanroom assembly and a modified sterilization protocol as recommended by Ben Clark. Also sterilization protocols can be modified further to be sufficient only for killing those organisms thought to be capable of growth.

Probability of Surviving UV Exposure (P_{uv})

The $< 1 \times 10^{-4}$ estimate used for Viking may be too high and should be reevaluated.

Probability of Growth (P_g)

The most significant factor affecting P_g is the lack of liquid water; as a result of this, P_g approaches zero. Growth would only be possible should there be oases due to geothermal activity. P_g should be adjusted down to account for the inability of Earth organisms to grow outside of such putative oases. The probability of such oases should be estimated on the basis of geophysical measurements. The maximum percentage of the Martian surface occupied by putative oases should be estimated. From this information, the probability of landing in such an oasis can be calculated.

What Should NASA Do?

1. Review available data and address discrepancies (e.g. UV data).

2. Review literature to estimate D values of psychrophiles/facultative psychrophiles. This information may be used to modify sterilization protocols.

3. Assess the number of the photo/lithotrophs that may contaminate the lander.

4. Seek input from geophysicists to set a ceiling on the percentage of the martian surface that could be covered by geothermal oases.

DIANA FRECKMAN

Probability of Growth of Terrestrial Organisms on Mars

The P_g estimates by the Space Science Board of 10^{-7} to 10^{-10}, depending on the region of Mars and its environment at that region, are too high in my opinion. I think, based on current evidence and knowledge of the Mars environment, that the P_g is very remote and should be much lower than the Space Science Board's P_g, perhaps 10^{-30}.

My area of expertise is a group of multicellular animals, nematodes, that are ubiquitous on earth, about 1-mm long, occur in streams, oceans, land, and whose habitats include the dry valleys of Antarctica, and warm desert soils to depths of 15m. Nematodes are all aquatic and require a film of water to live, reproduce, and grow. The soil nematodes can exist in very dry deserts and are found in the top 10cm of Antarctic Dry Valley dry soils. At 10°C in lab studies using Antarctic dry valley soils, they reproduce slowly over time. The other nematode requirement is a food source. Soil nematodes feed on bacteria, fungi, or unicellular algae as their food sources. Therefore:

1. For nematodes to grow on Mars, H_2O is required.

2. For nematodes to grow on Mars, bacteria would be required.

Can nematodes survive a trip to Mars? Who knows? Nematodes succeed on the Earth because they can, at any time in their life cycle, under severe environmental stress, enter into a cryptobiotic, an ametabolic state, and survive for years. This ametabolic state includes desiccation, osmotic stress, freezing; but, there is no information on UV. Studies have shown:

1. Nematodes can be desiccated and then subjected to vacuum, liquid N_2, scanning electron microscope, chemicals, etc. and then revived to be fully viable. Because they lose all free water, and have only bound water, they are extremely resistant.

2. Nematodes can be dispersed in air currents and are readily blown about (evidence in Texas and some from U.C. Davis). However, no data exists on their movement in the air in Antarctic dry valleys.

So, if nematodes were to be on the outside of the spacecraft, and if they entered a cryptobiotic state, e.g. anhydrobiosis, the highest probability would be that they would blow off the spacecraft while it was leaving the Earth. If they remained attached to the spacecraft they

could stay in a cryptobiotic state and maybe (1 in 1000 chance) get to Mars, and perhaps survive.

Can they grow and feed and live once they make it to Mars? Slim chance. Our recent work in Antarctica dry valleys (a 1990-1991 study, not yet published) has not shown any evidence of species from other continents being blown into or existing in the dry valleys. There appear to be only about 7 species of nematodes, 4 bacterial feeders and 3 omnivores in the dry valleys. Because the organic C is so low, we think the nematodes are not feeding on bacteria decomposing C, but on some chemo-type or photo-type bacteria. All species in the dry valleys appear to be endemic.

So, assuming that nematodes undergo cryobiosis, survive the trip, reach Mars, and have free water, they would still need environmental temperatures conducive to survival, and be able to survive the UV, pressure, etc.

I believe nematodes are one of the toughest animals alive. The fact that they occur in high numbers in <u>some</u> (about 65%) dry valley soils, and that their densities cannot always be correlated with water (soil moisture) leaves many questions applicable to early life. Further, it shows that there is a very simple food web in the dry valleys - and that a simple food web of bacteria/bacterial-feeding nematodes is required for growth on Mars.

Although I am not a microbiologist, examining desert soils, both warm and cold, and data from previous studies, has clearly shown that not all bacteria brought from the deserts grow in other habitats. Nematodes transfer bacteria, both internally and externally, but these will not always <u>survive</u> when transferred to varying environmental temperatures, and moistures. Once they survive, they have to grow. Our desert microbes have required considerable effort to grow and reproduce under laboratory conditions. Bacteria have to have a reasonable habitat, similar to the one from which they came, to live.

<u>Areas of Research Needed</u>

1. Nematode areas of research (survival):

   a) Survival under UV, vacuum (the limits).

   b) Percent blown and viability in cryptobiosis (wind tunnels).

c) Much more research on freezing (cryobiosis) limits (techniques to get them in and out of cryobiosis).

d) Meteorological data in soils in Antarctic dry valleys to learn the environmental ranges under which nematodes exist (e.g. their microhabitats).

e) Viability of any microbes attached to nematodes when the nematodes are in cryptobiosis.

2. Priorities for all terrestrial research:

a) Spore research! - identify means to eliminate spores - i.e., would wetting spores to revive them followed by fast drying or UV exposure kill them?

b) Much more work on microhabitats - set up microcosms which can be easily manipulated.

E. IMRE FRIEDMANN

In my opinion, the P_g values suggested by the SSB for growth of terrestrial microorganisms on Mars ($<10^{-10}$, 10^{-8}, 10^{-7}) are too high and should be substantially revised downward.

My reasons are the following:

1. <u>Physiological</u>

At 6-millibar pressure, no liquid water can exist on Mars. Although many prokaryotes are known to be extremely resistant to desiccation, for <u>metabolic activity</u> they require liquid water. This requirement alone rules out the possibility of growth for all <u>prokaryotes</u>.

However, some eukaryotes (fungi and algae, also in lichen associations) can utilize water vapor from the atmosphere. The lower limit, according to available experimental data, seems to be around 75% relative humidity ($a_w = 0.75$), perhaps slightly lower. (It is possible that the fungus <u>Xeromyces</u> has a lower limit - it needs to be studied). However, even such relative humidities are impossible on or near the surface of Mars, at least in the temperature range within which metabolic activity is conceivable.

On the basis of my knowledge, however, I cannot totally exclude the possibility that local "oases" with higher RH exist. But even if they do, the probability that such highly specialized eukaryotic microorganisms will be carried by the spacecraft is extremely low.

2. Ecological

If we assume, at least for the sake of argument, that habitable microenvironments exist on Mars, two predictions can be made:

a) Introduced organisms can successfully grow only if their new environment is within the range of their physiological potential. The martian microenvironments, even assuming optimal conditions, are too different from the spectrum of adaptability of any terrestrial organism for this difference to be successfully bridged.

b) Should habitable microenvironments currently exist on Mars, they would most probably be occupied by indigenous organisms, conceivably the descendants of life forms that originated on a more hospitable early Mars and have survived in hidden "oases." If so, such organisms are well adapted to their environment, and the obviously less adapted terrestrial immigrants would not have a chance to out-compete them.

RICHARD HANSON

Are the estimates of P_g arrived at by the Space Science Board in 1978 reasonable, too high or too low?

Our current knowledge indicates the following conditions exist on the surface of Mars:

The surface of Mars is exposed to sterilizing doses of ultraviolet radiation, the probability of the presence of liquid water existing on or near the surface is very low, and there are few reduced organic or inorganic compounds near the surface that could support growth of heterotrophic and chemolithotrophic bacteria. We know little about the redox potential of the environments, the pH if there is liquid water, and the buffering capacity of the soils. We know little about the availability of combined nitrogen (nitrate and nitrite) or soluble phosphates, sulfates, etc., on the surface of Mars.

These conditions impose several constraints on the survival and growth of all terrestrial organisms. Unless shaded from the UV by a lander, rock, etc. microbes including known endospores would be non-viable after several hours. The strongly oxidizing conditions would probably be lethal to most known bacteria as well.

The potential for the existence of thermal vents that may provide oases or environments with liquid water, reduced inorganic compounds, and temperatures that would allow the growth of mesophilic and thermophilic organisms is unknown, but is generally considered to be low according to the information presented to this group. The discovery of thermal vents would affect (increase) P_g for potential contaminants on a lander.

Given the conditions and potential substrates, only bacteria capable of survival during transit and distribution to a favorable environment are likely to grow. These bacteria would have to be capable of growth at temperatures near the freezing point of water, and the bacteria known to have these abilities also have restricted metabolic potential, although some algae grow in pockets of liquid water that exist for only a short period (hours per day) in glaciers and snow fields. Nearly all the remaining bacteria that grow at low temperatures are heterotrophs.

It is unlikely that the bacteria that have the characteristics necessary for growth and survival on Mars would be a major portion of bacterial populations contaminating a lander. If antiseptic methods were employed to reduce the bioburden on landers these bacteria would be more susceptible to killing by the antiseptics and pasteurization than most microbes.

I believe the value of P_g for subpolar regions is very small. I believe a value of 10^{-10} is high and is a number that has real meaning to many microbiologists who examine microbial survival in food products, pharmaceuticals, Antarctic environments, etc. Therefore, I would use a value less than 10^{-10} (e.g. 10^{-13}) for subpolar regions.

Although there are many uncertainties concerning the chemistry and physical characteristics of all potential microenvironments, I believe the environments near the surface of Mars, in subpolar regions, are more hostile than the most severe terrestrial environments in which the P_g value is less than 10^{-10}, assuming a species distribution similar to that of microbes found in fertile soils.

It is conceivable to me that reduced organic compounds may have been concentrated in polar cold traps. It is also conceivable to me that liquid water could exist in sealed pockets within ice

near the poles for short periods of time. If they do exist it is also possible that organisms indigenous to Mars inhabit these ecological niches because liquid water and organic compounds were present on Mars for a period of time that could have allowed evolution of terrestrial-like heterotrophic bacteria. These indigenous microbes may out-compete terrestrial bacteria that might find their way to the niche after surviving the UV radiation, because of opportunities for long-term adaptation to the environment. Therefore, I believe a P_g value of 10^{-7} to 10^{-9} is acceptable.

I feel the window in time for exobiology experiments before a human lands on Mars is relatively short (less than 40 years). Therefore, the opportunities for exobiology experiments that have a reasonable chance of detecting evidence for the evolution of life on Mars and to characterize organisms if detected, are limited. Experiments should not be unnecessarily compromised.

There is a need for research and new data that will provide for more realistic estimates of P_g. We know a great deal from enrichment culture experiments about the ability of microbes to grow in a wide range of environments. Without better information about the physical and chemical environment on the surface of Mars it is difficult to plan more meaningful experiments.

The need for information on the existence of thermal vents, small pockets of liquid water at or near the poles and the inorganic compounds (as opposed to elements) present on the surface of Mars is limited by the resolution of mapping experiments and perhaps cannot be realistically achieved to the satisfaction of most scientists. Therefore, I believe it is necessary to use known information on the martian environment to arrive at assumptions and conclusions. I do not foresee laboratory experiments in the near term that will improve or decrease my confidence in these conclusions.

I feel that sterilization of landers is an ideal that should be considered if payloads and experimental data are not compromised because of cost and the reliability or quality of instrumentation. However, the P_g value can be most effectively impacted by reducing the value of N for those microbes most likely to grow on the martian surface. I assume all landers will be assembled under clean-room conditions and that the nature and number of microbial contaminants will be restricted (i.e. the most common will originate from humans who work the environment). Heat treatment to reduce N by one D value (90%) would, in my estimation, reduce P_g significantly. A bioshield would be further insurance and should be considered.

LARRY HOCHSTEIN

The question of P_g is related to the presence of liquid H_2O. That is, the limiting factor for determining a value for P_g is evidence for the presence of H_2O since there is no evidence that terrestrial microorganisms can grow in the absence of H_2O.

The temperature and pressure values for Mars do not allow for the presence of liquid H_2O on the surface of Mars. Therefore, P_g approaches zero (i.e. the Space Science Board values are too high!).

As for the presence of subsurface H_2O, there is no evidence that such aquifers exist, therefore it is impossible to address this possibility.

Possible experiments:

1. The suggestion by Hansen that lyophilized organisms might be extremely resilient to UV should be examined.

2. It must be ascertained if there are terrestrial organisms that can grow in what is thought to be a Martian environment.

3. Are there organisms that can grow in brines other than NaCl?

4. Nature of nitrogen.

JOHN INGRAHAM

Probable Value of P_g

In the following, P_g is assumed to be the probability of a single bacterial cell from Earth landing at a random site on Mars and being able to grow and multiply. I believe that the greatest barrier to a bacterium from Earth being able to grow on Mars is the availability of water. All known bacteria require liquid water to grow. The temperature and aridity of Mars suggests that liquid water is probably not available there as judged by the average conditions. Possible martian aqueous microclimates exist, but not having been detected, one assumes that if they do exist, they are rare. To grow, the Earth organism would have to be deposited at such a rare site.

Other growth-precluding conditions are not as compelling. Temperature, at some times and places, is adequate to support microbial growth for brief periods. The atmosphere contains components that could support the growth of certain nitrogen-fixing photoautotrophs or chemoautotrophs; minerals in the soil could support the growth of others. The flux of lethal radiation is intense but, I believe, effective shadowing is imaginable. Taken together, the chances of a terrestrial bacterium growing on Mars must be very small indeed. But how does one estimate the probability? I guess the hypothetical water site on Mars must cover less than 10^{-4} of the surface and that potential Mars-growing bacteria would constitute less than 10^{-9} of Earth's bacterial population. In combination, the estimated P_g is considerably less than 10^{-10}.

Research, Conferences, Special Studies that Might Lead to a More Informed Judgement

I'm not sure that additional conferences or experiments would be useful, but if a conference were to be held, I would suggest that P_g be broken down into components, i.e. fraction of martian surface that might have liquid water; types of autotrophs that might grow (if water were available); abundance of such autotrophs on Earth.

HOLGER JANNASCH

Of the large number of different probabilities we have to deal with, an important one concerns growth of specific physiological types of known terrestrial microorganisms under conceivable martian conditions. If and wherever liquid water may occur (there is some probability that it exists at the polar caps and in brines), aerobic metal-sulfur or CO-oxidizing bacteria could thrive at oxic/anoxic interfaces within the soil; anaerobic chemolithotrophs could live in deeper layers. These probabilities are preceded by others:

1. The chance of these highly specific organisms to become part of the spacecraft contamination;

2. Their chance of surviving the space flight;

3. The chance that they would escape reaction with oxidants once deposited on the planet;

4. Their chance of reaching those few areas where their growth might be possible, including the deeper layers of soil

These four probabilities are extremely low, falling in the category of $P_g = 10^{-10}$ range.

The only reason to consider these chances at all is the scenario where in future missions the existence of extraterrestrial life on Mars would be a major issue — possibly flawed by uncertainties of earlier terrestrial contamination by spacecraft. (Such an uncertainty may already exist because of the large numbers of Soviet spacecraft that crashed on Mars and their doubtful sterilization history).

Considering the above reasoning, and in the light of the reports presented at this meeting, I believe in the differentiation of P_g into the three categories: $P_g = 10^{-10}$ for subpolar surface areas, $P_g = 10^{-8}$ for subpolar subsurface areas, and $P_g = 10^{-7}$ for polar areas are important. I also believe that their actual values are reasonable and not too low.

Sterilization

It seems possible to lower the exposure of the spacecraft to sterilization considerably by using heat for certain parts and chemical sterilization for others.

Research Suggestions

It appears to be of considerable interest to study the capabilities of certain known (as well as not yet known) terrestrial microorganisms to live under certain conditions characteristic for the martian environment. The organisms should be those that are the most likely contaminants as well as those most likely to live under martian conditions. The conditions should be studied one by one and in combination.

Studies of the most likely contaminating organisms will be straight forward considering low water activity, absence of organic substrates, low temperature, high oxidant level and radiation of the martian environment.

Studies of those organisms most likely to live under martian conditions would deal with new subjects: the isolation and subsequent study of — so far as we know — chemolithotrophic psychrophiles; one that we think exists is a pyritic-oxidizing acidophile. The likelihood that such organisms become spacecraft contaminants is low, but their study also contributes to the question of the possible existence of extraterrestrial life systems in general.

Biological Experiments Concerning Future Mars Missions

1. Coring, to look for oxic/anoxic interfaces.

2. Probing such interfaces with microelectrodes, to measure potentially life-supporting (chemosynthetic) oxidations of sulfur, carbon monoxide, methane, ammonia, and reduced metal compounds.

3) Measuring the potential *in situ* chemosynthesis by the addition of ^{14}C-labeled carbon dioxide.

HAROLD MOROWITZ

Based on the evidence presented, the probability of any microorganisms on a clean spacecraft growing in a martian habitat is vanishingly small but not zero. To recast the problem in expanded terms, consider the X kinds of terrestrial microbes. This is a grouping somewhat above the genus level and X is on the order of a hundred. Next, list possible kinds of accessible martian habitats; this number, Y, is no more than one hundred. There are XY theoretical possible kinds of contamination but for the vast majority of these P_g is zero. NP_g can be expanded into:

$$\sum_{ij} N_i \, p_j \, P_{gij} = NP_g$$

N_i = number of organisms of the ith kind.

p_j = probability of an accessible habitat of the jth kind.

P_{gij} = probability of the growth of the ith kind of organisms in the jth kind of habitat.

Determining N_i and P_{gij} are problems in microbiology; determining p_j is a problem in planetary geochemistry and geophysics.

For most ij's p_j is zero or P_{gij} is zero based on known information. The quantities N_i and P_{gij} are subject to experiment and within a year or two of feasible experiments this whole problem could be appreciably firmed up.

There are biological fundamentals to be considered:

1. The necessity of liquid water in cells.

2. The necessity of an energy source:

   a. Photosynthetic

   b. A redox couple

My sense is that the UV problem is secondary because action spectra are usually identical to UV absorption spectra, therefore external or internal UV shielding could protect cells; the shielding layer could even be very thin. It seems that the most conservative approach is to assume no UV inactivation.

I have great difficultly putting a number on P_g without the minimum expansion suggested above, but it is very small.

RONALD OREMLAND

Estimate of Value for P_g on Mars

I feel that multiple factors assure that the value of P_g for a microorganism on the surface of Mars introduced from a terrestrial source would be so low as to render the P_c for the equation to less than 10^{-3}. Hence, my subjective feel is that the value of P_g is less than 10^{-6}. I base this upon the fact that there are no evident sources of water, either in liquid form or at reasonably high humidity comparable to that encountered even in the most hostile terrestrial environment. When other factors are considered which would also constrain P_g, such as lack of available electron donors for energy, temperature extremes, harmful soil oxidants, lethal UV exposure, this insures a low value.

If planetary exploration of the Martian surface is achieved through employing reasonably clean probes (i.e., below 10^4 viable cells/m^2), the P_c factor achieved is even lower than the value required. I do not think that sterilization of the spacecraft, such as was attempted in the Viking missions, is necessary. If rigorous cleanroom procedures are maintained, then the only organisms likely to contaminate the surface of the spacecraft would be those associated with the flora of the human skin. These critters are unlikely candidates for survival on Mars. Although most of the microbiologists present at the conference enjoyed the intellectual task of imagining what type of bug could make a living on the martian surface (such as chemoautotrophs, methanotrophs, etc.) these critters are unlikely to be a major component of the "N" term of the contamination equation.

This brings me to my final point. The contamination equation is really no more than an exercise in logic, and hence it is not a verified equation of the physical or biological world. It does not specify the physiological diversity of microbes or factor in the ability of one type versus another to survive and grow in the martian terrain (i.e., a hardy chemoautotroph from

the Dry Valleys versus a skin Staphylococcus). Although my "gut" feeling is that survival of even the best adapted terrestrial critter is unlikely, I am uncomfortable with the equation. After all, it was this type of logic that resulted in the Challenger disaster: R. Feyneman pointed out that the NASA panel calculated such a disaster would be 1 in 10^{-6}, but it nonetheless happened. The equation for P_c is merely a format for points to be considered, but it is only as good as the subjective thoughts going into its making. A final calculated value for P_c of 10^{-8} based on a P_g arrived by consensus at 10^{-5} or less does not mean that a possible contaminating bacterium has read and understood the equation and promised to obey its ramifications!

MARGARET RACE

Background Thoughts:

• Given the current level of info/data on Mars conditions, it appears impossible to determine a reliable P_g in quantitative terms for any group of microbes (since P_g is dependent on a combination of geology and biology, and physical and chemical conditions.)

• It seems unlikely that any particular experiments using terrestrial microbes in artificial Mars conditions on Earth will yield data that could help assign a more accurate estimate of P_g (such experiments might be helpful or informative in many ways — but we'd always be guessing as to how to extrapolate to real Mars conditions). Our current P_g concerns relate largely to implementation with respect to sterilization at this time.

• The subtle forward contamination concerns (as discussed here) will be essentially moot once the first manned mission is launched because of the inevitable delivery of human associated microbiota to Mars (that will be the ultimate P_g experiment.) Thus, it seems our attention and concerns must really be focused on the opportunities for exobiology sciences between now and the first manned missions.

• P_g values by themselves are important only insofar as they affect P_c. Since the concerns about P_c will be greatest for missions with life detection/exobiology experiments and lesser for no-life detection missions, I agree with Ben Clark's dual approach for sterilization requirements.

<u>Dual Approach (in the face of our inability to satisfactorily resolve P_g):</u>

- For missions with life detection experiments use Viking-type "maximal" sterilization to reduce bioburden on landers and adjust orbits on orbiters.

- For <u>non</u>-life detection/exobiology missions use "reasonable" sterilization measures (not merely set by scientific input but also less extensive and less expensive) and based on our general knowledge of Mars as a very harsh environment and the apparent low probability of a lander "finding" a habitable spot. [Note: this does <u>not</u> mean the abandonment of all sterilization, only some reduction from maximal Viking type].

- Future emphasis for scientific experiments on Mars missions should concentrate on getting higher resolution, more accurate info on geological, physical, and chemical conditions on Mars in order to get a better idea of the probability of finding potentially habitable conditions or habitats on Mars. Only then can we really move toward more reliable estimated of P_g.

- Nothing discussed during these two days would allow anyone to <u>quantitatively</u> adjust the 1987 Space Science Board estimates of P_g. In the absence of additional data or information we are hard pressed to suggest other values, so I recommend that we accept these earlier figures as "operational P_g's".

DAVID WARD

My opinion on the question of the validity of the 1978 P_g estimates is based on a preference to formulate as scientific (as opposed to speculative) a solution as possible. I am also biased by my preference to take an optimistic stance that habitats suitable for life (as we know it on Earth) on Mars should be assumed to exist unless proven otherwise.

Reluctance to Lower P_g =

   Scientific uncertainty X optimism for life on Mars unless proven otherwise.

I assume that P_g does not include the probability of transport of a microbial contaminant from the lander to a suitable habitat (see comment below). The most important determinants of P_g are then likely to be:

1. The probability that a random contaminant microorganism could inhabit martian environments. On the basis of what we now know, such a microbe would likely need to be able to:

    a) Survive transport to the Martian surface (high probability).

    b) Grow at low temperature and water activity (a_w) (high probability, considering that many contaminants deriving from soil would be likely to do so).

    c) Grow under nutrition constraints provided by Mars (high probability, given the availability of reduced gases and O_2 and uncertainties about the availability of organic compounds in habitats otherwise suitable for life – e.g., moist and warm).

    d) Resist antimicrobial agents (i.e., oxidants) (high probability, as habitats that are moist and warm may have low oxidant levels)

2. The probability that the microbial contaminants would encounter a suitable habitat.

The latter is probably the more important determinant of P_g. On the basis of what we now know about the physical and chemical characteristic on Mars, it seems very unlikely that there are habitats where liquid water would be present near the surface. (Unless specific efforts will be made to penetrate the surface, concern over contamination significantly beneath the surface seems unwarranted). I am forced to imagine habitats where water vapor could reach the surface; places where surface temperatures are likely to be high enough or likely to already be depleted in water. Thus, I am forced to imagine places where geothermal anomalies coincide with water supplies to provide a continuous flux of water vapor to the surface. What is the probability of the occurrence of these situations? Could physical scientists place an upper limit on such a probability?

