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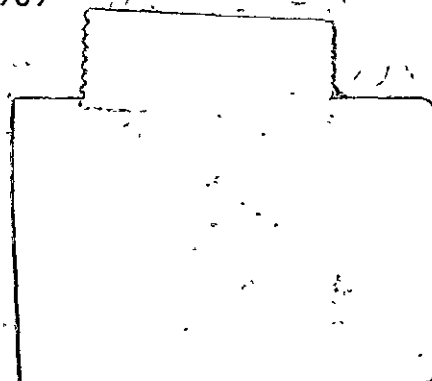
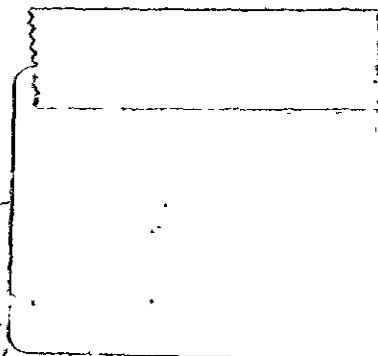
VIKING PROJECT

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INSTRUMENT TEAMS REPORT (NASA) 85 p

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VIKING
LANDER SCIENCE INSTRUMENT TEAMS REPORT
July 30, 1969



Prepared by the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Langley Research Center

Viking Project Office

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VIKING
LANDER SCIENCE INSTRUMENT TEAMS REPORT
JULY 30, 1969

Approved for
distribution by

A handwritten signature in dark ink, appearing to read "J. S. Martin, Jr.", written over a horizontal line.

James S. Martin, Jr.
Project Manager

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1.0 PREFACE

The purpose of this document is to present the science reports prepared by each of the Viking Science Instrument Teams for use in developing Viking Mission Definition No. 2 (M73-101-5). This document is to serve as a reference document and is a valuable source of detail information not included in Mission Definition No. 2.

2.0 INTRODUCTION

The Viking Missions are directed toward the exploration of the planet Mars, using two automated spacecraft each consisting of an orbiter and a lander. These missions are the first opportunities to make direct measurements in the atmosphere and on the surface of Mars.

In October, 1968, the NASA issued a Solicitation for the Participation of Scientists in the early Viking planning activities. Based on responses to this solicitation, the NASA selected Science Instrument Teams to participate in the science definition and early instrument development activities of the Viking Project. These teams selected in February 1969 are:

Entry

Alfred O. C. Nier*
Alvin Seiff
Michael McElroy
Nelson W. Spencer

Imagery

Thomas Mutch*
Alan B. Binder
Elliot C. Levinthal
Elliot C. Morris
Carl Sagan

Meteorology

Seymour L. Hess*
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Charles W. Hord
Jeffrey B. Pearce

Each Viking Science Instrument Team is involved in the planning and instrument development activity in the team's specific science area. The leaders of each of the Science Instrument Teams compose the Viking Science Steering Group, which is involved in the integrated science planning for the Viking Project.

The Science Instrument Teams have prepared a science report for their area of responsibility. These science reports are the substance of this document. The total science defined in this document are in excess of the Viking System capabilities as presently defined, and required action by the Viking Science Steering Group to define an integrated science payload within these anticipated capabilities. See Section 3.0 for Science Steering Group action.

The NASA issued an "Announcement of Flight Opportunity" (AFO) for the Viking Missions on July 15, 1969. The Investigators will be selected in December 1969. The Viking Mission Definition No. 2 (M73-101-5) and this document are further guides and references that can be used in responding to the AFO.

3.0 VIKING SCIENCE STEERING GROUP ACTION

The Viking Science Steering Group has been primarily involved in the integrated lander science planning. The objective of this planning activity has been to develop the science requirements to be used by the Viking Project Office for preliminary design purposes and in contract negotiations with the prime contractor. The task of the Science Steering Group was to develop science requirements based on the reports of the Science Instrument Teams and within the engineering constraints of the Viking system. The present science payload weight budget is 125 pounds for the orbiter-science and approximately 70 pounds for the lander science. It is possible to interchange lander and orbiter science weight. The Steering Group unanimously passed the following resolution during the July 17-18, 1969, Science Steering Group Meeting:

"It is the recommendation of the Viking Steering Group that a science payload, comparable with the 90 pound example discussed at the July 17-18, 1969, meeting at Langley, be considered as the requirement for the Viking scientific mission. A number of important additional goals have been identified, in case a larger payload is possible. At the request of the Viking Project Office, and for its guidance, a 70 pound payload was identified at the July meeting as a possible fall-back position."

The 90 pound payload referenced in the resolution is given below and the 70 pound payload is presented in Viking Mission Definition No. 2, M73-101-5.

<u>SCIENCE AREA</u>	<u>WEIGHT (lbs.)</u>
ENTRY	
Atmospheric Composition	18.7
Atmospheric Structure	2.0
LANDER	
Imagery	18.0
Biology	12.0
Organic Analysis	22.0
Soil Water	3.0
Meteorology	7.5
Radio	2.5
Seismometry	2.7
UV Photometry	2.9

The Steering Group recommended including a non-ablative aeroshell nose cap if an additional weight capability is available.

It should be noted that the weights given above include system weight difference that would be required to modify the lander as proposed by the Martin Marietta Corporation, based on Mission Definition No. 1 (M73-101-3). The total systems weight increase is 8.9 pounds.

4.0 SCIENTIFIC OBJECTIVES

The general objective of the Viking missions is to obtain scientific data which will significantly increase our knowledge of Mars with particular emphasis on providing information relevant to life on the planet.

The detailed objectives to be accomplished in satisfying the general objective for the Entry and Landed science are:

4.1 Entry

Determine the atmospheric structure and composition

4.2 Landed

- . Visually characterize the landing site
- . Search for evidence of living organisms
- . Search for and characterize organic compounds
- . Determine the amount and nature of water in the surface material
- . Determine the atmospheric composition and its temporal variations.
- . Determine the temporal variations of atmospheric temperature, pressure, wind velocity, and water vapor
- . Determine the seismological characteristics of the planet
- . Determine the UV radiation at the surface
- . Conduct scientific investigations using the lander radio and radar systems

For information on the detailed objectives of the orbiter, refer to Mission Definition No. 2 (M73-101-5).

5.0 ENTRY SCIENCE INSTRUMENT TEAM REPORT

This is the unabridged Science Definition Report of the Viking Entry Science Instrument Team. The Team members are:

Alfred O. C. Nier (Leader)

Nelson W. Spencer

Alvin Seiff

Michael McElroy

ENTRY SCIENCE DEFINITION NO. 2

I. Science Objectives

The purpose of the entry science is to obtain direct measurements which elucidate the physical and chemical state of the Martian atmosphere. Measurements are required to define the atmospheric composition and structure as functions of altitude. In addition, it is a goal to determine density and energy distribution of electrons in the upper atmosphere.

II. Science Rationale

The overall objective of the entry science is to define the present physical and chemical state of the Martian atmosphere. Not only will this information define the biological environment, it will also provide important input data on matters related to the evolution of the atmosphere and enhance our understanding of geophysical and meteorological phenomena in general. The following paragraphs elucidate some of the key scientific questions to which the entry measurements should be directed.

The Martian ionosphere may differ significantly from the terrestrial ionosphere since Mars has a trivial permanent magnetic field. The structure of the ionosphere may be determined in large measure by interactions between planetary ions and the solar wind. If such is the case, momentum transfer between planetary ions and the solar wind could represent a dominant mode for atmospheric escape. This escape would differ in at least one important respect from thermal (Jeans) escape - it would allow for escape of heavier gases with comparative ease. Measurements of neutral composition, ionic composition, and electron temperatures in the atmosphere above 100 km would clarify the physical conditions. The necessary measurements will not be obtained in any mission contemplated prior to Viking.

The photochemistry of CO_2 is a second area which should be studied. It is known that CO_2 is dissociated by ultraviolet sunlight and, under laboratory conditions, recombination can proceed very slowly. It is difficult therefore to understand the apparent stability of a predominantly CO_2 atmosphere. The solution may involve atmospheric chemistry, mass transport processes, and, conceivably, surface chemistry, perhaps with biological overtones. Height profiles of CO_2 , CO , O_2 , and O would clarify the actual situation.

Measurements of temperature, pressure, and wind in the lower atmosphere (below 100 km) would have important meteorological implications. Temperature measurements with spatial resolution of better than 5 km could reveal the presence of wave motions associated, for example, with tidal oscillations driven by the diurnal heat cycle. Measurements of horizontal winds as a function of height provide indirect data on the horizontal temperature gradients. Measurements of the vertical wind are relevant to studies of dust storms, and would aid in work related to at least one class of clouds

observed in the Martian atmosphere. Clearly, identification and classification of the several cloud types observed would be of great importance.

We consider it important to determine the presence and quantity of all gases with possible biological relevance - for example, O_2 , O_3 , and H_2O . Such data could clarify such questions as: Is the observed O_2 of biological or photochemical origin? If the latter were the case, an altitude profile could reveal a downward transport of gas. It is important that these data include altitude profiles which include the region of the atmosphere above the altitude of parachute deployment for the composition cannot be considered constant throughout the "mixed" atmosphere. It is to be noted, for example, that if measurements in the Earth's atmosphere were confined to the first 5 or 10 kilometers, they would ignore such obviously important facts as the O_3 layer and the associated thermal inversion.

Finally, we emphasize the obvious need to identify the mole fraction altitude profile of all abundant gases in the atmosphere. The altitude distribution of permanent gases such as N_2 , He, and A offer important insights into matters related to mass transport - for example, the relative roles of eddy transport and diffusive flow (the extent of the homosphere). It is worth recalling that, although the location of the turbopause has been defined empirically with some precision for the Earth, the physical processes which determine it are as yet elusive. It is not unlikely that the terrestrial situation will remain problematical until the opportunity arises to study similar phenomena on other planets such as Mars and Venus.

III. Recommended Measurements* and Purpose

1. Mass Analyses of Neutral Species

Atmospheric composition and abundance - biological implications - planetary evolution

2. Mass Analyses of Ions

Ionospheric physics and chemistry - planetary evolution - meteor debris

3. Electron Temperature and Density

Ionospheric physics and chemistry - planetary evolution

4. Optical Spectrometer Analyses of Lower Atmosphere

Atmospheric composition and abundance

5. Optical Transmission at Selected Wavelengths

Atmospheric composition and abundance - clouds

*Profiles unless otherwise stated.

6. Atmospheric Density, Pressure, and Temperature in the Lower Atmosphere

Atmospheric structure and dynamics

7. Vertical Distribution of Water in Lower Atmosphere

Biology and atmospheric physics

8. Vertical and Horizontal Winds at Low Altitudes

Dynamics of atmosphere

IV. Candidate Instruments and Specifications (The entries in this table correspond item by item to those in Section III.)

<u>Candidate instrument</u>	<u>Wt., lb</u>	<u>Dimen., in.</u>	<u>Power, W</u>	<u>Data rate, bits/sec</u>	<u>Mission phase</u>
1. Neutral mass spec. (a) closed with leak	10	$10 \times 8 \times 4$	7 to 12	200 ⁽¹⁾	$p_s > 0.1$ mb ($z \approx 100$ km) to retro-rocket firing
(b) open ion source ⁽³⁾	9	$10 \times 8 \times 4$	7 to 12	120 ⁽²⁾	$p < 10^{-4}$ mb
2. Ion mass spec. ⁽⁴⁾	$3-1/2$ ⁽⁵⁾	$4 \times 4-1/4 \times 9-1/4$	1	120 ⁽²⁾	$p < 10^{-4}$ mb
3. Langmuir probe	1	25 in^3	1	48 ⁽⁶⁾	$z > 70$ km
4. Optical spectrometer	2	$10 \times 3 \times 1-3/4$	0.5 cont. 2 during glow discharge 3.5 during calibration	84 ⁽⁹⁾	$1.5 \text{ km} < z < 80 \text{ km}$ ⁽⁸⁾
5. Multichannel radiometer (cloud detection experiment)	0.5	10 in^3	1 (3w. for 3 sec. calibration)	21	$5 \text{ km} < z < 30 \text{ km}$ $V < 2 \text{ km/sec}$

<u>Candidate instrument</u>	<u>Wt., lb</u>	<u>Dimen., in.</u>	<u>Power, W</u>	<u>Data rate, bits/sec</u>	<u>Mission phase</u>
6. Accelerometers	2	30 in ³	5	50	$a_x > 0.03$ m/sec ² to ground touch- down
Pressure sensors	1-1/2	3[3 × 4 × 3/4]	3	21	$p_s = 1$ mb to touchdown ($z \approx 100$ km)
Temperature sensors	2 × 1/2 1# total	32 in ³	<1 watt	16	Mach No. <4 Aeroshell, parachute and retro-rocket
7. (a) Dual channel IR radiometer	<1	2 × 2 × 4	1 watt 3 during cal- ibration	8	Flight path angle >12° (1 < z < 28 km)
(b) Hygroscope chemical or dewpoint detector		Awaiting development and demonstration of feasibility			
8. Doppler radar	0 ⁽¹²⁾	0 ⁽¹²⁾	0 ⁽¹²⁾	24	Parachute
Accelerometers,	0 ⁽¹³⁾	0 ⁽¹³⁾	0 ⁽¹³⁾	0 ⁽¹³⁾	
Pressure sensors					Aeroshell Parachute
Temperature sensors					
Gyroscopes	0 ⁽¹²⁾	0 ⁽¹²⁾	0 ⁽¹²⁾	0 ⁽¹²⁾	Aeroshell Parachute Retro-rocket

IV. Candidate Instruments and Specifications (Concluded)

<u>Instrument range</u>	<u>Accuracy required</u>	<u>Special requirements</u>
1. Masses 1 to 140 Dyn. range 10^6	Partial pressures within resolution ⁽¹⁰⁾ 5% for $x_i > 10\%$ and 10% for $x_i > 1\%$ but $< 10\%$	Through-flow atm. . sampling system with inlet on vehicle front face. Beryl- lium nose cap; measure p_s independently. Close at retrofire and reopen at ground.
$1 < m < 50$ Dyn. range 10^6	Partial pressures within resolution ⁽¹⁰⁾ 5% for $x_i > 10\%$ and 10% for $x_i > 1\%$ but $< 10\%$	Blow off seal after separation from orbiter. Ion source outside aeroshell, on vehicle front face.
2. 2.0 to 10^6 ions/cm ³ Masses 1 to 50	Relative number density within 10%, resolution ⁽⁵⁾	Ion port on vehicle front face mag. field < 1 gauss.
3. 10 to 10^6 ions/cm ³ $200^\circ \text{K} < T <$ $10,000^\circ \text{K}$	?	Sensor projects from aeroshell in forward direction, burns off during entry.
4. 3000-5000 Å 10 Å resolution, 10^{-7} to 10^{-10} amp at detector	Signal intensity within 6%	Through-flow atm. sampling system with inlet on vehicle front face. Beryllium nose cap ⁽⁷⁾ . 4200 bits of buffer storage.
5. $\lambda = 3500$ -5000 7000 Å, 100 Å bandpass	Intensities within 5%	Aft facing, calibrate before entry.

<u>Instrument range</u>	<u>Accuracy required</u>	<u>Special requirements</u>
6. High range axial Low range axial Lateral axial	0-150 ± 0.15 m/sec ² 0-6 ± 0.006 m/sec ² ± 10 m/sec ² ± 0.01 m/sec ²	Landed altitude must be known within 1 km. Sustain large overloads without loss of accuracy. High range axial accelerometer has test mass of vehicle c.g. Need $\ddot{p}, \ddot{\alpha}$ and $\ddot{\beta}, \ddot{\alpha}$ and $\ddot{\beta}$ or keep small, 3-axis readout within 1 m/sec.
$p_s = 1$ to 200 mb	2% of reading	Ported to vehicle surface < 0.1 sec lag time to pressure equilibrium. Simultaneous reading within 1 ms. Sensors must operate through all mission phases to ground.
100° K to 1000° K	1° at 250° K	Deploy at M = 4. Retain at aeroshell separation. Locate along vehicle sides near base.
7. $\lambda_1 = 1.385$ $\lambda_2 = 1.404$ $\Delta\lambda = 0.01$ 10^{-3} to 10^{-5} w/cm ² st. μ	Diff. in intensities of 2 channels within 5%	1. Window in vehicle nose 2. Nonablative nose cap 3. Detector T < 300° K 4. Alinement parallel to vehicle axis 5. α, β known within 0.1°
8. 0.1 to 200 m/sec	0.1 m/sec	Onboard data processing. Direction of velocity must be known relative to plane of entry.
Same as item 6. $\dot{\alpha}, \dot{\beta}$? $\alpha, \beta \pm 5^\circ$	Same as item 6. ? $\pm 0.1^\circ$	$C_D A$ to parachute within 3%. Onboard data processing. Both angles and rates needed.

