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VIKING LANDER: SUBSURFACE WATER ANALYZING PROBE

Technical Section

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ABSTRACT

In view of the extreme importance of the existence of water to the question of the possible existence of life and of planetary crustal change mechanisms, this experiment has as its primary objective the measurement of the water content of the subsurface soil of Mars at a depth where it is believed permafrost or at least a region of enhanced moisture content might exist.

The experiment utilizes a small terradynamic (soil penetrating) vehicle, which is to be released from the Viking Lander at an altitude of between 5000 and 6000 feet before the terminal descent on the vernier rockets begins, to implant a sensor package 3 to 5 feet beneath the surface. As it penetrates the soil, the vehicle separates into a probe which carries the primary instrumentation to depth and a tail section which remains partially above the surface; the tail section contains the power supply, secondary sensors, and transmitter and antenna assembly. The two sections remain linked by a hard wire umbilical which provides for power and data flow between the sections. The deceleration of the penetrating probe would be telemetered to the Lander to provide a record of the penetrability of the Martian surface (and, hence, some indication of its composition and density) and also to give the depth at which the probe comes to rest. Shortly after impact, a soil moisture subsystem would be activated to gather approximately 100 milligrams of soil at the depth of the penetrating probe. After the mass of the sample is measured, its water content would be determined by heating it in a sealed known volume and measuring the dew point of the resulting water vapor with a specular reflection dew point indicator. The penetrating probe and the tail section would each contain a pair of aluminum oxide hygrometer elements and one sensistor temperature sensor which, on request by an on-board programmer will measure temperature and absolute water content of the vapor phase in equilibrium with the surrounding soil. Once each 8 hours, the digitized output of the sensors would be transmitted by the RF link to the Lander.

It is expected that this apparatus will be able to measure the water vapor in equilibrium with the soil water in concentrations as low as 0.01 microgram per liter at -60°C and absolute soil water in amounts as small as 10 micrograms per gram of soil. The partitioning of water between the soil and vapor phases is a complex process. Hence, the measured absolute content of soil water would be used in conjunction with data from the soil experiments to be carried out at the Lander in developing a soil model for simulation studies which would then permit quantitative interpretation of the vapor phase data gathered throughout the mission.

The radioisotope power supply would provide an expected life for this instrumentation package in excess of the proposed 90-day mission for the Mars Viking Lander.

SUMMARY

Vehicle Characteristics

1	Weight	6.50 lb
2	Length	25 in.
3	Body diameter	1.25 in.
4.	Maximum fin diameter	6.00 in.
5.	Impact velocity	450-600 ft/sec

Lander - Vehicle Interface

1	Space required on lander lower deck (for swing-away release). ¹	26 in. x 1.5 in.
2.	Heat from the probe RTG to Lander (to be maintained at <100°C)	10 watts (thermal)
3.	Signal ² Requirements from the Lander	
	a. Erection signal	16,000 ft
	b. Release signal	
	450 ft/sec impact	4,700 ft
	500 ft/sec impact	6,800 ft
	c. Jettison signal	4,500 ft
4.	Orientation at Time of Release	5° cone about vertical

} Lander altitude when signal is generated.

Release Mechanism

1.	Gross weight	1.25 lb
2.	Jettisonable weight	1.00 lb

Communications - FM

Frequency	20 MHz
Power	100 mW
Bit rate per second	
During impact	28.82 k bits
Normal	14 bit

Receiver and Data Store on Lander

	A ³	B ⁴
1. Weight	0.38 lb	1.38 lb
2. Data storage		8 k bits
3 Volume	12 in. ³	44 in. ³
4. Power required	100 mW	13 watts during each readout period (~1 minute)

Gross Characteristics

Weight of the experiment prior to vernier rocket firing	8.13 lb	9.13 lb
Landed weight equivalent ⁵	4.38 lb	4.88 lb

Instrument Characteristics

1.	Accelerometer	Range	Accuracy
	Peak (earth g)	10,000 g	±2%
	Resonant frequency	30 kHz	
2.	Aluminum oxide hygrometer		
	Range for H ₂ O	0.01 μgm - 20,000 μgm per liter	±5% at -100°C ±2% at 30°C
	Range for temperature	-100°C to 30°C	
3.	Soil moisture		
	Useful range for H ₂ O	10 μgm - 0.1 gm per gram of soil 100 μgm - 0.01 gm	±50%
4.	Sensistor temperature sensors		
	Range	-120° to 30°C	±3°C

¹See Figures A-3 and A-12 for details of these specifications.

²Capable of firing 40,000 erg exploding bridgewire activating devices.

³If lander data store can be used.

⁴If separate store must be provided.

⁵Based on the assumption of 1 pound of fuel expended for each pound landed given by NASA at the preproposal briefing on September 12, 1969.

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SCIENTIFIC OBJECTIVES

NASA has defined the overall objective for the Viking missions to be the gathering of data which will "...significantly increase our knowledge of Mars, with particular emphasis on providing information relevant to life on the planet" [1] (emphasis ours). Since life as we know it cannot actively exist (i.e., multiply, grow, metabolize energy sources, etc.) in the absence of water, the detection and measurement of water on Mars is a vital adjunct to the direct search for living organisms.

Numerous theoretical studies [2,3,4,5, etc.] and simulations of the Martian surface environment [6,7] have suggested that water could stably accumulate in a subsurface permafrost region. Any such subsurface water reservoir must have come to equilibrium with the atmospheric water content in geological time. Recent measurements of the water vapor in the Martian atmosphere [5,8] as determined by high-dispersion spectroscopic studies in the $8200 \text{ \AA}$ band show 25 to 35 microns as the most probable value, which means that there is less than 0.0035 g/cm^2 of precipitable water in a vertical column of the atmosphere. Also, the Mariner 6 and 7 infrared spectrometer experiments indicated an absence of sensible water in the form of ice on the planet's surface [9].

In view of this demonstrated scarcity of atmospheric and surface water available for biological processes and the suspected existence of a subsurface reservoir of frost or ice, an experiment designed to detect and measure subsurface water is directly responsive to NASA's stated objectives. In fact, in the report on planetary exploration by the Space Science Board in June 1968 [10], a number two priority was assigned to such an experiment for the suggested 1973 Viking-Landed payload. The proposal presented herein describes such an experiment within the guidelines specified for participation in the Viking Lander program.

Before discussing the proposed implementation of the Subsurface Water Analyzing Probe experiment, it is necessary for us to develop briefly some of the arguments which determine critical parameters in the design (the depth at which a water measurement should be made, for example).

First, if permafrost exists in the mid-latitudes ($<45^\circ$), there is an apparent anomaly between the observed Martian surface temperatures [2] and the water vapor content of the atmosphere [5,8]. Table I shows the equilibrium partial pressure in millimeters of mercury for water vapor over ice at temperatures from -98° to 0°C [11].

TABLE I
Vapor Pressure of H₂O Over Ice

Temp. °C	0	2	4	6	8
-90	0.000070	0.000048	0.000033	0.000022	0.000015
-80	0.00040	0.00029	0.00020	0.00014	0.00010
-70	0.00194	0.00143	0.00105	0.00077	0.00056
-60	0.00808	0.00614	0.00464	0.00349	0.00261
-50	0.02955	0.0230	0.0178	0.0135	0.0106
-40	0.0966	0.0768	0.0609	0.0481	0.0378
-30	0.2859	0.2318	0.1873	0.1507	0.1209
-20	0.776	0.640	0.526	0.430	0.351
-10	1.950	1.632	1.361	1.132	0.939
-0	4.579	3.880	3.280	2.765	2.326

In a region near 25° north latitude, for example, the mean seasonal temperature would be -55°C, which would require a vapor pressure of 2.1×10^{-2} millibars, one order of magnitude higher than the observed values. Hence, in the absence of any dynamic effects, permafrost could not be expected to exist stably in the region for which the Viking Lander is targeted, 20° south to 30° north latitude.