In my opinion our ability to estimate P_g is limited by the uncertainties in calculating the probability of suitable habitats. Intuitively, I agree that the probability of habitats with liquid water is likely to be low, but we should seek a more scientific approach to estimating the limits of this term. Realizing that the 1978 P_g estimates were made "reluctantly" with the caveat that "we cannot absolutely rule out the existence of oases capable of supporting terrestrial life," I concur with the opinion that P_g is probably very low. The 1978 estimates of P_g are probably fair.

Suggestions for Future Research

1. On the value of N - The microbiological load on landers has been estimated by viable count procedures that are known to underestimate naturally occurring microbes by up to several orders of magnitude. I suggest that viable counts be compared to total direct counts so that we can learn how representative the cultivated species are in terms of their numbers, physiological potential and tolerances to environmental extremes (UV, low temperature, and low a_w.)

2. P_{uv} - The calculations presented by Haberle should be reviewed as they are inconsistent with earlier estimates. I am impressed that Haberle considered real conditions for UV exposure on Mars and assumed the highest UV tolerances we know of (e.g. those of <u>Micrococcus radiodurans</u>; this is particularly relevant if cultivated species in bioburden are low percentage of the total.) There may be new evidence of even higher UV tolerance (e.g. in <u>Chloroflexus</u>, Bev Peirson, University of Puget Sound).

3. Limits on the probability of geothermally driven surface water vapor habitats on Mars.

Even given the poor resolution limits we might be able to set a limit on the areal percentage of this type of habitat on Mars. Even if we can only detect geothermal fields, for instance, we can probably predict a low areal distribution of suitable habitat, based on the densities of individual geothermal surface features in the field. I suggest that physical scientists attempt such calculations. It might be possible in doing so to more scientifically substantiate a speculated low P_g.

LETTERS FROM INVITEES UNABLE TO ATTEND

University of Wisconsin–Madison

Thomas D. Brock
1550 Linden Drive
Madison, Wisconsin 53706 USA
608-262-1261 (Office)
608-238-5050 (Residence)

April 14, 1991

Dr. Harold P. Klein
Department of Biology
Santa Clara University
Santa Clara, CA 95053

Dear Chuck,

I have your letter about the workshop on Mars. I am afraid I will bow out on this one, but I might take the liberty of giving you a few free "ideas" on this question. Frankly, I do not think this is a scientific question, since it is not subject to testing or verification. It seems to me that one could easily make a case for sterilization, but one could also make the case that sterilization is a waste of time and money. I believe that the question will be answered more on emotional, financial, or political grounds than on scientific ones. If I were in charge of the whole operation and had absolute authority to make the decision, I would not sterilize any probes, since I think it would be more trouble than it was worth.

So much for my free ideas.

I am now retired from the University of Wisconsin and am spending most of my time these days running my publishing company, which has been doing books for Springer-Verlag and Butterworths on microbiology and biotechnology.

With best wishes,

Sincerely,

Thomas D. Brock
Professor Emeritus

INDIANA UNIVERSITY

DEPARTMENT OF BIOLOGY
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Bloomington, Indiana 47405
(812) 855-
FAX: (812) 855-6705

April 17, 1991

Dr. Harold P. Klein
Department of Biology
Santa Clara University
Santa Clara, CA 95053

Dear Chuck:

Thanks for asking my opinion on the possibility of growth of terrestrial organisms on Mars, in regard to a possible network mission to that planet.

My opinion as a microbial ecologist is that no known terrestrial organisms could grow on the surface of Mars. That hostile environment of low temperature, low atmospheric pressure, low water content, high UV flux and low reduced-carbon (based on Viking results) does not occur on Earth, so organisms cannot have been selected for those conditions. Terrestrial microorganisms are exquisitely molded to their particular environments. This is evidenced, for instance, by the long-standing recognition that we can cultivate in the laboratory no more than a few (probably <1%) of the organisms that might be observed in a particular environmental sample. This is because of inability to provide proper environment for growth under routine cultivation conditions. Even transfer of a microbial community from one terrestrial environment to another (e.g. in attempts at oil-spill degradation) has proved problematic. To be sure, organisms can "adapt" to new conditions to some degree. However, adaptation mechanisms do not operate over such extensive environmental change as would be confronted upon transfer of a terrestrial organism to the surface of Mars.

Although I do not believe that terrestrial organisms could thrive or even slowly grow on Mars, I note that some organisms, particularly resting states (e.g. spores, cysts) or dehydrated cells, could probably survive for extended periods (possibly years) even exposed on the surface of Mars. However, the probability that such organisms could grow on Mars is zero or nearly so.

In summary, I do not believe that terrestrial organisms pose a serious threat of infecting the Martian surface. I therefore feel that quarantine issues should not compromise Mars network missions. I note in passing, however, that I will be much more conservative when the time comes to consider the potential for back-contamination, from Mars to Earth, as sample-return missions are formulated.

I hope this response is sufficient for your needs at this time. Let me know if I can provide further information or comment. I am sorry I cannot make it to the Workshop.

Best regards,

Norman R. Pace
Professor

suz

CALIFORNIA INSTITUTE OF TECHNOLOGY

Division of Biology 156-29   Pasadena, California 91125

FAX: (818) 449-0756

April 23, 1991

Dr. Harold P. Klein
Department of Biology
Santa Clara University
Santa Clara CA 95053

Dear Chuck:

This is a summary of my views on the question raised in your letter of 4 April 1991; to wit, what is the probability of growth of terrestrial organisms on Mars? I regret that I cannot attend the meeting you are calling to discuss this issue.

I have been convinced for over 20 years that there is insufficient water on the planet Mars to support terrestrial life or anything like it. Two developments that occurred during 1965-70 brought me to this conclusion. First were the biological results obtained in the Antarctic dry valleys by colleagues of mine at the Jet Propulsion Laboratory. They found--confirming earlier observers--that a significant fraction of soil samples from these valleys were lifeless because of the prevailing dryness. In addition, a pond of unfrozen water in the dry valley region--the Don Juan Pond, saturated with $CaCl_2$--they also found to be sterile, although the freshwater inlets that feed it have microorganisms growing around them. This finding is important because $CaCl_2$-saturated solutions have often been suggested as a possible source of liquid water for Mars. It seems clear that evolution on our planet has not produced an organism capable of living at the water activity and temperature of this unusual pond. I know of no work since then that changes this conclusion.

The second development that affected my view of the possibility of terrestrial life on Mars was the appearance in 1970 of the study by Andy Ingersoll of the question of liquid water on the planet (*Science* **168**, 972). It has been known for a long time that Mars is far drier than Earth, but in this paper Ingersoll shows how much drier it is. Ingersoll sees no possibility of liquid water on the surface of Mars, except in saturated solutions of salts like $CaCl_2$--if such salts are available. (Saturated NaCl would not work.) To my knowledge, this paper remains the definitive work on the subject. It should be read by everyone interested in the question of life on Mars.

The foregoing findings convinced me that if life exists on Mars it does not require liquid water. As a result, the life-detection instrument my collaborators and I sent to Mars on Viking did not employ water in its basic mode of operation, as you well know. The findings of the Viking mission strongly reinforced the conclusions about water. If anything, they showed Mars to be even drier than had been supposed earlier. They showed, for example, that there is no nightly deposition of frost on the ground--frequently imagined in earlier days to serve as a source of liquid at sunrise.

Much more could be said on the question of the habitability of Mars, but the water question is the crucial one. To me, the case against against aqueous life seems open-and-shut, but it has been my experience that no matter how strong the evidence is, the idea of foreclosing on the possibility of life on Mars is anathema to some people.. To understand this phenomenon, one must remember that dreams and careers and whole industries have been built on the search for life on Mars, and these can amount to a significant lobby. In your position, it is essential to separate scientific from non-scientific pressures in order to reach a valid conclusion.

Yours sincerely,

Norman H. Horowitz
Emeritus Professor

ATTACHMENT 1

OVERVIEW OF THE MESUR MISSION
D.L. DEVINCENZI

Workshop Background

Presented to

Workshop on Planetary Protection Issues for the MESUR Mission

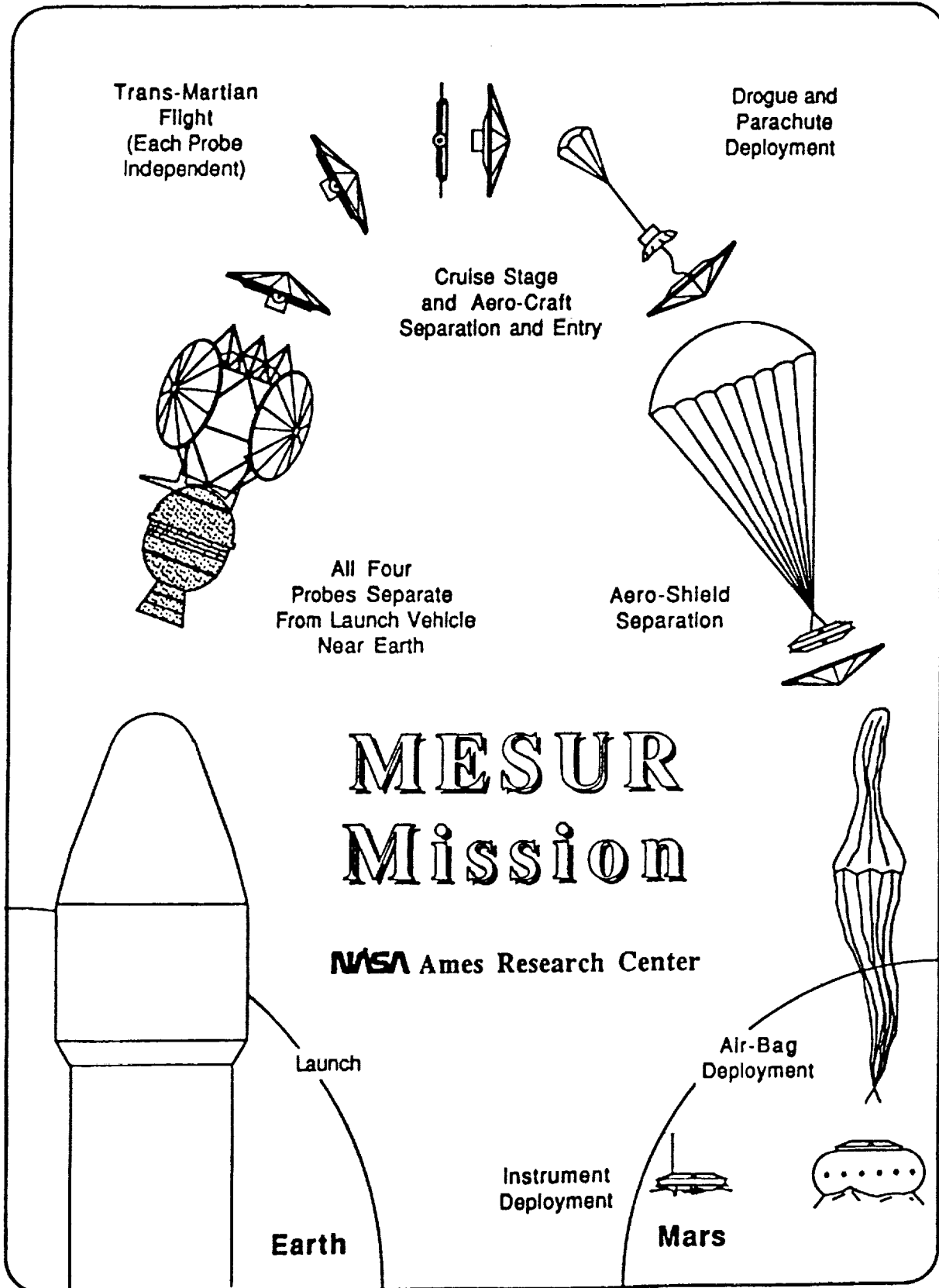Donald L. DeVincenzi

NASA Ames Research Center
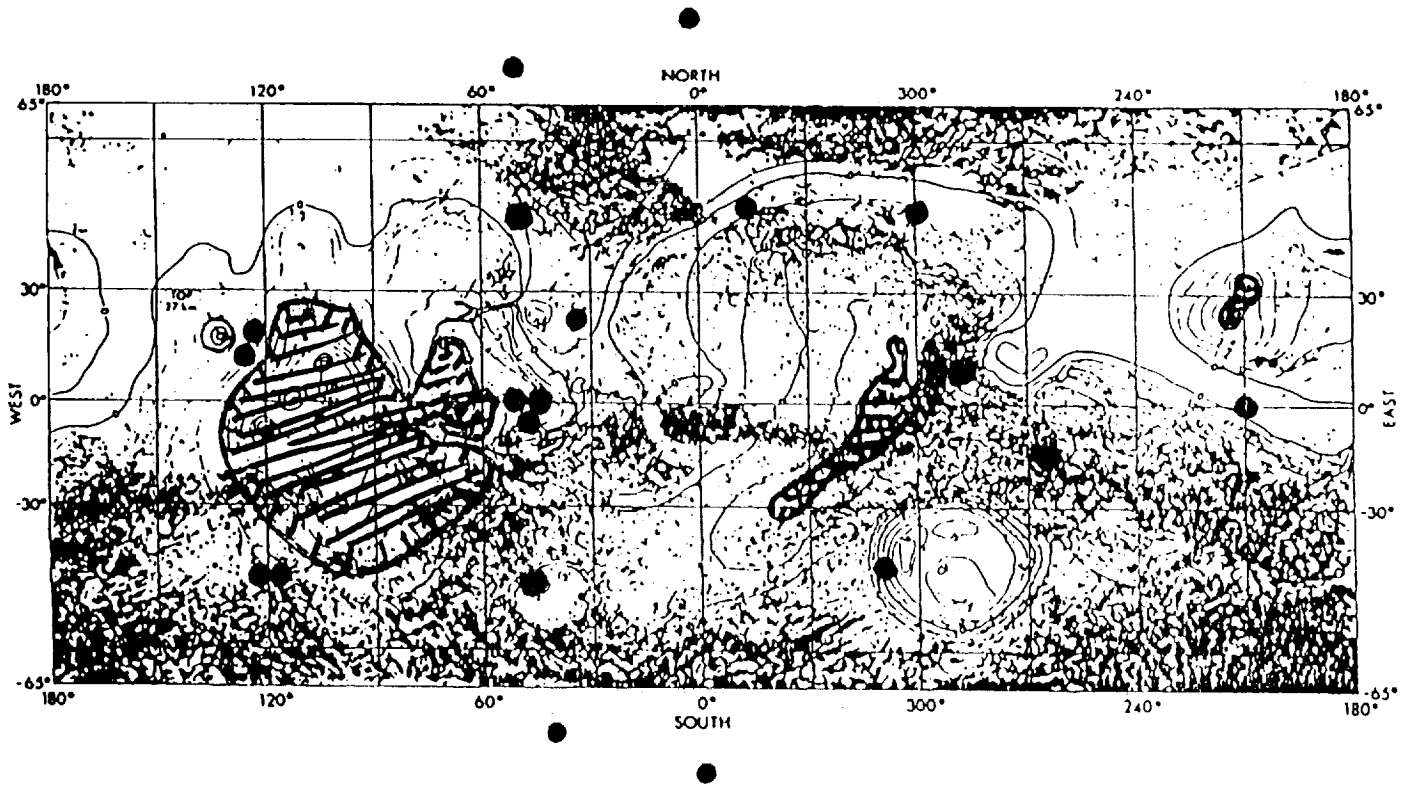
June 3, 1991

NASA
Ames Research Center

Space Science   Division

Trans-Martian Flight (Each Probe Independent)

Drogue and Parachute Deployment

Cruise Stage and Aero-Craft Separation and Entry

All Four Probes Separate From Launch Vehicle Near Earth

Aero-Shield Separation

MESUR Mission

NASA Ames Research Center

Launch

Air-Bag Deployment

Instrument Deployment

Earth

Mars

Network Configuration for a 20-Station MESUR Mission

Cross-hatched areas represent the regions where the surface elevation is greater than 5 kilometers above the Mars reference elevation (~6.1 mbar); these regions are not accessible to the landers.
Each ● represents one station.

Workshop Background
Planetary Protection Tasks for MESUR Phase A Study

- "Official" PP requirements for MESUR do not exist yet

  - Impact on design, schedule, cost needs to be known for Phase A

- Planetary Protection tasks for Phase A study (DeVincenzi)

  - Worst case scenario - use existing parameters; separate study conducted by Howell and Daspit of Bionetics Corp

  - More realistic scenario - re-evaluate basis for reqts; this Workshop chaired by Klein

- Primary distribution of Workshop report

  - MESUR Phase A study manager at ARC (Hubbard)

  - NASA Planetary Protection Officer at HQ (Rummel)

  - NAS SSB summer study on PP for Mars landers (Nealson)

NASA
Ames Research Center
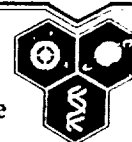
Space Science   Division

ATTACHMENT 2

OVERVIEW OF CURRENT PLANETARY PROTECTION POLICY
D.L. DEVINCENZI

Planetary Protection Policy

Presented to

Workshop on Planetary Protection Issues for the MESUR Mission

Donald L. DeVincenzi

NASA Ames Research Center

June 3, 1991

NASA
Ames Research Center

Space Science   Division

Planetary Protection Policy
<u>Background</u>

- Planetary Protection (PP)- control cross-contamination of planets

- Bases for PP Policy and Implementations

  - Treaty on "Outer Space"

  - International Organizations - COSPAR, IAF

  - U.S. National Academy of Science, Space Studies (Science) Bd

  - NASA Issuances

- Application of original Policy

  - Probability of contamination set at 1×10^{-3}

  - Compliance measured by: $Pc = N \times Pvt \times Puv \times Psa \times Pr \times Pg$

  - Bioload reduction impacts mission design, cost, schedule

NASA
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Space Science Division

Planetary Protection Policy

Implications

- **Look to NAS Space Studies Board for advice**

    - **Categorization of mission/planet combos**

    - **Definition of implementation approach**

- **Categorization of Mars missions**

    - **Viking would have been Category IV**

    - **Mars Observer is Category III**

    - **MESUR would likely be Category IV**

- **If MESUR is Cat IV, and probabilistic approach is used, then re-evaluation of probability factors is critically important**

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Planetary   Protection   Policy

<u>Mission/Planet   Categories</u>

Category	I	II	III	IV	V
Mission type	All	All	Orb	Land	SR
Exo interest	No	Yes	Yes	Yes	Yes
Possible contam	No	No	Yes	Yes	Yes
Range PP reqts	None	Doc Only	Doc + Implem	Doc + More Implem	TBD

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Space Science   Division
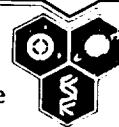
Planetary   Protection   Policy

Revised   Policy   of   1984

- Sustains commitment to preserving natural planetary conditions

- Eliminates the general quantitative guideline from policy

    - Deemphasizes but not eliminate use of mathematical models

    - Reserves quantitative criteria for selected cases

    - Proposes developing hard requirements for specific combos

- Implementation will be accomplished by exception

- Excepted cases defined by both mission type and target planet

NASA
Ames Research Center

Space Science   Division

ATTACHMENT 3

HISTORY OF P$_g$
H.P. KLEIN

" . . . any attempt to predict the probability of survival and growth on Mars or other planets (P_g) is purely speculative."

L. Hall, in *COSPAR Technical Manual No. 4*, P.H.A. Sneath, ed., 1968.

COSPAR PANEL ON STANDARDS FOR SPACE PROBE STERILIZATION

Resolution 26.5:

"... accepted as tentatively recommended interim objectives a sterilization level such that the probability of a single viable organism aboard any vehicle intended for planetary landing or penetration would be less than 10^{-4} and a probability limit for accidental planetary impact by unsterilized orbiting spacecraft of 3×10^{-5} or less....during the interval terminating at the end of the initial period of planetary exploration by landing vehicles..."

COSPAR Information Bulletin No. 20 (1964).

[Note: at this time, the COSPAR panel assumed a P_g of 1.]

P_g ANALYSIS: 1967-68

"The best analysis of the probability of growth might be based on conservative judgement values of those factors that can be defined...

The probability of a viable terrestrial organism
finding its way to a suitable microenvironment: 10^{-1}

The probability that one such species will grow
there: 10^{-1}

The probability of organism survival during
transition to that microenvironment: 10^{-1}

The probability that organisms will survive
radiation and other hazards in transit from the
spacecraft to the microenvironment: 10^{-1}

Several other probabilities affecting survival
and growth can be developed....

THE CONCLUSION FROM THIS PROCESS OF THE
APPLICATION OF JUDGEMENT AND REASON IS THAT THE
PROBABILITY OF SURVIVAL AND GROWTH ...ON MARS IS
NOT UNITY...BUT RATHER THAT IT LIES BETWEEN 1×10^{-2}
AND 1×10^{-8}, OR LESS. "

L. Hall, in "Developments in Industrial Microbiology", 1968.

Pg ANALYSIS: 1970

* ATTEMPTED TO DEFINE A SET OF MINIMUM
CONDITIONS ON MARS THAT WOULD SUPPORT THE
GROWTH OF THE MOST HARDY TERRESTRIAL
ORGANISMS.

   * CONSIDERED WATER ACTIVITY, NUTRIENTS,
      TEMPERATURES, UV FLUX, "ANTINUTRIENTS".

* ESTIMATED VALUE FOR Pg : 3×10^{-9}

   * WITH LESS THAN 10^{-3} CHANCE THAT P_g
      EXCEEDS 10^{-4}.

* RECOMMENDED THAT NASA USE Pg value: 1×10^{-4}.

Space Science Board Report, 1970.

Pg ANALYSIS: 1978 (POST-VIKING)

* Based upon "...a comparison between the known physical and chemical limits to terrestrial growth and the known and inferred conditions (on Mars)..".

* Subpolar regions within 6cm of surface: $Pg < 10^{-10}$

* Subpolar regions below surface: $Pg < 10^{-8}$

* Residual Polar caps: $Pg < 10^{-7}$

Space Science Board Report, 1978.

Control Number _028_

Date: ___12 - 1 - 73___

P (g)

PARAMETER TITLE: Probability of Growth, Mars

VALUE	
UPPER	10^{-6}
ACCEPTABLE	10^{-6}
LOWER	10^{-6}

APPLICATION	
MISSION	All
PLANET	Mars

PARAMETER DEFINITION: The probability that a terrestrial microorganism reaching the planet will grow and proliferate.

APPLICABLE SOURCE: All sources of viable terrestrial microorganisms reaching the planet.

CONSTRAINTS: In using this value for P(g), due consideration should be exercised in estimating other sterilization parameters, so as to avoid excessive safety margins in the implementation of planetary quarantine requirements.

REFERENCES: (1)   Ad hoc Review Group of SSB, Woods Hole, Mass., July 16-17, 1970.   [PQ-82]

(2)   Revised and New Planetary Quarantine Policies. Memorandum L.B. Hall, NASA/SL, PQO to Distribution, Aug. 24, 1971. [PQ-294]

Lawrence B. Hall   ___October 17, 1973___

Planetary Quarantine Officer   II-3   Date

HISTORY OF RECOMMENDED Pg VALUES
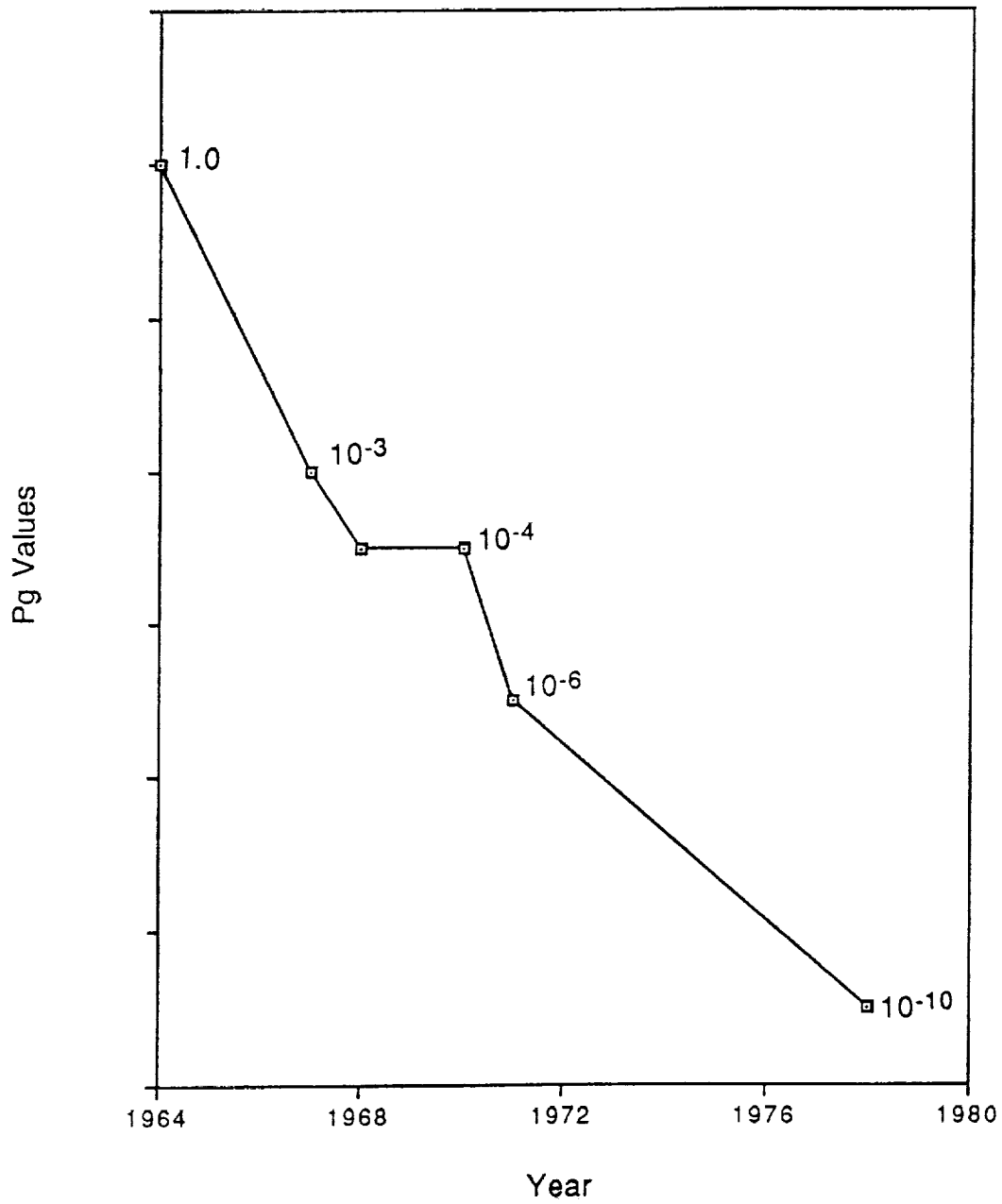
FROM: COSPAR TECHNIQUE MANUAL No. 4, P.H.A. Sneath, ed., (1968).