FOOTNOTES

1. 1 scan in 2 sec. 25 peak/scan 16 bits/peak.
2. 1 scan in 2 sec. 15 peak/scan 16 bits/peak.
3. Development of a combined instrument to serve both phases of flight is strongly recommended. Total weight might then be limited to 12 lb.
4. Development of a combined instrument for items 1(a) and (b) and (2) should be explored.
5. Resolution 20. Higher resolution may demand larger weight.
6. Assumes one voltage sweep/sec and 6 points on current-voltage curve to 8-bit accuracy.
7. Perhaps a common inlet system with mass spectrometer inlet.
8. From flow initiation to retro-fire.
9. 200 frequency bands, 10^8 Å wide, scanned at 50-second intervals with 3 detectors, 7-bit words.
10. Interference of adjacent masses at mass 50 $< 1/300$; at 2 mass numbers removed $< 1/3000$ at mass 50.
11. Interference of adjacent masses at mass 50 $< 1/100$.
12. This instrument is needed in landing guidance system and is not chargeable to this measurement.
13. Same instruments as listed in item 6.

6.0 BIOLOGY SCIENCE INSTRUMENT TEAM REPORT

This is the unabridged Science Definition Report of the Viking Biology Science Instrument Team. The Team members are:

Wolf Vishniac (Leader)

Joshua Lederberg

Norman H. Horowitz

Alexander Rich

Vance I. Oyama

Gilbert V. Levin

VIKING SCIENCE DEFINITION NO. 2

Active Biology Experiment

Introduction

This document is an attempt to synthesize several types of biological investigations in a manner to permit their performance in an integrated package. It is subject to modification which may result either from engineering evaluations or from scientific considerations as a result of Mariner VI and VII results.

The examination of the Martian surface for living organisms is based on the following approaches: Visual imagery, atmospheric analysis, chemical composition of the surface, biochemical activity, and enumeration of active particles. In this context visual images represent a high risk -- high gain observation, in the sense that the detection of what is unmistakably a living organism would be highly conclusive, while the absence of such an observation provides the biologist with no direct information on the presence or absence of living organisms, though it contributes to his understanding of the environment. The detection of traces of certain gases in the course of atmospheric analysis may suggest, though not prove conclusively, the presence of living organisms, in particular if diurnal or seasonal variations should be observed. The gases that would be of interest here are those that are described below under Gas Analysis. The study of the chemical composition of the Martian surface has the advantage of providing information independent of the presence or absence of living organisms, but the disadvantage that the presence of organic compounds may be suggestive, but never conclusive, evidence for biological activity. The observation of biochemical activity has the advantage of being independent of the growth of organisms that may be present, although growth would naturally enhance any activity observed, but the disadvantage that such observations may conceivably be based on too geocentric a design. Furthermore, a low rate of changes may in some instances suggest the role of non-biological rather than biological catalysis. The observation of an increase in particles in suspension has the advantage of providing an independent physical measurement which would support the chemical observations, but the disadvantage that it is strictly dependent on growth and can be carried out only in an aqueous medium.

After describing several types of measurements that can be conducted, an integrated instrument is proposed which combines several of the measurements described, and the directions in which the capability of such an instrument could be expanded should weight and power considerations make such an expansion possible is indicated.

General Scientific Objectives

1. At the time of the first examination of the surface of Mars the structure of the experiments must be based on an unavoidable minimum of geocentric assumptions. It is assumed that, should living organisms exist

on Mars, their biochemistry is based on carbon and water. While alternative assumptions are experimentally approachable, they are inappropriate for a first mission.

2. Measurements must be carried out more than twice. The strategies applicable to different capabilities of repeating observations is described later.

3. It is more important to repeat experiments in time rather than in space. That is, if experimental capability is severely restricted, it is preferable to study a single sample site repeatedly, hopefully in the course of seasonal variation, rather than examining many sample sites a single time within a short period.

4. It is more important to examine a single sample by different principles, rather than carry out a sample examination with refined variations of a single principle, assuming all other constraints to be equal.

5. The sensitivity of an observation should be directed primarily at the detection of any life. The characterization of such life is at present of secondary importance.

6. In general experimental conditions should be close to the conditions of the Martian environment, except that a variation in water content is contemplated, on the assumption that water may be one of the most important limiting factors for life on Mars.

7. The observations chosen should complement each other in such a manner as to confirm results and minimize ambiguities.

8. Stress has been laid on the formation or fixation of carbon dioxide. This stress results partially from the present view of the composition of the Martian atmosphere, and partly from the geocentric assumptions made. Each experiment which describes the fixation or evolution of carbon dioxide is intended to include at the same time carbon monoxide in the same proportion in which it exists in the Martian atmosphere. At a lower priority hydrogen sulfide may also be considered in such experiments.

9. The integrated package must withstand terminal sterilization. No sterile insertion of medium or other components is contemplated.

Sampling

The biological interest is centered on samples taken from approximately the top three centimeters. The instrument is designed to examine a mixture of the top three centimeters. In the event that the sampling device is capable of reaching down several tens of centimeters, it is required that the top three centimeters be examined separately. Should such a deep sample be available, it may be desirable to examine it separately, but in no case should it be mixed with the surface layers.

The type of sample most useful for biological examination is loosely divided soil. Pebbles of one centimeter in diameter, or larger, are unlikely to give useful data. Particles up to two millimeters in size are ideal for the investigations. It is preferable to have the soil sample undergo as little mechanical processing as possible. It is recognized that a minimum of manipulation and processing may very well have to take place. In any event, the processing should not raise the temperature of the soil sample above the maximum Martian temperature for any appreciable length of time. Forty degrees centigrade for a few seconds may be tolerable, but not desirable. Fifty degrees centigrade is excluded.

Optional Type of Sampling

In the absence of an immediate prospect for in situ examinations, consideration may be given to the injection of a mixture of organic compounds into a selected and identifiable site. Conceivably such a procedure may lead to a local enrichment of micro-organisms, and a sample taken from this identified site after a period of weeks may contain a higher number of living organisms. This technique has been successful in the accumulation of certain rare terrestrial organisms.

Specific Experimental Objectives

The following investigations have been considered in arriving at an integrated instrument package.

1. Photosynthetic and respiratory fixation of carbon dioxide

The ecological basis of life in all environments is photosynthesis. It is therefore to be expected that carbon dioxide will be incorporated into organic matter by at least one Martian species in the light. In addition it is plausible, though not necessary, that some respiratory fixation of carbon dioxide may occur, corresponding to the heterotrophic carbon dioxide fixation on Earth.

A soil sample, either as dry as ambient conditions make it or slightly humidified by exposure to water vapor, is incubated under a mixture of labeled carbon dioxide and carbon monoxide in the approximate proportions in which these gases occur in the Martian atmosphere. The absolute pressure should be maintained near Martian ambient pressure. If an overpressure is required to implement the investigation, this overpressure should not exceed one additional Martian atmosphere. The sample is illuminated with ambient light or artificial light that approaches Martian intensity and spectral distribution.

After an incubation period of one or more diurnal cycles the sample is heated to 600° C and the volatile pyrolysis products are flushed into a chromatographic column which retains organic compounds but not carbon dioxide which is thus eliminated. A subsequent increase in the temperature of this column to 700-800° C releases the organic compounds and at the same time causes them to be oxidized to carbon dioxide, in which form they can be introduced

into a counter for a determination of radioactivity. The radioactivity so indicated is derived from the labeled carbon dioxide which was incorporated into organic matter.

2. Respiratory* carbon dioxide fixation

Assuming a metabolism in which carbon dioxide is a starting product for photosynthesis and an end product of respiration, it is plausible that some carbon dioxide is also fixed during respiration - an analogy with terrestrial examples. In a significant variation of the first described experiment, a Martian soil sample is moistened with a solution containing selected organic compounds and incubated in an atmosphere of labeled carbon dioxide and carbon monoxide. The introduction of organic compounds serves to stimulate respiration, although the nature of such stimulation is not understood even in terrestrial soils. It is known-however, that terrestrial soils show an increased respiratory activity upon the addition of organic compounds, even long before significant portions of the organic substrates have been oxidized. After some period of incubation, the soil sample, or an extract of it, is freed of water and residual labeled carbon dioxide. This sample or extract is then pyrolyzed as in the first described experiment to determine the radioactivity incorporated in the organic compounds.

3. Carbon dioxide released from previously fixed carbon dioxide

This investigation is dependent on the respiratory release of carbon dioxide which has previously been fixed either during photosynthesis or during respiration. It has the advantage that no assumption needs to be made about the nature of the endogenous storage product, and that it gives an insight into the kinetics of the process observed if measurable amounts of labeled carbon dioxide are released, but it suffers from the disadvantage that it is of necessity less sensitive (since only a portion of the fixed carbon dioxide is so released) and, that instead of depending on a single biological process, it depends on the sequential occurrence of two biological processes. A Martian soil sample is incubated as described under experiment 1 or under experiment 2 to allow for the fixation of radioactive carbon dioxide. At the end of the incubation period the sample is flushed with nonradioactive carbon dioxide or, if necessary, the excess carbon dioxide is "gettered". From this point the release of radioactive carbon dioxide in the dark is measured as a function of time. Terrestrial analogies for this observation can be found either in the respiratory release of carbon dioxide in the dark from algae that have previously carried out photosynthesis in the light, or in the respiration of organisms which have accumulated radioactive storage products.

* "Respiration" is used here in the strict sense, release of energy within the cell, that is, non-photosynthetic electron transport to an acceptor which need not be free

4.. Carbon dioxide release from added labeled organic compounds

This observation depends on the decomposition of one of a selected number of radioactive organic compounds, and the likelihood that one of such decomposition products will be carbon dioxide. It can be improved by simultaneous monitoring for the release of other volatile carbon products, such as methane, or hydrogen sulfide from labeled sulfur containing organic compounds. The soil sample is moistened with a solution containing a mixture of carbon 14 (and possibly sulfur 35)-labeled organic compounds and it is incubated. The release of radioactive carbon dioxide (and/or hydrogen sulfide) is therefore strongly suggestive of a fermentative capacity of indigenous microorganisms.

5. Light scattering as a measure of increase in particles

This approach is intended to observe an increase in microorganisms by independent physical measurement which in turn can support the observations of chemical changes. A liquid sample can be obtained either by the extraction of a soil sample with water, by extraction with a solution of organic compounds, or by the introduction of a small soil sample into a liquid medium. Light scattering must be of sufficient sensitivity to detect a change in 10^3 to 10^4 particles (1/2 micron latex spheres and *E. coli* K-12 to be used for calibration) per cm^3 . Unlike the preceding observations, this method depends on growth and on the use of an aqueous medium which is unlikely to be familiar to the Martian environment.

6. Gas exchange

The metabolism of microorganisms in Martian soil may lead to the formation of gases other than carbon dioxide or carbon monoxide. A soil sample, wet or dry, with or without added organic compounds, is therefore monitored periodically for the changes of gases which may take place in the headspace above it. Of particular biological interest would be analysis for the following gases: carbon dioxide, carbon monoxide, hydrogen sulfide, hydrogen, hydrogen cyanide, nitrogen, oxides of nitrogen, ammonia, oxygen, and methane. While it is not required that all of these gases be detected a simultaneous monitoring of several of them is desirable especially those which are not detected in other observations, i.e. not CO_2 and CO. Gas analyses should have a sensitivity of 10 nanomoles for each of the gases mentioned. The accuracy of the gas analysis must be capable of distinguishing changes in concentration of 1 percent within each decade of concentration.

General Experimental Requirements

Samples must be incubated at $10 \pm 5^\circ \text{C}$. The integrated instrument package must have access to Martian daylight and to ambient atmosphere as required. It must be possible to control the partial pressure of water as required. Within the spacecraft environments it must be possible to detect radiation from ^{14}C or ^{35}S at 50 cpm above background.

Experiment Selection and Sequence of Operation

Subject to engineering constraints, the integrated instrument package will combine investigations 1, 3, 4, and 5 as described under Scientific Experimental Objectives. As a minimum the package requires the analysis of three different soil samples by the entire combination of experiments. If not more than three sets of measurements can be performed, then the first set will be initiated soon after landing with a sample from a selected sampling site. In accordance with one of the principles outlined in the introduction, the remaining two sets of measurements would then be performed before and after the wave of darkening. A more detailed analysis of imagery of the area which is accessible to the sampler may result in the selection of a sampling site more desirable than the initially selected site. A sample from such a site would then be used to initiate the second set of measurements and a sample from the same site would initiate the third set after the wave of darkening.

If the integrated instrument package possesses the capability to perform more than three sets of measurements, the strategy becomes as follows. If all sampling sites look alike, one set of measurements is initiated soon after landing, and the others from the same sampling site, after varying periods such as two weeks, one month, and two months. Should the instrument be capable of performing as many as seven sets of measurements, then consideration may be given to examining two different sampling sites. These sites could be either two locations that appear visually different or two different depths from the same location. Thus the first set of measurements would again be initiated soon after landing, half the remaining ones at various time intervals with samples from one sampling site, and the other half, during the same time interval, with a sample from the other sampling site.

Additional Technical and Scientific Considerations

It is instructive to examine the chosen investigations from additional points of view. Experiment I is a "one-shot" experiment. It is an experiment in which an arbitrary period of incubation is allowed after which the amount of carbon dioxide which has been fixed is determined. It would require a large number of instrument modules containing experiment I to obtain kinetic data on the time course of fixation. Experiment 3 may yield kinetic data. Although the initial period of incubation again is fixed, the rate of CO₂ release in the dark can give kinetic data on respiration or fermentation if this release of radioactive carbon dioxide can be monitored on a continuous basis. Experiment 4 is also capable of yielding kinetic data only if the amount of labeled carbon dioxide released can be monitored on a continuous basis. Experiments 5 and 6 are specifically designed for measuring the time course of events. Experiment 5 is a non-destructive measurement which can be carried out on a continuous basis, while experiment 6 is intended for the analysis of a series of gas samples and can provide a series of values as a function of time.

The interpretation of the data can be strongly dependent on whether or not kinetic data are available. From this point alone, a large number of modules with opportunity for frequent repetitions of measurements is highly desirable,

at least for those experiments which do not, by their very nature, measure the time course of events.

The addition of organic compounds is subject to two considerations. The compounds chosen must be compatible with sterilization requirements, since aseptic insertion is specifically ruled out (good candidates are salts of fatty acids, some 4-carbon dicarboxylic acids, lactic acid, and glycerol). It is recognized that all organic compounds undergo some changes upon heating if either the temperature is high enough or the period of sterilization is prolonged. In terrestrial experience such changes for the most part do not significantly influence the growth of microorganisms, except for a few notable instances. The choice of organic compounds represents a strong geocentric influence if such compounds should be too specific for specialized metabolic processes. Two-carbon compounds, such as glycine, acetate glycol and ethanol are probably good candidates for useful substrates consumable by any organism whose biochemistry is based on carbon and water. In any event, variety, stability, and simplicity must be the guiding principles. Experiment 4 is specifically dependent on the addition of nutrients, and experiment 5 may benefit but is not necessarily dependent on them.

The sample sizes for the experiments require generally fractions of one gram. One to several grams per sample should therefore be ample to satisfy the entire integrated instrument package. Experiments in which the moisture is raised above ambient Martian moisture must be pressurized with respect to the Martian atmosphere. A 20-50 percent over-pressure either with Martian atmosphere or with an inert gas, such as helium, is certainly sufficient. Other noble gases should not be used, since they are known to exert toxic effects on terrestrial organisms. While as a rule it is preferable to maintain pressures near Martian ambient pressure, it is hard to envisage ill effects as the result high pressure. Terrestrial microorganisms do not seem to be affected until atmospheric pressure exceeds normal pressure by some three orders of magnitude.

Since illumination should resemble Martian sunlight, a quartz fiber light pipe could conduct light to the incubation chamber and thus preserve both the intensity and the spectral range which reaches the Martian surface. There is, of course, no way of telling that this is either necessary or desirable. On the other hand, microorganisms buried in the sample would be exposed to lower light intensities and, because of selective scattering, be exposed to disproportionately less ultraviolet radiation. A light pipe can provide illumination for only part of the day, and it is therefore useful to consider the requirements that artificial illumination would have to meet to extend "day light" for longer periods of time.