On the other hand, if we assume that Mars expires volatiles at a rate proportional to the earth, the observed atmospheric water content is too low by a factor of approximately 10^{-5} to 10^{-6} (3×10^{-6} [4], 5×10^{-6} [5]), and consequently, storage or loss mechanisms must be postulated.

The Martian simulation studies of Young, Deal, et al. at Ames [6, 7] showed that a permafrost layer developed at approximately 6 inches beneath the surface in their simulated "equatorial" region after 6 months of cycling; this differs from a diffusion dependent decay, with depth, of moisture content a condition that would have been expected in the absence of dynamic processes.

In soil, there is a normal tendency for water in the vapor phase to move from the warmer to the colder regions [12, 13], and the lower the absolute temperature the more effective a given temperature difference between the regions in pumping water vapor becomes. Figure 1 shows the water flux as a function of $\Delta T/T^2$ for a sample of Millville silt as determined by Taylor [12].

Figure 1. Water Flux, J_w , as a Function of the Thermal Driving Force, $\Delta T/T^2$. The dotted lines represent the vapor phase transfer.

The important point, though, for a discussion of the diffusion of water vapor in Martian soils is that, because of the low ambient temperature ($\sim 55^{\circ}\text{C}$), the upper limit of the thermal driving force (in Figure 1, 8×10^{-5}) is achieved at a temperature difference of only 4 degrees. When we consider that the seasonal excursion may be as much as 100 degrees, the magnitude of the thermal pumping effects on the soil water distribution are apparent. Unfortunately, none of the data which can be gathered by remote observation (including orbiting instruments) can be used to estimate the diffusivity (to water vapor) of the Martian soil.

The next two sections discuss the problematical issues of the expiration of volatiles through the planet's crust due to rock decomposition processes in the interior and the seasonal pumping of water vapor concentrations in the soil. If either or both of these processes are active, subsurface water measurements become all the more important. However, the justification for the experiment is independent of these hypotheses, since the detection of subsurface water is in itself an important experimental objective.

It is possible to estimate the rate at which Mars can be expected to expire water due to the decay of rocks under pressure, heat, and radioactive processes if it is assumed that the planetary processes are similar to those postulated by Rubey [14, 15] and Kulp [16] for the earth.

The surface area of Mars, computed using the mean equatorial radius of 3393.4 ± 4 km, [17] is $1.45 \times 10^{18} \text{ cm}^2$. Mars has a mass of 0.1065 earth mass. Hence, if we assume that the production of volatiles by the decay of rocks is proportional to the planetary mass and use Rubey's estimate [14, 15] of 10^{11} to 10^{12} grams of water expired per day for the earth, we find that Mars should expire between 10^{10} and 10^{11} grams of water per day. This might appear to be an excessive figure in view of the measured 25 to 35 microns [5, 8] of precipitable water in the Martian atmosphere; however, this figure can be reconciled with observations. If the partial pressure of water is 35 microns, the atmosphere must contain a total of 5×10^{15} grams of water [5] so that the annual (Martian) replenishment represents only 0.14 percent of the total. If we assume that the Martian water balance is stable, then this replenishment must be accounted for by loss processes such as disassociation of the water and loss of the gases, chemical bonding at newly exposed exfoliated rock surfaces, etc., and stable entrapment in regions whose mean temperature is lower than -90°C (corresponding to the equilibrium temperature of ice for a vapor pressure of 35 microns). It is difficult to estimate the quantitative performance of these competing processes; however, it does not appear unreasonable that they could jointly serve as a sink to maintain the Martian water balance.

If the planet does expire on the order of 7×10^{12} to 7×10^{13} grams of water per year through a surface of $1.5 \times 10^{18} \text{ cm}^2$, then the mean annual flux must be $2 \times 10^{-5} \text{ g/cm}^2$; i.e., approximately 20 micrograms of water per year per square centimeter of surface. This should represent an equilibrium flux from the interior of the planet to the crust. If a region has a mean temperature sufficiently low to prevent the escape of the water to the atmosphere, Owen and Mason [5] have estimated that a seven meter column of permafrost could have accumulated in geological time. On the other hand, Leighton's calculations [2] indicate that a stable permafrost region is not to be expected at latitudes lower than 45° north. Dynamic processes, however, could still account for the seasonal existence of permafrost.

The Mars Engineering Model [17] gives the following typical values for the specific heat and thermal conductivity of the Martian surface:

Specific heat	$0.17 \pm 0.02 \text{ cal/g } ^\circ\text{K}$
Thermal conductivity (at surface)	$10^{-4} \leq k \leq 10^{-3} \text{ cal/cm sec } ^\circ\text{K}$

We assume that these apply to the first few meters of the crust as well. A simplified model of the seasonal temperature cycle is a sinusoidal variation between -110°C and 0°C , which is consistent with the data in [17] and Leighton's estimates [2] of mean temperatures for 20 to 30° north latitude.

$$T = -55^\circ \left\{ 1 + \cos (9.15 \times 10^{-3} t) \right\}$$

where t is in days.

The temperature at a depth x below the surface is given by

$$T_x = -55^\circ \left\{ 1 + e^{-kx} \cos (9.15 \times 10^{-3} t - kx) \right\} \quad (1)$$

Equation (1) can be solved by setting $T_x = -90^\circ$ to find the maximum depth at which a temperature of -90°C can be expected to occur (ignoring the possible effect of a heat flow from the interior of the planet).

$$e^{-kx} \cos (9.15 \times 10^{-3} t - kx) = 0.6363$$

or

$$kx \leq 0.4520$$

If we use the value $k = 10^{-3}$ for thermal conductivity, we find that the maximum depth which should experience a -90° or lower temperature is

$$x_{\max} = 153 \text{ cm (or 5.02 feet).}$$

The wave length of the annual temperature cycle is

$$\lambda = 21.3 \text{ meters}$$

if the thermal conductivity is taken to be 10^{-3} and

$$\lambda = 6.68 \text{ meters}$$

if the lower bound of $k = 10^{-4}$ is used. Thus, the zone of soil in stable (saturated or subsaturated) balance with the atmosphere penetrates only to a depth of 0.072 wavelengths before the temperature change is attenuated to a point where the maximum excursion is less than 35°C . This wave propagates with an apparent velocity of 3 cm/day so that 50 days after the surface temperature rises above -90°C there is no longer any region of the soil below this temperature. Since the mean temperature is at or below -90°C for approximately 190 days in the annual cycle, there is a region of soil at or below -90° for 240 days or for 35 percent of the year. During this time, there should be a net gain of moisture by the soil from the atmosphere and a blockage of any expiration back to the surface. If the diffusivity of

the soil for water vapor is fast compared to the velocity of the trailing edge of the low-temperature zone, this peristaltic pump action provides a mechanism for concentrating water vapor near the region where the temperature rises above the equilibrium vapor pressure. An effect similar to this was observed by Young et al. [6] in their work with the Martian environment simulator. In spite of the fact that the mean temperature was only -20°C in their "equatorial" region, after a 6-month cycle they found a well-defined permafrost layer 6 inches beneath the soil [7]. The important feature was that they carried out a simulated diurnal cycle with temperatures that dropped to -70°C in their simulated night, which "pumped" water vapor down into the soil. In geological time this stable region undoubtedly would have penetrated deeper.