TENTATIVE NOMENCLATURE AND ANALYTICAL BASIS FOR USE IN PLANETARY QUARANTINE

(Prepared by the working party on standard mathematical symbols and techniques and on a nomenclature suitable for use in connection with space probe sterilization: L. B. Hall, C.-G. Hedén and A. A. Imshenetsky with expert advice from R., G. Cornell, S. Schalkowsky, O. Hertzberg and others—modified in accordance with comments made by the Study Group on Standards for Space Probe Sterilization during the spring of 1967.)

The following symbols for quantitative parameters, events and the probabilities of the occurrence of these events is recommended for use by all nations in the formulation of planetary quarantine standards and analysis aimed at demonstrating adherence to these standards.

GENERAL PRINCIPLES

Events involving a spacecraft are denoted by <u>capital letters</u>. <u>Small letters</u> denote events for which the basic unit is an individual organism. A <u>prime</u> means that the symbol in question refers to spacecraft or organism(s) for which sterilization has not been attempted, while the absence of a prime means that the symbol involves spacecraft(s) or organism(s) exposed to a sterilization procedure. A <u>subscript</u> on a spacecraft event symbol denotes that the event involves a particular lander or flyby. The absence of a subscript on a spacecraft event symbol and the absence of a general statement that the entire analysis applies to a specific mission means that the event is defined relative to the entire period of biological exploration. A <u>dummy subscript</u> is used to indicate a series of landers exposed to a sterilization procedure: i = 1, 2, 3 . . ., N. Similarly the total number of vehicles not exposed to sterilization is denoted by N' and the dummy subscript used to indicate a series of such flybys is j, j = 1, 2, 3 . . ., N'. Figures in parenthesis denote the various sources of contamination. The word "viable" is used to indicate latent as well as immediate capacity for multiplication during the period of biological exploration.

LIST OF SYMBOLS

E   = "expected value of"

N   = total number of landers, exposed to a sterilization procedure, from all nations during the period of biological exploration.

N'	=	total number of unsterilized vehicles (orbiters, flybys etc.) from all nations, during the period of biological exploration.
T	=	time of biological exploration (years).
n_o	=	number of viable organisms on (or in) a lander after this has been exposed to sterilization but prior to launch.
n_o'	=	number of viable organisms on (or in) a spacecraft prior to sterilization.
n	=	number of viable organisms, reached by or exposed to a sterilization treatment, upon arrival at the vicinity of the planet.
n'	=	number of viable organisms on (or in) any one unsterilized vehicle (orbiter, flyby etc.) or ejecta from the spacecraft upon arrival in the vicinity of the planet, i.e., at the time when they become a contamination hazard.
C	=	contamination during the entire period of biological experimentation being considered (T). M, V, etc. as subscripts after the letter may be used to indicate planets - Mars, Venus, etc.
s	=	survival of organism(s) on (or in) a spacecraft, which has been exposed to a sterilization procedure, after a space journey, including a planetary landing or, at least, the arrival at a position where it could possibly contaminate the planet under consideration.
s'	=	survival of organism(s) on (or in) a non-sterilized vehicle at the time just indicated for s.
f'	=	failure of guidance system causing impact of unsterilized spacecraft on subject planet.
r	=	release of viable organism(s) from a spacecraft subjected to sterilization on the surface or into the atmosphere of the subject planet.
r'	=	release of viable organism(s) from a non-sterilized vehicle as just indicated for r.

g   =   growth and spread of viable organism(s) deposited at
               random on the planet's surface, leading to planetary
               contamination.

P   =   probability of contaminating a planet during the entire
               period of biological exploration (T) regardless of the
               source of contamination or its exposure to attempted
               sterilization. M, V, etc. as subscripts after the
               letter may be used to indicate Mars, Venus, etc.

P(C)   =   probability of contaminating a planet during the entire
               period of consideration (T), through the agency of a
               spacecraft, which has gone through a sterilization
               process.

P(C')   =   probability of contaminating a planet during the period
               under consideration (T) by impact with a non-sterilized
               spacecraft.

P(C")   =   probability of contamination from a non-sterilized
               vehicle, of all sources (ejecta, etc.) other than acci-
               dental impact of the vehicle itself, during the period
               under consideration.

P(s)   =   probability that organism(s) on (or in) a spacecraft,
               subjected to a sterilization procedure, will survive
               through a space journey, as defined for s.

P(s')   =   probability that an organism on (or in) a non-
               sterilized spacecraft will survive through a space
               journey, as defined for s.

P(f')   =   probability of guidance failure causing impact of
               unsterilized spacecraft on subject planet.

P(r)   =   probability that a viable organism from a spacecraft,
               exposed to a sterilization effort, will be released on
               the surface of the planet under consideration.

P(r/s)   =   probability that a viable organism from a spacecraft,
               which has gone through a sterilization procedure will
               be released on the surface of the subject planet, given
               that it has survived through a space journey.

P(r'/s')   =   probability that a viable organism from a non-
               sterilized spacecraft will be released on the surface
               of the subject planet, given that it has survived
               through a space journey.

P(g)   =   probability that a viable organism, deposited at random
                  on the planet's surface by a spacecraft that has been
                  subjected to sterilization, will grow and spread.

P(g')   =   probability that organisms, which have not been exposed
                  to a sterilization procedure, will grow and spread if
                  deposited at random on the planet's surface.

P(g/s)   =   probability that an organism from a spacecraft, which
                  has gone through a sterilization procedure, will grow
                  and spread on the subject planet, given that it has
                  survived a space journey, as defined for g and s.

P(g/s,r)   =   probability that an organism from a spacecraft, which
                  has gone through a sterilization procedure, will grow
                  and spread on the subject planet, given that it has
                  survived the space journey and has been released on the
                  surface of the subject planet, as defined for g, s, and
                  r.

$P(g_i/s_i)$ =   probability that an organism from the ith spacecraft,
                  subjected to sterilization will grow and spread on the
                  subject planet, given that it has survived a space
                  journey, as defined for g and s.

$P(g_j'/s_j')$ = probability that an organism from the jth non-
                  sterilized spacecraft will grow and spread on the
                  subject planet, given that it has survived the space
                  journey, as defined for g and s.

$E(n_i/s_i)$ =   expected number of viable organisms on the ith space-
                  craft, subjected to sterilization after a space
                  journey.

$E(n_j'/s_j',r_j')$ = expected number of viable organisms on the jth non-
                  sterilized spacecraft, after a space journey and
                  release on the subject planet.

t   =   total sterilization time (hrs.).

D   =   the time required to reduce a microbial population of a
                  single species by one decade at a specific temperature.
                  Subscripts h, c, and r together with dosage value would
                  indicate defined populations resistant to heat, chemi-
                  cal sterilants, or radiation. An additional subscript
                  may be used to indicate the temperature ($^{\circ}$C) at which
                  D applies.

ATTACHMENT 4

PAST IMPLEMENTATION OF PP POLICY
L. DASPIT

PAST IMPLEMENTATION
OF PLANETARY PROTECTION POLICY

· VIKING '75 MISSION

presented by
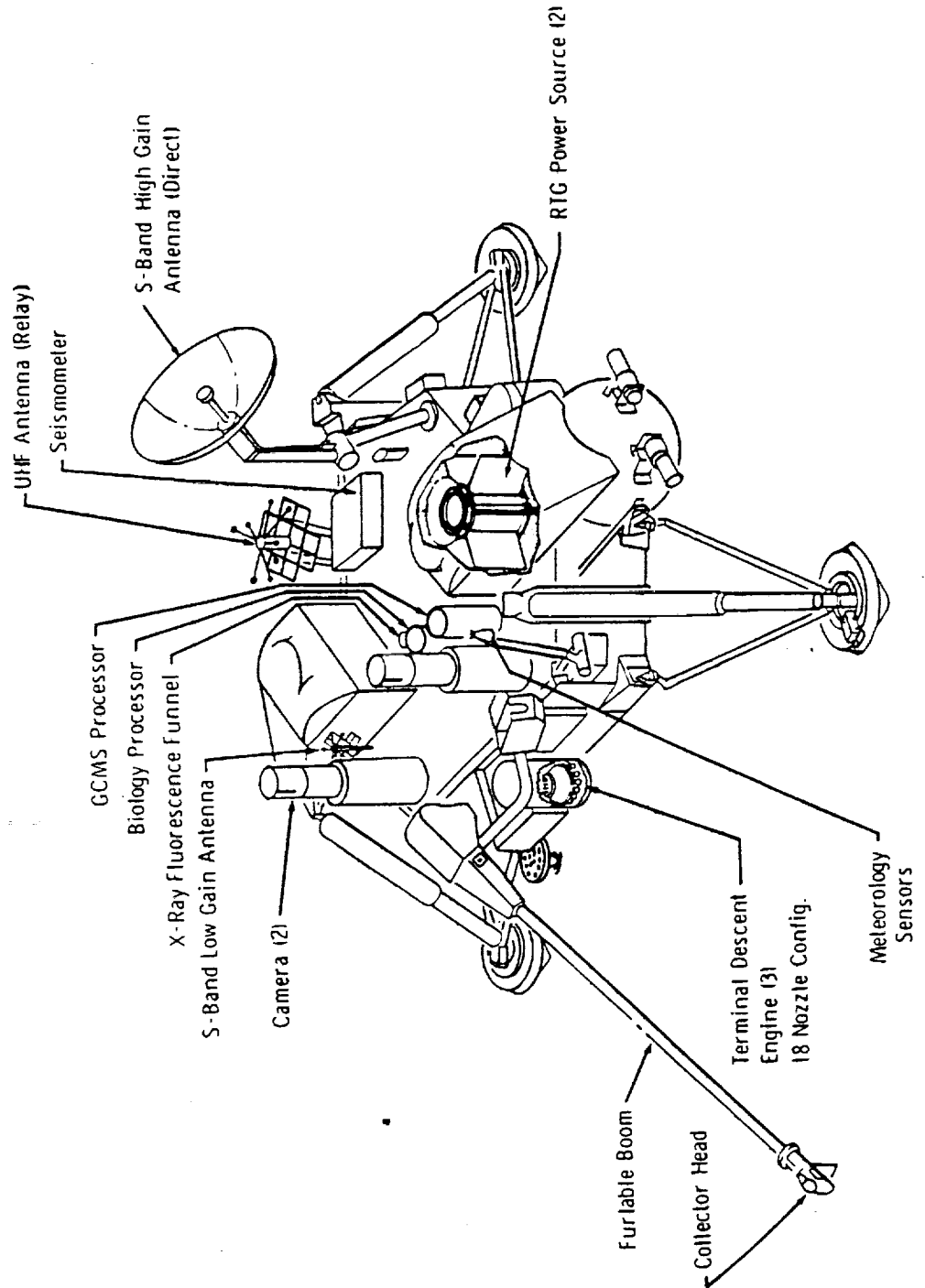### Leo Daspit

BIONETICS CORPORATION

NASA AMES RESEARCH CENTER WORKSHOP ON

PLANETARY PROTECTION ISSUES: PROBABILITY OF GROWTH
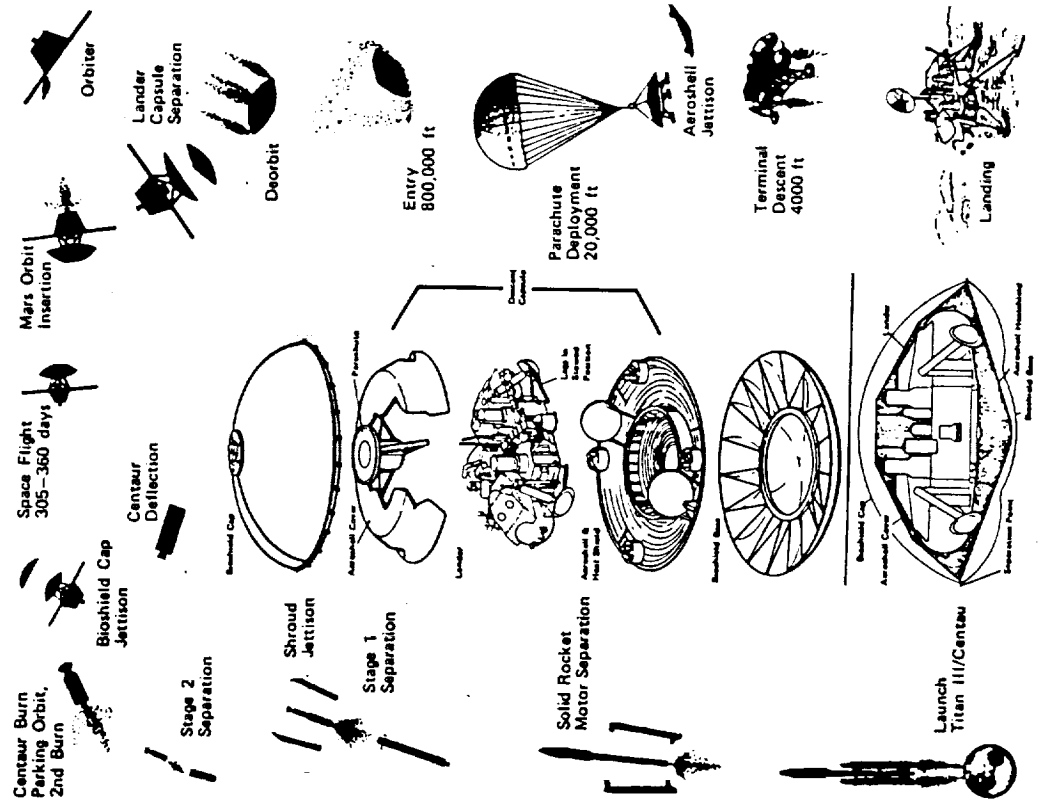
JUNE 3-4, 1991

PROJECT REQUIREMENTS AND CONSTRAINTS

- ## Cospar Risk Recommendation

  - P_c for Mars = 1×10^{-3}

- ## Cospar Recommended Period of Risk Containment

  - Period of Biological Interest

- ## Interpreted and Imposed Requirements & Constraints

  - Final P_c for the Viking Mission (2 launches) = 2×10^{-4}

- ## Interpreted Period of Biological Interest

  - 50 Years from December 31, 1968

VIKING LANDER CAPSULE

UHF Antenna (Relay)

Seismometer

S-Band High Gain Antenna (Direct)

RTG Power Source (2)

GCMS Processor

Biology Processor

X-Ray Fluorescence Funnel

S-Band Low Gain Antenna

Camera (2)

Meteorology Sensors

Terminal Descent Engine (3) 18 Nozzle Config.

Furlable Boom

Collector Head

SEQUENCE OF EVENTS–LAUNCH THROUGH LANDING

VIKING SPACECRAFT

Omni Directional
S-Band Antenna

Engine
Nozzle

High Gain
S / X-Band
Antenna

UHF Antenna

Solar Panels

VLC
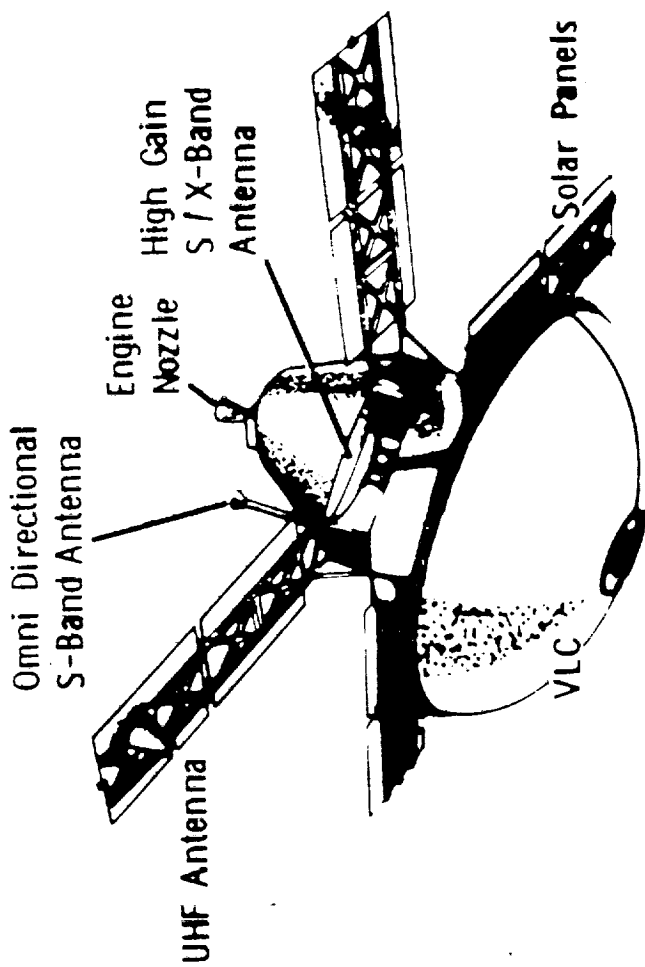
PROJECT REQUIREMENTS AND CONSTRAINTS

SUBALLOCATE TO POTENTIAL CONTAMINATING EVENTS

- **Large Impactables**

  -- Trajectory & Navigation, Orbit Life-time, Spacecraft Disintegration

- **Ejecta-Efflux**

  -- Orbiter, Centaur, Bioshield Cap, Bioshield Base

- **Viking Lander**

  -- Sterilization, Recontamination Before and During Launch, Recontamination During Cruise

- **Reserve**

DERIVED REQUIREMENTS AND CONSTRAINTS

```
Mission
Allocation
      │
      ▼
Event
Breakdown/
Sub-Allocation
      │
      ▼
OPTIONS:
Mission Analysis & Design
Vehicle Engineering
Consolidate Studies & Major
Options
      │
      ▼
Detailed Analytical
Estimates of
Probabilities
      │
      ▼
Comparison With
Allocation
      │
      ▼
Optimized
Allocation
      │
      ▼
REQUIREMENTS

Comparison With Allocation ──► Readjustment of Allocation ──► OPTIONS
```
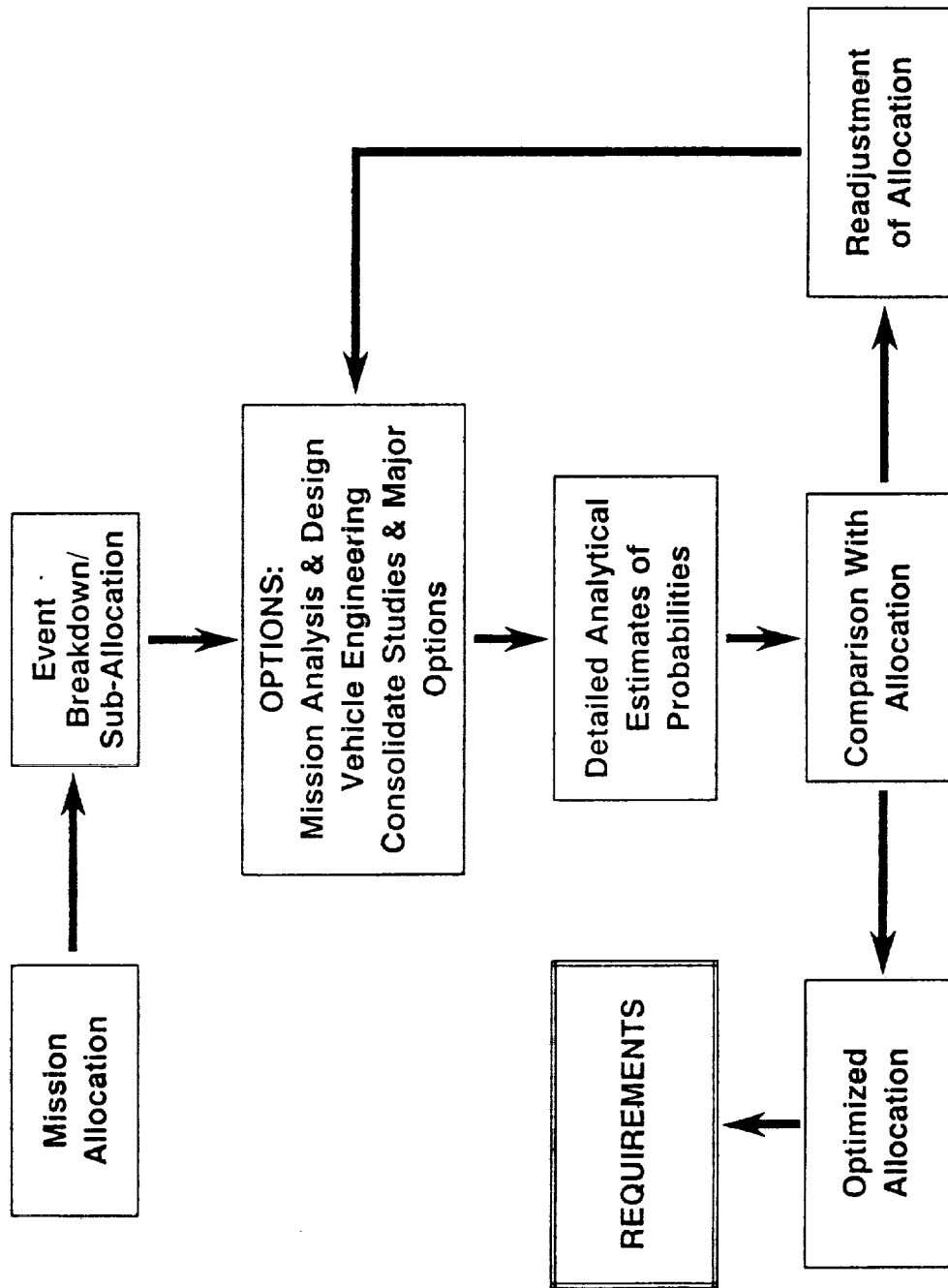
MISSION PROBABILITY OF CONTAMINATION EQUATION

$$P_c = P_c(LI)_{LV} + P_c(LI)_{VO} + P_c(LI)_{BC} + P_c(LI)_{BB} + \Sigma P_c(EE)_{LV} + \Sigma P_c(EE)_{VO} + \Sigma P_c(EE)_{BC} + \Sigma P_c(EE)_{BB} + \Sigma P_c(VL_i)$$

Where:

P_c is the probability of contaminating Mars with one or more organisms;

$P_c(LI)_{LV} + P_c(LI)_{VO} + P_c(LI)_{BC} + P_c(LI)_{BB}$ are the probabilities that Mars will be contaminated by the large impactable sources: launch vehicle, Viking Orbiter, bioshield cap, and bioshield base, respectively;

$P_c(EE)_{LV} + P_c(EE)_{VO} + P_c(EE)_{BC} + P_c(EE)_{BB}$ are the probabilities that Mars will be contaminated by the ith ejecta-efflux source of the launch vehicle, Viking Orbiter, bioshield cap, and bioshield base, respectively:

$P_c(VL_i)$ is the probability that Mars will be contaminated by the ith contamination source of the Viking Lander.