Ancillary Measurements and Information Provided By Other Viking Instruments

The biological examination of the surface of Mars is to some extent dependent on imaging (sample selection site), analysis of the atmosphere, and data which may be provided by the Molecular Analysis Team's Instrument. Data on the nature of the immediate environment are also required, such as diurnal

temperature variations, water content of the atmosphere and its diurnal variation, variation of the temperature with depth at least as deep as the sample reaches. The nature of the soil in terms of porosity, compressability, and transparency, while not essential, would provide valuable ecological information. Meteorological information may contribute to our knowledge of the distribution of Martian microorganisms, should they exist in the surface layers of the soil. Within the integrated instrument package itself it is required to monitor the temperature of the incubation chambers and the light intensity which reaches them through the light pipe. It is also required that the Molecular Analysis Team's Instrument examine samples from the same site from which samples for the biological observations are obtained.

Instrument Configuration

Subject to engineering constraints imposed by the mission, the integrated instrument package will contain a combination of the previously described experiments in accordance with the priority guidelines presented. The total instrument weight will be constrained to a near 10 pound requirement. The volume of the package will be approximately 700 cubic inches with a maximum dimension of 10 inches. Power Consumption of the instrument will be as follows:

- A. Peak Power - 30 watts for 3 to 4 minutes
- B. Average Power - 5 watts
- C. Standby or Steady Power - 2 watts

It should be noted that if artificial light rather than a "light pipe" is used to provide illumination for photosynthesis, the power requirements would increase, however weight might decrease. Data output from the instrument will be approximately 10^3 data bits per day.

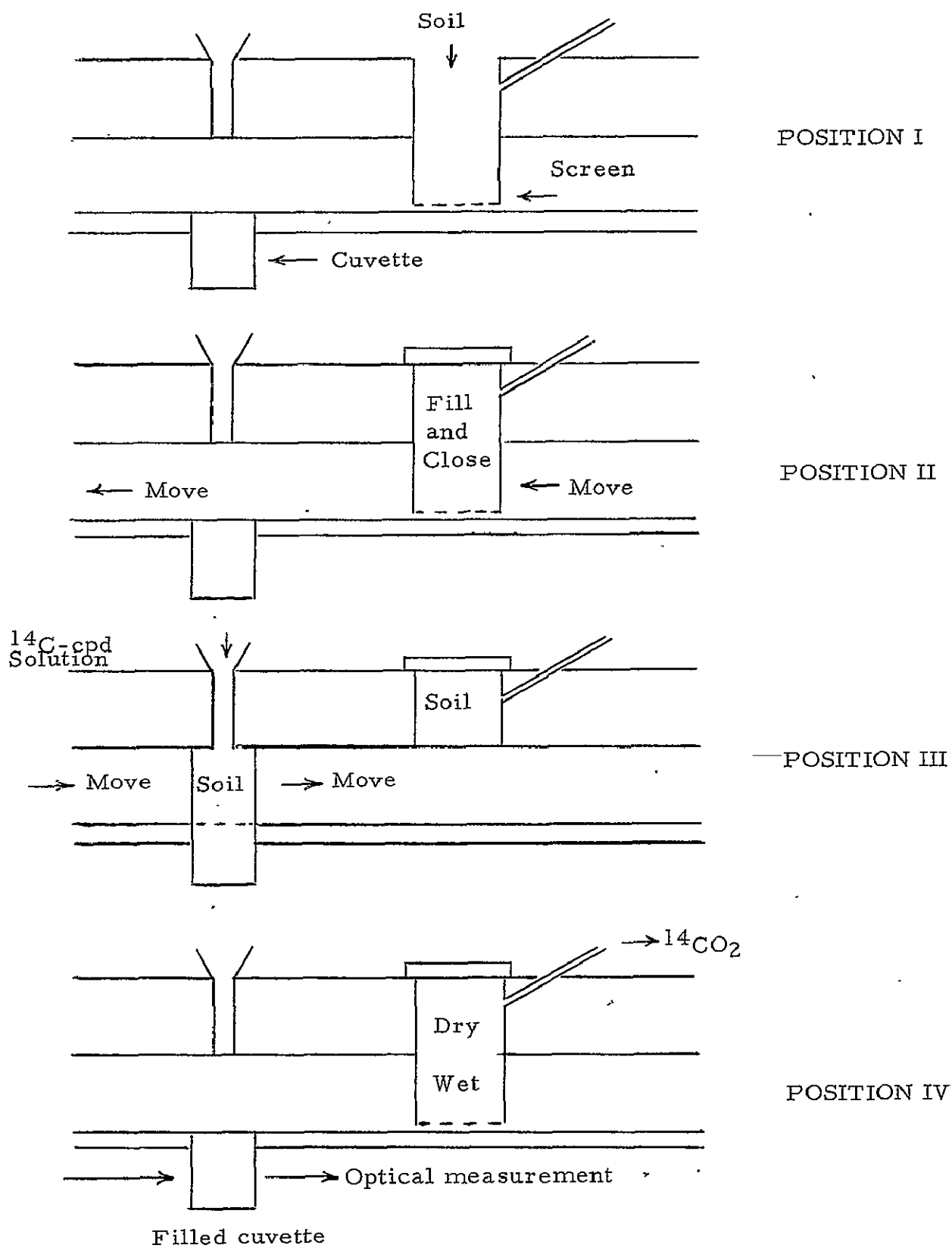
The following description suggests one manner in which we envisage the function of the integrated instrument package, and is not meant to be an engineering specification. However, the following paragraphs describe the functions which are required. We consider two module which together would constitute the integrated instrument package. The first module should be capable of carrying out experiment 1 (photosynthetic or respiratory fixation of carbon dioxide) with the ability, if feasible, to carry out on command experiment 3 (carbon dioxide released from previously fixed carbon dioxide). In this module a soil sample, either dry or moistened, is incubated under an atmosphere containing labeled carbon dioxide for a period of time which can be terminated on command. The system should then be freed from excess labeled carbon dioxide and the evolution of labeled carbon dioxide in the dark monitored for several hours. It should be possible to initiate and terminate this second phase on command or, alternatively, go directly to pyrolysis. The purpose of introducing these alternatives is to proceed in a manner most suitable to the rate at which reactions appear to occur. Should a rapid fixation of carbon dioxide have taken place in the light, then it is also possible that a significant evolution of labeled carbon dioxide will be observed in the dark.

The second phase of the experiment is then capable of yielding kinetic data on respiration. Should it prove to be impossible to obtain data in the second phase of the experiment, there is still the possibility that a low but measurable fixation of carbon dioxide has taken place in the light and can be detected only by pyrolysis and subsequent determination of radioactivity. In the event of a consistent failure to detect release of radioactive carbon dioxide in the dark, the second phase of this procedure would then be by-passed in subsequent analyses.

The second module of the package combines experiments 4 (carbon dioxide release from added organic compounds) and 5 (observation of growth by light scattering). Without attempting to engineer this module a mode of operation is suggested in the attached drawing. A soil sample is percolated with a solution of C^{14} -labeled organic compounds until a transparent cuvette, separated from it by a screen, and located below, is filled with liquid. The wet soil sample is then slid aside so as to seal off the cuvette and simultaneously come in contact with additional dry soil. This move accomplishes two purposes. The cuvette now contains a soil extract, microorganisms if they were present in the soil and have been partly washed off, and additional organic matter. The soil sample, upon being brought into contact with additional dry soil, is no longer saturated but will establish a moisture gradient in the second soil sample until equilibrium is reached at a water concentration which is below complete saturation. It is required that some of the soil moistened with a solution of radioactive compounds is near the top of the soil sample, or that an additional sample of radioactive material be placed on top. Alternatively, the outlet for $^{14}CO_2$ can be near the bottom, moist, portion of the soil sample.

The cuvette now serves for light scattering observations, while the soil sample can be monitored for the evolution of radioactive gases.

Combination of Experiments 5.3.4 and 5.3.5



7.0 IMAGERY SCIENCE INSTRUMENT TEAM REPORT

This is the unabridged Science Definition Report of the Viking Imagery Science Instrument Team. The Team members are:

Thomas Mutch (Leader)

Elliot C. Morris

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Alan B. Binder

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SCIENCE DEFINITION NO. 2 FOR IMAGING EXPERIMENT

1973 VIKING MISSION (LANDER)

The Viking Imaging Experiment

I. Science Objectives

The imaging experiment for the 1973 Viking Lander is superficially straightforward. However, it would be a mistake to think, first, that the goal is nothing more than return of a few pictures of unspecified quality or, second, that the decisive "scientific" content of images is low. In fact, the imaging experiment has unrivalled potential for meaningful scientific results.

As indicated below, specific goals can be tabulated under the headings biology, geology, and meteorology. The overriding goal for the imaging experiment - and, indeed, all experiments on the 1973 Viking mission - is to provide information which will test the thesis that life exists (or might have formerly existed) on Mars. The geological and biological goals are complementary. For example, present surface characteristics may indicate paleoconditions favorable for the formation of life.

Biological Goals

1. Mapping of landing site to provide framework for understanding of imaging science results as well as results from other experiments. Mapping will provide the geometrical framework from which quantitative information can be obtained regarding such things as size, shape, distribution, position, and orientation of objects. Construction of topographic maps will contribute information not only in the area of biology, but also in the areas of geology and meteorology.
2. Search for living forms which might be revealed in a variety of situations: attached or unattached, moving or stationary, near-microscopic forms in the near-field or larger forms silhouetted on the local horizon.
3. Observation of a real redistribution of the substrate by living forms: burrows, track and trails, bioturbation.
4. Search for fossil forms; observation of organically induced or controlled stratification patterns.
5. Determination of possible biological causes for variations between light and dark areas.
6. Determination of possible biological causes for the wave of darkening.
7. Search for technological artifacts.

Geological Goals

1. Same as (1) under biological goals. Characterization of size distributions for rock fragments is particularly important.
2. Characterization of detailed land forms in the near field and regional landforms in the far field according to slope distribution and surficial texture.
3. Determination of rock morphology, texture, mineralogy, and chemical composition. Primary reference here is to rock fragments with size on the order of a few millimeters to a few meters, but analogous analysis could be carried out on finely comminuted dust or on regional surfaces. The imaging experiment will not supply complete or unequivocal information on mineralogy and chemistry, but multispectral analysis by the imaging system will probably be more definitive than results from any of the other Lander experiments. Among the more important specific goals are the following:
 - a. Distinguish between the various proposed models for weathered surface materials (e.g. limonite dust, limonite-stained rocks, siderite)
 - b. Determine surficial differences between light and dark areas. These differences might be caused by variations in biology, lithology, or particle size. Characterization of both regions, of course, requires two landers.
 - c. Investigate diurnal and seasonal changes such as wave of darkening and nocturnal frost deposits.
4. Determination of presence and character of rock stratification with emphasis on those structures which may be indicative of past life (e.g., biologically generated stratification) and ancient life-supporting conditions (e.g., water-laid sediments or aeolian deposits indicating a dense atmosphere).
5. Presence and character and evolution of regolith. Particle size distribution.
6. Transportational mechanisms as demonstrated by movement of materials around footpads and by general redistribution of surface materials during mission. Specific emphasis will be on aeolian transportation and deposition.

Meteorological Goals

1. Observation of clouds both close to the Martian surface and near-vertically over the spacecraft.
2. Observation of dust storms from near field to horizon.

3. Definition of atmospheric scattering and extinction by observations of the sky and sun from the horizon toward the zenith.

II. Science Rationale

Keeping in mind that this is a first, reconnaissance mission to the Martian surface, the goals specified in Section I can best be met by a camera system that provides low and high-resolution images. However, at this early date it would be a mistake not to plan for several additional capabilities of high scientific merit. An important guideline is that all accessories should be conceived and designed so that they do not endanger or seriously complicate the primary dual-resolution camera system.

In preparing this science definition we have, on the one hand, tried to be realistic in estimation of development time and cost for all items but, on the other hand, we have attempted to avoid the trap of considering only "proven" camera equipment. We recognize that savings in money and gain in reliability inexorably force mission engineers and administrators to favor simple, proven equipment. However, we are confident that everyone recognizes that the stated goal of the mission is acquisition of scientific information - as much and as meaningful as possible. We hope that agreement on this point will lead to immediate implementation of programs in instrument development as recommended in this report.

The present document serves as an important first step in defining the requirements for a successful camera experiment. However, it is no more than a first step. Some of the camera requirements will be modified following assimilation of Mariner 1969 results and earth-based telescopic observations during the next three months. It is essential that scientists and engineers maintain close contact over this period. Some of the requirements take on reality only when a specific spacecraft geometry becomes known. Again this implies that preliminary numbers will not be thoughtlessly perpetuated when discussion between scientists and engineers can lead to meaningful modification.

III. Science Measurements

Priorities

A first landed mission with the measurement capability specified under Priority 1 is an adequate starting point but, by itself, will fall short of fulfilling the stated science goals of the mission. To sufficiently characterize the Martian environment and to adequately prepare for future investigations of the planet it will be necessary to employ additional capabilities for the imaging system. From the many possible candidates we have included those capabilities listed under Priority 2. There is not now sufficient engineering information to further narrow the list. For that reason development studies should be emphasized in the next few months. At least several of the capabilities - and preferably all - should be included in the final experiment.

Priority 1

A. Qualitative measurements required

1. Low resolution panoramic photographs and high resolution narrow-field photographs.

B. Quantitative measurements required

1. Two image resolutions: a low resolution scanning system with a scanning resolution of 0.1° and a high resolution system with a scanning resolution of 0.01° . It is our judgement that the reliability requirements necessitate two cameras.

Justification. The low resolution has been determined to be adequate for reconnaissance photography and for analysis of many geologic features. The high resolution is essential for a differentiation of inorganic and possible organic structures in the near field as well as for high resolution views of the far field. It is axiomatic that the amount of scientific information will increase with any increase in range of magnification. The goal of 0.01° is chosen here because it is consistent with the "first-look" goals of the mission and also appears to be consistent with the requirement for a feasible camera (especially if a continuous focusing requirement is relaxed in favor of step focusing).

2. Each camera should have scanning rates which are compatible with direct and relay transmission to Earth. As pointed out under the priority 2 section, the additional capability of fast scanning on the order of 10^5 or 10^6 bits per second may be very desirable.

3. Calibration and image quality requirements are further specified in Appendix A.

C. Operational requirements

1. Commands for a representative low-resolution panoramic view and a detailed high-resolution view of the sampler area should be pre-programmed so that the image data can be transmitted during the first orbiter relay period immediately following landing.

Justification. An early picture of the sampler area is necessary to guide selection of sample sites. Assuming the worst case, that the spacecraft does not live through the first night, it is essential to get a representative view of the Martian surface.

2. Following the pre-programmed sequence described in (1) provision should be made for series operation of two cameras during a given communication opportunity. Command requirements for both the low and high resolution cameras include start/stop/deploy, azimuth aim, elevation aim, horizontal field, vertical field, and focus. Commands should be updated on as near to a real-time basis as possible.

Justification. Almost all images will be for targets of opportunity defined in previous images. Consequently, continual flexibility in camera use and orientation is required. A more complete sequence analysis will be possible when mission communication constraints are more firmly established.

3. The capability of taking imagery data during a large fraction of the Martian day is required during the full 90-day mission.

Justification. Observations of the surface under different angles of solar illumination, as a function of the diurnal cycle, is important for understanding the photometric properties of the surface and the effects of shadowing. Secondly, there may be diurnal changes of the surface (e.g., front deposits, dust deposits) and changes in biological conditions on the surface which would not be recorded if the observation periods were short and limited to a certain time of day. The need for long observing periods may be satisfied by one of or a combination of the following: (1) onboard storage of 10^7 bits, (2) direct link to earth for 10 hours via a steerable antenna, (3) nearly continuous apoapsis link with the orbiter and (4) daily periapsis link with the orbiter.

4. Images of sampling sites should be obtained preceding and following each sampling event.

Justification. Interpretation of results from the biology and molecular analysis experiments is enhanced by knowledge of the physical properties of the sample (e.g., particle size, texture, surface brightness, depth below the surface). Such information implies "before" and "after" pictures.

D. Special requirements

1. Both cameras should be mounted as high as feasible and at least 1.5 meters above the base of the spacecraft. Both cameras should have within their field of view two footpads (assuming a three-legged spacecraft) and the entire area accessible to the surface sampler. The requirement for elevated camera mounts should not preclude the possibility that a movable boom might include one operating position close to the surface.

Justification. Both cameras should see as much of the surface near the spacecraft as possible. A camera permanently mounted low on the spacecraft might be "blinded" were the spacecraft to land in a depression or in a tilted position. Focusing problems for the high-resolution camera are minimized if the ground surface is at a high angle to the optic axis of the camera (e.g., if the camera is mounted high).