If these mechanisms are at work in the Martian surface, it appears likely that there would exist a region of enriched moisture content in the vicinity of 5 feet below the Martian surface. This may be in the form of a permafrost which sublimates during a part of the year and escapes to the atmosphere, or it may simply be a region which periodically has an enriched moisture content due to a transient low temperature. If the Viking Lander should be targeted for a site further north than 25° , the probability of a stable moisture region should increase rapidly. Leighton's calculations [2] indicate that stable permafrost should exist at 5 feet or less below the surface for all latitudes above 45° north.

We have concluded that the most interesting depth at which to implant a water sensing probe on Mars would be 3 to 5 feet beneath the surface. The Lander is being designed to operate for 90 days; since the thermal wave propagates through the Martian surface at 1.2 inches per day, this would make it possible for the deep instruments to observe changes in temperature and humidity which were the consequences of thermal events at the surface approximately half-way through the mission—if the probe also has a 90-day life expectancy. The Subsurface Water Analyzing Probe experiment was designed, therefore, to place instrumentation packages on the surface and at 3 to 5 feet below the surface to measure temperature and water content of the soil to the highest accuracy possible (see summary sheet) within practical limitations of power, size, weight, and impact survivability. The system proposed here, since it does not remain on the Lander, must include power, controls, etc., for a 90-day autonomous mission, with the data from the sensors being transmitted periodically to the Lander for relay to the orbiter.

EXPERIMENT

This experiment involves three functionally distinct units: a terradynamic (soil penetrating) vehicle (Appendix A) to emplace a subsurface instrumentation package; a launch mechanism on the Lander to orient and release the vehicle at the correct time (Appendix A); and a Lander-based receiver, data conditioning circuitry, and buffer memory (Appendix C) to receive the data transmissions from the probe transmitter and forward the data to the Lander data memory units.

Figure 2 shows the present design of the terradynamic vehicle. The vehicle forward of Station 16.00 is called the probe or penetrator in the following discussion, and the section between Station 16.00 and Station 25.00 is referred to as the tail section. The forward 8 inches of the probe is loaded with ballast to provide the desired terradynamic properties, and the instrumentation and cable compartments occupy the next 8 inches. The tail section houses the power supply and transmitter aft of a 3-inch section of crush-up shock mitigation material.

The vehicle is stowed between the decks of the Lander during the interplanetary flight and the initial phases of reentry. The sequence of actions which lead up to the deployment and release of the vehicle and which characterize the first part of its mission are described below.

At $T = 67$ seconds, when the aeroshell is separated from the Lander, the lock on the vehicle stowage compartment would be released.

At $T = 70$ seconds a signal from the Lander program sequencer would activate an explosively driven valve* to connect a high pressure nitrogen bottle to the hydraulic cylinder which erects the probe before $T = 40$ seconds. At an altitude of between 5000 and 6000 feet (depending on the descent rate of the Lander) the programmer generates a release signal and the vehicle is dropped in free fall, before the terminal descent on the vernier rockets begins.

The release altitude will be selected so that from free-fall acceleration the probe will impact at approximately 500 feet per second. Shortly after the probe is released, the release mechanism itself is jettisoned to eliminate dead weight during the final descent phase.

Upon impact with the Martian soil at approximately 500 feet per second, the vehicle slows down to about 450 feet per second by the time the forward face of the tail section first touches the soil. The tail taper wedges into the hole made by the probe, and, depending on the type of soil encountered, stops in anywhere from 3 to 12 inches. The power supply and transmitter in the tail section continue to travel forward for another 2.5 inches compacting the crush-up shock mitigation material. This lowers the peak load seen by these components to approximately 13,500 g (which is within the demonstrated state of the art for all of the components except the power supply subsystem).

* 40,000-erg exploding bridgewire activated secondary explosive device which can tolerate the sterilization cycle.

Figure 2. Mars Lander: Subsurface Water Analyzing Probe

Figure 3. Functional Block Diagram of the Subsurface Water Analyzing Probe

The wedging of the tail into the probe hole and the accompanying high g loads cause separation of the probe from the tail and guarantee that the antenna attached to the tail will remain above ground and capable of transmitting to the Lander.

The terradynamic probe would telemeter a penetrability profile for the deceleration it experiences for penetration of up to a maximum of 50 feet in depth (limit of the umbilical cable) with a mean resolution of ± 2 percent. These data would be relayed to the Lander while that vehicle was still above the tail section of the probe, so that a very high probability of recovery of deceleration data occurs, even if communications failures, etc., should later interfere with system operation. It is possible to form a very good model of the surface stratigraphy from this record as analysis of over a thousand penetrating vehicle tests on earth has shown [19]. Any information gained by the Lander-based instruments on surface density and composition or seismic indications of crystal composition will be used to improve this model. If a permafrost region should exist, there is no doubt that the upper edge of the region will be marked by a sharp change in deceleration as has been seen on the several tests conducted from Eielson AFB into permafrost.

These data, when interpreted in conjunction with an indication of high soil water content from soil moisture measurement, would give the depth of the upper limit of the permafrost to within a few inches.

Immediately after the probe comes to rest, a soil sample (approximately 100 milligrams) will be taken through the side of the probe (Appendix C) and weighed. This sample is then heated to 200°C in a chamber by means of a sealed pellet of a gasless heat powder developed at Sandia Laboratories, and the dew point of the resulting gases is determined by using standard specular reflection techniques. (Key parts of this instrument have been laboratory tested for this purpose.)

If the ambient temperature is -60°C , the instrument will be able to measure soil water over the range 10^{-5} to 10^{-1} grams of water per gram of soil.

The accuracy of this instrument is not constant over the range of soil water but is expected to be approximately ± 50 percent over the range of 10^{-4} to 10^{-2} grams of water per gram of soil. These data should supplement those obtained in the Lander-based soil moisture and soil pyrolysis experiments.

After these two one-time experiments are completed, the instrumentation begins its 8-hour normal cycles, i.e., once every 8 hours the 20-MHz FM transmitter is turned on for 18 seconds of transmission at 100 MW. During this time, the main instrumentation consisting of matched aluminum oxide humidity elements and silicon resistor (sensistor) temperature transducers would be interrogated and the readings relayed to the Lander. Figure 3 is a functional block diagram of the entire Subsurface Water Analyzing Probe experiment after deployment. The control circuits, explosively activated valve and piston motor connected with the release mechanism will have been jettisoned before landing and are therefore not indicated. A detailed discussion of the instrumentation and electronics appears in Appendix C.

SOIL MOISTURE - INTERPRETATION

The one-time soil moisture measurement described above has the advantage that it makes a direct measurement of the water content of the soil sample (subject to the assumption that the readsorption of the soil is low during the span of the measurement).

The aluminum oxide humidity elements, however, measure the absolute water content of the gas phase in equilibrium with a sample of (moist) Martian soil. Unfortunately, the water content of the gas phase over a soil sample is not simply related to the water content of the soil. This balance is ordinarily represented by a "moisture sorption isotherm," which behaves qualitatively as shown in Figure 4.