PROBABILITY EQUATION FOR LANDER CONTAMINATION

$$P_{c_M} = P_g \sum_{i=1}^{n} N_{l_i} P_{vt_i} P_{uv_i} P_{sa_i} P_{r_i}$$

P_c = Probability of Contamination by Lander Sources

P_g = Probability of Growth and Proliferation

N_l = Burden at Launch

P_{vt} = Probability of Survival of Interplanetary Vacuum and Thermal

P_{uv} = Probability of Survival of Ultraviolet Radiation

P_{sa} = Probability of Survival of Entry Heating

P_r = Probability of Release

PROJECT REQUIREMENTS AND CONSTRAINTS

PARAMETERS PROVIDED BY OTHERS

- **Indicator Organism and Lethality Parameters**
  - D Values of .5 to 5 hours at 125°C - <25% RH @ 0°C% 760 mm Pressure Z Value = 21°C

- **Probability of Release (Soft and Non-Nominal Landing)**
  - 1×10^{0} to 1×10^{-4} Depending on Location

- **Probability of Surviving Ultraviolet Radiation**
  - 1×10^{0} to $<1 \times 10^{-4}$ Depending on Location and Exposure

- **Encapsulated Microbial Density**
  - 130 Spores/cc of Non-metallic Spacecraft Material

- **Probability of Growth**
  - 1×10^{-6} Chance of Growth & Proliferation

VIKING STERILIZATION APPROACH

- **Minimize effects of Sterilization**

  - Utilize Component Flight Acceptance Testing for Encapsulated Burden Reduction

  - Terminal Sterilization To Be Controlled by Mated and Surface Burden

  - Use Self-sterilizing Propellants and Pre-sterilized Pressurants

  - Require No Reheat of Repaired Components Which Achieve the Appropriate Internal Heating During Terminal Sterilization

- **Use NO Sterile Insertion or Sterile Repair Techniques for Hardware**

DERIVED REQUIREMENTS AND CONSTRAINTS

ENGINEERING REQUIREMENTS (HEAT COMPATIBILITY)

Component Heat Compatability Design Development & Qualifiaction Tests

System Flight Acceptance Tests

Lander Sterility Requirements

STERILIZATION REQUIREMENTS (MICROBIAL LOAD REDUCTION)

Component Flight Acceptance Tests

Terminal Sterilization
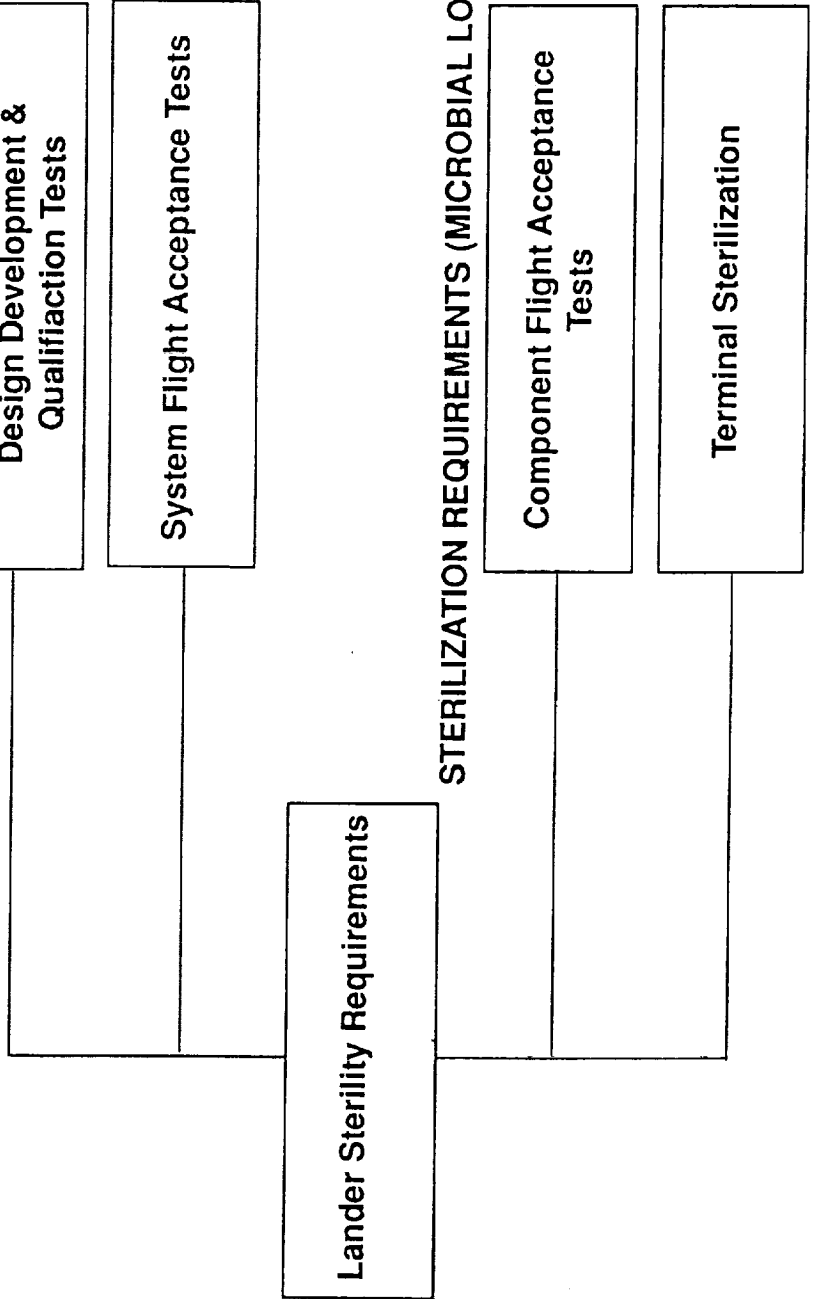
A GRAPHIC ILLUSTRATION OF THE COMPONENT AND SYSTEM HEAD CYCLES INITIALLY USED BY THE VIKING PROJECT
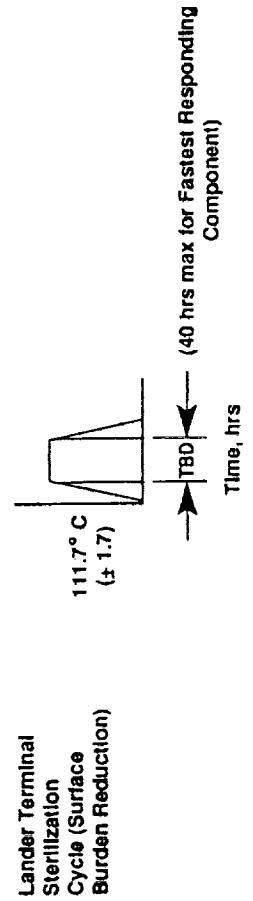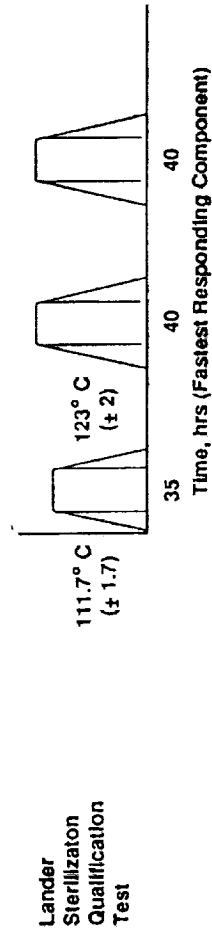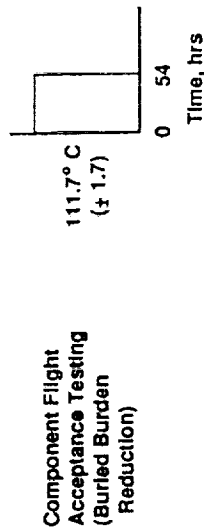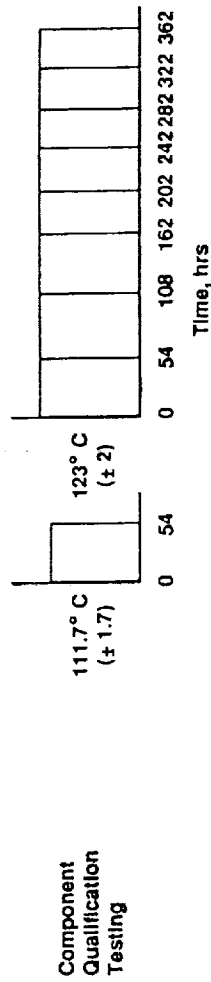
THERMAL ANALYSIS APPROACH AND VERIFICATION

```
Component ──▶ Thermal
              Analyses ──▶ Development Tests          ──▶ Component Flight Acceptance Heat
                           Verify Thermal                 Compatibility Test
                           Analyses                       Kills Buried Burden


Lander ──▶ Thermal
           Analyses ──▶ Thermal Effects       ──▶ Proof Test         ──▶ Fit Capsule
                        Test Model                 Capsule                Term. Sterilization
                        Verify Thermal             Refines Thermal        Kills Mated and
                        Analyses                   Test Data              Surface Organisms
```
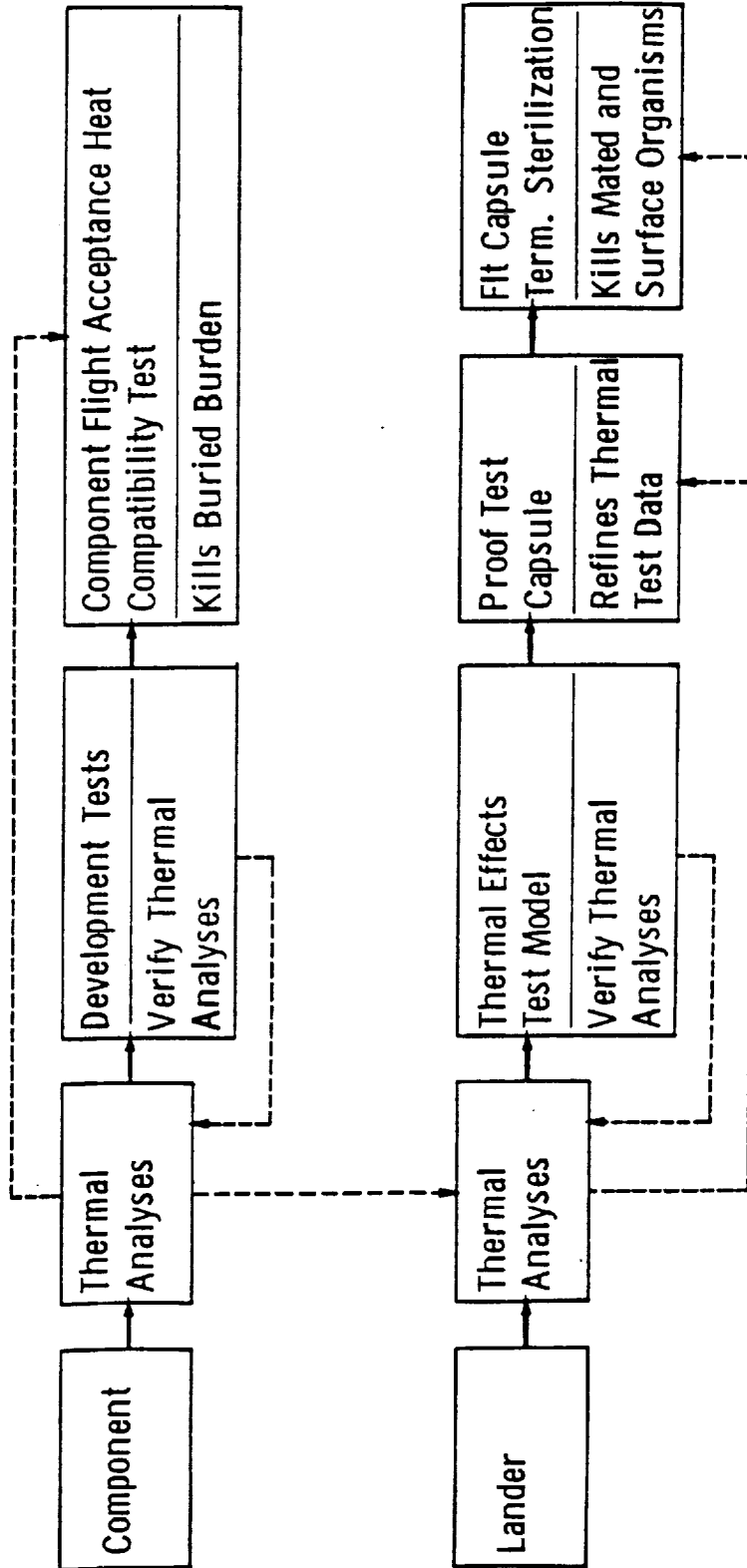
VERIFICATION

- ## Component Heat Tests

  - ¦ Verifies Component Analysis

  - ¦ Provides System Analysis Update Data

- ## System Heat Tests

  - ¦ Verifies System Analysis

  - ¦ Verifies Ability to Meet System-Imposed Constraints and Requirements

  - ¦ Establishes Terminal Cycle Operational Constraints and Requirements

DERIVATION OF TERMINAL STERILIZATION CYCLE

VARIABLES REMAINING

- Bio-burden on Flight Vehicles

- Division of Burden on Vehicles (Zones)

- Final Division of Allocation

- Time to Achieve Humidity Specification

VERIFICATION

PROOF TEST CAPSULE (PTC) STERILIZATION

- **Objectives**

  -- To Provide Verification That the Sterilization Requirements Could Be Achieved on a Functional Flight type Vehicle.

  -- To Qualify the Processes Used to Accomplish the Above.

- **Differences in TETM and PTC**

  -- Functional Components

  -- Bioassay Data

VERIFICATION

THERMAL EFFECTS TEST MODEL (TETM)

Sterilization Objectives

- To Establish That the Terminal Sterilization Requirements and Constraints Could be Achieved.

- To Establish That PP Requirements and Constraints Could be Achieved Within the Bounds of the Derived Engineering Requirements and Constraints.

- To Establish the Heating Cycle Conditions Required to Achieve the PP Requirements and Constraints.

DERIVATION OF TERMINAL STERILIZATION CYCLE

- **Bioassay Milestones**

  - Pre-environmental Testing

  - Pack and Ship to KSC

  - Post Mate Disassembly

  - Post Mate Reassembly

- **Perform Bioassays on PTC and All Flight Vehicles**

  - Surface and Mated Burden

STERILIZATION CYCLE OF VLC-1 (JUNE 20-22, 1975)
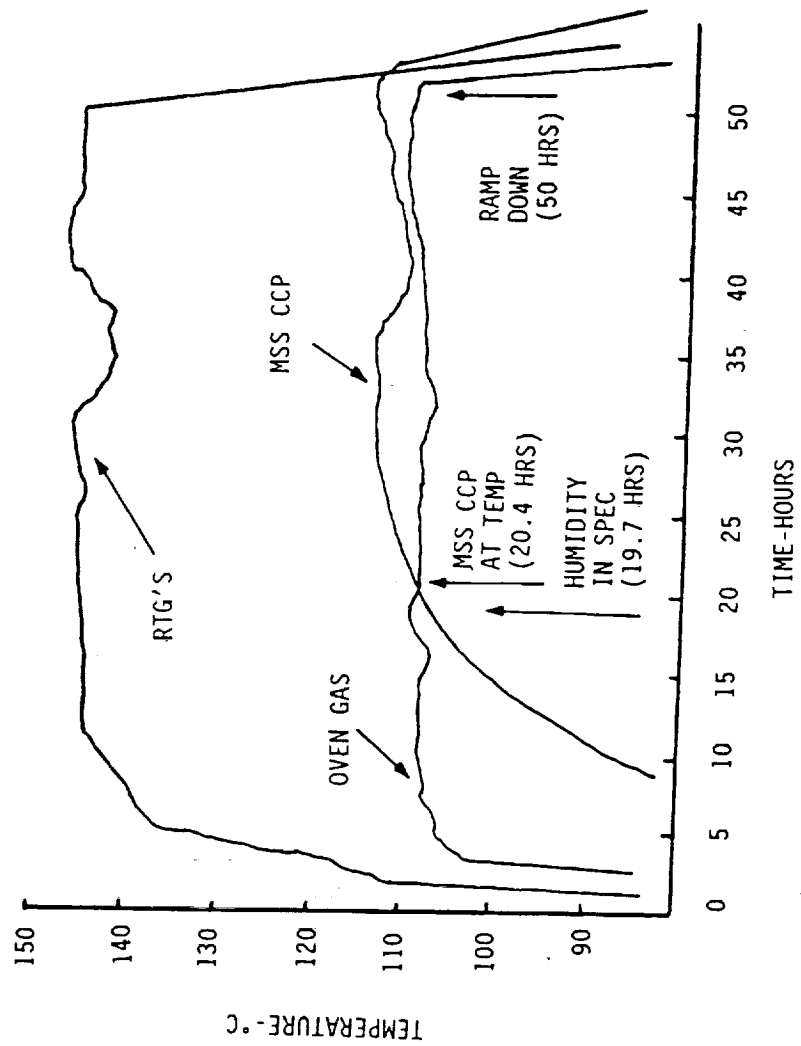
VLC-1 ALLOCATED VERSUS ACTUAL P_c

Burden Category	Allocated P_c	Actual P_c
Surface	6.0×10^{-6}	1.8×10^{-12}
Mated & Pseudo-Mated	1.0×10^{-6}	5.5×10^{-11}
Encapsulated	4.0×10^{-6}	8.7×10^{-7}
Encaps Repairs & Waivers	3.0×10^{-6}	2.5×10^{-7}
Total	14.0×10^{-6}	1.12×10^{-6}

STERILIZATION CYCLE OF VLC-2 (JUNE 15-17, 1975)
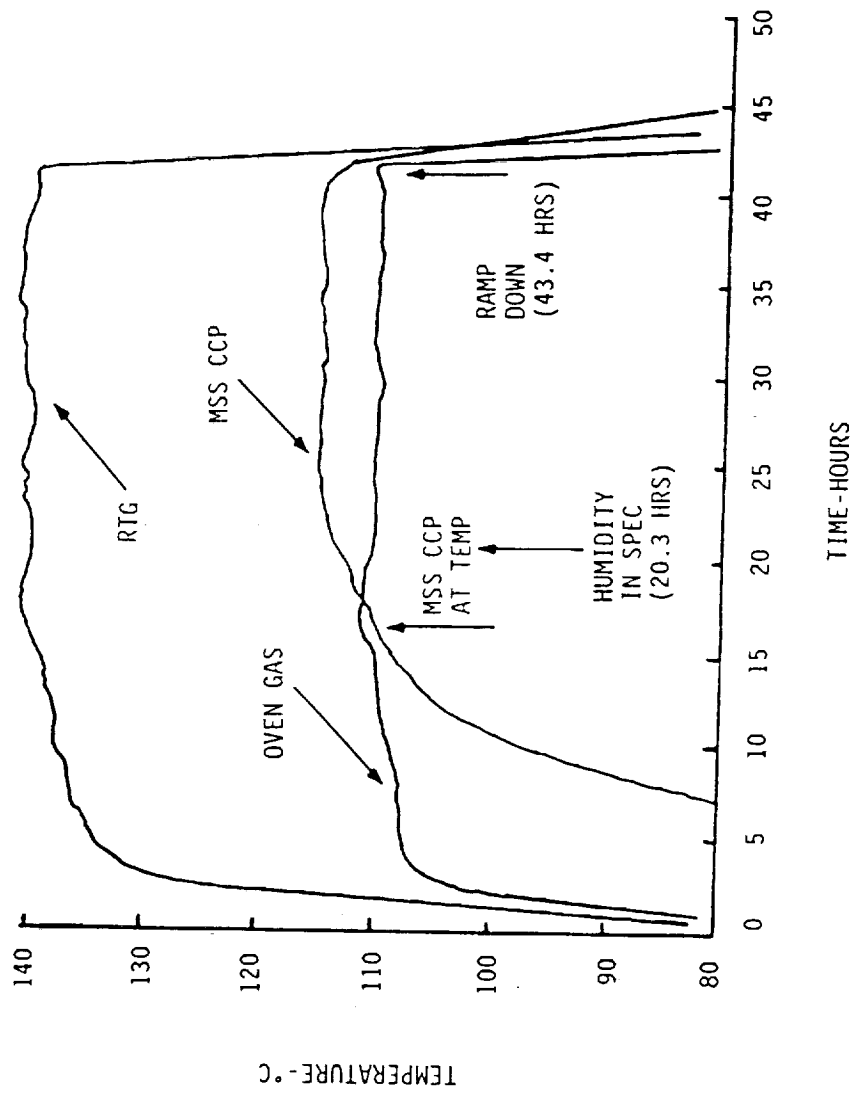
VLC-2 ALLOCATED VERSUS ACTUAL P_C

Burden Category	Allocated P_c	Actual P_c
Surface	6.0×10^{-6}	4.22×10^{-12}
Mated & Pseudo-Mated	1.0×10^{-6}	1.09×10^{-9}
Encapsulated	4.0×10^{-6}	1.04×10^{-6}
Encaps Repairs & Waivers	3.0×10^{-6}	3.44×10^{-7}
Total	14.0×10^{-6}	1.39×10^{-6}

OTHER SPACECRAFT HARDWARE REQUIREMENTS

- ## Orbiter Requirements and Constraints

  - Assembly in Cleanroom Environment

  - Cleaning to Reduce Particulates and Bio-burden

  - Biological Assays Prior to Mating with Lander and Encapsulation in Shroud to Insure Burden Level Compliance

- ## Nosefairing

  - Cleaning of Interior Surfaces Prior to Spacecraft Encapsulation

  - Biological Assays Following Cleaning to Insure Burden Level Compliance

  - Class 100 Air Supply Following Encapsulation

VIKING LANDER RTG COOLING LOOP
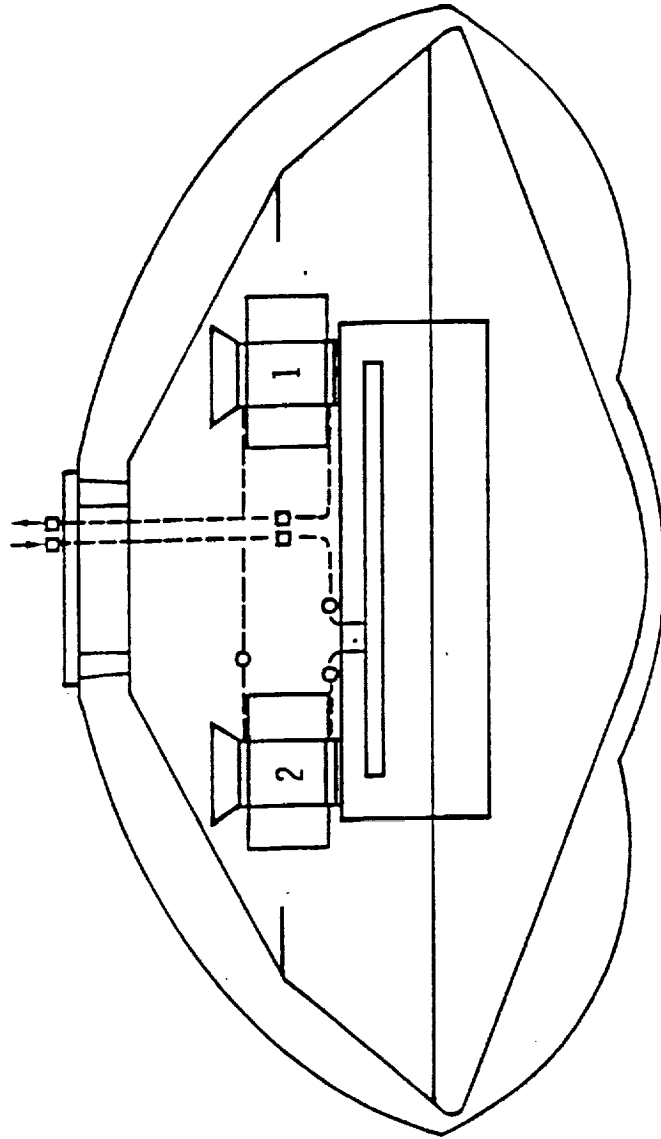
VIKING MISSION CONSTRAINT SUMMARY

- Viking Lander Dry Heat Sterilized

- Launch Vehicle/Centaur Injection on Trajectory Dispersed From Normal

- Deflection of the Centaur to Reduce Probability Impact

- S/C Aim Point Biasing Away From Preferred Success Point

- S/C Perform Mid-Course Maneuvers to Remove Bias

- S/C and Orbiter Periapsis Altitude Dispersion

- Specified Orbit Lifetime for Orbiter and Bioshield Base

- Orbiter and Bioshield Base Ejecta Efflux Probability Calculations

LANDER RECONTAMINATION PREVENTION REQUIREMENTS

- Pressurized Bioshield (5 inches of H_2O Pressure)