2. The low-resolution camera should have the capability to point azimuthally in 6° increments. Pointing precision relative to a fixed reference point on the spacecraft should be 365° in the nominal horizontal plane of the lander. Vertical field of view shall be 70° , with vertical pointing capability for angular coverage from 60° above to 60° below the horizontal plane of the lander in 10° increments.

Justification. The pointing capability permits the operator to designate particular fields of view as the mission proceeds and, in this way, to reduce data. The vertical field of view is selected to assure complete imaging of the near-field and of a significant part of the sky. The possibility that the spacecraft lands in a tilted position also demands large vertical field of view capability.

3. The high-resolution camera should have pointing capability of 1.5° both azimuthally and vertically. Pointing precision azimuthally and vertically should be 2 resolution elements. All viewing positions accessible to the low-resolution camera should also be accessible to the high-resolution camera. Field of view should be 500×500 picture elements.

Justification. Same as for (2)

4. Both cameras should be mounted so that optimal resolution capability is not seriously degraded by camera vibration during operation.

5. The spacecraft should contain a mechanism for determining local vertical relative to the cameras' fields of view with accuracy of 0.5° .

6. The cameras should have shields adequate to protect the optics from the local environment, particularly contamination by dust.

E. Data requirement

1. High-resolution images contain approximately 1.5×10^6 bits; low-resolution images 1.5×10^7 bits.

Justification. Clearly this figure can be adjusted, but probably not radically modified. It is based on assumptions about picture size, resolution element size, and gray-level encoding as specified elsewhere in this report. It presumes no major onboard data processing.

2. Provision should be made to obtain and transmit pictures throughout the 90-day mission. The exact schedule depends on appearance of targets of opportunity, operation and transmission schedule for other experiments, and final communication constraints. For purposes of imagery sequence planning a minimum data requirement is 1.5×10^7 bits per day for 90 days. At least 50 percent of this should be obtained at rates no less than 15,000 bits per second. Examples of images obtainable with 1.5×10^7 bits are:

- (a) one 360° low-resolution monospectral panorama
- (b) 120° low-resolution panorama in three-band color
- (c) ten high-resolution $5^\circ \times 5^\circ$ monospectral pictures

Justification. As specified elsewhere, particularly under C 3.

3. Data rates and justifications are stated under B 2.

4. No firm requirements are set for data compression, but several of the more likely schemes should be evaluated.

Justification. Obviously, data compression schemes lead to some picture degradation. This degradation is most acceptable when the imaged scene, or equivalent scenes, represent thoroughly known standards against which the degraded image is compared. Because the Martian scene is not thoroughly known, data compression is conceptually unattractive. However, the more likely processing programs should be examined with the understanding that they might be economically included to be used in case of significant transmission loss during the mission.

Priority 2

Listed below are four capabilities which have significant scientific merit. No internal hierarchy of priorities is intended at the present time. Development studies should be pursued promptly with the aim of making final feasibility choices between the several capabilities as soon as possible.

1. Stereoscopic capability. Vertical base stereo with at least one meter base is the most desirable configuration. Stability requirements should not take into account the worst expected wind conditions but should be relaxed to satisfy the median condition.

Justification. Stereo images are important for construction of near-field maps, for accurate deciphering of three-dimensional structures on near-field objects, and possibly for ranging to selected objects as an aid in determining focus selection for subsequent imaging with the high-resolution camera.

2. Multispectral analysis.

a. Visual color images - compositing of three broad-band images in the visual part of the spectrum to produce "natural" color.

Justification. Earth-based telescopic observations indicate that color may be an important property on Mars for identifying and differentiating surficial materials. Because of our everyday experience in analyzing visual color this will prove to be a very useful reconnaissance tool.

b. Multispectral narrowband filtering. The goals are twofold: generation of images in preselected pass bands and generation of spectrometric curves for particular spots, $\sim 1^\circ$ or less in size. That combination of detectors, band filters, and wedge filters which provides optimum response and accuracy should be selected. Representative accessible bands of scientific interest are centered at 1.5, 2.0, and 3.1 microns (non-gaseous H_2O), .45, .55, .7, and .9 microns (Fe^{+++}) 1.0 microns (Fe^{++}) and 2.6 and 3.5 microns (certain organic molecules). Additional bands will have to be measured on either side of the central band. Exact designation of bands

for multispectral analysis should come in September, 1969, following assimilation of data from the 1969 Mariner experiments and from ground-based observations.

Justification. Multispectral analysis is an extremely important reconnaissance tool for surveying the chemistry of the Martian surface, particularly for gaining information about the presence and distribution of water, iron-bearing minerals, and organic matter. The spot analyses will permit construction of spectral "signatures". The scanning analyses will permit successive spatial analyses for a given narrow band.

c. Polarimetric measurements. Combination of polarizing filters in order to determine degree and plane of polarization.

Justification. Of value in determining textural and lithologic properties of surficial materials. Polarimetric properties of fine-grained material and coarse rock fragments provide a means for discriminating, classifying and mapping the distribution of these materials on the Martian surface. Polarimetric properties vary with differences of surface texture, chemical composition and grain size. At large phase angles large Fresnel polarizations are expected, providing potential information on real and imaginary parts of the refractive index for surface materials and on particle size distributions.

3. Quasi-microscope. Should permit examination of part of the sample used for biological and chemical analyses. Required resolution is on the order of 10 microns. Capability for examination both by transmitted and reflected light should be present. The image might be obtained in one of the following two ways.

a. A standard high resolution $(0.01)^\circ$ camera designed to point toward a specially prepared collection plate on the spacecraft. To obtain necessary high magnification the plate may have to be moved close to the camera. Alternately, a mirror image of the plate may be obtained, with appropriate provision for additional magnification by an auxiliary lens system.

b. A fiber optic-lens combination designed either to be positioned a fixed distance from a collection plate, or to be inserted at an appropriate position in the sample collection system.

Justification. This is a very broadly defined requirement but it does, nonetheless, represent some narrowing of Priorities. Monitoring of wind-blown dust may be a natural capability of the system and is desirable but is not a requirement. Since design of a microscope is so closely associated with design of a sampler mechanism and design of the processing chambers for biological and chemical analysis, feasibility decisions must parallel, in time, design of this interfacing equipment. Visual characterization of the sample which will be biologically and chemically analyzed could assume the highest order of scientific importance as the mission unfolds.

4. Motion detector. The scientific goal is receipt of a picture, or series of pictures, recording object motion. In order to have a reasonable chance of achieving this goal it will be necessary to monitor continuously, or for long periods of time, a given near field or far field of view. The monitoring device might be a piece of equipment separate from the camera and consisting of a fixed optical element and a series of light detectors arranged in the focal plane. A rapid change of light level recorded by the detectors as an object crossed the field of view would trigger the high resolution camera to fast scan the monitored area. Onboard comparative processing of successive images might permit isolation of the moving object for selective transmission. The detection logic should preclude triggering by gradual changes of light level associated with changes in sun angle and progressive changes in shadowing.

This experiment probably requires a fast-scan mode on the order of 10^5 resolution elements per second. It also implies long-term access on-board data storage capability of at least 10^5 bits.

Justification. Of all the possible additional capabilities this is the most provocative and speculative. In early studies of life detection experiments suitable for Mars motion was assigned a high ranking as being one property with unequivocal significance. Consequently, the scientific value of a motion detection experiment is, in principle, great. The feasibility of the total experiment may depend not so much on expensive and time-consuming hardware development as on relatively inexpensive and rapidly obtainable systems analyses. In sum, then, we urge prompt investigation of this additional capability.

APPENDIX A

IMAGE QUALITY REQUIREMENTS

1.0 INTRODUCTION

The purpose of this document is to define the image quality requirements and calibration requirements which shall be used during the negotiation and early contract phases. In addition, targets are defined, which shall be used in evaluating radiometric image quality. This document represents the present status of information and shall be revised as necessary when new information becomes available.

2.0 CAMERA SYSTEM REQUIREMENTS

The requirements contained in this section pertain to the following cameras:

1. Low Resolution - 0.10 scanning resolution
 - a. Wide-band monospectral
 - b. 3-band colorimetric
 - c. Narrow-band multispectral
2. High Resolution - 0.01 scanning resolution, wide-band monospectral.

The present document does not specify radiometric requirements for the colorimetric or multispectral imagery, since exact designation of spectral bands will be made following assimilation of Mariner '69 data and ground-based observations.

2.1 Radiometric Requirements

2.1.1 Standard Targets

The following standard targets shall be used in evaluating image quality.

- a. Radiometric Characteristics - The standard targets shall have the same radiometric characteristics as the surrounding surface. The photometric model used for this analysis is given in reference 2.

- b. Target Size and Shape - The standard target size and shape are defined as the system resolution element given by:

$$D_R = \sqrt{2} \beta L$$

where: D_R = Diameter of the resolution element in meters

$\sqrt{2}$ = Kell Factor

β = Scanning resolution in radians

L = Lens to target distance in meters

c. Target Orientation - The targets shall have a slope of (θ) with respect to a flat surface and may be oriented at any azimuth angle with respect to the optic axis to yield maximum contrast.

2.1.2 Required Photometric Image Quality

The quality of the reconstructed image shall be considered acceptable if the system achieves the minimum image quality requirements given below.

2.1.2.1 Low Resolution System (0.10 degree scanning resolution)

a. The low resolution system shall achieve a minimum system signal-to-noise ratio (S/N) of three (3) for the specified target when scanning through three hundred and sixty (360) degrees in azimuth and lander-to-target surface distances of one (1) to one thousand (1,000) meters over a range of sun zenith angles of zero (0) to sixty (60) degrees. No camera focus adjustment shall be required to satisfy these S/N requirements.

b. The low resolution system shall have sufficient dynamic range for linear response across the range of luminance values for the targets, and sun angles considered in Section 2.1.2.1.a.

2.1.2.2 High Resolution System (0.01 degrees scanning resolution)

a. The high resolution system shall maintain a minimum system signal-to-noise ratio (S/N) of three (3) over each 5×5 degree sector (field-of-view) when scanning a target field with standard targets placed at camera azimuth angles of zero (0) to three hundred and sixty (360) degrees and lander-to-target surface distances of one (1) to one thousand (1,000) meters over a range of sun zenith angles of zero (0) to sixty (60) degrees. The camera system shall achieve these (S/N) requirements with one (1) focus setting per sector (field-of-view). These requirements shall be met without the use of automatic focus.

b. The high resolution system shall have sufficient dynamic range for linear response across the range of luminance values for the targets and sun angles considered in Section 2.1.2.2.a.

2.1.2.3 General Requirement

The signal-to-noise (S/N) values specified in Sections 2.1.2.1.a and 2.1.2.2.a, shall be achieved in such a way that the peak signal of the image of the maximum out-of-focus target does not fall below eighty (80) percent of the peak signal of the in-focus target.

2.1.3 Specification of Minimum Slope Values

a. Monospectral Wide-band Coverage

The monospectral imagery shall meet the specified image quality requirements for the following slope values. Slope values pertain to both the Low and High Resolution Systems.

$\theta = 8$ degrees for relay communications**

$\theta = 2$ degrees for direct communications**

Scan rates correspond to new data rates of: 19,000 bits/sec for relay communication; and 330 bits/sec for direct communication, at six (6) bit encoding.

b. Multispectral Narrow-band Coverage

Designation of spectral bands should come in September 1969 following assimilation of data from the Mariner '69 data and ground-based data. No specification of image quality for multispectral coverage is given in this document, however the Contractor shall identify detectors and filters which could meet the general requirements set forth in Priority 2 of the Science Rationale.

2.1.4 Calibration Requirements

The system shall have sufficient absolute calibration to allow determination of the radiance of the surface within a 3 sigma accuracy of ± 7 percent.

In addition, the system shall have sufficient relative radiometric calibrations to allow determination of the relative radiance between any two (2) image points within a 3 sigma accuracy of ± 2 percent.

**For purposes of preliminary camera evaluation, the following values may be assumed:

$\theta = 2^\circ \quad \Delta\Phi = 0.002$

$\theta = 8^\circ \quad \Delta\Phi = 0.008$

$\Delta\Phi$ = Change in photometric function

8.0 METEOROLOGY SCIENCE INSTRUMENT TEAM REPORT

This is the unabridged Science Definition Report of the Viking Meteorology Science Instrument Team. The Team members are:

Seymour L. Hess (Leader)

Conway B. Leovy

James A. Ryan

Robert M. Henry

VIKING PROJECT MISSION DEFINITION NO. 2

Meteorological Science

I. Science Objectives

A. To measure directly the atmospheric environment at and near the surface of Mars.

B. To measure directly those properties of the general circulation of the atmosphere that will confirm or deny predictions of existing theory and will broaden our understanding of that circulation.

C. To obtain data on medium-scale and small-scale phenomena such as cyclonic storms, fronts, and dust devils.

D. To elucidate the structure of the surface boundary layer and its diurnal variation.

E. To support other experiments with needed meteorological data.

F. To provide data that will facilitate engineering design for future missions.

G. To provide data that will guide design of scientific experiments on future missions.

II. Science Rationale

This section will deal with the various objectives listed in Section I and relate them to specific measurements listed in priority order in Section III.

A. Atmospheric environment.- Clearly one objective of a landed science experiment should be to determine the properties of the environment. Such elements as pressure, wind speed, wind direction, temperature, water vapor content, and turbidity are all matters that have been speculated upon and, in some cases, measured crudely from Earth. The Viking mission will be the first opportunity to measure these elements directly, thus it is very important to do so. The absolute accuracies specified in Section III are, in most cases, modest since it is not necessary to obtain the maximum possible accuracy to bring our knowledge of the Martian environment to a useful and far more satisfactory state. Furthermore, the frequency of sampling need be only high enough to define the diurnal cycle and a few of its higher harmonics. The sole exception to this is the need to detect rapid aperiodic phenomena that are expected. This will be discussed in more detail later in Section III under the heading of "Standard meteorological sampling plan."

B. General circulation.- It will not be possible to define the global circulation pattern in a truly satisfactory fashion from only two surface

observation points. However, it will be possible to look for confirmatory evidence of existing theories as well as to provide observational bounds for future theoretical interpretation. Thus, one must make measurements that will reveal the amplitude of the solar tide in pressure, wind speed, and direction, and in temperature since it has been predicted that these amplitudes will be large.

Furthermore, these elements are predicted to have appreciable amplitude of annual variation. In particular, the possibility that a major constituent of the atmosphere, carbon dioxide, may condense into and sublime from the polar caps suggests a large annual range of surface pressure. Since neither of the landers will be near a polar cap, this is the only Viking observation that could bear upon its properties. The planned 90-day lifetime of the landers may not be long enough to give useful information about the 687-day sidereal period. Thus it is important to take advantage of two characteristics of the planned lander system. One is that the nuclear power source has a very long useful lifetime and the other is that the meteorological data transmission requirements are low. This means that useful atmospheric data can be transmitted at a low bit rate for long periods of time. To make possible the functioning of a long-term automatic weather station on Mars, several sensor systems have been specified to have a useful lifetime after landing of 2 years, that is, one Martian annual cycle.

The chief way in which surface observations can be related to a fundamental aspect of the general circulation is by rendering more significant the thermal-infrared mapping done from Earth and to be done from Mars orbiters. The infrared data relate closely to the temperature of the ground-air interface. However, a very significant and time-dependent lapse of temperature with height is expected in the first meter of elevation. Thus, a comparison of infrared radiometric data with directly measured atmospheric temperatures will make the entire body of radiometry a much more useful element of the planetary meteorological scheme.

C. Medium- and small-scale phenomena.- We have every reason to expect that the Martian atmosphere has cyclonic storms of appreciable dimensions, frontal structures similar to those on Earth, and certain smaller scale entities such as dust devils. These are aperiodic phenomena, some of which have a time scale sufficiently short that special data-sampling techniques may be required. This will be discussed more completely below under "Standard meteorological sampling plan." The goal is to record the occurrence of such events and the accuracies specified in Section II will suffice to do so.

D. Surface boundary layer.- The layer of air within a few hundred meters of a planetary surface is profoundly affected by the presence of that boundary. This is a layer in which turbulent vertical transport of such properties as momentum, water vapor, and enthalpy are very important, and in which substantial diurnal variations occur. Much can be learned about these vertical transport processes by examining time-averaged vertical profiles of wind speed, moisture, and temperature. Attention is being restricted to momentum and heat solely because the water vapor measurement on Mars is so

very difficult. The interaction of the atmosphere with its lower boundary is an essential part of the mechanism by which the atmosphere is driven since thermal energy to run the atmospheric engine is derived largely by transport to and from the ground (by turbulence and by radiation), while dissipation of momentum is achieved in significant measure by its turbulent transfer down to the ground.