Figure 4. Typical Sorption Isotherm

The region A represents the adsorption phase for soil moisture. During this phase, the soil adsorbs each additional bit of moisture so energetically that the moisture content of the gas above the soil is essentially unchanged by changes in the soil moisture. Soils with large quantities of hygroscopic salts, such as dry lake bed deposits, characteristically have extended flat regions, while inert soils such as very clean sand free of salts and organic matter have comparatively short adsorption plateaus.

Cameron [18] found in his study of desert soils, which characteristically have a patina of deliquescent salts on the soil particles from the leaching process of runoff water, that the relative humidity of the soil was rarely less than 85 percent, even when the air immediately above the surface showed a relative humidity of as low as 15 percent.

The region B represents saturation, i. e., that level of water content in the soil at which the gas phase becomes saturated. Further, addition of water to the soil cannot increase the capacity of the gas phase for water vapor.

The region marked C is the most interesting, since a measurement of the water vapor content of the gas phase here can be used to find the water content of the soil for a *known soil*. There is also a hysteresis loop between the adsorption curve corresponding to increasing water content of the soil and the desorption curve corresponding to decreasing water content. The vital point here is that these curves are characteristic of a material; hence, the quantitative interpretation of the measurements of the water content of the vapor phase over a Martian soil will require the development of a model for the soil.

We have used sand in laboratory experiments to calibrate the sensors and verify the operation of the aluminum oxide hygrometers in the Martian atmosphere (80 percent CO₂ and 20 percent Ar) at 6.5 millimeters of mercury and temperatures from -60° to 0°C.

The interpretation of the data from the aluminum oxide hygrometers would be made by constructing a model soil for Mars based on the chemical and physical characteristics found by the Lander-based instrumentation and then by developing families of moisture sorption isotherms in the high altitude chambers at Sandia where the aspects of the Martian environment vital to humidity measurements could be simulated for extended periods of time (months). In the absence of chemical data, one would be forced to construct a model which had the observed properties of density, thermal conductivity, etc. The probable absence of liquid water on Mars is a decided advantage for the model maker, since the mechanism for enriching surface soils with water adsorbers on earth is the deposition of such materials from solution.

A major part of the Subsurface Water Analyzing Probe experiment would be the laboratory experimentation, following a successful probe experiment conducted to develop a Martian soil model consistent with the observations for quantitative interpretation of humidity data.

In the event that the soil water content is in either region A or B of Figure 4, the direct soil moisture measurement is the only way of obtaining quantitative data on the amount of water present. If the soil contains more than 10 percent water, we will only be able to determine that it exceeds this bound. If the Martian soil has a broad adsorption (A) plateau, then the direct soil moisture measurement should give quantitative results for quantities of soil water too small to be seen by the aluminum oxide hygrometer.

RESULTS EXPECTED

This experiment is expected to provide the following raw data:*

1. Penetrability profile (deceleration) at an accuracy of ± 2 percent of the indicated values to the depth (≤ 50 feet) penetrated by the probe.
2. An absolute soil moisture measurement at depth for soil water in amounts between 10^{-5} and 10^{-1} grams of water per gram of soil.
3. Water content of the vapor phase in equilibrium with the soil at depth and near the surface for water vapor concentrations between 0.01 and 20,000 micrograms per liter.
4. Temperature at depth and near the surface for values between -120° and 30°C to an accuracy of $\pm 3^{\circ}\text{C}$.

The questions which this experiment should answer are the following.

Primary Questions:

1. Is there a greater soil water concentration in the vicinity of 3 to 5 feet below the surface than would be expected from stable equilibrium with the Martian atmosphere?
2. If the answer to (1) is yes, then:
 - a. What is the amount of soil water present?
 - b. Is the soil water in the form of permafrost and, if so, where is the upper edge of the permafrost?
 - c. Is the soil water content stable and, if not, does it depend on the fluctuations in surface temperature?
 - d. Do the measurements contradict or agree with the hypothesis that Mars expels water from the interior?
 - e. Does the soil water content reach a saturation level that could provide easily accessible water (during the experiment)?
3. What is the best soil model, based on all of the data returned by the Viking experiments, for soil water calculations for Mars?

*See Appendix C for details concerning the range and accuracy of the sensors involved.

Secondary Questions:

4. What is the physical composition of the surface, that is,
 - a. Do there exist strata or is the material homogeneous?
 - b. How does the density vary with depth?
 - c. What is the penetrability of the surface?
5. What is the thermal conductivity of the surface material?

We have already indicated in the description of the experiment and in Appendices A and C how the raw data will be utilized to answer the questions posed above; however, one point should be reiterated. If the soil water levels are such that the aluminum oxide humidity elements are within their operational range, then the quantitative interpretation of these data in terms of soil water content will require the development of a Martian soil model consistent with the several Lander-based experiments. Families of moisture sorption isotherms would then be constructed by simulating, in the high-altitude environmental test chambers at Sandia, those aspects of the Martian environment which would affect soil/vapor-phase water balance. Therefore, if we postulate a successful experiment on Mars, we must conduct a complementary program in the laboratory in order to interpret the returned data to a form suitable for answering the questions posed above.

SCIENTIFIC EXPERIENCE OF PROPOSERS RELEVANT TO THIS SPECIFIC INVESTIGATION

The relevant inhouse staff experience which Sandia Laboratories can call upon to successfully design, test, and field the Subsurface Water Analyzing Probe is only indicated by the experience of the "core" team which would start the project. A better indication of Laboratory competence is the fact that Sandia has pioneered development in four of the most important areas of technology involved in this experiment.

The Sandia Laboratories have been active in terradynamics since 1961 with both empirical and theoretical studies. Appendix A, devoted to terradynamics, and the references cited there show the extent of Sandia's involvement in this discipline. Some of the parameters covered in the approximately 2000 field tests conducted in natural earth materials are: impact velocities (V) of 60 to 2600 feet per second; weights (W) of 1 to 5860 pounds; projectile diameters (D) of 0.25 to 30 inches; nose shapes of approximately 15 basically different configurations; W/A (projectile weight divided by its cross-sectional area) ratios of 1 to 38 pounds per square inch; impact angles of 16 degrees from the horizontal to 90 degrees (vertical); depths of penetration (Z) up to at least 220 feet; natural earth materials including rock, concrete, gypsite deposits, sandstone, sand, ice, permafrost, mud (soft clay), desert alluvium, and water. Many of the tests were instrumented to provide details of the deceleration environment during the penetration event.

Starting in the early 1960's, the Laboratories began the development of telemetry (TM) and instrumentation equipment which would survive extremely high-g environments. We now have operational TM packages which can operate through a combined environment of 15,000-g linear and 15,000-g centrifugal acceleration, i.e., ~21,000 g. One of our field test programs has successfully exposed a complex instrumentation and TM package, used for data recovery on the program, to higher than 10,000-g impact (hard landing) shock for more than a thousand test shots. This program also required that the batteries operate through the shock period as well as immediately afterwards.

Sandia Laboratories also pioneered the development of the aluminum oxide hygrometer in the period between 1958 and 1963. Several publications which resulted from this program are cited in Appendix C; U.S. Patent No. 3075385 was granted to the U.S. AEC for the basic device developed at Sandia.