- Venting Through HEPA Filters

- Pressurization Through HEPA Filter (3 in Series)

- Use of Self-sterilizing Propellants

- Cooling of RTG's with Sporicide

- Blowdown of RTG Cooling System with Hot N_2 at Pad

- Incorporation of "Line of Sight" Shields on Bioshield Base

- Exposure of Base Cover to UV Flux in Mars Orbit

ATTACHMENT 5

PHYSICAL PROPERTIES OF MARS
R. HABERLE

BASIC PROPERTIES OF MARS AND EARTH

PLANETARY PROPERTIES	MARS	EARTH
MASS, kg	6.46×10^{23}	5.98×10^{24}
RADIUS, m	3394	6369
ACCELERATION OF GRAVITY, m/sec^2	3.72	9.81
ORBIT ECCENTRICITY	0.093	0.017
SPIN-AXIS INCLINATION, deg	25.2	23.5
LENGTH OF YEAR, Earth days	687	365
LENGTH OF SOLAR DAY, sec	88,775	86,400
SOLAR CONSTANT, W/m^2	591	1373

ATMOSPHERIC PROPERTIES	MARS	EARTH
PRINCIPAL CONSTITUENTS, by volume	CO_2 (95.3%)	N_2 (78.1%)
	N_2 (2.7%)	O_2 (20.9%)
	Ar^{40} (1.6%)	Ar^{40} (0.9%)
	O_2 (0.13%)	CO_2 (0.03%)
MEAN MOLECULAR WEIGHT	44	29
TOTAL MASS, kg	2.4×10^{16}	5.3×10^{18}
MEAN SURFACE PRESSURE, mbar	6	1013
NEAR-SURFACE TEMPERATURE RANGE, K	145-245	220-310

Composition of the Atmosphere of Mars

Species	Abundance (mole fraction)	Reference
CO_2	0.953	Owen *et al.*, 1977[b]
N_2	0.027	Owen *et al.*, 1977[b]
[40]Ar	0.016	Nier *et al.*, 1976[a]
O_2	0.13%	Barker, 1972
CO	0.08%	Kaplan *et al.*, 1969
	0.27%	Young and Young, 1977
H_2O	(0.03%)[a]	
Ne	2.5 ppm	Owen *et al.*, 1977[b]
[36]Ar	0.5 ppm	Owen and Biemann, 1976
Kr	0.3 ppm	Owen *et al.*, 1976
Xe	0.08 ppm	Owen *et al.*, 1976
O_3	(0.03 ppm)[a]	Lane *et al.*, 1973
	(0.003 ppm)[a]	Noxon *et al.*, 1976

Species	Upper limit (ppm)	Reference
H_2S	<400	Beer *et al.*, 1971[b]
C_2H_2, HCN, PH_3, etc.[b]	50	Hom *et al.*, 1972
N_2O	18	Hom *et al.*, 1972
C_2H_4, CS_2, C_2H_6, etc.[b]	6	Hom *et al.*, 1972
CH_4	3.7	Hom *et al.*, 1972
N_2O_4	3.3	Hom *et al.*, 1972
SF_6, SiF_4, etc.[b]	1.0	Hom *et al.*, 1972
HCOOH	0.9	Beer *et al.*, 1971[b]
CH_2O	0.7	Beer *et al.*, 1971[b]
NO	0.7	Hom *et al.*, 1972
COS	0.6	Hom *et al.*, 1972
SO_2	0.5	Hom *et al.*, 1972
C_3O_2	0.4	Hom *et al.*, 1972
NH_3	0.4	Hom *et al.*, 1972
NO_2	0.2	Hom *et al.*, 1972
HCl	0.1	Beer *et al.*, 1971[b]
NO_2	0.1	Owen *et al.*, 1975

[a]Very variable.

[b]A host of other exotic species are listed in the original paper, but are of no known planetological significance.
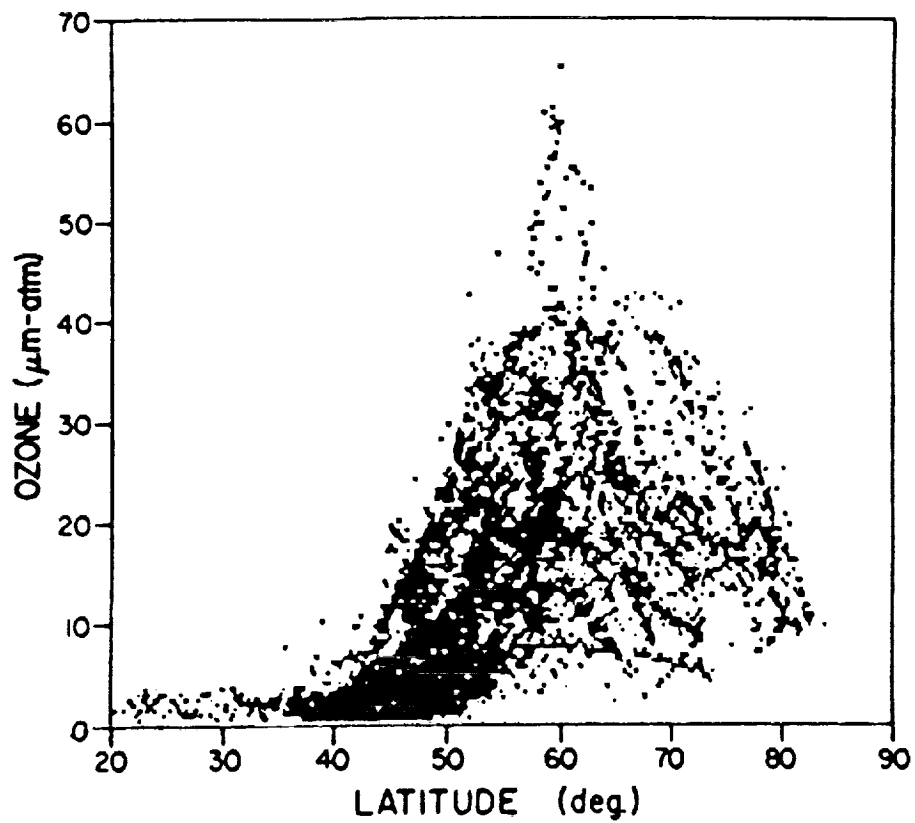
Mariner 9 measurements of the ozone column abundance
during the northern winter, $L_s = 330 - 360°$, in the
northern hemisphere (Barth, 1985).

Viking Observations of Mars' Atmospheric Water Vapor (column abundance pr-μm)

Atmospheric Pressure at the Surface of Mars (All years)
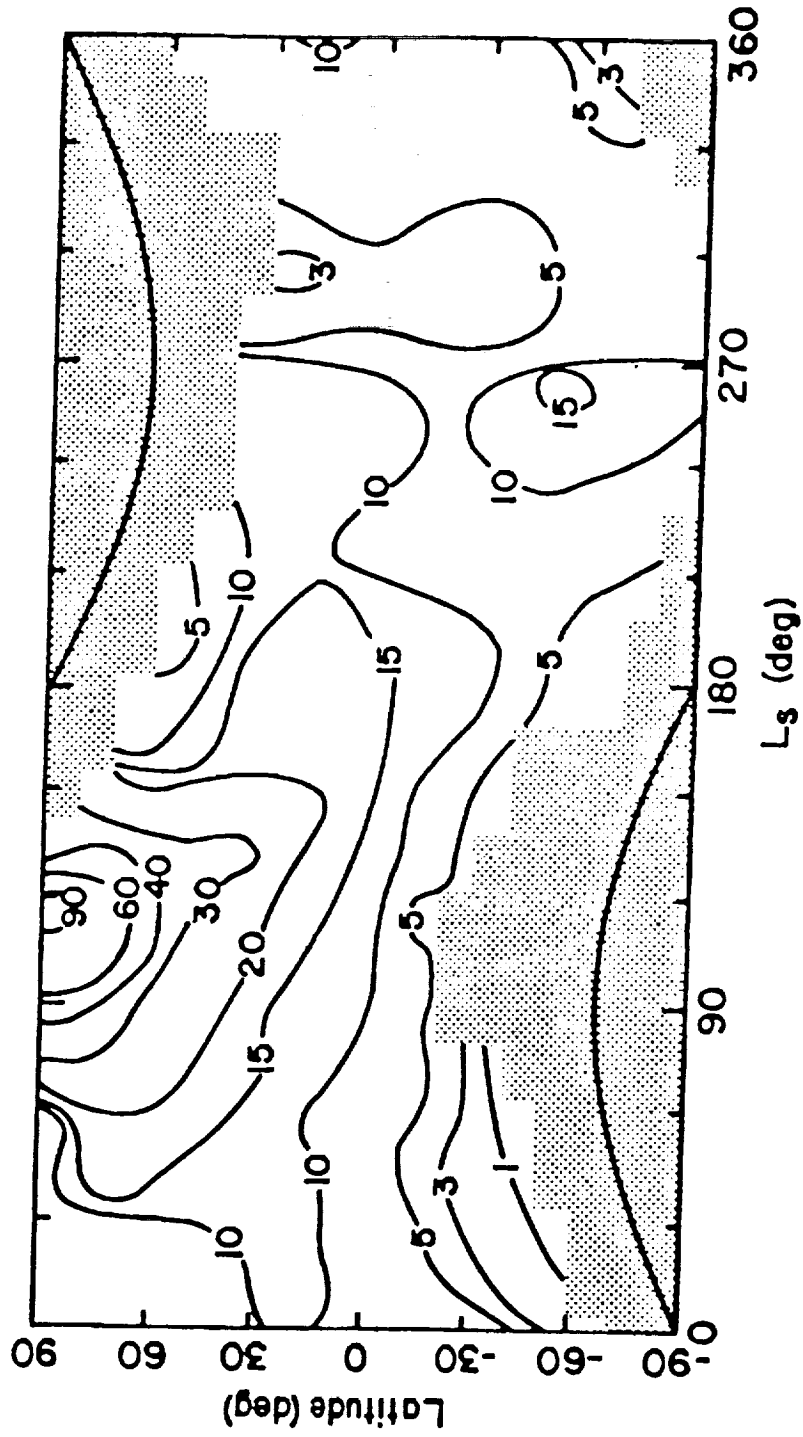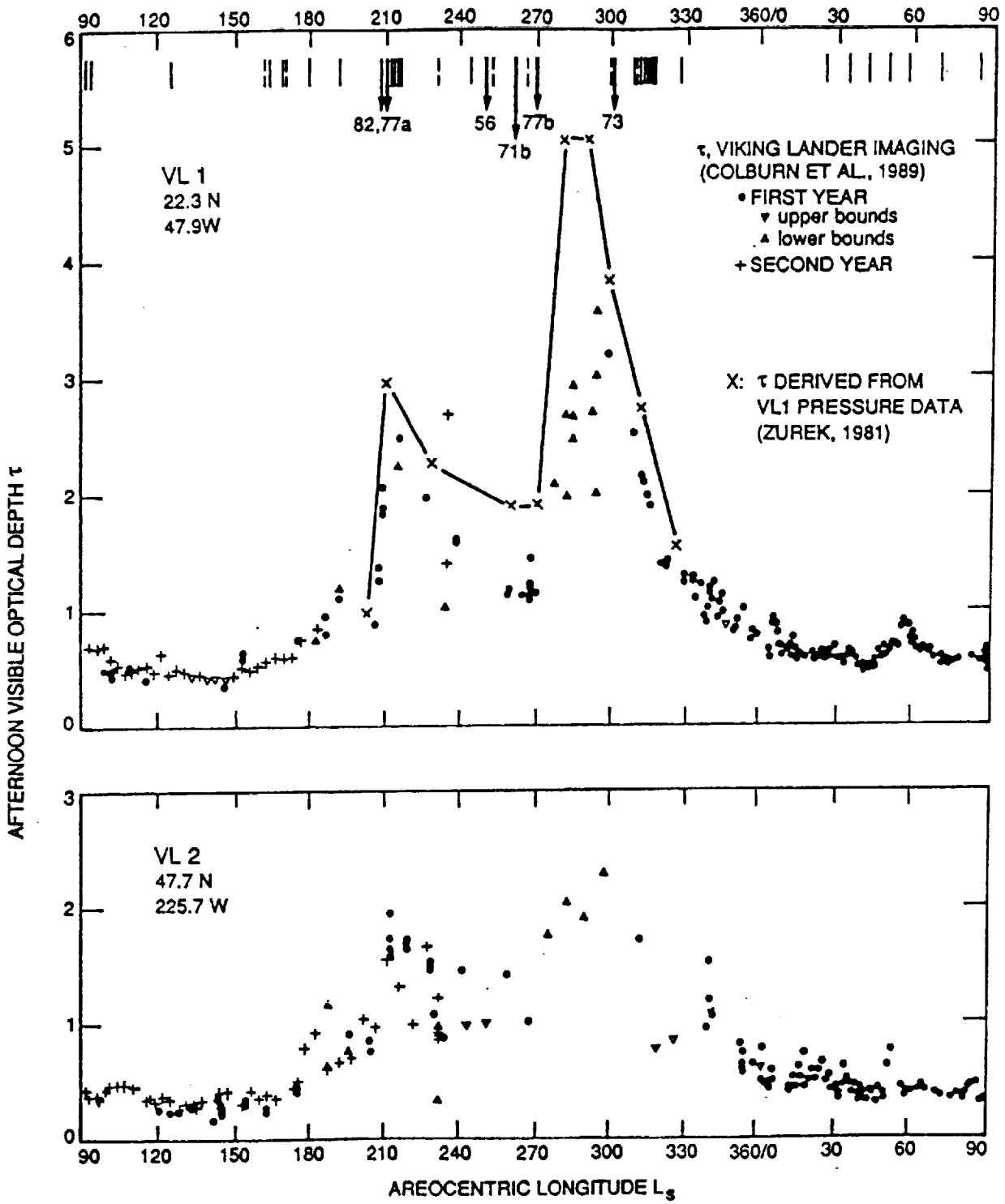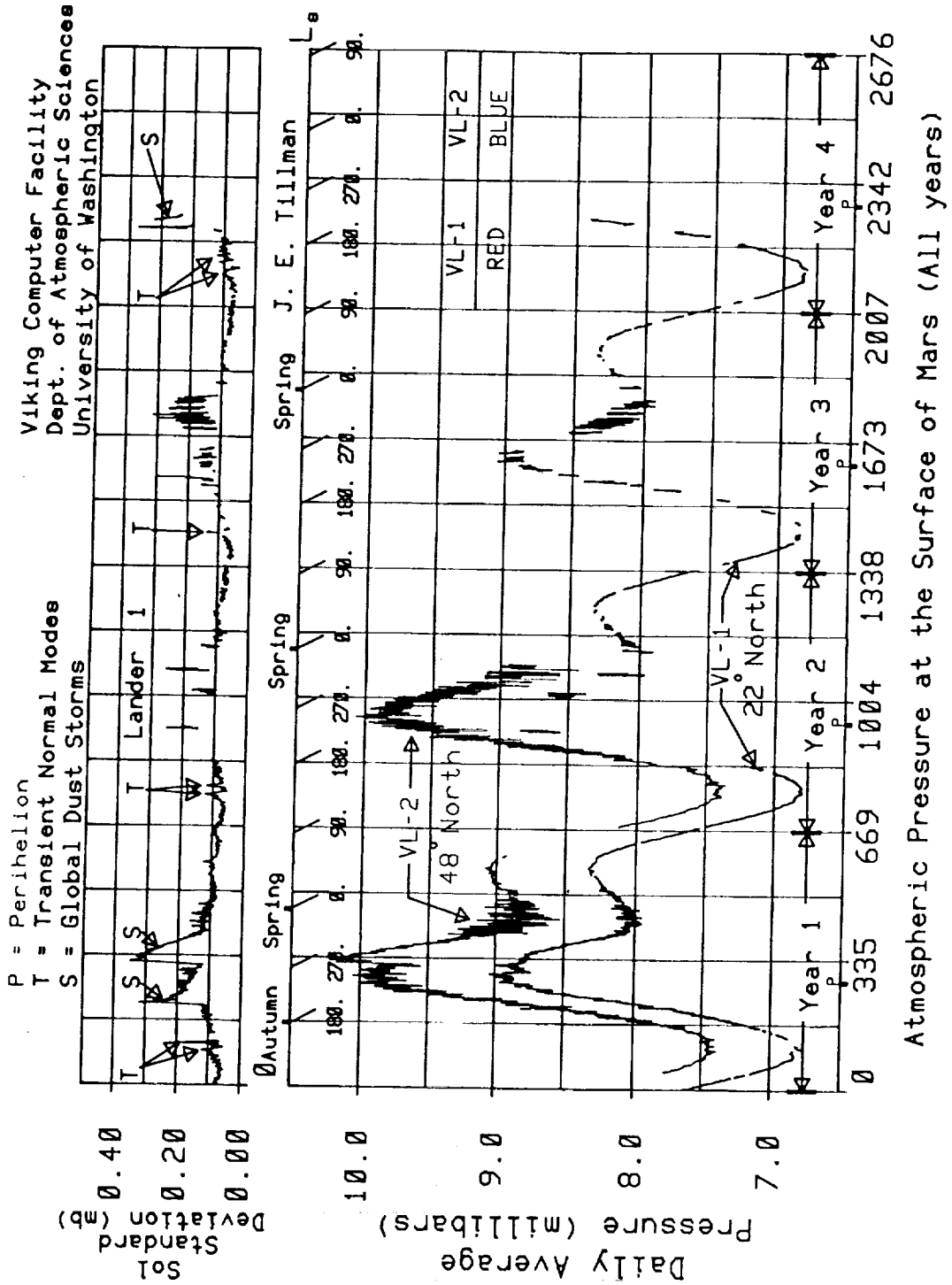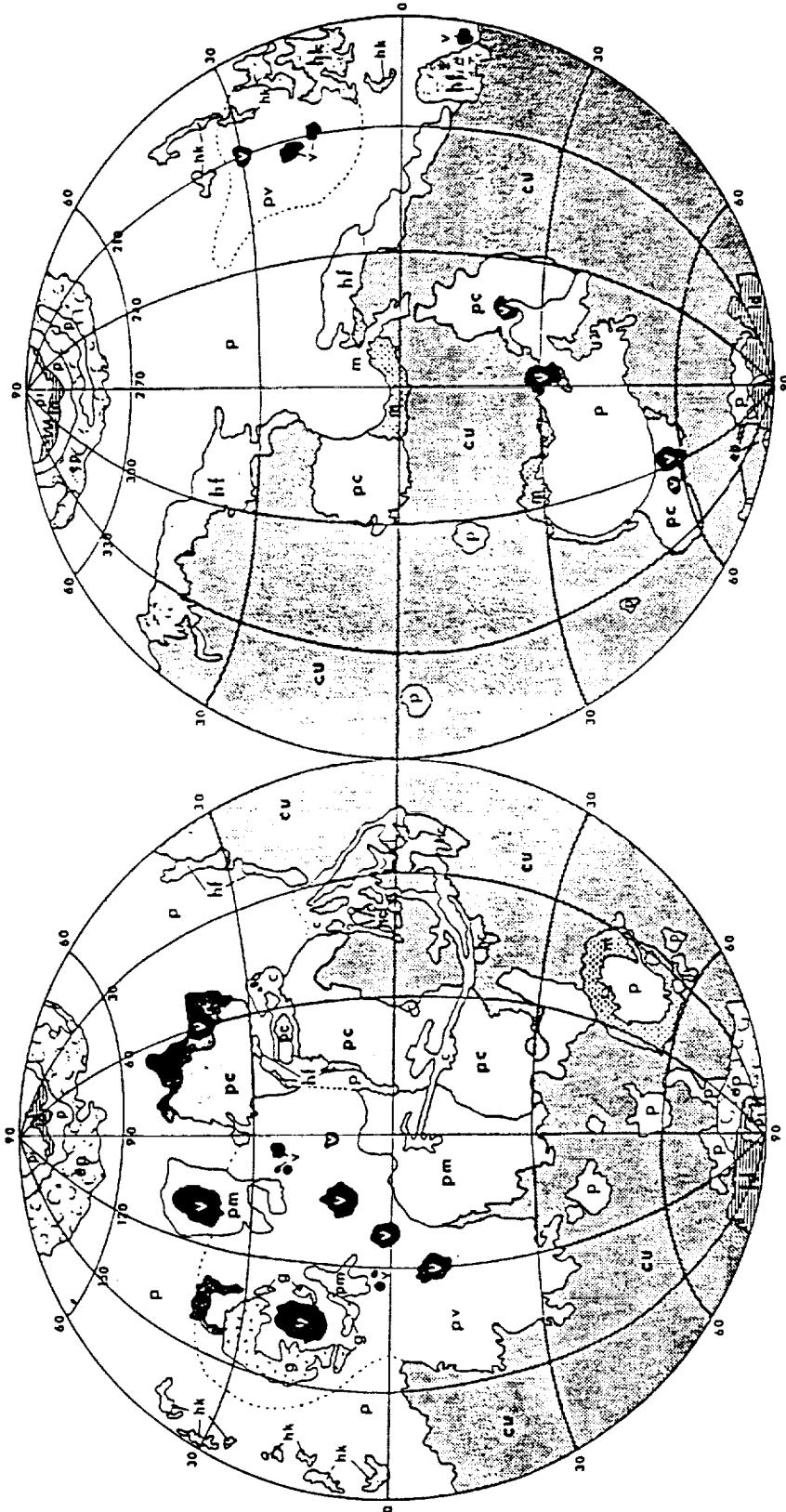
Legend: pi (permanent ice)   ld (layered deposits)
          ep (etched plains)   v (volcanic deposits)
          pc (cratered plains)   hc (hummocky terrain, chaotic)
          hk (hummocky-knobby)   c (channel deposits)
          p (plains, undivided) g (grooved terrain)
          cu (cratered terrain)   m (mountainous terrain)

Figure 6-2b.   Physiographic provinces of Mars [6-12].
               (Based on Mariner 9 data.)