The requirement for determining these transports is to measure at least four 5 minute averages per hour of wind speed and temperature at least two elevations in the boundary layer. These levels must be far enough apart that meaningful differences can be detected. A ratio of 10:1 in these two heights should be adequate if the measurements can be made to somewhat greater relative accuracy than the absolute accuracy deemed feasible for more general purposes. This is the rationale behind the specifications given under this heading in Section III.

Since relatively small differences in speed and temperature are significant here, the perturbing effects of the lander and its power source become quite important. It is believed that the vertical profile will be representative if measured at a deployed distance of about one lander diameter, assumed to be 2 meters, but this should be checked experimentally. Since the simplest rigid mast could not be more than a lander diameter long, its height has been specified also to be 2 meters. It would be useful to increase both the deployment distance and the mast height.

Even at a modest deployed distance, the measurements cannot be meaningful if the mast is downwind of the lander. Therefore, if reliable data is to be obtained at all wind directions, it is necessary to have at least two such masts 180° apart.

E. Support of other experiments. - The biological experiment requires meteorological data in support of its purposes. The two most important of these are probably water vapor and pressure. If, as seems possible, the well-known "wave of darkening" represents a transport of vapor across latitude circles and a biological reaction thereto, it is important that biological runs be performed before and after the arrival of the darkening phenomenon. Comcommitant measurements of water vapor will assist in deciding when to perform these experiments and will provide direct information to be correlated with the results.

Pressure is of great importance because the present range of its uncertainty includes the triple point of water (6.11 mb). It is mandatory that measurements be made to ascertain whether the pressure is above or below this critical value so that the possibility of occurrence of liquid water can be determined.

Temperature will be needed to establish the environment within which any life must exist and to interpret any positive results that may be obtained.

Wind data can indicate when fresh particulate matter has been blown onto the lander site so that a new sample for biological or chemical analysis

is available. This use of the wind data can be the equivalent of having a sampler arm miles in length. Moreover, information on wind direction will be useful to experiments gathering soil and atmospheric samples.

Information on wind gusts will be of importance in the two experiments that rely upon the lander providing a steady platform; namely, imagery and seismometry.

Finally, local turbidity measurements will aid the ultraviolet experimenters in determining whether fluctuations measured are due to low level dust or to events at a higher elevation and will aid in interpretation of imagery from the orbiter and the lander.

F. and G. Data for design of future missions.- It is clear that future landers on Mars can profit greatly from the environmental data to be gathered by Viking. It must be an important goal of this mission to gather the data needed for both scientific and engineering purposes in the future. The set of variables to be measured and the specifications have been chosen with this important purpose in mind.

III. Specific Scientific Measurements

Standard meteorological sampling plan.- The data complex to be outlined here is referred to later in this document by the initials SMSP.

There are two quite different data sampling rates appropriate to some of the goals and methods outlined above. For most purposes, one wants a repetition rate sufficient to define the diurnal cycle and some of its higher harmonics. This suggests hourly averages of each of these meteorological elements throughout the Martian day. On the other hand, the detection of rapid events of special interest such as frontal passages, dust devils, and wind gusts that will affect seismometry and imagery call for a much more rapid sampling rate. The following discussion is based upon the assumption that onboard data storage capacity and data transmission rates will preclude making observations at frequent intervals with all the detailed data being transmitted to Earth.

Let the slow data requirement be an average over time T of the element desired. Let the rapid data requirement be an average over time t of the element desired. One can then store each t -mean for a total of T or T/t items per sensor. Then appropriate commandable onboard logic can decide whether an "interesting event" has occurred during T . If so, the entire ensemble of detailed data or a selected portion thereof is to be sent at the next available transmission. If not, the T -mean is to be formed out of the T/t pieces available and stored elsewhere for later transmission. The storage capacity would then be available for recording the detailed data for the next period of observation. One possible choice of T and t leads to data that could be accommodated in 6000 bits of onboard storage. If room has to be provided to store several potential periods of detailed "interesting" data before transmission becomes possible, this requirement will rise accordingly.

It should be made possible to alter T and t by command from Earth because this will:

(1) Permit other experiments to be activated at opportune times which otherwise may be missed.

(2) Permit the storage and telemetry requirements to be varied. This is particularly important as regards needs at night versus day and early versus late in the mission. Additionally, it permits adoption of a low telemetry and low data-storage mode during times when other experiments impose heavy demands.

(3) Permit modification of the measurement rationale as required by earlier findings (e.g., our expectations may turn out to be wrong).

The minimum value of t should be at least as large as the response time of sensors.

The time units to be used should be based upon the mean solar day on Mars of $24^h 39^m 35^s$. This is necessary because all elements to be measured are expected to have a strong daily cycle and, in order to analyze that cycle, the data must be available at time intervals that are very closely integral fractions of the solar day.

Priority 1 - Surface atmospheric pressure. It is required to measure this to an absolute accuracy of ± 0.1 mb in the range 1-30 mb SMSP. There are many commercially available pressure sensors of which a likely candidate is the diaphragm - capacitance gage. Deployment from the lander is unnecessary, but care should be taken to avoid dynamic wind effects on the pressure measured. The sensor should maintain requirements over at least 2 years of operation on the surface of Mars.

Priority 2 - Atmospheric water vapor. It is desired to measure this, in terms of frost-point temperature, to an absolute accuracy of $\pm 2^\circ$ K within the range 180° K to 255° K. It will suffice to measure this element once every 2 hours. Certain possible sensors will require calibration after arrival on the planet. Deployment from the lander at a distance of at least 2 meters from the nearest point is essential if the sensor makes a strictly local measurement. Redundancy at three azimuths around the lander is an alternative to deployment. No one sensor can presently be identified as satisfactory or indicated. Candidate systems include infrared measurements of the rising and setting sun, Al_2O_3 sensor, frost-point hygrometer, and quartz sorption hygrometer. If possible, the selected sensor should have a useful lifetime of at least 2 years after arrival at the planetary surface.

Priority 3 - Wind, speed direction, and temperature. These three are an interrelated group. Speed is required to be measured to an absolute accuracy of ± 10 percent of the indicated value in the range 2 ms^{-1} to 150 ms^{-1} ; wind direction to an absolute accuracy of $\pm 10^\circ$ relative to planetary coordinates as well as relative to the lander; and temperature to an absolute accuracy of $\pm 3^\circ$ K in the range of 100° to 350° K SMSP. The thermal and physical

influence of the lander itself requires that wind speed and temperature sensors be provided at at least two azimuths around the lander. Wind direction, however, can be measured at one point, preferably as high as possible. A location on top of the mast carrying the imaging camera would be best. Even with redundancy in measurement of temperature so that an upwind reading can be used, there may be serious radiation effects from the lander body and from the nuclear power source. Thermal radiation shielding from nuclear power units may well be required.

Temperature and wind speed can be measured usefully at any of a number of heights. It is important to get above the very lowest part of the boundary layer so that an elevation of at least 1 meter is desirable.

Feasible instruments include:

- A. Wind speed - cup anemometers or a hot-film anemometer.
- B. Wind direction - wind vane or the hot-film configuration that provides wind direction as well.
- C. Temperature - resistance wires are the preferred instrument.

A useful lifetime of 2 years after landing is desired.

Priority 4 - Measurement of a vertical profile of mean wind speed and mean temperature in the boundary layer. These measurements are to be made on two masts at least 2 meters tall, deployed at least 2 meters from the nearest point of the lander and separated by 180° . Speed and temperature are to be measured at at least two elevations, such as 2 meters and 20 cm above the planetary surface. The relative accuracy of the sensors must be such that the difference in speed will be known to ± 5 percent of the wind speed between 10 ms^{-1} and 150 ms^{-1} and the difference in temperature will be known to $\pm 0.5^\circ \text{ K}$ in the range 100° K to 350° K . Although not an integrally necessary part of the boundary-layer measurement, the determination of the temperature of the air-ground interface is most conveniently mentioned here. This is a highly desirable measurement and has the same deployment requirements. SMSP.

These data are required during the planned 90-day lifetime of the lander. However, it will be useful if the system were capable of continuing in operation for 2 years. Suggested instruments are the same as those in Priority 3. The instrumentation and deployment required for this experiment will satisfy all the requirements of Priority 3 except for wind direction.

Priority 5 - Atmospheric turbidity. This is a measurement of the atmospheric content of small particulate matter in the vicinity of the lander. The prototype of a suggested instrument is a nephelometer developed by Charlson and Ahlquist (University of Washington). Sequencing of the data should be coordinated with that of the photometer experiment and the imaging experiment.

A tube enclosing this scattering experiment may be unnecessary if the scattering column is at least 1 meter away from reflecting surfaces.

It is desired to measure scattering coefficients between $5 \times 10^{-5} \text{ m}^{-1}$ and 10^{-2} m^{-1} with a sensitivity of $5 \times 10^{-5} \text{ m}^{-1}$. This latter figure could be changed to $2 \times 10^{-4} \text{ m}^{-1}$ if necessary.

It would be desirable to make measurements at two different wavelengths to gain information about particle size distribution. For example, two bands at 3500 to 4500 Å and 5500 to 6500 Å might be chosen.

IV. Instrument Information

Most of the sensors suggested, together with the necessary electronics, are very modest in weight and power requirements. The potentially heavy requirement is for masts to support the wind direction sensor and the vertical profile measurements. Since a mast will be required for the camera, it seems best to use it to support the wind direction instrument also. Initial dimensions of the deployed masts for the vertical profile have been based upon the assumption that they will be rigid. This is not necessary, and unfurlable masts made of spring material can certainly be considered to save weight. A certain amount of flexing in the wind can be tolerated without degrading the data. Very preliminary estimates lead to a total weight of about 10 pounds and power required of about 10 watts.

Special problems envisioned are the following:

A. Thermal radiation shielding from the nuclear power source may be needed to minimize spurious effects on temperature sensors.

B. Resistance wires for thermometry should have the smallest possible diameter to minimize solar radiation errors. However, they need to be thick enough to run little risk of breakage owing to impact by particulate matter. These contradictory requirements will have to be compromised. It may be necessary to use a tough metal for these wires because the standard platinum is so soft that an excessive thickness may be required.

C. Radiative and physical effects of the lander will have to be minimized either through deployment or through redundancy at several azimuths. In the latter case, the wind direction will indicate which of the redundant data is acceptable.

D. Any device with moving parts (cup anemometers, wind vane) will need special attention to bearings to insure adequate long-term lubrication and freedom from the effects of air borne dust.

E. Measurement of water vapor is a substantial problem primarily because no sensing system has yet emerged as clearly adequate for the task. Beyond this, however, this measurement requires sensitivity to a few parts per million of water and is therefore vulnerable to a severe contamination

problem. Two sources of spurious water can be recognized: water contained in or generated by the hydrazine of the lander engines, and water evolved from the lander surfaces or experiments contained within it. Again, redundancy of instruments at several azimuths may be necessary to insure that an uncontaminated sample of air is being measured.

Some water vapor sensors require shielding from dust and some require ventilation.

V. Additional Data Required

A. Atmospheric composition. - The landed chemical analysis and the entry mass spectrometry both have the capacity to determine directly the major as well as minor constituents of the atmosphere. For meteorological purposes it will suffice to do this well enough to give the mean molecular weight and other bulk thermodynamic properties to within ± 5 percent.

B. Vertical profiles of temperature. - Such data in the lower 40 to 50 km of the atmosphere are of great interest. Two uses can be mentioned as examples: (1) the mean static stability is a fundamental parameter in the theory of general circulation of planetary atmospheres, (2) the phenomenon of "blue haze" and its clearing may be explainable in terms of fluctuations in this profile and the condensation and sublimation of thin ice clouds. The data needed can be obtained by direct entry measurements and by a variety of radio occultation experiments.

C. Vertical profiles of water vapor concentration. - Again, this is of great interest in the lower 40 to 50 km in order to determine whether water vapor is or is not a uniformly mixed constituent. Such profiles can be measured during entry and, possibly, by infrared methods from the lander or the orbiter.

D. Vertical profiles of horizontal wind. - Since surface data alone gives only a limited insight to the general circulation, it is highly desirable to obtain any possible data about the vertical variation. Furthermore, such data are important for engineering design of future entry vehicles. This information is obtainable only during entry.

E. Soil moisture. - The water vapor content of the lower atmosphere is surely related to the water content of the surface material as well as to condensation processes, vertical turbulent transport, and horizontal advective transport in the atmosphere. If one is to begin to understand this complex of processes, it is necessary that soil moisture be measured. This seems to be most properly a function of the chemical analysis experiment.

F. Orbital infrared radiometry. - As has been pointed out earlier, the only truly global observation contemplated that bears directly on the atmospheric general circulation is infrared thermal mapping. This ties in with the lander measurements because it is only through comparison of direct surface thermometry with indirect radiometric measurements that the latter can be made optimally useful in assessment of the general circulation.

G. Imagery of the lander instrumentation and site.- Imagery can provide information essential to interpretation of the data received. For example, the deployed masts for measurements in the boundary layer will have design values for the height of sensors above ground. The actual heights will probably be different, depending upon soil bearing characteristics, surface slope, etc. Data is needed to determine the actual elevations. The nature of the lander location must be determined to ascertain if there are natural obstructions at certain azimuths that would make some of the data unrepresentative and to assess the degree of disturbance of the site caused by the act of landing.

H. Site selection.- The meteorological experiments would be greatly aided by a site which is flat and unobstructed by major terrain relief within several tens of kilometers of the lander. Minor relief of the dimensions of the lander vehicle are undesirable within 100 m of the site. More than one areographic relationship of the two landers can be identified that would be profitable meteorologically.

1. Same longitude but as far apart as possible in latitude.
2. Same latitude but separated by 30° to 60° of longitude.
3. Landers separated by a modest distance so that both can be served by the same orbiter operating as a data transmission link.

In any case it is desirable that the relative elevation of the two landers be known to an accuracy commensurate with the precision of measurement of pressure so that the pressure data can be corrected to a common elevation and compared. For a relative accuracy of pressure between the two landers of 0.1 mb, this height difference should be known to about 100 m.

I. Cloud movements.- These can be detected by imagery from the orbiter. This could contribute greatly to our understanding of the general circulation.

9.0 MOLECULAR ANALYSIS SCIENCE INSTRUMENT TEAM REPORT

This is the unabridged Science Definition Report of the Viking Molecular Analysis Science Instrument Team. The Team members are:

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SCIENCE DEFINITION NO. 2

MOLECULAR ANALYSIS TEAM

I. Science Objectives

- A. Determination of the organic compounds present at and in the surface of Mars.
- B. Determination of the composition of the atmosphere at the surface.
- C. Determine the quantity, location and physical state of water present.
- D. Obtain some information concerning the nature of the inorganic surface material.

II. Science Rationale

A. Organic Analysis.- This experiment is designed to analyze the Martian surface for its organic content by vaporizing the material into a gas chromatographic column which in turn is connected to a mass spectrometer. The heating is to be accomplished in steps to vaporize those materials present which have sufficient vapor pressure, and ultimately to decompose pyrolytically non-volatile substances to volatile degradation products from which the nature of the material can then be deduced. The experiment is designed with systems of terrestrial origin such as soils in mind, but care has been taken to avoid any limitation to terrestrial systems and to assure that any types of compounds that may be produced upon heating the Martian sample and is capable of passing through a gas chromatograph will thus be detected and analyzed. In order to analyze materials not transmitted by the gas chromatograph, provision is also made to vaporize the material directly into the mass spectrometer. In addition, this approach provides redundancy in case of a malfunction of the gas chromatograph and may also permit the detection of very small traces of organic material that would not be sufficient to give a signal when separated in many fractions.

Samples (at least 8) are to be taken at various intervals during the entire 90-day mission to obtain a profile of the organic components in order to determine whether there are any changes during that period of time. A variety of samples are required for examination including: samples before and after the wave of darkening; samples analyzed in collaboration with the biological experiments; samples at various distances from the spacecraft and depths from the surface; and samples at long time intervals.

The integrated soil oven/gas chromatograph/mass spectrometer system shall have a dynamic range such that the system can analyze a soil sample assuming the volatile organic material from the sample ranges from 5 to 5000 ppm; and assuming the volatile organic compounds, when separated from one another by the gas chromatograph, will be divided into one peak containing 80% of the volatile organic compounds and 100 peaks of equal size containing the remaining 20% of

the volatile organic compounds. Five percent inert gas evolution will not incapacitate the system.