Sandia Laboratories is already committed to design the primary 28-watt RTG power supplies for the Viking Lander. The Space Isotope Power Department, which is carrying out this task for the AEC, would be the same group that would design the isotope power supply for the Subsurface Water Analyzing Probe. The first half of Appendix B is indicative of the Laboratories' independent involvement in research and development for isotopic power sources.

The other areas of technology required to implement this program are equally strong at Sandia; however, they do not necessarily represent a unique competence or a pioneering development at Sandia.

The following persons are the core staff for this experiment. The relevant experience of these individuals is briefly indicated.

Gustavus J. Simmons, Division Supervisor
Systems Planning Staff
Initial logic design for Vela Hotel satellite
Project manager - ionospheric physics research

William N. Caudle, Division Supervisor
Terradynamics Division
Manages Sandia's terradynamics R&D program

Wendell D. Weart, Division Supervisor
Underground Physics Division
Research in soil physics

Harold R. Vaughn, Division Supervisor
Aeroballistics Division
Extensive experience in high-altitude (low density) aerodynamics

Paul A. Stokes
Exploratory Systems
Development of micropower 5-year lifetime electronic circuitry

R. Stanton Reynolds
Satellite Sensors Division
Vela Hotel satellite sensors
Project engineer for the development of a seismic system for ARPA

Ragon Kinney
Space Isotope Power Department
Development of new low power radioisotope power supplies

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APPENDIX A

TERRADYNAMIC PROBE

Terradynamics

The term "terrodynamics", which has recently been coined to describe the study of soil penetration, is defined as: "A branch of dynamics that deals with the motion of soil and other solid materials and with the forces acting on bodies in motion relative to those materials." Sandia Laboratories has been active in both empirical and theoretical studies of terrodynamics since 1961. Some of the parameters covered in the approximately 2000 field tests conducted in natural earth materials are impact velocities (V) of 60 to 2600 feet per second; weights (W) of 1 to 5860 pounds; projectile diameters (D) of 0.25 to 30 inches; nose shapes of approximately 15 basically different configurations; W/A (projectile weight divided by its cross-sectional area) ratios of 1 to 38 pounds per square inch; impact angles of 16 degrees from the horizontal to 90 degrees (vertical); depths of penetration (Z) up to 220 feet; and natural earth materials including rock, concrete, gypsite deposits, sandstone, sand, ice, permafrost, mud (soft clay), desert alluvium, and water. Many of the tests were instrumented to provide details of the deceleration environment during the penetration event. The most reliable method of obtaining a deceleration record is to mount one or more accelerometers and the necessary signal conditioning components in the projectile probe and to trail a transmitter and antenna approximately 200 feet behind the free falling projectile so that the transmitter remains above the ground; by these means penetration data are continually transmitted to a nearby receiver until the probe comes to rest.

Several systems have been developed employing terradynamic concepts whereby special electronic sensing equipment is air dropped into physically inaccessible locations and later commanded to transmit the data. These systems penetrate the ground at velocities up to 530 fps (greater than proposed design for the Viking program) without damaging the electronic equipment. The systems normally employ a penetrating probe and a detachable afterbody containing the antenna which is left at the soil surface; the antenna is connected to the probe by an umbilical line. Several thousand of these units, many of which employ the detachable afterbody concept, have been field tested.

Based on the field test results, the following empirical equations [A-1] which show the effect each parameter has on depth of penetration were developed; these equations are commonly used to predict penetration depth:

$$Z = 0.53 SN \sqrt{W/A} \ln(1 + 2V^2 10^{-5}), V < 200 \text{ fps} \quad (1)$$

$$Z = 0.0031 SN \sqrt{W/A} (V - 100), V \geq 200 \text{ fps} \quad (2)$$

where

Z = Penetration distance, feet

S = Soil constant

N = Nose performance coefficient

W = Projectile weight, pounds

A = Cross-sectional area, square inches

V = Impact velocity, feet per second.

The exact mechanisms of earth penetration are not well understood, but certain phenomena which provide an insight into these mechanisms have been found to occur with each penetration event. Very little cratering of the soil occurs during entrance of the projectile, i. e., the hole is generally "clean"; however, there is a slight upheaval of the soil around the entrance hole. The volume of the soil permanently upheaved is always greater than the volume of soil displaced by the projectile and its resulting hole. The hole left by the projectile is usually slightly smaller than the projectile itself, which implies that soil is accelerated away from the projectile during penetration and then rebounds after the projectile passes. In the immediate vicinity of the projectile, the soil is often comminuted and is always compacted. The primary mechanism of penetration appears to be through shearing action. A large volume of soil around the penetration hole (or tunnel) is sheared as indicated by the usual increase in volume (and thus decrease in density). The sheared zone coincides with the soil upheaval at the surface, and the change in soil density within the sheared zone accounts for the volume of soil upheaved. When flat or blunt-nosed projectiles are used, a soil "point" or "nose" formed during the first few inches of penetration remains essentially intact during the remainder of the penetration event.

The angle of attack of a projectile with the soil (angle between the axis of projectile and the velocity vector) is important to the structural integrity of the unit. One cause for a change in angle of attack from the drop angle is a side component of velocity produced by wind. An angle of attack of approximately 3 degrees is acceptable, because the angle is reduced to zero immediately after soil penetration. Normally the only projectile/soil interaction during penetration is on the nose, as shown by the paint totally scuffed from the nose of the 1-inch diameter projectile shown in Figure A-1. The paint on the sides of the projectile is only slightly scuffed, but note that on one side the scuffing is much more pronounced than on the other (Figures A-1 and A-2)--the result of impact at a slight angle of attack with the soil. The projectile shown in the figures impacted a very hard, dry, silty clay at 700 fps and penetrated to a depth of 5 feet. The weight of the unit was 2.02 pounds.

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Figure A-1. One-inch Diameter Penetrator, Forward Section

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Figure A-2. One-inch Diameter Penetrator, Full View

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Subsurface Water Analyzing Probe

The proposed penetrator is illustrated in Figure A-3. Maraging steel 18 Ni (200) was selected for the probe material as the best balance between toughness and high strength, and Ta-222 (Tantalum with 10-1/2% by weight Tungsten and 2.5% Hafnium) was selected as the ballast material for its high density and high strength. The probe configuration (nose shape, diameter, and length) was designed for its terradynamic performance characteristics, and the detachable afterbody configuration was designed partially for terradynamics (flared portion) but primarily to provide aerodynamic control.

Under contract to Sandia Laboratories, the Terramechanics Laboratory at Texas A&M University is conducting a series of earth penetration tests. The penetrator employed is similar to the probe described above, and a trailing line is used to "hard wire" the deceleration data to nearby recording equipment. The line has been trailed successfully at velocities up to 500 fps. A similar line would be a likely candidate for the umbilical to connect the mass penetrator probe and afterbody. Single strand steel wire (0.0065 inch diameter and 450,000 psi minimum yield strength) is obtained from U. S. Steel, and Victor Wire and Cable insulates and twists four strands of the wire together. The resulting combination has 100 volts dielectric strength in salt water and 4.7 ± 1 ohm per foot resistance, both at 25°C. The umbilical cable would also be packaged in KEL-F grease (a 3M Teflon-like polymer) in the probe to ease its exit from the storage well and minimize the chances of insulation failure during the deceleration period.