NEW TOPOGRAPHY
ZONALLY AVERAGED
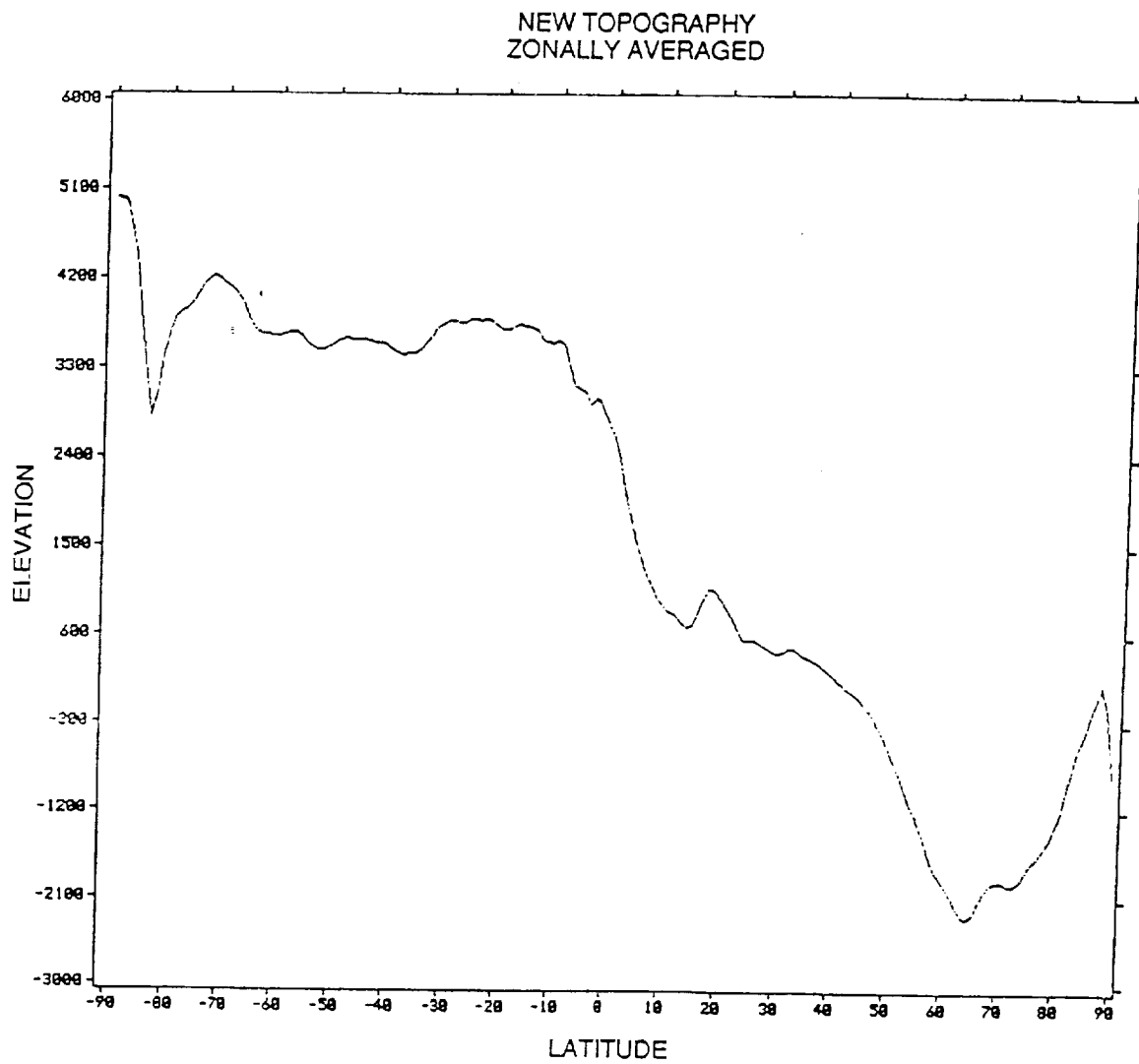
Zonally-averaged topography on Mars. Based on the Mars Digital
Terrain Model.
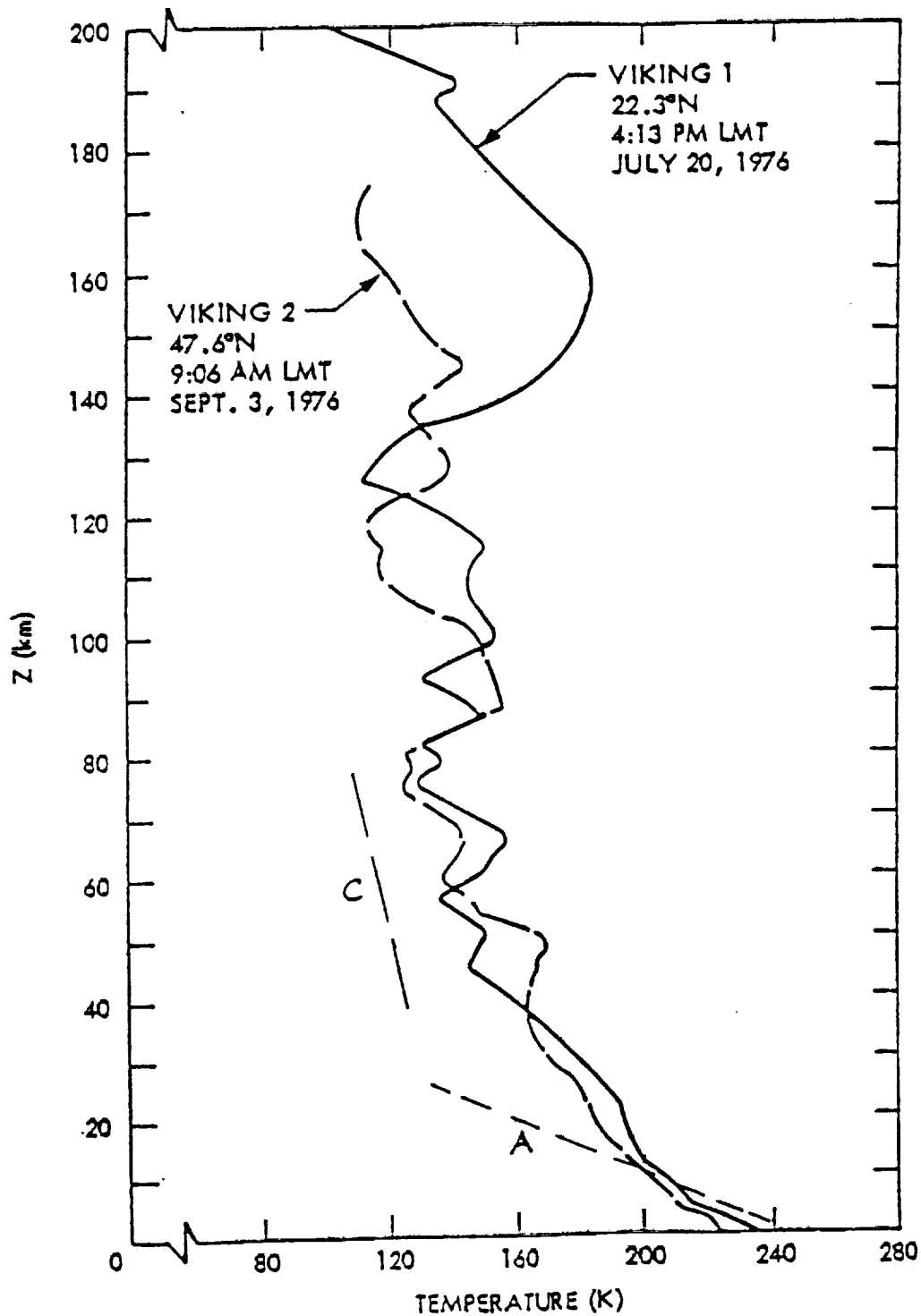
Atmospheric temperatures as measured by the Viking Landers during their descent to the surface.

AEROCENTRIC LONGITUDE OF THE SUN L$_S$ (deg)


AEROCENTRIC LONGITUDE OF THE SUN L$_S$ (deg)
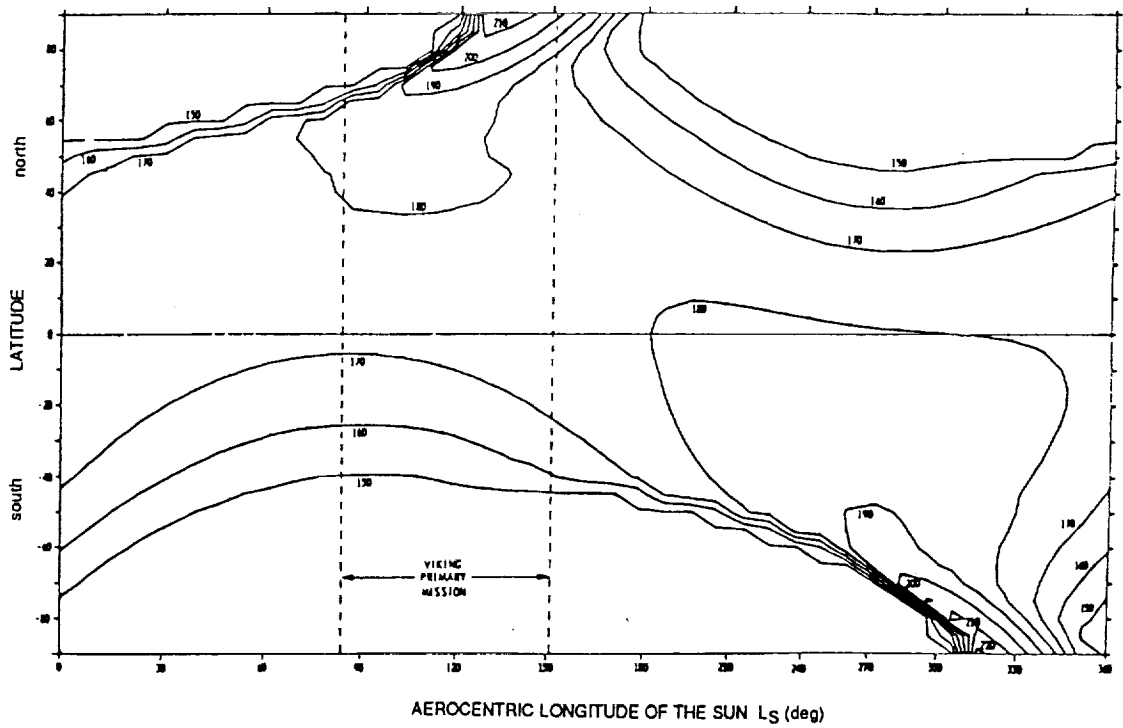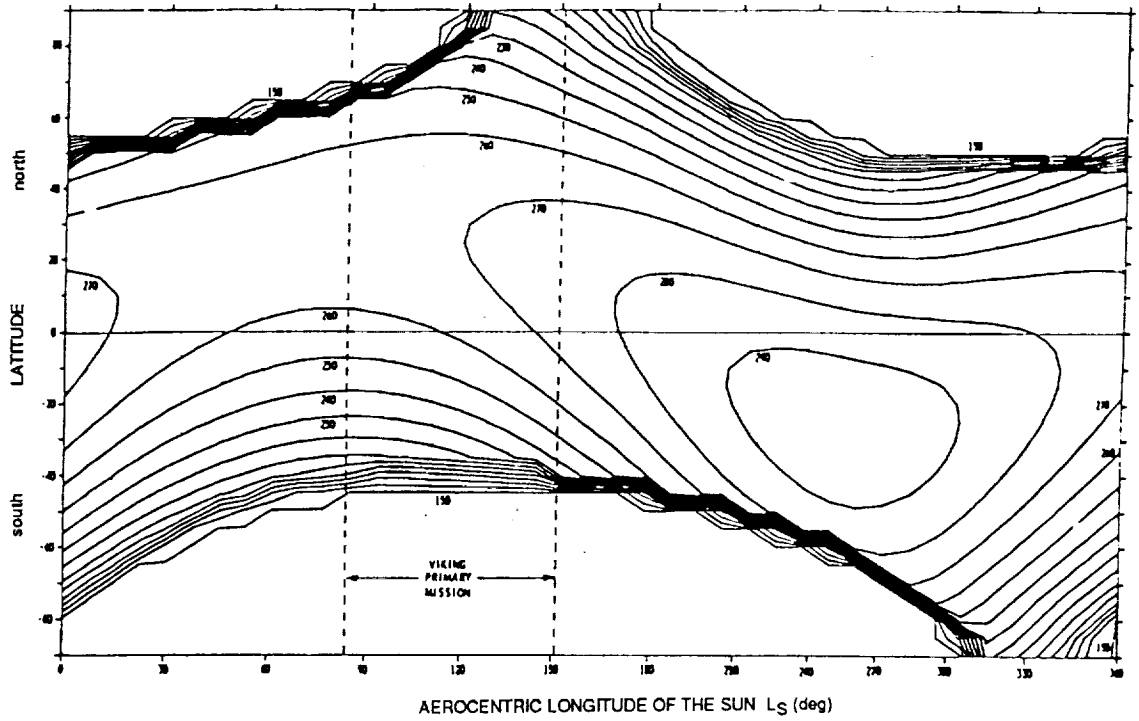
Diurnal surface temperature mean and extremes for the primary Viking thermal model (A* = 0.25 and I = 6.5). The dashed lines indicate the seasonal range of the primary mission. Top figure: maximum temperatures; bottom figure: minimum temperatures.

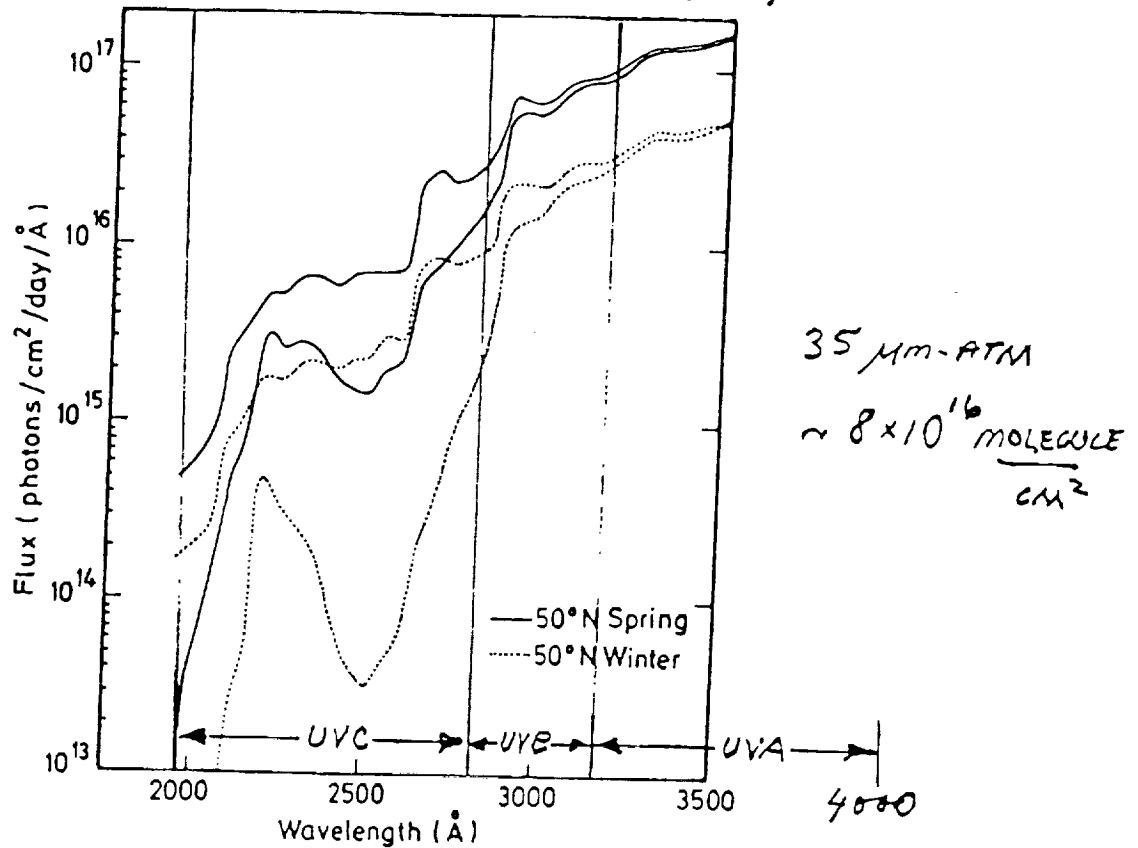## DAILY AIR TEMPERATURES AT VIKING LANDER 1
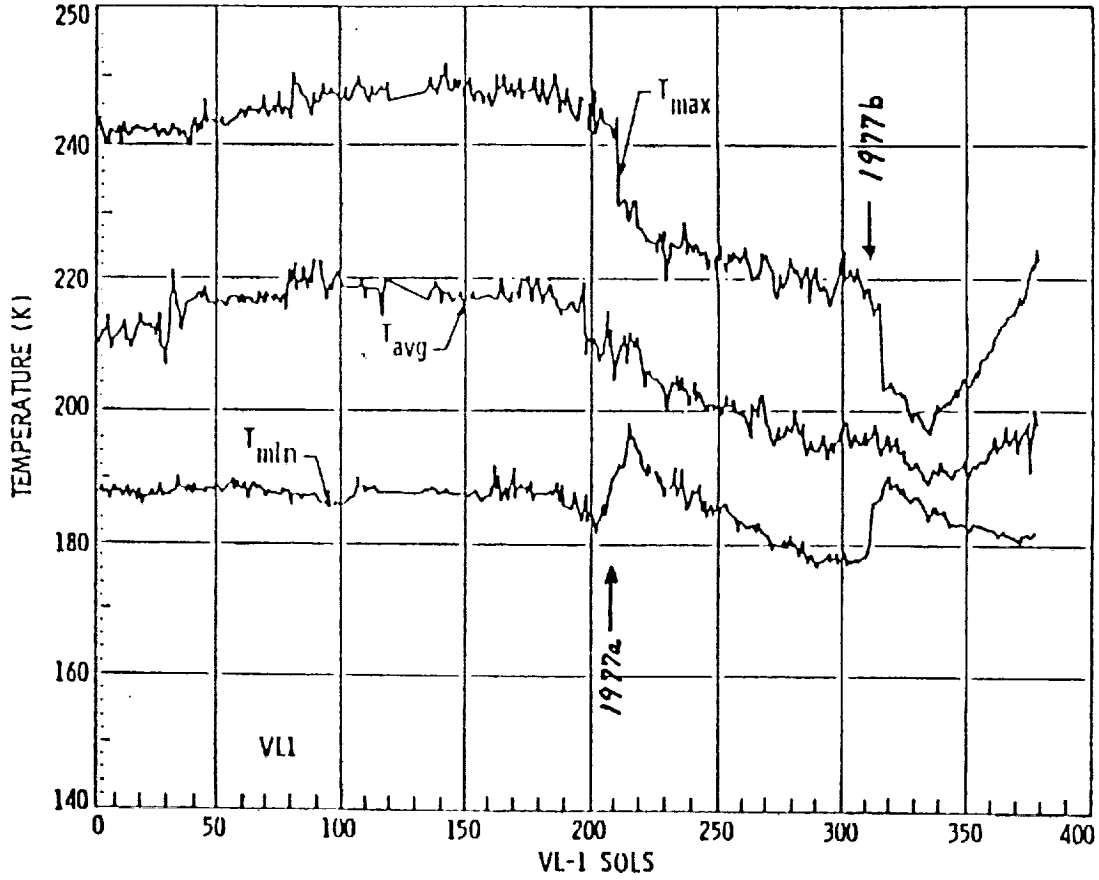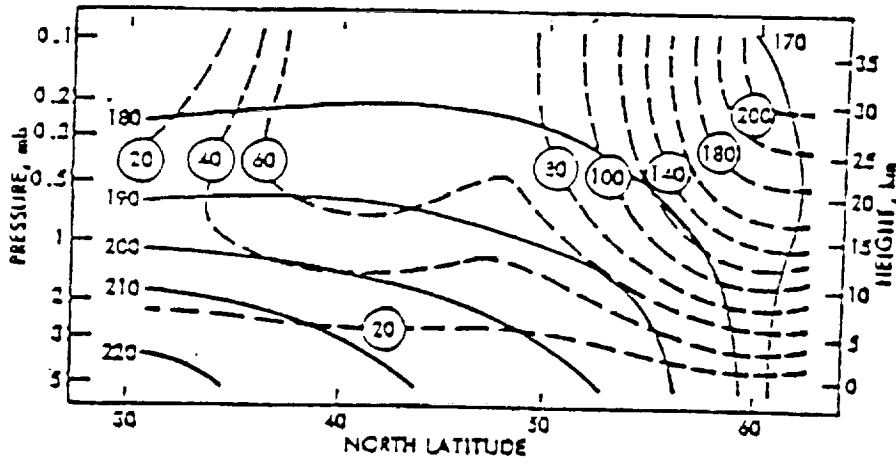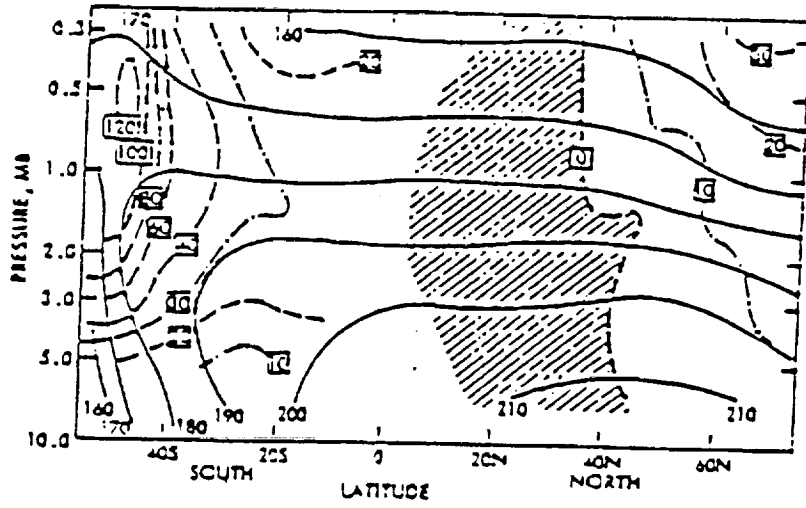
Zonally-averaged temperatures (solid lines, °K) and infrared zonal wind speeds (dashed lines, m/s): (a) Northern spring, (b) Late Northern winter.
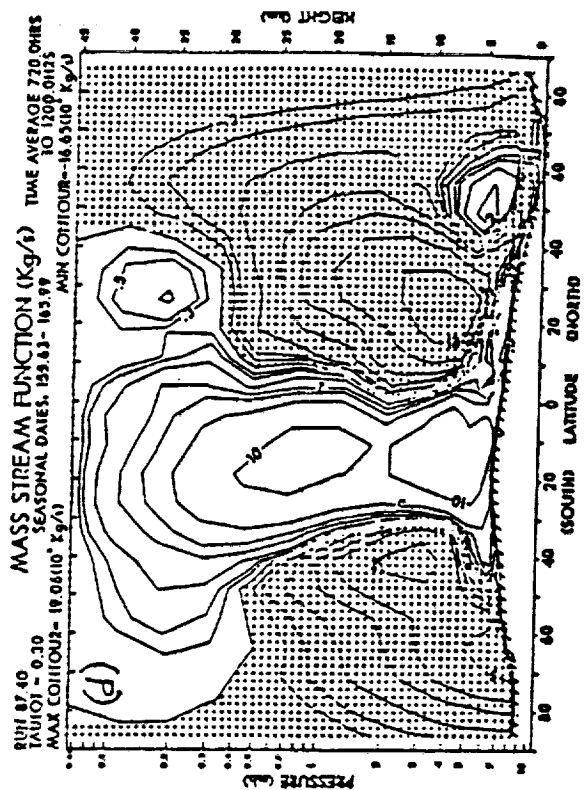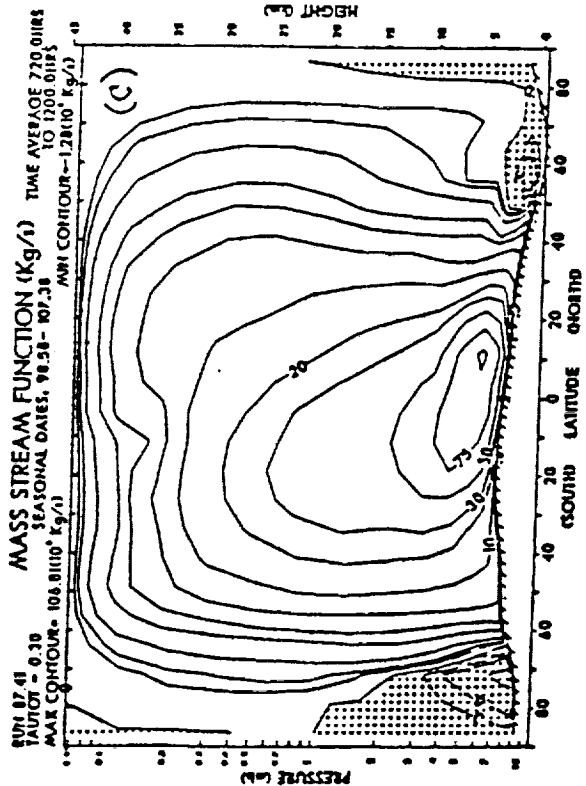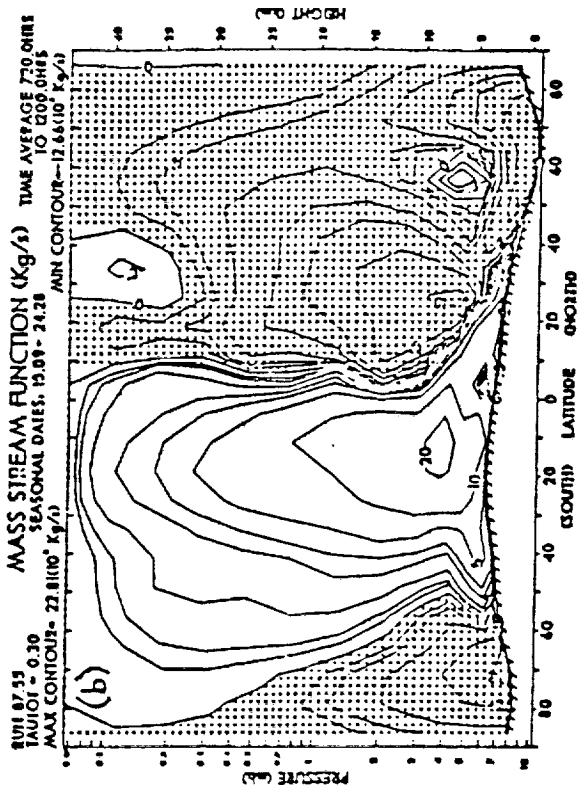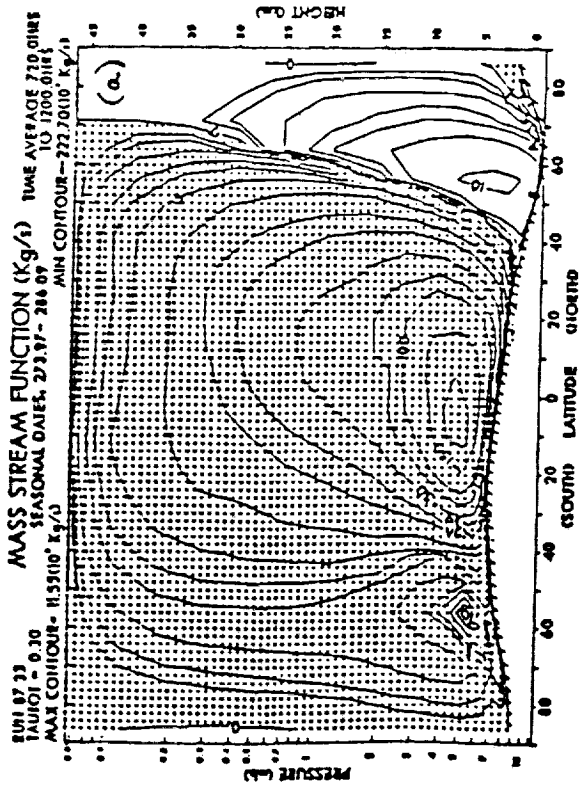
Solar Radiation Incident on the Martian Surface