TABLE I.- TENTATIVE SOIL ORGANIC ANALYSIS SCHEDULE

Soil Samples				Calendar		Experimental Parameters		Comments
Analysis Number	Sample Number	Distance from Lander	Sample Depth	Day Sample Loaded	Day Sample Analyzed	Oven Size	Oven Temp	
1	1	Far	0-5 cm	3	3	S	150	Same Sample as 1st Biology
2					4	S	500	
3	2	Far	0-5	5	5	S	300	
4					6	S	500	
5	3	Near	0-5	4	7	S	150	
6					8	S	500	
7	4	Far	5-10	9	9	S	150	
8					10	S	500	
9	5	Far	0-5	16	16	L	150	Pre Wave of Darkening
10					17	L	500	
11	6	Far	0-5	26	26	L	150	Post Wave of Darkening
12					27	L	500	
13	7	Middle	0-5	44	44	L	150	
14					45	L	500	
15	8	Far	0-5	85	85	L	300	
16					86	L	500	
EGA-1	9	Far	0-5	88	88			
DIRECT-MS	1	Far	0-5	3	89			Same Sample as 1st Biology

Atmospheric Analyses On Days: 1,2,3,15,25,31,37,43,49,55,61,67,73,79,84

B. Atmospheric Analysis.-- The primary purpose of the atmospheric analysis is the identification of spectroscopically undetectable constituents of the Martian atmosphere and the determination of their abundances, including possible variations. It is suggested to do the necessary measurements either with a separate experiment package such as an optimized mass spectrometer and/or gas chromatograph or as a minimal experiment (abundance and isotopic ratios of the major constituents including nitrogen) using the mass spectrometer involved in the organic analysis described above. The more desirable maximum experiment would be an analysis of the atmosphere for all major and minor constituents including isotopic ratios and temporal variations of condensable constituents. In either case, there must be provision for discrimination between CO and N₂. It must also be possible to carryout several analyses, to test for both diurnal and long term variations.

There will be four analyses on each of the first three days spaced during the day and night and every six days thereafter including one immediately prior to each organic analysis. Each analysis consists of six MS scans with the filters and six scans without the filters.

The significance of the atmospheric analysis can be considered from at least three points of view:

1. The abundances and isotopic ratios of the major constituents must be known to evaluate the evolutionary history of the atmosphere and its relation to the history of the planet.
2. The abundances of possible minor constituents such as oxygen, methane, hydrogen sulfide, etc., can be used to evaluate the chemical equilibrium of the atmosphere and thus test for the presence of active processes, either biological or geological.
3. Diurnal and seasonal variations of condensable constituents can be correlated with the presence of ground deposits, clouds, variations in atmospheric pressure, and the wave of darkening.

C. Soil Water Analysis.-- A determination of water in its several possible forms is of primary importance to the life detection, the atmospheric analysis, and meteorological facets of the Viking 73 Mission. The possible forms of water may be arranged in a gradational series ranging from the bulk phases, ice and water through (a) water imbibed or absorbed by the soil matrix (b) water held in interlayer or zeolitic positions, (c) water bound in crystalline hydrates, and (d) hydroxyl groups (lattice water) integrally bonded in crystal lattices. In addition, H₂O and OH may exist in true solution in glasses and glass-like, amorphous mineral phases. Detection and measurement of the water evolved during programmed heating of a sample of Martian soil can indicate, with relatively little ambiguity, the amounts of water present in any or each of the states mentioned above.

Although the H₂O in some of the above forms is very tightly bound, its importance as a source for ultimately biologically available water should not be overlooked. Not only may Martian organisms have greater capacity for extracting this H₂O, but it may also be released by a variety of geochemical

processes, such as oxidation, devitrification, recrystallization, and other alteration processes. The presence and nature of all kinds of hydrate phases is also of great importance in evaluating the possible water-forming processes that may take place, or have taken place, on the planet. It is therefore essential to the water determination experiment that the heating cycle be carried to sufficiently high temperatures to provide information on all the probable hydrate phases in the Martian surface materials. The gases evolved will be analyzed for water and CO_2 using specific detectors. At least one experiment at the end of the organic analysis series will involve analysis of the effluent gases for other constituents such as CO_2 , H_2S , SO_2 , S_2 , NH_3 and nitrogen oxides, using the organic analysis mass spectrometer. The data will be correlated with the associated thermal effects to yield information about the mineralogical character of the surface material. This information will bear on the water problem by the identification of high-temperature hydrates as mentioned above, and by determining the presence and identity of hygroscopic salts that might be responsible for the existence of a life-supporting liquid phase with low vapor pressure. The identification of such hygroscopic salts is also essential to the interpretation of the low-temperature thermal analysis for soil water because of their effect on the freezing point depression.

The mineralogical data can also provide a preliminary evolution of the processes of weathering, erosion, transport, and sedimentation on the Martian surface, and shed light on the extent of planetary differentiative and geologic history, permitting assessment of the past as well as the present hospitality of the Martian environment for life. Information derived in this manner will also be useful in that it will:

- (1) Provide biologists with accurate estimates of the amounts and availability of water accessible to living organisms.
- (2) Provide meteorologists with estimates of water exchange between soil and atmosphere, an important part of the mass and energy balance at the Martian surface.
- (3) Provide hydrologists and geochemists with estimates of the water balance, including subsurface water storage.

The method to be employed should utilize a scanning calorimeter equipped with H_2O and CO_2 detectors as well as a similar oven connected to the mass spectrometer for at least one final experiment with complete effluent gas analysis. If scanning calorimetry is employed, it is necessary that endotherms occurring in the ratio of 1:7 within 5°C of each other in the temperature range -2° to 5°C be distinguished and measured. It is necessary to correlate the sample temperature with the successive appearance of increments of evolved gases to within 1 or 2°C in the vicinity of 0°C and to within about 10°C in the vicinity of -100°C and $+1200^\circ\text{C}$, respectively. Analyses are to be made within three days of touchdown and should be repeated whenever the results of the meteorological measurements indicate the occurrence of large fluctuations in atmospheric water, the deposition of frost etc., are revealed during the lander lifetime.

The experiment, in brief, consists of the following operations: (a) load oven with sample, (b) sample heated at programmed rate, (c) evolved vapors led to sensor, into a gas chromatograph column, to a pinhole inlet to the mass spectrometer, (d) at the same time endothermic and exothermic reactions within the sample are sensed, measured and correlated with sample temperature and (e) the gases evolved during the programmed scan analyzed and correlated with each thermal event.

TABLE II.- SOIL WATER ANALYSIS

Soil Samples				Calendar		Experimental Parameters		Comments
Analysis Number	Sample Number	Distance from Lander	Sample Depth (cm)	Day Sample Loaded	Day Sample Analyzed	Oven Size	Oven Temp (°C)	
1	1	Far	0-5	3			750	
2	4	Far	5-10	9			750	
3	5	Far	0-5	16			750	Pre Wave of Darkening
4	6	Far	0-5	26			750	Post Wave of Darkening
5	9	Far	0-5	88	88		750	EGA

III. Science Measurements

1. Mass Spectrometer

<u>Item</u>	<u>Minimal</u>	<u>Nominal</u>	<u>Maximal</u>
Mass Range	12-140	12-200	12-300
Resolution	Unit resolution or better w/20% valley	Unit resolution or better 10% valley 12-140; 20% valley 140-200	Unit resolution 10% valley 12-200; 50% valley 200-300
Scan Speed	< 30 sec	< 15 sec	(1) < 10 sec 12-300 or (2) < 30 sec 12-150
Reliability of mass value	Correct nominal mass for each maximum	Correct nominal mass for each maximum	Correct nominal mass for each maximum

III. Science Measurements (Continued)

1. Mass Spectrometer

<u>Item</u>	<u>Minimal</u>	<u>Nominal</u>	<u>Maximal</u>
Electron Energy	One value in range from 50-100 ev	Two values 70 ev + one in range 12-25 ev	Three values in ranges 50-100e 25-35 ev, 12-18 ev

2. Direct Input Sample Oven

Number of Samples	1	1	3
Qty of Samples	50 mg	50 mg	Choice of 10 & 50 mg for each of three samples
Heating rate	< 20° C/min.	< 20° C/min. w/feedback	< 30° C/min. w/feedback
Maximum Temp.	500° C	500° C	500° C
Minimum Temp.	Ambient	Ambient	Ambient

3. Atmospheric Inlet for Mass Spectrometer

Number of Samples	1	60	60
Pretreatment	Removal of CO & CO ₂	With and without removal of CO & CO ₂	With and without removal of CO & CO ₂

4. Gas Chromatograph for Mass Spectrometer

<u>Item</u>	<u>Minimal</u>	<u>Nominal</u>	<u>Maximal</u>
Number of Samples	6	8	8
Qty. of Samples	50 mg	Choice of 25 & 250 mg	Choice of 25 & 250 mg
Sample Temp.	500° C	Choice of 2: 150° C ±10° 300° C ±20° 500° C ±25°	Choice up to 3: 150° C ±10° 300° C ±20° 500° C ±25°
Heating Rate	< 30 sec. ambient	< 30 sec. ambient to maximum	< 30 sec. ambient to maximum

III. Science Measurements (Continued)

4. Gas Chromatograph for Mass Spectrometer

<u>Item</u>	<u>Minimal</u>	<u>Nominal</u>	<u>Maximal</u>
Max. Temp. Column	200° C	200° C	250° C
Temp. Program	1 fixed program	1 fixed program	2 or more choices
Time for GC	30 min.	45 min.	45 min.
Efficiency (theoretical plates)(using silicon Igepal)	10,000	50,000	100,000
Universal GC Detector	yes	yes	yes
Carrier Gas Separator (shall not preclude the analysis of sulfurs or halogen containing compounds)	yes	yes	yes
Sample splitter	yes	yes	yes
Splitter Dynamic Range	1 or 25	>25	>25

5. Atmospheric Gas Chromatograph

Equiv. Efficiency	3 ft. to 1/16 in. molecular sieve	3 ft. to 1/16 in. molecular sieve	3 ft. to 1/16 in. molecular sieve
Column Temp.	125° C	125° C	125° C
GC Time	20 min.	20 min.	20 min.
Carrier Gas Separator	yes	yes	yes
Detector	Separate detector	Separate detector	Separate detector

III. Science Measurements (Continued)

6. Soil Water Analysis

<u>Item</u>	<u>Minimal</u>	<u>Nominal</u>	<u>Maximal</u>
Forms of H ₂ O to be measured	solid liquid bound	solid liquid bound plus adsorbed in hydrates	solid, liquid, bound plus adsorbed H ₂ O in more stable hydrates and crystal lattices
No. of samples	4	5	6
Depth of samples	surface	surface plus at 5-10 cm	surface plus one at 5-10 cm and one at 10-20 cm

Measurements:

ΔH_{fusion} and $\Delta H_{\text{vaporization}}$	DTA	Differential Scanning Calorimetry (DSC)	Differential Scanning Calorimetry (DSC)
Detectability	0.1% equiv. H ₂ O to total sample weight (.08 cal/gm _{sp} le)	0.05% equiv. H ₂ O to total sample weight (.04 cal/gm _{sp} le)	0.05% equiv. H ₂ O to total sample weight (.04 cal/gm _{sp} le)
Range	0.08 - 250 cal/gm _{sp} le	0.04 - 250 cal/gm _{sp} le	0.04 - 250 cal/gm _{sp} le
Accuracy	±50%	±25%	±25%
<u>Sample Temperature</u>			
Range	Ambient to 300° C	Ambient or -20° C whichever is lower to 750° C	Ambient or -120° C whichever is lower to 1200° C
Accuracy	±2° C to 200° C ±10° C from 200° C to 300° C	±1° C to 200° C ±5° C from 200° C to 750° C	±1° C to 200° C ±5° C from 200° to 1200° C
Special Require- ment	Temperature scan rate low enough to distinguish endothermes in a ratio of 1:7 between -2° C and 5° C	Temperature scan rate low enough to distinguish endothermes in a ratio of 1:7 between -2° C and 5° C	Temperature scan rate low enough to distinguish endothermes in a ratio of 1:7 between -2° C and 5° C

III. Science Measurements (Continued)

6. Soil Water Analysis

<u>Item</u>	<u>Minimal</u>	<u>Nominal</u>	<u>Maximal</u>
Effluent Gas Composition	H ₂ O & CO ₂	H ₂ O & CO ₂ plus CO, O ₂ , SO ₂ , H ₂ S	All gases
Detectability	H ₂ O, CO ₂ to: 0.1% sample wt.	H ₂ O, CO, O ₂ , SO ₂ , H ₂ S to: 0.05% sample wt.	All gases to: 0.01% sample wt.
Accuracy	Factor of 2	Factor of 2	Factor of 2
Range	0.001 - 0.4 gm/gm _{sp}	.0005 - 0.4 gm/gm _{sp}	.0001 - 0.4 gm/gm _{sp}

7. Soil EGA by Mass Spectrometry

Forms of H ₂ O to be measured	same as for sensor-EGA experiments described above		
No. of samples	1	1	1
Depth of samples	0-5 cm	0-5 cm	0-5 cm

Measurements:

Heat effects as in sensor-EGA experiments

Sample temperature as in sensor-EGA experiments

Effluent gas composition:

Gases determined all detectable by MS up to mass 100

Accuracy	±10% in range 10 to 50 wt % ±20% in range 0.5 to 10 wt %	±5% ±10%	±1% ±1%
Detectability	0.5 wt % of soil sample	0.1 wt % of sample	0.05 wt % of sample
Range of conc'n.	0.5 to 50 wt % of sample	0.1 to 50 wt % of sample	0.05 wt % of sample

III. Science Measurements (Continued)

8. Sample Acquisition

<u>Item</u>	<u>Minimal</u>	<u>Nominal</u>	<u>Maximal</u>
Location	Anywhere	Beyond the direct retrorocket contamination area and directed by imagery data.	Beyond the direct retrorocket contamination area and directed by imagery data.
Depth	Scrape surface	Choice of 2: 0-5 cm 5-10 cm	Choice of 3: 0-5 cm 10-15 cm 25-30 cm
Auxiliary Equip.	Soil temperature	Soil temperature	Soil temperature

A. Special Requirements

(1) Environmental

magnetic: less than 0.1 gauss.
thermal: -50° to $+50^{\circ}$
vibration:
radiation:
electrical:
chemical: no release of gases (except He and CO_2) and no H_2O or organic compounds during or shortly before acquisition of an atmospheric or soil sample.

(2) Orientation

(3) Location on Spacecraft: reachable by sampler and away from sources of contamination. Atmospheric inlet located away from and up wind of the biological experiment.

(4) Distance from Spacecraft: inside.

(5) Deployment: n.a.

B. Type of data

(1) GCMS

(a) Maximum oven temperature.

(b) Oven heating time.

(c) A representation of the gas chromatogram (e.g., output of GC detector every 5 seconds.

(d) Temperature of Gas Chromatographic column at 5 min. intervals.

(e) Total energy input to the splitter.

(f) The following data for each mass spectrometer scan:

1. The time (relative to the start of the gas chromatogram) of start of scan.

2. Total ion current at that point.

3. An indication of the mass number of all peaks with an intensity greater than 1.5% of the base peak.

4. Same for peaks of intensity between 0.2 and 1.5% of base peak.

5. The intensities of all peaks of those listed under (3) to an accuracy of $\pm 10\%$ of that intensity.

10.0 RADIO SCIENCE INSTRUMENT TEAM REPORT

This is the unabridged Science Definition Report of the Viking Radio Science Team. The Team members are:

Von R. Eshleman (Leader)

Dan L. Cain

William H. Michael, Jr.

Mario D. Grossi

RADIO SCIENCE INSTRUMENT SCIENCE DEFINITION NO. 2

I. Science Objectives

The aim of the Viking Radio Science Instrument Team is to maximize the potential scientific capabilities of the Viking radio communications and radar landing systems, consistent with their prime objectives.

Measurements of scientific interest include:

A. Atmospheric and ionospheric properties along the entry trajectories, over the landing sites, and over many other locations and for many local times at Mars;

B. The locations of the landers, possible short-term, centimeter-scale, seismic motion of the landers, the spin vector of Mars, and the planetary radii at the landing sites;

C. Physical and electromagnetic properties of the surface layer of Mars at the landing sites, to depths of many meters, and other radio reflecting properties of the surface and its topography along the tracks of the orbiters;

D. Gravitational moments of Mars, effects of the asteroid belt on its orbit, perturbations due to the mass of Phobos, and other phenomena in the area of celestial mechanics;

E. The interplanetary medium, the density, dynamics, and magnetization of the solar corona, and the general-relativistic effect of the mass of the Sun on electromagnetic waves and on the motion of Mars.