Soils Models for Mars

Two soil models were used in the design of the penetrator. Soil Model 1 was defined as: "Three to five inches of sand overlaying a porous lava-like substrate. Below 3 feet, the lava is filled with ice." The soil constant

Figure A-3. Mars Probe

(referring to "S" in the penetration equations) for the overlaying sand is estimated to be between 10 and 15. The strength of sand is directly related to confining pressure, which in nature is directly related to the soil overburden. Therefore, the top few inches of sand offer very little resistance to penetration. The lava-like substrate is envisioned as being a fine honeycombed structure of rather soft rock. The penetrability probably, depending largely on porosity and on unconfined compressive strength, ranges from $S = 1.5$ to 6. Earth materials of similar penetrability would range from a welded tuff (Thirsty Canyon, Nevada) to a desiccated dry lake playa (near Edwards AFB, California). If the lava were essentially filled with ice, the minimum and maximum penetrability would be reduced to $S = 1$ and $S = 3$, respectively. If there were no permafrost, the values of $S = 1.5$ to 6 should apply to all depths of interest. As the amount of ice varies from maximum to none, the penetrability will obviously vary from the permafrost condition ($S = 1$ to 3) to the non-permafrost condition ($S = 1.5$ to 6).

Soil Model 2 was defined as: "Dry loose topsoil (like desert wind blown sand). At 3 feet and below, the sand is frozen solid with ice." This soil would be similar to that found in the sand dunes of southeastern California. The penetrability of the solidly frozen sand would be approximately the same as in Soil Model 1 ($S = 1$ to $S = 3$), because the primary source of strength is the ice. Soil Model 2 without ice would vary from $S = 6.5$ to 20 at about 5 feet below the surface. At a given depth, the penetrability of sand is probably most affected by grain size, gradation, and density (a loose sand might be easy to penetrate while a sand well-packed, as by vibration, might be very hard).

The Mars penetrator is designed for soils varying in penetrability by a factor of 20. If the penetrator were used on earth, it should be terradynamically satisfactory over approximately 95% of the earth's land mass. It should also be noted that available "best estimates" indicate that the unit should perform equally well on the moon. The other 5% of the land surface includes very hard rocks, near vertical rock cliff faces, and very soft soils (marshlands) in which the penetrator would fail by either breaking up or penetrating too

deeply. In the latter case, the umbilical connecting the probe to the tail section, which remains on the surface, would be broken.

Terradynamic Performance Analysis

The depth of penetration of the probe can be determined by applying the penetration equations, (1) or (2), or the nomogram (Figure A-4) which is a graphical representation of the equations. For the layered soils described above, it is necessary to apply the equations to each layer, i. e., calculate the change in velocity in the first layer, proceed to the next layer, and finally reduce the velocity of the probe to zero and determine the total predicted depth of penetration. Experience with similar configurations has provided the basis for estimates of the penetration performance of the afterbody. Figures A-5 and A-6 show the predicted maximum and minimum depth of penetration for the probe and the rest positions of the afterbody for each soil model when no permafrost is encountered. Figures A-7 and A-8 show the same parameters for the case in which a compact permafrost exists from 3 feet downward in the soil. The "S" number for each layer is shown on the figures. An impact velocity of 500 fps was selected to provide acceptable generation depths in the largest possible range of materials (in terms of penetrability).

The first information expected from the penetrator is the deceleration record during penetration, which should be obtained even before the lander is positioned and brought to rest. It should be noted that even if the probe (or the lander) were damaged or destroyed at impact, even a partial deceleration record could be useful in providing data on the penetrability of the Mars sub-surface. However, if the deceleration record were complete, the depth of penetration of the probe could be determined (by double integrating the record) to an accuracy of ± 5 percent. Also, if only a partial deceleration record were obtained, the penetrability and the thickness of all soil layers encountered before the deceleration signal is lost could be determined to the same accuracy.

Figure A-4. Graphical Representation of Penetration Equations

Figure A-5. Soil Model 1, No Permafrost; 3 to 5 Inches Sand Overlaying a Lava-Like Substrate

Figure A-6. Soil Model 2, No Permafrost; Dry Loose Topsoil, Like Desert Wind-Blown Sand

Figure A-7. Soil Model 1, Permafrost; 3 to 5 Inches Sand Overlaying a Porous Lava-Like Substrate

Figure A-8. Soil Model 2, Permafrost; Dry Loose Topsoil, Like Desert Wind-Blown Sand

One of the detachable-afterbody penetrating systems that has been developed is shown in Figure A-9. Afterbody detachment occurs at the point where the total fin span changes from 11.5 inches (probe) to 10.5 inches (afterbody). The penetrator, which is illustrated in Figure A-9, (44 inches long and weighing 37 pounds), was air dropped and impacted a soft silty clay at 270 fps. The measured penetration depth is shown on the figure. Figure A-10 is a tracing of the deceleration versus depth record for the probe and the afterbody; after the afterbody separates from the probe, its deceleration is shown as a dashed line.

During a typical penetration event, the only appreciable contact between the penetrator and the soil or rock is on the nose of the penetrator, as observed from the ablated paint on the penetrator in Figure A-1; originally this penetrator was completely red.

An obvious question is whether a sufficient fraction of the kinetic energy of the penetrator probe would be converted to heat when the probe comes to rest to produce significant changes in the soil. In several drops of terra-dynamic vehicles in permafrost at Eielson AFB in Alaska no indication of melting was observed when the vehicle was recovered. Calculations made for the subsurface water analyzing probe indicate that approximately 0.02 BTU would be added to the soil in the form of heat at the rest position of the probe; i. e., less than 0.1 percent of the kinetic energy at impact.

Aerodynamic Performance Analysis

The aerodynamic behavior of the penetrating vehicle after its release from the Lander was calculated using a computer code developed for flight analysis of vehicles of this type. Atmospheric data for the analysis were taken from the Mars Engineering Model [A-2]. The following aerodynamic and body constants were used for the penetrating vehicle.

Figure A-9. Three-inch Diameter Detachable Afterbody Penetrator

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Figure A-10. Deceleration vs Depth for Detachable Afterbody Penetrator

Weight	= 6.5 lbs
Center-of-Mass	= 10.04 inches aft of nose tip
Pitch (and Yaw) Moment-of-Inertia about the Center-of-Mass	= 0.0704 slug/ft ²
Roll Moment-of-Inertia about the Axis of Symmetry	= 0.007 slug/ft ²
Axial Force Coefficient = C_A	= 8.85
Static Margin	= 32.8% of body length
Normal Force Coefficient = C_{N_α}	= 0.682 per degree
Pitching Moment Coefficient = C_{M_α}	= 0.291 per degree
Damping Moment Coefficient = C_{M_q}	= -27.95 per radian
Reference Area = Body Cross Section	= 0.00852 ft ²
Reference Length - Body Length	= 2.08333 ft

Although these coefficients have been calculated for angles of attack up to 20°, all aerodynamic flight calculations (using a 6 degree-of-freedom computer code) were made with the small angle (constant value) approximation. Because of the lack of any firm information as to the attitude and roll behavior of the lander at the time of release of the penetrator, the calculations were made with the assumption that there was no roll and that the predominant trajectory at release was vertically downward. The results of these calculations are summarized in the first sixteen rows in Tables A-I and A-II.

Table A-I contains the data obtained by using the "minimum density" atmosphere given in the engineering model (Reference A-2). Table A-II contains the data obtained by using an atmosphere of 100% carbon dioxide, a surface pressure of 6.5 milibars, a surface temperature of -33°C, a lapse rate of 1.341°C per thousand feet, and a tropopause altitude of 50,000 feet.