KUHN & ATREYA (1979)

A comparison of the radiation incident on the Martian atmosphere and at the surface for 50° N Spring and 50° N Winter. The uppermost curve for each season corresponds to the radiation incident on the atmosphere

	UVʙ	UVᴀ
Wavelength Int.	280 - 320 nm	200 - 280 nm
Optical Depth	0.02	0.2
Mean Energy Flux	0.3 Wm⁻²	0.15 Wm⁻²
RGE	10^{-2}	1
Energy X RGE	0.003 Wm⁻²	0.015 Wm⁻²
1/e Lifetime	55.6 Hours	11.1 hours

Some environmental limits for microbial life

| Conditions	Examples of microorganisms that grow in such conditions
High temperatures (45°C - 100°C) (Hot springs, volcanic soils, compost heaps)	Eucaryotic cells $\leq$ 60°C Photosynthetic procaryotes $\leq$ 70°C Non-photosynthetic procaryotes $\leq$ 100°C
Acid hot springs (pH 1, 90°C)	*Sulfolobus acidocaldarius*
Low temperatures (-20°C(?) to 30°C) (Oceans, ice and snow surfaces, caves, refrigerators and freezers).	Many "psychrophilic" yeast and bacteria.
Acid and alkaline conditions (Hot springs, alkaline lakes, and soils, some industrial effluents, acid mine waters, coal mine refuse piles)	pH 1-5 *Thiobacillus* and *Acetobacter* spp. Eucaryotic algae pH 4-8 Many bacteria and other microoganisms pH 8-11 *Bacillus circulans* and other bacilli *Ectothiorhodospira halophila*; blue-green algae pH 2-10 *Penicillium* and other fungi.
Salt solutions NaCl: 0.01 M 0.3 M 0.3 - 3.0 M 2.5 - 5.0 M 0- 5.0 M	Many microorganisms Marine microorganisms Moderate halophiles (some of them marine) Extreme halophiles Salt tolerant microorganisms
Low water activity (in concentrated salt or sugar solutions, or on surfaces in dry atmospheres)	a_w 1.00 - 0.95 Many microorganisms 0.88 - 0.75 Extreme halophiles 0.97 - 0.65 *Xeromyces bisporus* 1.00 - 0.60 *Saccharomyces rouxii*
Radiation (Dose giving ca. 37% survival figures for UV (ergs mm^{-2}) and ionizing radiation (kR) respectively	*Escherichia coli* 500 2 *Saccharomyces cerevisiae* 800 3 *Bodo marina* 50,000 — *Micrococcus radiodurans* 6,000 150
Heavy metals (acid mine waters, laboratory reagents)	Many microorganisms are inhibited by low concentrations (10^{-5}-10^{-6}M) of heavy metals; others (e.g., thiobacilli) grow in 1% copper; some fungi can grow in saturated CuSO$_4$

This table gives approximate values and some examples, mostly taken from articles in Kushner, 1978a and Kushner, 1980. Other environments that have been called "extreme" including high pressure, low nutrients, aerobic and anaerobic conditions, are discussed in Kushner, 1980.

MARGULIS *ET AL.*

TABLE II

Approximate Limits for Growth and Survival of Terrestrial Microorganisms

| Factor	Limits for growth	Limits for survival (1-hr exposure)		References
		Vegetative cells	Spores	
Temperature	>15°C <85°C	<85°C <4°K	<160°C <4°K	Brock (1966), Emerson (1968), Ernst (1968), Farrell and Rose (1967), Fogg (1969), Porter (1946)
Water activity	>0.9*	0 to 1	0 to 1	Beers (1958), Cochrane (1958), Fogg (1959), Horowitz *et al.* (1972), Charlang and Horowitz (1974), Ingram (1957), Porter (1945), Scott (1957), Webb (1965)
Pressure	600 bars	3000 bars	20,000 bars	Johnson (1957), Zobell (1970)
pH	11.5	12	13-14 in 15.3 M for about 3 weeks (*B. subtilis*)	Deal *et al.* (1975), Porter (1945), Souza *et al.* (1975), Thimann (1963), Souza (1976, personal communication), Sussman and Halvorson (1966)
Ultraviolet radiation (2600 Å)	—	0.1 joules/cm²	0.1 joules/cm²	Donnellan and Stafford (1968), Schechmeister (1968)
Ionizing radiation	—	2-4 Mrad	2-4 Mrad	Goldblith *et al.* (1953), Kirk and Othmer (1969), Silverman and Sinskey (1968)
Nutrients	See text			

* >0.6 for halophiles.
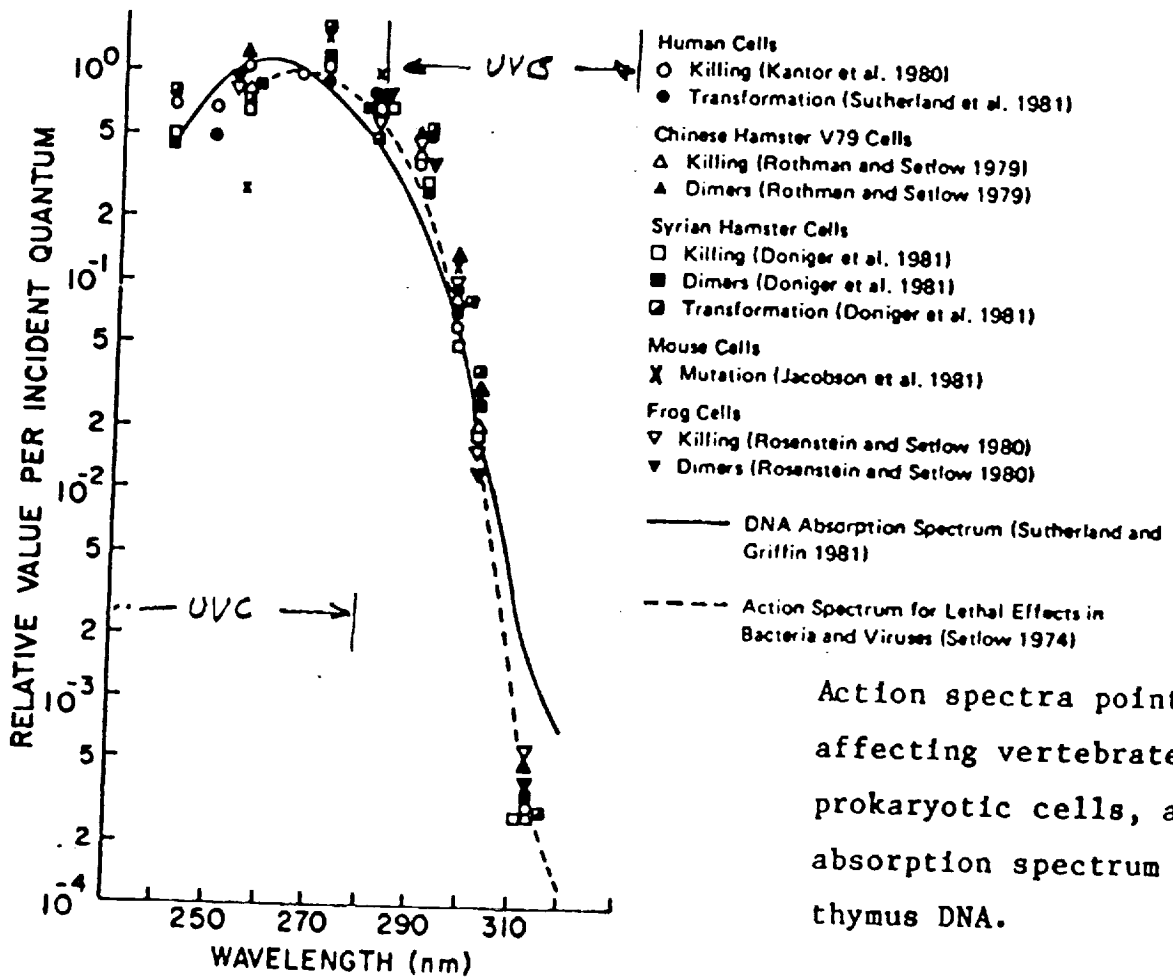
Action spectra points for affecting vertebrate cells, prokaryotic cells, and the absorption spectrum of calf thymus DNA.
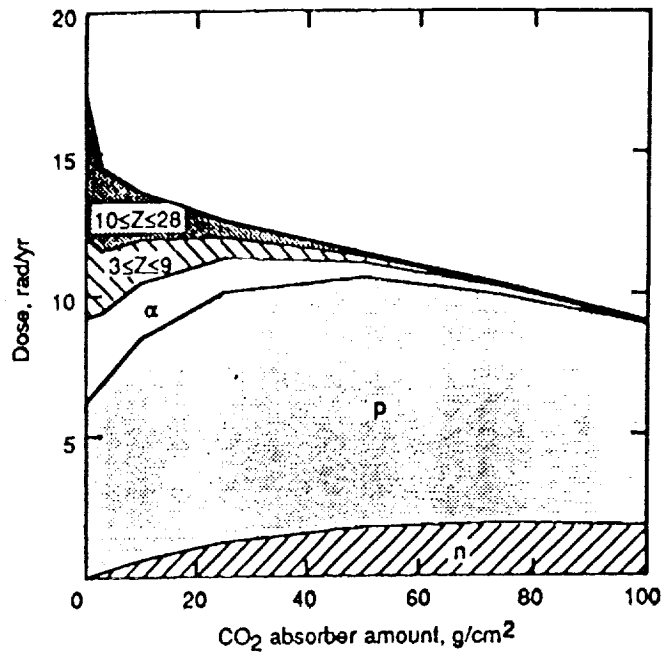
Annual skin dose contributions from specified particle constituents as a function of carbon dioxide absorber amount for GCR.
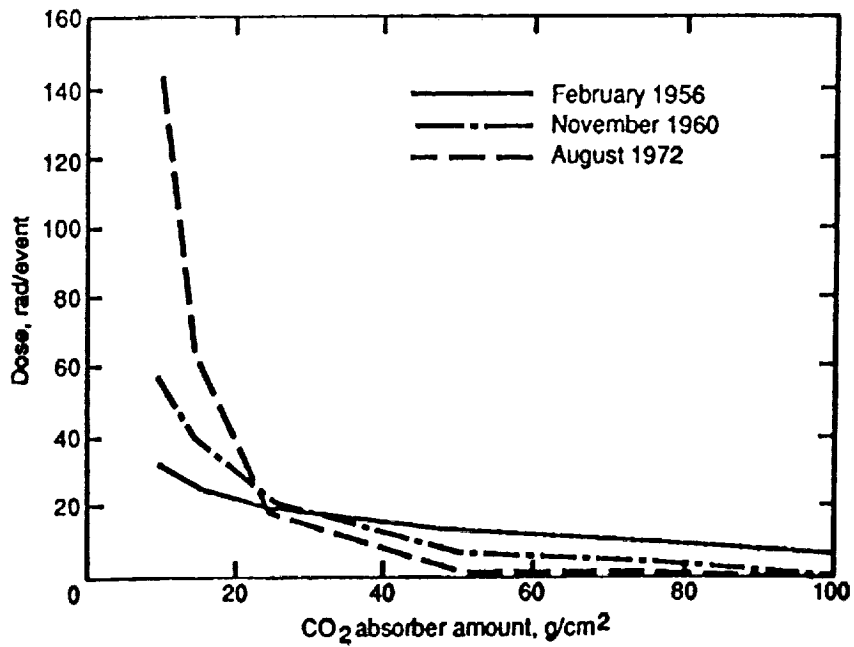
Skin dose as a function of carbon dioxide absorber amounts for three solar flare events.
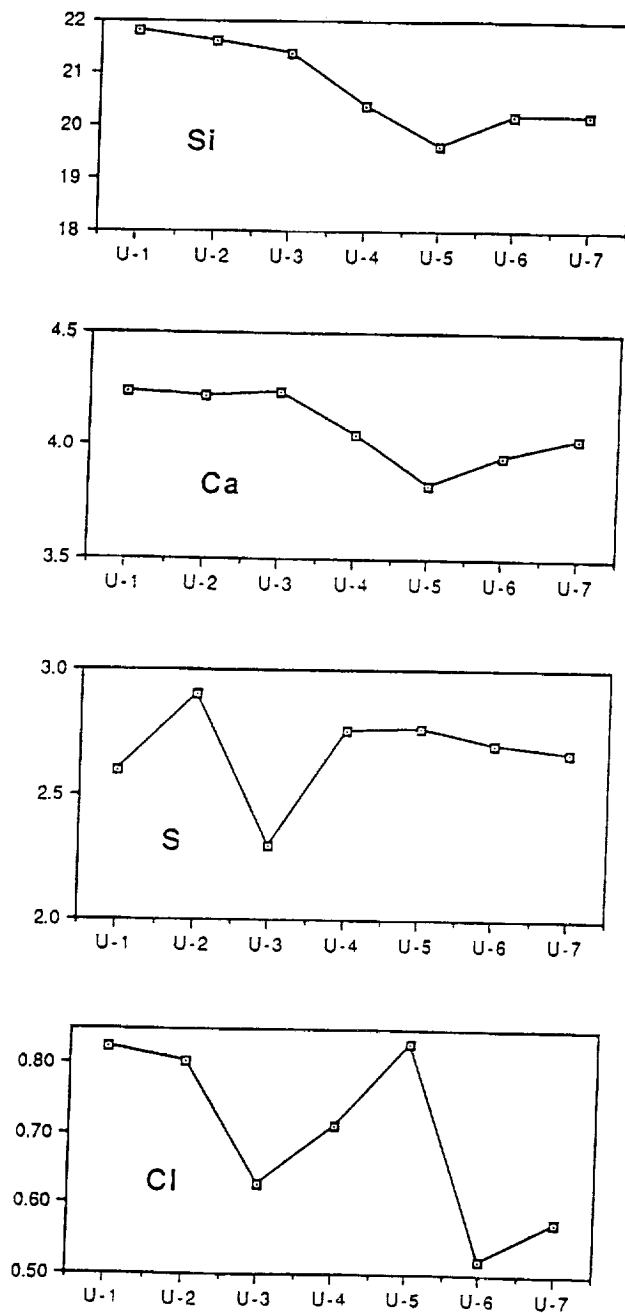
ATTACHMENT 6

CHEMICAL PROPERTIES OF MARS
B. CLARK

CANDIDATE SOIL COMPOSITION

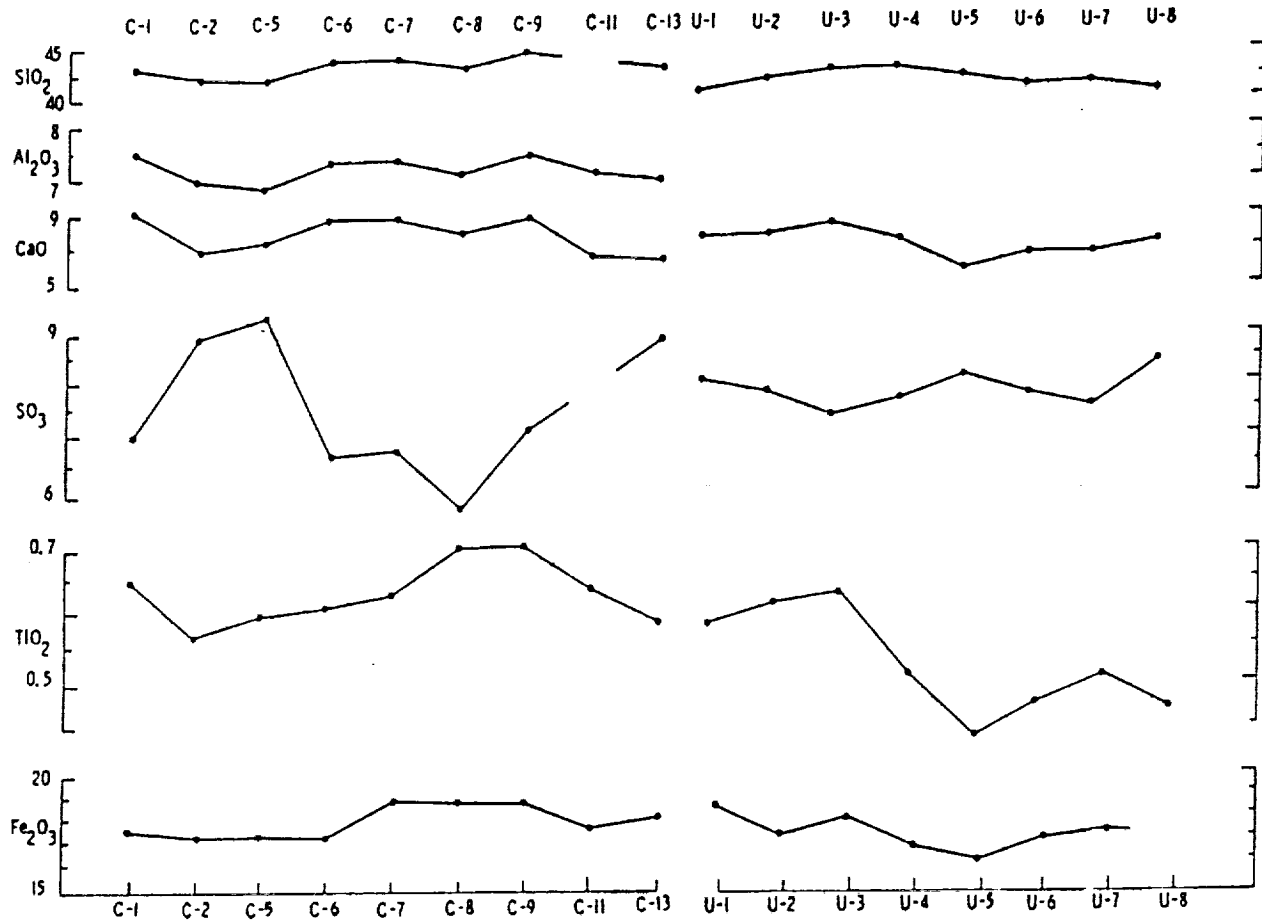Montmorillonite Clay   79%

Sulfate (Mg)   13%

Carbonate (Ca)   7%

Chloride (Ca)   1 - 2%

ELEMENT VARIABILITY WITH SAMPLE (VIKING)

Elemental concentration for silicon, calcium, sulfur, and chlorine in seven different samples taken at the Viking Lander II Site (Utopia)

CLARK ET AL.: CHEMICAL COMPOSITION OF MARTIAN FINES

Analytical results, ordinate: percent concentration by weight, plotted on the same logarithmically scaled basis for each oxide; abscissa: sample number (C, samples taken at Chryse Planitia; U, samples taken at Utopia Planitia).

Anti-correlation of sulfur with silicon in soil samples from Utopia and Chryse   sites
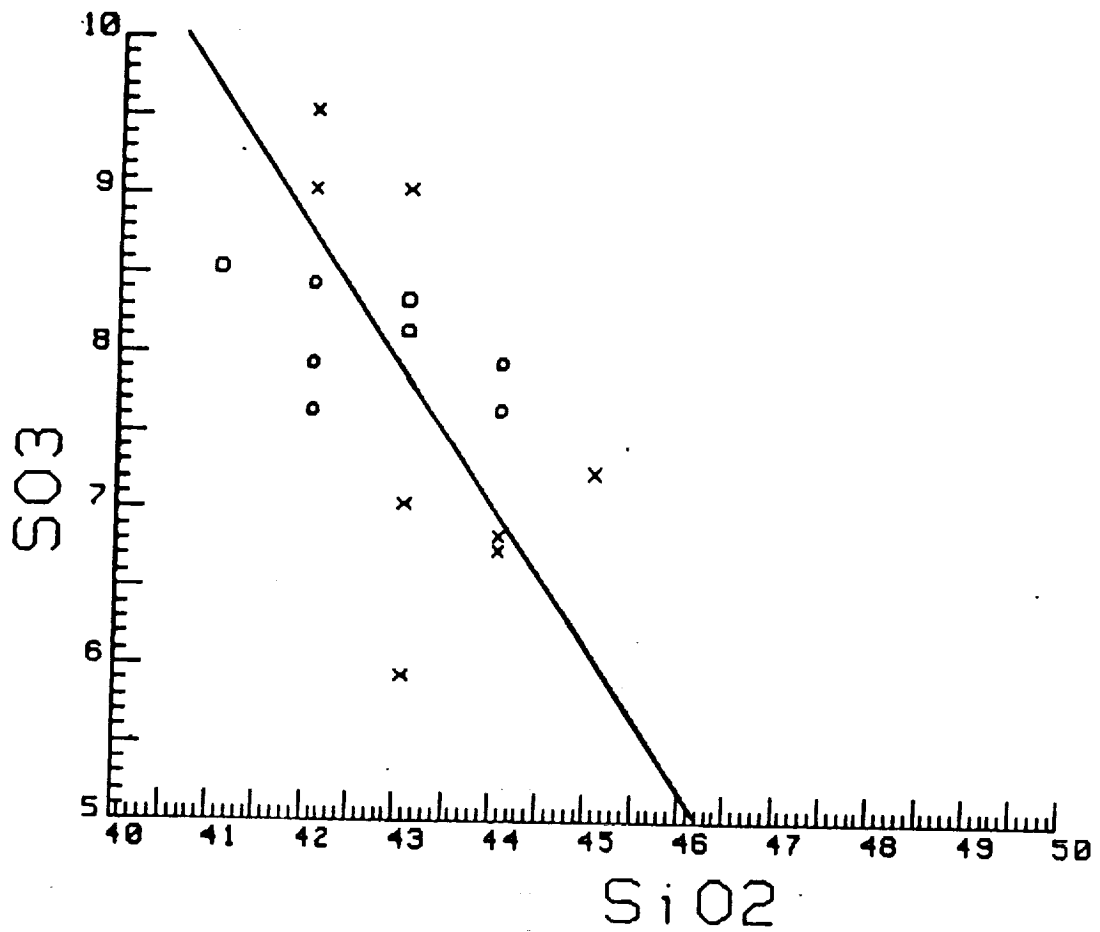
CANDIDATE EQUIVALENT MODES　(SHERGOTTY MINERAL PHASES)

	MARS*	SHERGOTTY
PIGEONITE	60	36
AUGITE	4.5	38
PLAGIOCLASE	34	23
OLIVINE	–	–
ILMENITE	0.3	0.3
TITANO-MAGNETITE	2.2	2.7

* SILICATE FRACTION IN REGOLITH FINES

RELATIVE ANALYSES

	C-6 (Bot.Deep hole)	U-6 (Mid-deep hole)
Si	17.2	18.9
Al	1.62	1.61
S	2.26	2.46
Cl	0.45	0.41
Ca	3.82	3.94
Ti	0.21	0.29
Fe	13.0	12.7