II. Science Rationale

The initial conceptual design and operational plans for the lander radio and radar systems have, of course, been determined almost entirely from the mission support requirements for communications, tracking and landing. Some of the above experiments in radio science and in celestial mechanics can be conducted with no change from these initial plans.

However, very much more scientific return is possible if modifications are made. We of the Radio Science Instrument Team take as our task the determination of ways of maximizing the scientific profit with minimum loss in terms of cost and inconvenience in the mission support areas (communications, tracking and landing).

Since more than one scientific aim may be achieved by one change in a radio system, we choose to present the Scientific Definition in terms of a listing and description of proposed system capabilities beyond those of the initial bench-mark design. Since we are proposing perturbations to existing conceptual designs, our order of priority in this document is determined both by expected scientific return and by consideration of the impact of the

proposed change on mission support and mission operations. That is, our highest priorities are for what we believe will yield the most science for the least trouble and cost.

As a starting point, we assume that S-band apparent range-rate ($\dot{R}$) apparent range (R), and signal amplitudes are to be measured between the landers and the Earth (L-E links) and between the orbiters and the Earth (O-E links) based on coherent, round-trip, S-band, continuous-wave and modulated-wave propagation. We assume the initial conceptual design of a 400 MHz, open-loop, non-coherent, data link between each lander and either orbiter (L-O links). Finally, we assume that there will be several landing radar systems.

Ideally, we would like to have range-rate and range measured on all of the links (L-E, O-E, L-O, and O-O), including corrections for dispersion such as can be provided by using two coherently related frequencies. That is, differential dispersive range-rate ($\Delta\dot{R}$) and differential dispersive range (ΔR) dual-frequency measurements would make it possible to determine the columnar content of electrons along all of the paths for study of various plasma regions, and for correcting apparent range-rate ($\dot{R}$) and range (R) measurements to determine true range-rate and range for maximum accuracy in the celestial mechanics experiments. These measurements would be applicable to the science objective given in I-A, B, D, and E.

In principle, the lander-radar echoes could provide information about the surface and near sub-surface of Mars at the landing sites. Bistatic radar echoes over the paths O-Mars-E or E-Mars-O could provide topographic information and Mars-crust data along the tracks of the orbiters. Monostatic radar carried in the orbiters could also provide such data. Of particular interest would be the possible detection and location of sub-surface water. These measurements would be applicable to the science objectives listed in I-C.

Polarization measurements on the L-E and O-E links would be particularly interesting for study of the solar corona, if the spacecraft are still operational when Mars is near superior conjunction. Should dispersive measurements not be possible, polarization would help partially for correcting apparent range-rate and range data to determine true range-rate and range. The correction would be for the effects of the terrestrial ionosphere, but not for the interplanetary medium.

Accurate tracking data on the L-O and L-E paths during entry could provide data on spacecraft deceleration and translation due to atmospheric density at high altitudes and winds at low altitudes.

We consider separately the direct links and the bounce (radar) links. Our order of priority for the direct links is listed here, with fuller descriptions in the next section:

1. Measure $\dot{R}$, apparent range-rate, on the L-O links. Add $\Delta\dot{R}$, R , and ΔR , capability on this link at lower priority than the other four items listed here.

2. Add dispersion measurement capability (at least $\dot{\Delta R}$, but also ΔR as second priority) on the O-E and L-E links.

3. Measure $\dot{R}$ (but also $\dot{\Delta R}$, R , and ΔR , in that order of importance) on O-O links.

4. Measure range-rate and range parameters (apparent values and corrections for dispersion) on the L-O and L-E links during landing.

5. Measure Faraday polarization effects on the O-E (first priority) and L-E links.

We are continuing our study of the feasibility and potentialities of surface-bounce studies. Of particular interest are suggestions to:

1. Use lander-radar echoes to study the crust of Mars at the landing site.

2. Use the S-band and/or VHF system for bistatic radar (surface-bounce) studies of the crust and topography, using O-Mars-E links and/or E-Mars-O links.

We do not feel that these subjects can be specified in terms of equipment parameters without more study and detailed interaction between radar system designers and those directly interested in the scientific potentialities.

The S-band O-Mars-E link bistatic measurements could be done with no change in present bench-mark design, and would only involve S/C reorientation and reception with special equipment on earth as operational requirements. An up link experiment could be much more sensitive, but would require more S/C equipment and data. The use of lower frequencies would be desirable.

With regard to the lander radar, we suggest that the very high importance of the possible detection of subsurface water is sufficient to outweigh its low probability of success, so that the design of the lander radar system should be strongly influenced by the scientific requirements. This implies that a relatively low frequency be used (perhaps on the order of 100 MHz). It may be that a CW instead of a pulsed system would best satisfy the dual requirements for a lander radar system for low altitude altimetry and for study of the crust.

A meeting is planned for the near future to explore these matters more fully.

III. Science Measurements (Direct Links)

A. Priority 1: Apparent range-rate on L-O links.

Required Measurements: $\dot{R}$ on L-O links.

How Accomplished: There appear to be two possibilities for including a reference frequency in the L transmitted spectrum which can then be measured in O to determine R: (1) Derive frequency of L 400 MHz transmitter from oscillator locked to earth via S-band system; or (2) Depend on the stability of a free-running oscillator in L. On O, the frequency would be measured by comparison with an oscillator locked to earth by its S-band system, or by comparison with a free-running oscillator. The data would consist of a count of beat-frequency zero-crossings. There are additional possibilities for measuring R over the sum of two or all three of the separate legs of the triangle (E-L-O-E).

Accuracy: $\dot{R}$ to at least 1 ms^{-1} , preferably to 10^{-2} ms^{-1} .

Range: $\dot{R}$ measurable to 10^4 ms^{-1} .

When: On every fifth pass of an O over a L, or more often if possible.

Antennas: As presently planned.

Data: On each data pass, make independent measurements every minute requiring at least 24bps during pass.

Additions: At lower priority, measure $\dot{\Delta R}$, R and ΔR on L-O links, by techniques discussed below.

B. Priority 2: Dispersion on O-E and L-E links.

Required Measurements: $\dot{R}$, R, $\dot{\Delta R}$, ΔR , and signal amplitudes.

How Accomplished: Three possibilities: (1) Use O "wake-up" transmitter coherent with S-band, and L 400 MHz communications transmitter coherent with S-band, for O-E and L-E links; (2) Add a small X-band beacon on O and L, coherent with S-band for downlink measurements; or (3) Go up-link at 400 MHz and S-band to communications receivers, with circuitry to provide dispersive results to data system.

Accuracy: $\dot{R}$ to $10^{-3} \text{ msec}^{-1}$ (10 minute run) and R to 15 m per measurement, as in present S-band operations. $\dot{\Delta R}$ and ΔR measured with sufficient accuracies to detect electron columnar effects of $10^{12} \text{ m}^{-2} \text{ s}^{-1}$ (2 minutes) and 10^{16} m^{-2} per measurement, respectively. These last numbers can be transcribed to velocity and distance metrics by multiplying by $r_e \lambda^2 (2\pi)^{-1} \text{ m}^3$, where r_e is the electron radius ($2.8 \times 10^{-15} \text{ m}$) and λ equals $(\lambda_1^2 - \lambda_2^2)^{1/2}$, where λ_1 is the longer wavelength. Thus for 400 MHz, and S-band, $\dot{\Delta R}$ and ΔR are $2.5 \times 10^{-4} \text{ ms}^{-1}$ and 2.5m, respectively, while for an S-X system they are about 10^{-5} ms^{-1} and 10^{-1} m , respectively. Plasma studies still of great interest even if accuracies are a magnitude poorer, and celestial mechanics corrections still valuable at two magnitudes poorer.

Range: $\dot{\Delta R}$ and ΔR measurements should be able to provide unambiguous plasma measurements up to $10^{17} \text{ m}^{-2} \text{ s}^{-1}$ and 10^{21} m^{-2} .

When: O-E links of high priority for occultations. For celestial mechanics, fewer long continuous runs wanted on O-E and L-E links rather than many short runs. L-E links should work to 90° zenith angle at the L, if possible. Added advantages in celestial mechanics if more than one (up to four) of the links are operated simultaneously for some of the runs. Special interest in extended lifetime of O or L, and operation for several weeks at superior conjunction.

Antennas: For combined S-band and 400 MHz links, might use presently planned S/C antennas and reception at upgraded (for operation at S-band as well as 400 MHz) Arecibo dish. With higher gain S/C antennas at 400 MHz which are directed toward earth, could use DSN antennas. For S-X combination, the two channels could share the high-gain S/C antennas, and reception could be in single dishes at the DSN sites, or at a few non-DSN sites. For the up-link option, a 400 MHz transmitter at Stanford or at Arecibo might be used, but making it coherent with up-link S-band would be difficult.

Data: Taken on ground in down-link options, in manner similar to that used for Mariner IV and V cruise and occultation. For up-link, S/C data requirements similar to dual-frequency experiment on Mariner V.

C. Priority 3: Measurements on O-O links

Required Measurements: $\dot{R}$, $\Delta\dot{R}$, R and ΔR , in that order of priority.

How Accomplished: Have the S-band transponder on one of the two orbiters operate either in the standard way for the O-E link, or change by command to transmit on the up-link frequency and receive on the down-link frequency. Then R and $\dot{R}$ could be measured between the two orbiters. A similar change in operation of the 400 MHz system (assuming the O's have transmitters as well as receivers) would add the possible measurement of $\Delta\dot{R}$ and ΔR .

Accuracy and Range: As in B above.

When: Particular interest when O-O ray path is near occultation, but celestial mechanics applications at other times.

Antennas: Same as provided for other purposes. May be advantageous to orient SC for the times when the O-O link is active.

Data: Fifteen minute runs, 4 per orbit, 1 orbit every 5 days. Approximately 66 bps during run.

D. Priority 4: Measurements during landing

The measurements would be those of A and B, but conducted during landing so that the atmospheric effects of deceleration and translation could

be measured as accurately as possible. It should be noted that tracking during the crash of LO V seems to show a lunar atmosphere 10^{-7} that of earth.

E. Priority 5: Faraday polarization measurements

Required Measurements: Faraday angle measured at DSN sites on O-E and L-E links.

How Accomplished: Transmit linear polarization on S-band (and possibly on 400 MHz). Measure polarization angles at earth by the technique used by G. Levy during superior conjunction of Pioneer 6.

Accuracy: One degree

Range: Zero - 180 degrees

When: During a few weeks when Mars is near superior conjunction

Antennas: Linear transmitted polarization

Data: Taken at DSN sites, as in Pioneer 6 experiment

IV. Instrument Information

III-A For use of free-running oscillator, may not require any increased power or weight on L. For locked oscillator, perhaps 0.5w and 1 pound required on L. On O, receiver modifications and counter estimated at 0.5w, 1.5 pounds. Addition of range and dispersion on L-O links estimated at 2w, 3 pounds on both L and O.

III-B For option (1), may not require any additional power and weight. Option (2) would be an X-band 100mw beacon for 3w of prime power, 3 pounds total weight, on both L and O. Option (3) would require receiver redesign and data system on L and O, for perhaps 0.5w, 1 pound.

III-C No impact on L. For O, redesign work, but not large impact on weight and power.

III-D May only require different turn-on time for lander equipment.

III-E No added weight or power.

11.0 SEISMOMETRY SCIENCE INSTRUMENT TEAM REPORT

This is the unabridged Science Definition Report of the Viking Seismometry Science Instrument Team. The Team members are:

Don L. Anderson (Leader)

Robert L. Kovach

Gary Latham

Frank Press

George Sutton

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SEISMIC EXPERIMENT SCIENCE DEFINITION NO. 2

Seismology

I. Science Objectives

A. To determine the amplitude, spectrum, polarization, and source of the continuous background microseism activity.

B. To determine whether Mars is a tectonically active planet and to determine the level, nature, and location of tectonic activity.

C. To determine the internal structure and composition of Mars; specifically, to determine if Mars has a crust and a core and to determine if the mantle of Mars is similar in composition to the mantle of the Earth.

D. To determine the influx rate of meteorites.

E. To determine the mechanical properties of the material near the lander.

II. Science Rationale

The National Academy of Sciences* has recommended that the Nation's planetary program should be designed to provide for progress in our understanding of:

- (1) The origin and evolution of the solar system.
- (2) The origin and evolution of life.
- (3) The dynamic processes that shape man's terrestrial environment.

*"Our view is that no single goal, such as the determination of whether life exists in other parts of the solar system, should be set for the planetary program. Rather, it should be emphasized that the scientific return from planetary exploration will flow into many areas of science and thereby strengthen them.

"Because of the rich contribution that planetary exploration can make to a broad range of scientific subjects, we recommend that the planetary exploration program be presented not in terms of a single goal but rather in terms of the contribution that exploration can make to a broad range of scientific disciplines.

"The most important single instrument for study of the interior is a seismometer landed on the surface. Analysis of seismic signals permits a

*Planetary Exploration 1968-1975, Report of a Study by the Space Science Board, Nune 1968, National Academy of Sciences, National Research Council.

good first-order determination of (a) the compressional wave velocity versus depth, (b) the density versus depth, and (c) the existence and locations of earthquakes. The first two are of direct interest in the study of planetary interiors and lead to certain inferences about the composition of the interior. Their determination depends heavily on the existence of earthquake-like disturbances. The third permits a few fairly firm inferences about how the internal dynamics of Mars compare with the Earth.

"The seismicity of Mars is a most informative measure of the planet's internal regime. Questions of interest here are: Is Mars highly seismic, aseismic, or slightly so? If it is seismic, do the epicenters cluster along narrow structural belts? The relevance of these questions stems from recent discoveries about the relations of the Earth's seismicity to its large-scale internal motions. It has been found that major "thin" (50 to 100 km) shells of the Earth's surface, with continental dimensions, are moving relative to each other at rates of about 2 to 20 cm per year. These motions are apparently driven by heat generated in the mantle and produce nearly all the Earth's seismicity, which occurs along the boundaries between shells. Information on the seismicity of Mars can indicate the extent to which it shows the same tectonic style. This is of direct relevance to the question of the history of Mars, the history of its volatiles, and the amount of heat generated in its interior."

The above comments from the National Academy of Science Space Science Board Report summarize concisely the scientific rationale of the seismic experiment. The extended lifetime of the landers and the fact that simultaneous information will be available from two locations on the planet, since Viking will be a dual mission, considerably enhance the value of the seismic experiment. In fact, the seismic experiment is the only one that capitalizes directly on the dual nature of the mission. Marsquakes can be unambiguously detected and located if they are recorded on two separated three-component seismometers. Ten to twenty seismic events dispersed around the planet will permit a first-order model for the internal structure of Mars to be developed. The advantages to be gained from a long-lived experiment are obvious. Useful but incomplete internal models can be developed from fewer events, but the total absence of seismicity over the recording period would also be significant.

In addition to determining the seismic activity and the structure of the interior of Mars, the seismic experiment is designed to measure the background noise level and some of its characteristics (frequency, amplitude, variability, polarization, etc.). Seismic noise takes on a new meaning in a completely unknown environment. On the Earth, instrumental sensitivity is limited by the background noise and the response of seismic instruments is designed to minimize unwanted vibrations which are due to microseisms and atmospheric disturbances. Sources of noise on the Earth are fairly well known and are usually of little interest to the seismologist except for occasional studies where distant meteorological phenomena have been identified in remote areas where they would otherwise have gone unreported. Meteorological phenomena such as winds, barometric and temperature changes

couple effectively into the ground as seismic energy and can be detected at large distances by seismic observatories where they are recorded as continuous background "noise." On Mars the origin and characteristics of this kind of "noise" are important, both for fundamental problems of the meteorology of Mars which cannot be answered by meteorological observations at a single point, and also for reasons of optimal seismometer design for future landers. Most of the background vibrations, regardless of their source, are due to traveling surface waves. The periods, polarization, and velocities of these waves give information about the structure of the outer layers of the planet.

The seismic experiment is intended to provide information about this kind of "noise" which, on Mars, is actually a useful "signal," and also to detect conventional seismic waveforms generated by tectonic activity and meteorite impacts. Because of the biological emphasis of this particular mission, the proposed seismic instrument is a minimal system in the sense that weight constraints limit it to measurements of the high frequency end of the seismic spectrum.