TABLE A-I

Minimum Density Atmosphere

Release Altitude (ft)	Release Velocity (ft)	Penetrator Pitch Attitude at Release (degrees north of vertical)	Wind Velocity (ft/sec from the south)	Impact Velocity (ft/sec)	Time of Fall After Release (sec)	Pitch Frequency (Hz)	Maximum Pitch Angle (degrees)	Pitch Damping Rate-Time to 1/2 Amplitude (sec)	Maximum Ground Range (ft)	Mach Number Range
4000	300	0	0	430.1	10.95	-	-	-	0	0.35-0.50
4000	400	0	0	503.5	8.85	-	-	-	0	0.46-0.58
4000	500	0	0	584.5	7.37	-	-	-	0	0.58-0.67
4000	600	0	0	670.4	6.30	-	-	-	0	0.70-0.77
5000	300	0	0	456.5	13.21	-	-	-	0	0.35-0.53
5000	400	0	0	526.0	10.79	-	-	-	0	0.46-0.61
5000	500	0	0	603.6	9.06	-	-	-	0	0.58-0.69
5000	600	0	0	686.7	7.77	-	-	-	0	0.70-0.79
6000	300	0	0	481.5	15.33	-	-	-	0	0.35-0.55
6000	400	0	0	547.5	12.65	-	-	-	0	0.46-0.63
6000	500	0	0	622.1	10.69	-	-	-	0	0.58-0.72
6000	600	0	0	702.7	9.21	-	-	-	0	0.70-0.81
7000	300	0	0	505.0	17.36	-	-	-	0	0.35-0.58
7000	400	0	0	568.0	14.44	-	-	-	0	0.47-0.65
7000	500	0	0	640.0	12.27	-	-	-	0	0.58-0.74
7000	600	0	0	718.2	10.61	-	-	-	0	0.70-0.83
5000	400	5	100	525.1	10.80	0.29-0.40	19.0	22.0	7.91	0.48-0.62
5000	400	5	0	525.9	10.79	0.33-0.45	5.0	22.0	0.52	0.46-0.61

Reynolds Numbers Based on Length Vary from 5.0×10^4 to 1.3×10^5 .

Dynamic Pressures Ranged from 0.58 to 3.79 lb/ft².

TABLE A-II

Most Probable Atmosphere

Release Altitude (ft)	Release Velocity (ft)	Penetrator Pitch Attitude at Release (degrees north of vertical)	Wind Velocity (ft/sec from the south)	Impact Velocity (ft/sec)	Time of Fall After Release (sec)	Pitch Frequency (Hz)	Maximum Pitch Angle (degrees)	Pitch Damping Rate-Time to 1/2 Amplitude (sec)	Maximum Ground Range (ft)	Mach Number Range
4000	300	0	0	427.1	10.99	-	-	-	0	0.38-0.53
4000	400	0	0	499.7	8.88	-	-	-	0	0.50-0.63
4000	500	0	0	579.9	7.40	-	-	-	0	0.63-0.73
4000	600	0	0	664.8	6.32	-	-	-	0	0.75-0.83
5000	300	0	0	452.8	13.26	-	-	-	0	0.38-0.56
5000	400	0	0	521.3	10.84	-	-	-	0	0.50-0.65
5000	500	0	0	597.9	9.10	-	-	-	0	0.63-0.74
5000	600	0	0	679.9	7.81	-	-	-	0	0.75-0.85
6000	300	0	0	477.0	15.41	-	-	-	0	0.38-0.60
6000	400	0	0	451.8	12.72	-	-	-	0	0.50-0.68
6000	500	0	0	615.3	10.74	-	-	-	0	0.63-0.77
6000	600	0	0	694.6	9.26	-	-	-	0	0.75-0.87
7000	300	0	0	499.7	17.45	-	-	-	0	0.38-0.63
7000	400	0	0	561.5	14.53	-	-	-	0	0.51-0.70
7000	500	0	0	632.1	12.34	-	-	-	0	0.63-0.79
7000	600	0	0	708.8	10.68	-	-	-	0	0.76-0.89
5000	400	5	100	519.7	10.86	0.50-0.63	19.0	16.4	14.6	0.52-0.66
5000	400	5	0	521.2	10.84	0.50-0.63	5.0	16.4	0.052	0.50-0.65

Reynolds Numbers Based on Length Vary from 1.0×10^5 to 2.9×10^5 .

Dynamic Pressures Ranged from 1.10 to 7.01 lb/ft².

The last two rows in each table are the results of calculations made to determine the pitch behavior and damping rates as well as the effects of winds on the falling penetrator.

The minimum release velocity (300 ft/sec) and the minimum release altitude (4000 ft) used in calculating the tables were taken from the engineering model at the time the parachute is released from the lander. The maximum values of release velocity and release altitude were chosen to extend beyond the range over which the penetrator could be expected to survive. The 5° initial attitude angle was chosen as representing a reasonable estimate of the tilt of the lander at the time of the release of the penetrator.

An examination of the data in these tables indicates that the atmosphere has a very limited effect on the penetrator. For either atmosphere, the damping is slight, so that little help can be expected from the atmosphere in aligning the penetrator to a desired impact angle. However, the lateral winds, if sufficiently high, can cause rather large pitch oscillations which damp slowly. In the cases examined for wind effects, a wind of 100 ft/sec blowing continuously on a penetrator falling from 5000 ft at 400 ft/sec caused the attitude angle to change from 5° at release to 19° a few seconds later. This wind velocity may be too large for a representative case, but, if a more probable wind velocity of 40 ft/sec were used, the increase in the initial attitude angle should drop to about 10.6° . If this were damped at the time of impact to, say, 70% of its initial value, the impact angle would be about 7.4° from the vertical. This sensitivity to lateral winds can be ascribed to the large static margin. Careful consideration should be given to this problem, because too shallow an impact angle could result in breakup of the penetrator. One solution would be to encase the penetrator in a light plastic shell contoured to provide the desired aerodynamic characteristics.

In Figure A-11, the relationship of the release altitude, the release velocity, and the impact velocity for the two atmospheres is shown for a fall in a vacuum. These relationships may be used to determine the "drop windows" for vehicle release.

Figure A-11. The Relationship of Release Altitude, Release Velocity and Impact Velocity for Two Atmospheres

Terradynamic Vehicle Release Mechanism

After the aeroshell separates and before the Mars lander descends to 8000 ft (about 24 seconds), the stored Probe Vehicle will be rotated 90° from its horizontal position to a vertical position. This rotation will be accomplished by a small hydraulic cylinder which receives its pressure from a sealed gas bottle which is connected to the hydraulic cylinder by a bridgewire-activated explosive valve. This mechanism is shown in Figure A-12.

Release of the probe from the lander is initiated by the firing of the explosive latch pin, and possibly the release squib on the antenna, when the lander is at an altitude which will give the desired impact velocity of close to 500 ft per second; release should occur at a time when the lander is oriented within a 5° cone about the vertical.

After the terradynamic vehicle is released and has descended to 4,500 feet, a third explosively driven piston motor is fired to jettison the launch rail, detent mechanism, hydraulic cylinder, and gas bottle; only 0.25 pound of residual dead weight from the launch mechanism will be on the lander at the time the vernier rockets are fired for the final landing descent maneuver.