SAMPLE ANALYSIS SYSTEM OF THE X-RAY FLUORESCENCE SPECTROMETER

SAMPLE ANALYSIS
CHAMBER

SOURCE
HOLDER AND
RADIATION
SHIELD

PROPORTIONAL
COUNTER

Cd-109
SOURCE

REINFORCED
THIN FILM
WINDOW

SILVER
CALIBRATION
PLAQUE

RADIATION
SHIELD
(TUNGSTEN)
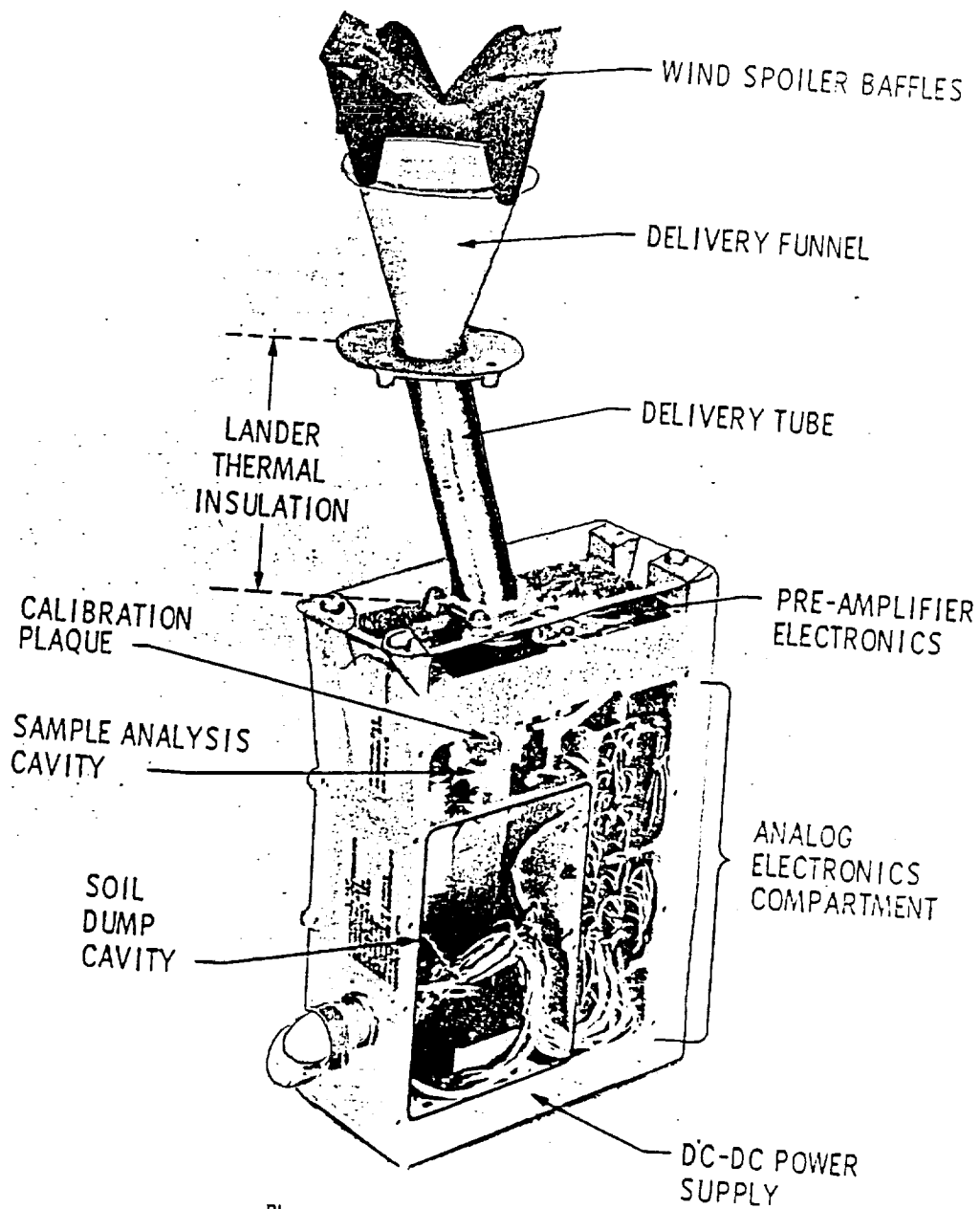
ZINC
PIGMENT

DUMP VALVE

PIVOT ASSY
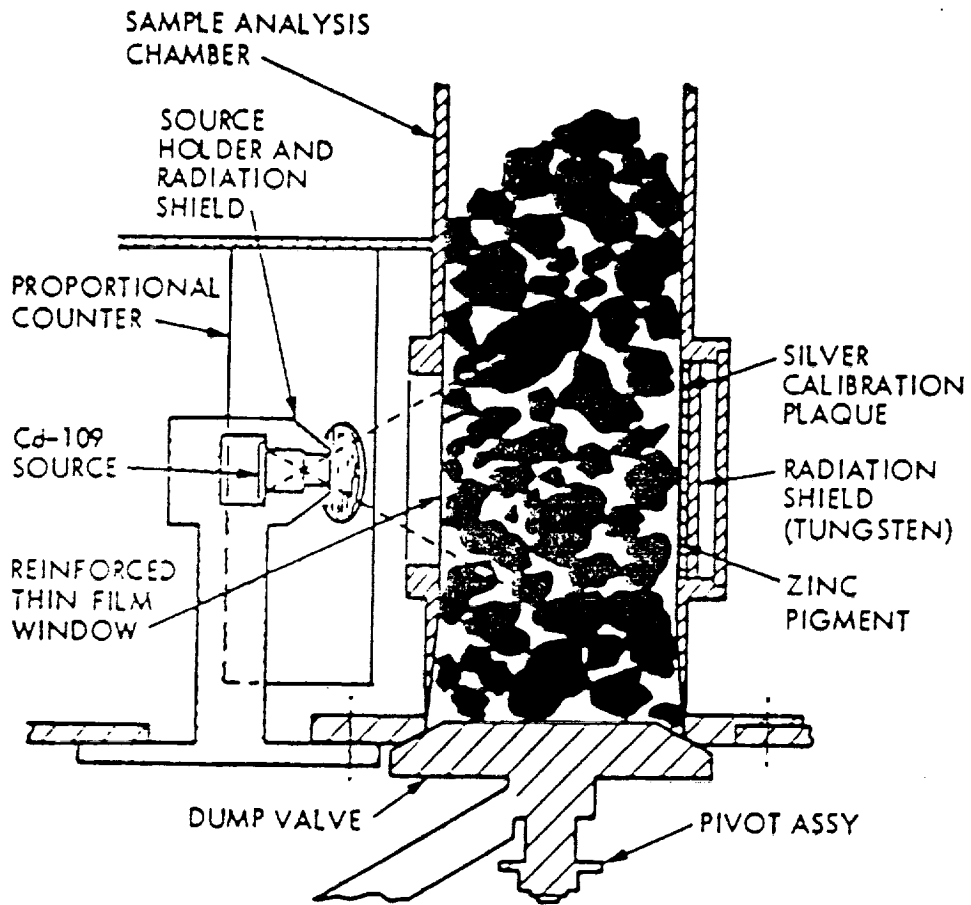
HEAVY VOLATILES

**Hg, Pb, Bi, Tl
As, Br, Se
Cd, Sb, In, Sn
Zn, Cu**

Possibly: Cr, Mn, Fe, Co, Ni, Ge, Ga, Rb

SALT-RICH REGOLITH

	Meas. Limits	Model
Sulfates	8 - 15%	12%
Chlorides	0.5 - 1.5%	1%
Bromides	<30 - 150 ppm	50 ppm
Carbonates	0 to	0 - 4.5%
Nitrates	10%	0 - 0.5%
Total	8 - 25%	13 - 18%

WIND SPOILER BAFFLES

DELIVERY FUNNEL

DELIVERY TUBE

LANDER
THERMAL
INSULATION

PRE-AMPLIFIER
ELECTRONICS

CALIBRATION
PLAQUE

SAMPLE ANALYSIS
CAVITY

ANALOG
ELECTRONICS
COMPARTMENT

SOIL
DUMP
CAVITY

DC-DC POWER
SUPPLY

Photograph of spare XRFS flight unit (FLT-1).

ATTACHMENT 7

WATER ON MARS?
F. FANALE

GLOBAL DISTRIBUTION AND MIGRATION
OF SUBSURFACE ICE ON MARS

Fraser Fanale[1], James Savail[1], Aaron P. Zent[2], and Susan Postawko[1]

A thermal/diffusive model of H_2O kinetics and equilibrium was developed to investigate the long-term evolution and depth distribution of subsurface ice on Mars. The model quantitatively takes into account (1) obliquity variations; (2) eccentricity variations: (3) long-term changes in the solar luminosity; (4) variations in the argument of subsolar meridian (in planetocentric equatorial coordinates); (5) albedo changes at higher latitudes due to seasonal phase changes of CO_2 and the varying extent of CO_2 ice cover; (6) planetary internal heat flow; (7) temperature variations in the regolith as a function of depth, time, and latitude due to the above factors; (8) atmospheric pressure variations over a 10^4-year time scale; (9) the effects of factors (1) through (5) on seasonal polar cap temperatures; and (10) Knudsen and molecular diffusion of H_2O through the regolith. The migration of H_2O into or out of the regolith is determined by two boundary conditions, the H_2O vapor pressure at the subsurface ice boundary and the annual average H_2O concentration at the base of the atmosphere. These are controlled respectively by the annual average regolith temperature at the given depth and seasonal temperatures at the polar cap. Starting from an arbitrary initial uniform depth distribution of subsurface ice, H_2O fluxes into or out of the regolith are calculated for 100 selected obliquity cycles, each representing a different epoch in Mars' history. The H_2O fluxes are translated into ice thicknesses and extrapolated over time to give the subsurface ice depth as a function of latitude and time. The results show that obliquity variations influence annual average regolith temperatures in varying degrees, depending on latitude, with the greatest effect at the poles and almost no effect at 40° lat. Insolation changes at the pole, due to obliquity, argument of subsolar meridian, and eccentricity variations can produce enormous atmospheric H_2O concentration variations of ≈6 orders magnitude over an obliquity cycle. Superimposed on these cyclic variations is a slow, monotonic change due to the increasing solar luminosity. Albedo changes at the polar cap due to seasonal phase changes of CO_2 and the varying thickness of the CO_2 ice cover are critically important in determining annual average atmospheric H_2O concentrations. Despite the strongly oscillating character of the boundary conditions, only small amounts of H_2O are exchanged between the regolith and the atmosphere per obliquity cycle (<10 g/cm^2). The net result of H_2O migration is that the regolith below 30-40° lat is depleted of subsurface ice, while the regolith above 30-40° lat contains

permanent ice due to the depth of penetration of the annual thermal wave. This result is supported by recent morphological studies. The rate of migration of H_2O is strongly dependent on average pore/capillary radius for which we have assumed values of 1 and 10 μm. We estimate that the H_2O ice removed from the regolith would produce a permanent ice cap with a volume between 2 x 10^6 and 6 x 10^6 km^3. This generally agrees with estimates deduced from deflationary features at lower latitudes, depositional features at higher latitudes, and the mass of the polar caps. © 1986 Academic Press, Inc.

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DISTRIBUTION AND STATE OF H₂O
IN THE HIGH -LATITUDE SHALLOW SUBSURFACE OF MARS

Aaron P. Zent[1], Fraser Fanale[2], James Savail[2], and Susan Postawko[2]

A quantitative model of the state, distribution, and migration of water in the shallow martian regolith is presented. Reported results are confined to the region of the planet greater than 40° lat. The calculations take into account (1) expected thermal variations at all depths, latitudes, and times resulting from seasonal and astronomically induced insolation variations; (2) variations in atmospheric P_{H_2O} and P_{CO_2} resulting from polar insolation variations and regolith adsorptive equilibria; (3) feedback effects related to latent heat and albedo variations resulting from condensation of atmospheric constituents; (4) two possible regolith mineralogies; (5) variable total H_2O content of the regolith; (6) kinetics of H_2O transport through the Martian atmosphere and regolith; and (7) equilibrium phase partitioning of H_2O between the condensed; adsorbed, and vapor phases. Results suggest that the adsorptive capacity of the regolith is important in controlling the state and distribution of high-latitude H_2O,unweathered mafic silicates favor the development of shallow ground ice at all temperate and polar latitudes, while heavily weathered clay-like regolith material leads to a deeper ground ice interface and far more extensive quantities of adsorbed H_2O. The capacity of the high-latitude regolith for storage of H_2O and the total mass of H_2O exchanged between the atmosphere, polar cap, and subsurface over an obliquity cycle is found to be relatively

independent of mineralogy. The maximum exchanged volume is found to be 3.0 x 10^4 km^3 of ice per cycle. Implications for the history of the polar caps and the origin of the layered terrain are discussed. Results also suggest that seasonal thermal waves act to force adsorbed H_2O into the solid phase over a wide variety of latitude/obliquity conditions. Seasonal phase cycling of regolith H_2O is most common at high latitudes and obliquities. Such phase behavior is highly dependent on regolith mineralogy. In a highly weathered regolith, adsorbed H_2O is annually forced into the solid phase at all latitudes $\geq 40°$ at obliquities greater than approximately 25°. Seasonal adsorption-freezing cycles which are predicted here may produce geomorphologic signatures not unlike those produced by terrestrial freeze-thaw cycles.

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THE WATER AND OTHER VOLATILES OF MARS

Fraser P. Fanale[1]

Some of the volatiles believed present on Mars, water in particular, are not adequately accounted for by what has been found in the atmosphere or on the surface. Water should be abundant on Mars and, in fact, the summertime residual (permanent) northern ice cap is known - on the basis of temperature - to be composed of water ice even though plated over with an extensive veneer of CO_2 frost part of the year. The southern ice cap differs by being too cold to be water ice once its own plate of winter CO_2 has sublimed, inferring that the residual cap is itself composed of frozen CO_2. However, there is reason to believe that the southern cap is a periodic rather than permanent feature, triggered by some as yet unknown phenomenon and sustained over a period of time by a self-preservation process. Layered terrain of ice and dust at both poles indicates a cyclic, climatic process over time, produced by large oscillations in Mars' obliquity and eccentricity – much as a similar but less pronounced cycle has produced glacial and interglacial periods on Earth. No other reservoirs of water ice have been detected on the surface of Mars to help explain where the predicted water might be, but Viking data include evidence for the probability that much of the missing water is in the

martian regolith - with the most significant amounts located poleward of latitudes ±50 degrees. Numerous features indicative of permafrost between those latitudes and the ±30 degrees latitudinal bands have also been identified. A variety of models have been developed to study the possible emplacement and distribution histories of water ice or the location of brines. It seems clear, in any case, that the dry martian surface almost certainly harbors significant amounts of water and other volatiles humans may one day need.

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POSSIBLE MARTIAN BRINES: RADAR OBSERVATIONS AND MODELS

Aaron P. Zent[1], Fraser Fanale[2], and Ladislav E. Roth[3]

The 1971 and 1973 Goldstone 12.6-cm radar observations of Mars are separate data sets which include reflectivity as a function of latitude, longitude, and season. It has been argued that secular reflectivity variations of Mars' surface are indicated by the data and that shallow subsurface melting is the causal mechanism most compatible with the observations; however, the melting hypothesis conflicts with accepted notions of the state and distribution of water on Mars. We examine the data to identify temporal and spatial domains within which statistically significant changes in measured reflectivity are clustered. A few reflectivity changes may be genuine; others may be due to ephemeris errors or binning during data reduction. Brines which might satisfy the best supported reflectivity variations are out of equilibrium with the chemical megaenvironment. It is unclear whether such a brine, if emplaced in the Martian regolith at a depth shallow enough to affect the radar reflectivity, could survive even a single freeze-thaw cycle. We suggest that some combination of unique scattering properties or some as yet unidentified process other than melting is responsible for any genuine reflectivity variations. © 1990 American Geophysical Union.

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POSSIBLE MARTIAN BRINES:
EQUILIBRIUM AND KINETIC CONSIDERATIONS

Aaron P. Zent[1] and Fraser P. Fanale[2]

We calculate the fate of postulated near surface brines on Mars. No stable brine system can exist on Mars today. The integrated H_2O flux from a subsurface H_2O reservoir is greater than zero at all latitudes where the highest recurring temperature exceeds the eutectic of chemically reasonable brines. Nonequilibrium brine systems or brine systems in dynamic equilibrium are possible. We calculate the rate of H_2O mass loss from subsurface brines as a function of latitude, depth, regolith porosity, eutectic temperature, and pore size. Some brines may exist in the near-equatorial subsurface of Mars for periods on the order of 10^7 years. Seasonally variable radar reflectivity of the Martian surface has been interpreted as indicative of melting of subsurface brines (Zisk and Mouginis-Mark, 1980). We present a model for a chemically reasonable brine that could reproduce radar results and estimate the escape rate of H_2O molecules from such a brine. The presence of a low-permeability duricrust may be required to preserve such a brine for reasonable periods and to prevent detection of an areally extensive subsurface system by the Viking MAWD instrument. A porosity no lower than 20-30% should suffice to reduce H_2O escape fluxes to the required rates. © 1986 American Geophysical Union.

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ATTACHMENT 8

STRAWMAN STRATEGY
TO EVALUATE PLANETARY PROTECTION COMPLIANCE
B. CLARK

Model of Forward Contamination

In spite of the intrinsic problems with any quantitative modeling of the probability of contamination (P_c), from a pragmatic standpoint it will be necessary to provide such a model in order to demonstrate compliance with policy and to evaluate the relative value of the various strategies that will be undertaken to reduce bioburden.

The model should take into account not only the level of biological organisms on the lander vehicle, but strategically selected attributes of various organisms. Suggested attributes include:

- heterotrophic (extremely low P_g on Mars),
- thermophilic (ditto),
- photoautotrophic (examine thermal limits and UV susceptibility),
- non-spore forming (low probability of surviving trip to Mars (but lyophilized specimens could survive at some probability < 1.0),
- psychrophilic (best P_g, but probably much lower D values for a selected thermal process),
- chemoautotrophic (e.g., sulfate reducers),
- and perhaps others.

The idea is that by one or more attributes, the residual population on a lander at launch can be classified into different groups each with a different N_i, P_{gi} and in some cases other factors (the *i* subscript refers to the ith group). The P_c is then summed over these groups to get the total. Hopefully, those groups with highest P_{gi} have other factors (such as number, thermal environment, etc.) which mitigate their effect on the overall contamination probability.

Although this modeling effort is somewhat involved, I believe it could be done almost totally analytically, with perhaps little or no expensive laboratory work. It could, however, help identify any major unknowns or assist in determining the sensitivity of P_c on various "sterilization" protocols. If lab work were found to be desirable, it could be a guide to those areas of investigations most critically affecting the final result (e.g., are there sporulating psychrophiles, or can chemoautotrophs be prevented from contaminating the lander in significant numbers?).

Sterilization Protocol

It seems extremely unlikely that MESUR could be flown without *some* special procedures relevant to sterilization. Even though we learned some pertinent new information from Viking, the project could be subject to the criticism that it was sacrificing the scientific future and ecological responsibility to an unwillingness to step up to the true cost of the mission. On the other hand, it is my conviction that if Viking-class sterilization were imposed on MESUR at the outset, a 10-20% increase in development costs could result. This is partly because MESUR is intended to be low cost compared to mega-projects such as Viking (MESUR has 16 landers and 1 orbiter for about one-fourth the cost of the 2 landers and 2 orbiters for Viking). MESUR will not have the same manpower infrastructure that Viking could afford. However, paperwork seems to have increased today over what it was during the Viking tenure (even though that project was in fact rather thoroughly overrun with documents).

A reasonable intermediate could be the following:

Divide the P_g into three bioburdens: bulk materials, mating interfaces, and free surface contamination (this is similar to the Viking approach). For all bulk materials and components, examine the manufacturing processes to establish whether the material is already free of internal contaminants. For example, metal alloys should be clean, except for surface cracks. Silicon chip components are manufactured under high temperatures, often utilizing toxic chemicals, UV light, and particulate-controlled conditions. On the other hand, epoxy formulations may be susceptible to microbial contamination. This includes printed circuit boards (e.g., G-10) and graphite epoxy (GrEp) structural materials. Such materials could be subjected to bulk heat sterilization prior to use or during incorporation into an assembly (note: GrEp is often processed in autoclaves). An example of when not to heat sterilize is after a printed circuit board has all its components installed (if wave soldering is employed, the board surface is probably sterilized by that process).

I specifically recommend that neither entire black boxes nor the entire lander be heat sterilized as a unit. These abnormally high temperatures cause large stresses upon all interconnections. Rather, the high-temperature (~125°C) heat treatments would be only to achieve reduction in bulk, embedded bioburdens.*

From this point on, surface decontamination would be the rule, using alcohol or other suitable disinfectants (component and environmentally-acceptable chemicals). As far as interfaces are concerned, they would be re-cleaned each time a re-mate was necessary (this tends to be

standard practice in many cases anyway). At the time of button-up of the spacecraft, a final surface disinfectant wipe would be performed and samples taken to verify that the surface bioburdens were indeed acceptable.

Also, a bioshield should be ruled out if at all possible. Rather, the launch vehicle's shroud interior and other internal items, such as support structure, should be subjected to surface decontamination to minimize the transfer of microorganisms to the landers prior to ejection. These transfers would presumably be surface-to-surface, with a suitably small and negligible probability that a microorganism could reach a fully occluded location. In addition, if deemed necessary from calculations performed with the model, the lander could be "toasted" in the solar UV on the route to Mars (note: this could prove difficult because of the spin-stabilization strategy). An alternative might be some type of "baggie" around the lander which burns off high in the martian atmosphere, but such an approach would add modeling problems all its own. In any event, eliminating bioshields would greatly simplify the approach.

If instrumentation for the detection of organics or life were ever flown on MESUR, or if a probe were targeted toward a then-discovered habitable zone (e.g., active volcanic caldera or fumerolic vent field) then it would be appropriate to consider augmented protection against survival of indigenous terrestrial organisms. However, these would be special cases that could easily justify the additional measures. In other words, for now the model should examine the joint probability of an undiscovered highly habitable area (oasis) and MESUR fortuitously landing there. This probability will be quite small, and therefore acceptable. This means that P_g for nominal MESUR landed missions should be based upon our general knowledge about Mars and not upon presumption or speculation about special, so-far unobserved favorable environments. The latter are special cases which need to be taken into account only if such environments are discovered and pinpointed mission landings become practicable.

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* I specifically do not agree that this "buys" reliability unless the unit or lander is extensively tested after the heat treatment. This could not be done on Viking and we essentially took a chance. The normal margin for thermal exposures beyond what is expected in the actual mission is 25°C; I suggest standing by this value. For bringing out the reliability of units, thermal cycling between a hot case and cold case, each with the above margin, is standard practice. Five to ten cycles is a good rule of thumb, and builds confidence without undue concern that the units are being stressed more than necessary. This relatively mild cycling, performed at high vacuum, might be sufficient to rid the units of embedded or occluded psychrophiles.

omit to End

ATTACHMENT 9

LISTS OF PANELISTS AND OTHER PARTICIPANTS

PANELISTS

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ATTACHMENT 10

AGENDA

AGENDA

Monday, June 3, 1991

8:15 am	REGISTRATION AND COFFEE	
8:30 am	Welcome & Purpose of Workshop	H.P. Klein
8:45 am	Overview of Current Planetary Protection Policy	D.L. DeVincenzi
9:15 am	History of P_g	H.P. Klein
9:45 am	Past Implementation of Planetary Protection Policy	L. Daspit
10:15 am	COFFEE BREAK	
10:30 am	Mars: Physical Properties	R. Haberle
11:45 am	LUNCH BREAK	
1:00 pm	Mars: Chemical Properties	B. Clark
2:00 pm	Mars: Where is the Water?	F. Fanale
3:00 pm	COFFEE BREAK	

3:15 pm   Discussion Session I:
               • Preliminary Assessment of the Growth
                 of Terrestrial Microbes on Mars

5:15 pm   ADJOURN

6:30 pm   COCKTAILS AND DINNER
                ROYAL PALACE CHINESE RESTAURANT

Tuesday, June 4, 1991

8:15 am   COFFEE

8:30 am   Discussion Session II:
               • Develop Workshop Position(s) on P_g
               • Make Writing Assignments

9:30 am   BREAK

9:45 am   Participants Prepare Documentation

11:45 am   LUNCH BREAK

1:00 pm   Summary Session:
               • Review Documentation
               • Prepare Final Workshop Recommendations

3:00 pm   ADJOURN

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13. ABSTRACT (Maximum 200 words)

This is a report of a workshop, "Planetary Protection Issues for the MESUR Mission: Probability of Growth (Pg)," held in Palo Alto, California on June 3-4, 1991. The purpose of the workshop was to re-evaluate the existing guidelines for the probability of growth of terrestrial organisms on Mars that were established by the National Academy of Sciences following the Viking mission. A panel of specialists in microbiology and allied fields reviewed this issue in the light of current information about the physical and chemical environments expected on Mars. Their deliberations resulted in the virtually unanimous conclusion that the existing Pg guidelines were either appropriate or that the values for Pg should be further reduced. Individual assessments of this problem by each of the participants, together with those of additional invited experts, are included as part of this report.

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