III. Science Measurements

A. Qualitative Measurements Required.

1. Three perpendicular components of ground motion will be measured over as broad a frequency range as possible in the interval 0 to 100 Hz with maximum sensitivity in the range of approximately 0.05 to 10.0 Hz. Data compression will be achieved by averaging the ground motion over suitable periods of time. Dynamic range is increased by narrow band filtering the data at two or three frequencies. The seismic experiment will therefore generate a maximum of nine channels of continuous data. A trigger mode of operation will be set into operation when an event of large amplitude occurs; this effectively increases the sample rate for a short period of time.

B. Quantitative Measurements Required

1. Resolution

50 millimicrons or less of ground displacement at 1 Hz

2. Accuracy

±10 percent of true ground motion amplitude

3. Range

40 dB or greater dynamic range capability for each channel

4. Timing precision

A relative timing precision of 1/2 second is required;
1/10 second is preferred

C. Operational Requirements

1. Sequence

- a. Deploy, if necessary
- b. Uncage
- c. Calibrate; recalibrate at least once every 5 days
- d. Determine orientation (to within 5° for both azimuth and level)
- e. Run continuously with an averaging time dictated, in part, by the lander storage and transmission constraints and the bit rate requirements of other experiments when they are operational.

2. Command

- a. Turn on - turn off
- b. Uncage
- c. Calibrate
- d. Change gain
- e. Change trigger threshold
- f. Change filter settings
- g. Suppress trigger
- h. Override trigger
- i. Change integration or averaging time
- j. Change sampling rate
- k. Change mode (continuous to trigger or event mode)

3. Calibration

- a. After deployment on the Martian surface, the calibration of each axis of the seismometer will be performed using transient and sine wave input. This calibration will be compared to an absolute preflight calibration to determine changes in certain seismic detection parameters. Calibration will be performed by putting a forcing current through the seismometer calibration coil. This signal can be programed and provided by the lander as well as on Earth command.

4. Longevity

- a. Since the background noise level is presumably time variable and the occurrence of Marsquakes is expected to be erratic both in space and time, a long-lived experiment is extremely desirable. Although the seismic experiment is designed as a preliminary and reconnaissance experiment, it is conceivable that if Mars is tectonically active or if a sufficient number of large meteorites strike the surface, a fairly detailed structure for the interior of Mars can be inferred from a long-lived seismic

experiment. The case for longevity and the simultaneous operation of two landed seismometers cannot be overstated.

5. Prerequisite or Corequisite Scientific Measurements

- a. In a sense the present minimal seismometer package is a prerequisite for later, more ambitious seismic experiments on Mars.
- b. The meteorological and seismological experiments are complementary. Measurement of the local winds will help to reduce the ambiguity of identification of triggered events. Background noise that does not correlate with the local meteorology can be attributed to other sources. The combination of seismic, meteorological, and orbital photography information can give information about the motions of weather fronts. The time variability of the seismic background gives information about meteorological variability over a much larger area than a single meteorological observatory.

D. Special Requirements

1. The seismometer sensor may be mounted internal to the spacecraft, in the bottom of a leg, or deployed external to the lander. If the sensor is placed inside the lander, the lander should not vibrate by self-induced or meteorologically induced loading by more than the minimum detectable signal within or below the pass band of the instrument unless the sensor can be isolated from such vibrations and, at the same time, maintain firm coupling with the Martian surface. The latter can be accomplished by placing the seismometer sensor in a footpad. If the sensor is attached to the lander during operation, the lander transmissibility should be greater than 0.8 for frequencies lower than 10 Hz and have no undamped resonances less than 10 Hz; this is to keep the lander from acting as a mechanical filter to seismic signals in the period range of interest. It is preferable to deploy the sensor external to the spacecraft.
2. The orientation of the sensor should not be critical for operation; however, it is preferable that it be level to within 15° . It is desirable that the orientation of the sensor in deployed configuration be known to within 5° in both azimuth and level.
3. Variations in magnetic fields produced in the interior of the sensor by the lander and its subsystems should not exceed 7×10^{-8} webers/m²-sec in the pass band of the seismometer system. This is not a stringent requirement.
4. The sensor and the associated electronics do not have to be in the same part of the lander. The seismometer should operate in the temperature range 100 to 300° K without thermal control. It is desirable that the sensor temperature be monitored to $\pm 5^\circ$ C. It is desirable that the temperature of the central electronics package be monitored to $\pm 5^\circ$ C and that the

electronic components should be designed to operate within the temperature range -10°C to $+50^{\circ}\text{C}$.

E. Data Requirements

1. Provision should be made for A-D conversion of a minimum of nine channels (three components at three frequencies). During most of the duration of the seismic experiment, the possible sampling rate (during the triggered mode) may be as high as two samples per second per channel. A sampling rate of up to 20 samples per second per channel should be provided for real-time transmission of seismic data during certain portions of the experiment.

A 10-second averaging time will permit a fairly accurate characterization of the background level and will also give a crude representation of most of the phases from a distant seismic event. In this scheme nine channels of data (three components at three frequencies) will generate 7.2×10^5 bits per day. An alternate mode using only six channels (three components at two frequencies) will generate 4.8×10^5 bits per day. Other options include combining the horizontal components or sampling them alternately. With two filtered outputs from each component, this would generate four channels of data and 3.2×10^5 bits per day. This is the preferred compromise background mode and can be taken as a design goal.

The triggered mode will require approximately 10^5 bits per day. This assumes that 10^4 bits can accurately characterize a signal and therefore allows for 10 triggered events per day. A signal can be fairly accurately reconstructed from 2 samples/sec from each channel if there is no requirement that the samples be taken at equal time intervals. This requires aperiodic access to the A-D converter and memory or a buffer storage capability.

Triggered events will be stored only up to some fraction of the maximum allotted storage allocated to the seismic experiment. For events in excess of this allocated amount, only the amplitudes and relative times of the triggering event will be stored. Alternatively, the total number of bits generated per event can be reduced by decreasing the sampling rate, by decreasing the time length of the triggered signal to be stored, or by decreasing the number of channels to be stored. In the triggered mode, the minimum sampling rate is 2 samples/sec per channel (aperiodic sampling), the minimum sample length is 3 seconds, and the minimum number of channels is three (one frequency from each of the three components). The optimal sample length is 3 minutes for each triggered event. The averaging and triggering schemes are similar to those required in the meteorological experiment and the electronics might well be shared.

2. The data processor will provide the following:

- a. Amplification of the seismic signal from each sensor
- b. Low-pass filtering and averaging of the microseism
(i.e., background) signal

- c. Detection and storage of seismic events plus
time of event

The combination of high frequency roll-off filters with the seismometer response provides a band pass filter.

Priority II.- Expanded Seismometer System

The purpose of the expanded seismometer system is to provide an instrument which will be more sensitive to long-period seismic signals. The longer period instrument is desirable since long periods suffer less attenuation and therefore travel longer distances. In addition, long-period surface waves can be measured. With a single seismometer and a single large Marsquake, it is possible, in principle, to determine the structure throughout the depth of the planet. This system would be preferred if additional weight, volume, and power can be made available for the seismic experiment. The expanded instrument would be triaxial and intermediate in period (2 to 5 sec). The minimum detectable signal at 1 Hz would be 1 millimicron. The weight of such an instrument would be approximately 15 pounds, including electronics.

12.0 UV PHOTOMETRY SCIENCE INSTRUMENT TEAM REPORT

This is the unabridged Science Definition Report of the Viking UV Photometry Science Instrument Team. The Team members are:

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ULTRAVIOLET PHOTOMETER SCIENCE DEFINITION NO. 2

I. Science Objectives

- (1) To measure the amount of solar radiation in the middle ultraviolet reaching the local environment where the spacecraft has landed.
- (2) To characterize the absorber which may protect the surface from ultraviolet light as either a molecular absorber, such as ozone, or a large particle scatterer, such as dust or haze.
- (3) To measure changes in ultraviolet shadowing due to clouds, and to provide information about their constitution.
- (4) To determine whether or not the blue haze - blue clearing phenomenon is atmospheric.
- (5) To find out if the passage of the wave of darkening over the lander site is atmospheric in its nature - or more specifically to see if its occurrence is related to atmospheric changes seen by an ultraviolet photometer.
- (6) To provide the phase function of the dominant scatterer(s) and determine whether the dominant scatterer is a molecular species or a large particle Mie scatterer such as dust or an aerosol.
- (7) To determine the local scale heights, i.e., distributions with altitude, of the absorption and the scattering components of the middle ultraviolet opacity.

II. Science Rationale

Remote ultraviolet measurements can sample from the outside into optical depth $\tau = 1$. The important point is whether $\tau = 1$ is reached at the very surface of the planet or in some boundary layer above the planet surface. This boundary layer might take the form of large particle opacity such as clouds of dust or aerosols. Another possibility is that molecular absorption could result in a boundary layer opacity.

It is known that one of the crucial constraints for Earth biology to exist in its present form is that the atmosphere must shield the environment from ultraviolet radiation shortward of about 2800 Å. This constraint arises because various key organic molecular groupings are destroyed by ultraviolet radiation. The threshold wavelengths range from about 2200 Å to 2800 Å depending upon the molecular grouping, i.e., proteins, DNA, etc. The presence of CO₂ in the Mars atmosphere means that environmental shielding is provided shortmeans that environmental shielding is provided shortward of about 2000 Å. On the Earth shielding shortward of 2000 Å is provided by O₂. The important question is whether the Mars environment is shielded in the 2000 Å to 2800 Å wavelength range by some atmospheric species, such as ozone as on the Earth, or by some other atmospheric phenomenon. The penetration of middle ultraviolet

radiation to the surface of Mars would not necessarily rule out biological forms. This penetration would, however, impose important boundary conditions upon the forms that Mars biology could assume. In a more general sense it can be said that solar energy must reach the environment for life to develop and exist; however, the solar flux which does reach the environment limits the types of biological forms obtainable.

The middle ultraviolet shielding that occurs in the Earth's atmosphere has a double significance. First of all, it allows for the development of radiation sensitive biology, and second, it indicates the presence of ozone (O_3). Ozone can be formed only in the presence of O_2 . The high equilibrium density of O_3 in the Earth's atmosphere can occur only because of the large amount of O_2 present. It has been estimated that only about 0.1% O_2 would exist in the Earth's atmosphere in the absence of photosynthesis. The detection of middle ultraviolet opacity due to O_3 in a planetary atmosphere is in itself indicative of biological activity. For this reason it is important to classify any ultraviolet absorption mechanism as being due to a loosely bound molecular absorber, such as ozone, or as being due to a dust or haze condition which might exist on Mars.

It is implicit in the preceding discussion that ultraviolet photometry at the surface of Mars provides data which contribute in various ways to the meteorologic, imaging, and biologic studies of Mars. It is also true that the complete interpretation of the ultraviolet photometer experiment is dependent upon the other lander science experiments. In this sense a lander ultraviolet photometer should be configured in a way to maximize the total scientific return when conflicts are not a problem.

III. Science Measurements

I. First priority measurements

A. Quantitative Measurements Required

It is proposed here that the opacities at 2500 Å and 3400 Å be measured. The 2500 Å wavelength lies in the middle of the ozone Hartley band absorption system and also lies in the wavelength region of biological importance. The use of a second wavelength, 3400 Å, acts as a control wavelength and provides information about the nature of the absorber. Loosely bound molecular absorbers such as O_3 and NO_2 have very large absorption cross sections at 2500 Å but are quite transparent at 3400 Å. If the opacity at 2500 Å is due to a planet wide haze or dust layer, then its effect would also be present at 3400 Å due to the slowly varying wavelength dependence of Mie scattering.

In choosing the experimental method, it was originally felt that the most desirable instrument would form an image of the sun and discriminate against off-axis light to minimize the effect of ground reflection. However, the necessity of tracking the sun makes this method prohibitively complicated. Another method would use a detector with uniform sensitivity in all directions.

In this method one would essentially measure the sun's intensity from zenith to sunset and find the atmospheric opacity this way. The reflections off the Lander itself would make this method difficult. In fact, any method which proposes to look directly at the sun seems to require moving parts and necessitates an instrument which mechanically extends up in one manner or another. All of the problems of looking directly at the sun are complicated by the necessity of making measurements near sunset (or sunrise) in order to measure optical depths which may be as small as τ (2500 Å) $\sim$ 0.05 to 0.20.

The method suggested essentially uses the major atmospheric constituents as "omnidirectional detectors" which in turn "relay" the amount of solar flux they received to a "receiver" on the Lander itself. The "relay" process is, of course, Rayleigh scattering. Mie scattering may play a role if dust or haze is the dominant scattering process. The Lander instrumentation that accomplishes this would be an ultraviolet photometer with a small field of view which looks in the zenith. The concept is then to look at scattered solar radiation rather than to look directly at the sun. The use of the small field of view zenith geometry allows for the detection of clouds which may pass above the lander which would not be possible if, for example, 2π or 4π detection geometries were used. The most useful intensity measurements occur between solar zenith angles of 60° to about 100° , i.e., until the sun is about 10° below the horizon. Measurements of this type give the phase function of the scatterer, the optical depth of the scatterer and pure absorber, and information about the altitude distributions of both the scatterer and the absorber.

B. Operational Requirements

In order to determine the gross lander ultraviolet radiation environment, three readings on each channel would be sufficient. In order to take full scientific advantage of the presence of these detectors on the Mars surface each channel should be sampled at least every eight minutes during daylight and until the sun is 10° below the horizon.

The electronics should be wide dynamic range covering about three orders of magnitude on each channel.

It is desirable for the photometer to be able to survive for 90 days to monitor time varying phenomena although the question of the gross ultraviolet radiation environment will be known after the first lander sunset.

The field of view of the instrument should be made as small as possible compatible with satisfactory sensitivity. A practicable size might be $10^\circ \times 10^\circ$.

The instruments off-axis light sensitivity should be down by a 10^{-5} factor at 30° off-axis.

The photometer band pass should be about 100 Å on both channels.

C. Special Requirements

The location on the lander is not crucial.

The field of view of the photometer should be completely free of obstructions to 30° off axis. The landed instrument should be pointed within 30° of the local zenith.

The instrument must be able to withstand direct solar illumination. If the detector system cannot be built to tolerate direct solar illumination then the instrument must be equipped with a protective mechanism such as an iris.

D. Data Requirement

Each measurement will require about 8 bits. If each channel is sampled every 8 minutes the nominal data rate is 2 bits per minute.

2. Second Priority Measurements or Modifications

If each channel were sampled more often than at the 8 minute centers described above, the intensity measurements can be inverted into more detailed altitude distributions of the scattering and absorbing constituents. The additional benefit of more rapid sampling is to improve the sensitivity of the instrument to small time scale atmospheric phenomena, such as the passage of a cloud over the lander. The data rate would have to be increased to accomplish an increased sampling rate.

If the field of view of the instrument is made significantly smaller than the nominal $10^\circ \times 10^\circ$ size discussed here, then smaller clouds will fill the field of view of the photometer and become detectable. The consequence of this change would involve the use of a more sensitive detector and probably a heavier one than is contemplated in the discussion of first priority measurements.

The use of additional channels with appropriate filters could more thoroughly cover the 2200 - 2800 Å wavelength range of biological interest. The implementation of this change would involve an increase in weight. The increase in weight might not be proportional to the number of channels used if the electronics were shared. The increase in data rate would depend directly upon the number of channels used. Appropriate filters would have to be found.

The photometer might be mounted in conjunction with a pointable camera on a vertically extended mast. The mounting of the photometer would be nominally 90° with respect to camera direction. This geometry would allow the photometer to be pointed in additional directions besides the zenith and enhance its analysis capability. This mounting, on a camera mast, could be a way of assuring that the photometer has an unobstructed field of view, a first priority requirement.

IV. Instrument Information

The basic instrument, capable of performing the first priority measurements, would have two detectors, or at least two detecting surfaces. The detectors can be photodiodes or small photomultiplier tubes with appropriate interference filters. The two detectors would have a sunshade(s) and could share a single electronic subsystem. The power and weight requirements should be less than 1/2 watt and 1/2 pound, respectively, and quite possibly closer to 100 milliwatts and 100 grams.

V. Additional Data Required

The simultaneous observations of the landing site by orbiting science instruments, while not a contingency, can greatly enhance the value of the ultraviolet photometer data. Specifically, an orbiting ultraviolet spectrometer scanning through the photometer wavelengths and observing the landing site at varying viewing angles can provide separation of the planet albedo into surface and atmosphere reflected components. Orbital imaging of the landing site may tell when the wave of darkening passes by and determine when visual clouds cover the landing site.

APPENDIX

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