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Figure A-12. Mars Probe on Mars Lander

APPENDIX B

POWER SUPPLIES

General

The Subsurface Water Analyzing Probe has three different power requirements which correspond to the three distinct phases of its operation: impact (Phase 1), transmit (Phase 2), and quiescent (Phase 3). These requirements are summarized below.

	Penetrator Power Requirements		
	Impact	Transmit	Quiescent
Transmitter	1.0 watt at 22 volts	1.0 watt at 22 volts minimum for 0.5% duty cycle	
Logic Circuits	500 milliwatts at 6 volts	150 milliwatts at 6 volts	15 milliwatts at 6 volts
Accelerometer	200 milliwatts at 10 volts	---	---
Instrumentation	Intermittant demand to fire 40,000-erg bridgewires	35 milliwatts	35 milliwatts
Secondary Battery Recharge	---	---	50 milliwatts $E \geq 3$ volts

It is probable that a different supply will be required for each phase of the power cycle. Figure B-1 is a block diagram of the power supply subsystem. The components shown in this figure are discussed in detail in this appendix.

Figure B-1. Block Diagram: Power Supply Subsystem

Radioisotope Generator

A radioisotope generator was selected for the power generating component of the power supply subsystem because the size, ruggedness, and capability for continuously producing power offered advantages over a solar cell design in the environment anticipated for the penetrator. In that solar cells are more susceptible to the anticipated variable factors of the Martian environment such as dust deposition by wind than a radioisotope supply, a radioisotope source was selected for the primary power supply.

The size and weight limitations imposed by the penetrator design led to the choice of two different designs as potential candidates for the generator. One is a thermionic generator based on the Isomite* technology developed by Donald W. Douglas Laboratories (DWD) and the other is the tubular thermoelectric module developed by Westinghouse Astronuclear Laboratories (WANL).

The Isomite thermionic generator is attractive because it possesses characteristics inherent and common to all thermionic generators, i. e., small size, high power-to-weight ratio, relative insensitivity to changes in heat rejection temperatures, and high heat rejection temperatures.

The basic Isomite design (Figure B-2) makes maximum use of the available heat from the radioisotope fuel by enclosing the emitter surface with the collector shell. The resulting design is a very compact, relatively (approximately 3 percent) efficient device.

A process developed by DWD for obtaining low work function surfaces on the tantalum electrodes eliminates the need for high emitter temperatures; therefore, fuel containment problems at high temperatures are precluded.

Development of the Isomite cells is relatively advanced. Cells of from 100 microwatts to 20 milliwatts, some of which have undergone life tests of over 10,000 hours, have been constructed. No deterioration has been observed other than that attributable to the decay of the fuel.

* Isomite is a Trade Mark owned by McDonnell Douglas Corporation.

Figure B-2. Typical Isomite Thermionic Converter Designed by Donald W. Douglas Laboratories

The WANL compact module is a tubular, thermoelectric module which is constructed of stacks of washers of PbTe thermoelectric material autoclaved into a compact, void-free device. The design is illustrated in Figure B-3. The module is attractive primarily because the design is highly resistant to impact and therefore offers an alternate approach for meeting the shock environment imposed by the penetrator.

Designs using this approach would be fueled internally by placing a fuel capsule in the center void of the module. A high specific power fuel such as ^{244}Cm will be required to produce sufficient heat flux for optimum operation of the module.

Development of the module is also relatively advanced. Some early modules have been on life test for over 30,000 hours. More recent modules using design improvements have been on test for over 5000 hours with no degradation in performance.

Generator Feasibility Studies

Feasibility studies were performed for both tubular module and Isomite designs to establish the suitability of these approaches and to better emphasize the advantages and disadvantages of each design. Because of uncertainties associated at this time with the efficiencies of the battery charge circuit, battery, and DC/DC converter, designs were analyzed for power outputs which would span the most likely power range required of the generator.

In that the following studies are not complete, the impact of changes in generator design on nuclear safety cannot yet be assessed. However, past experience shows that, in general, the weight and volume of the generator package must be increased over that of the conventional design to include reentry protection and to insure impact survivability of the fuel container.

Tubular Module Studies -- Tubular module studies were performed by restricting analysis to that of active circuit length, i.e., the portion of the

Figure B-3. Typical Tubular Thermoelectric Converter Designed by Westinghouse Laboratories

generator containing the thermoelectric material as shown in Figure B-4. By taking this approach, one can accurately establish a bound on generator efficiency, output voltage, weight, and size. Neither the fuel capsule nor the end enclosures necessary to secure the capsule in the module is considered in this initial study. The addition of these items will result in increases in the weight and length of the converter and in heat losses in the final design. The magnitude of these effects will depend greatly on capsule design and generator fueling procedures.

Two diameter sizes for the module were considered for the tubular module studies. The results are summarized in Tables B-I and B-II. A 1.6-inch O.D. was selected as one module size because most developmental work at WANL has been on modules of this size. The 1-inch module was selected for study because it is more compatible with penetrator size constraints.

The most apparent problem brought forth from these analyses is the large fuel inventory required. This presents the problem of rejecting into the Martian environment sufficient heat to allow battery and power supply electronics to operate at reasonable temperatures. Most of this inventory is required because of the large end losses inherent in the present module design.

The fuel selected for the tubular module designs was $^{244}\text{Cm}_2\text{O}_3$. This fuel has sufficiently high power density and half life to be useful in the tubular module, and the present developmental status makes it a reasonable choice for a 1973 mission.

Isomite Studies -- Table B-III summarizes the results of analyses on three Isomite designs. Results of these three designs bracket the expected performance from an Isomite generator for the penetrator power supply.

An evaluation of developmental status, half-life, power density, and potential safety hazards, has led to the selection of two fuels as candidates for an Isomite generator: $^{147}\text{Pm}_2\text{O}_3$ and $^{238}\text{PuO}_2$. A comparison of performance

Figure B-4. Suggested Design Alterations to Isomite Cell for High Impact Environments

TABLE B-I

Summary of Module Characteristics for a 1-Watt Design
Based on Westinghouse Tubular Module Technology

Output Power (watt) (e)	1	1
Output Voltage (volts)	1.9	0.48
Module O.D. (inches)	1	1.6
Module I.D. (inch)	0.25	0.5
Active Length (inches)	13.8	0.9
Module Weight (grams)	1380	240
Fuel	Cm_2O_3	Cm_2O_3
Fuel Power Density (watts/cm ³)	20.4	20.4
Fuel Loading (watts) (t)	245	104
Fuel Weight (grams)	108	46
Module Efficiency (%)	0.40	0.96
Hot Junction Temperature	625°F	700°F
Cold Junction Temperature	575°F	500°F

TABLE B-II

Summary of Module Characteristics for a 0.25-Watt Design
Based on Westinghouse Tubular Module Technology

Output Power (watt) (e)	0.25	0.25
Output Voltage (volt)	0.47	0.12
Module O. D. (inches)	1	1.6
Module I. D. (inch)	0.25	0.5
Active Length (inches)	3.45	0.225
Module Weight (grams)	345	60
Fuel	Cm_2O_3	Cm_2O_3
Fuel Power Density (watts/cm ³)	20.4	20.4
Fuel Loading (watts) (t)	74	80
Fuel Weight (grams)	32	35
Module Efficiency (%)	0.34	0.30
Hot Junction Temperature	625°F	700°F
Cold Junction Temperature	575°F	500°F

TABLE B-III

Summary of Cell Characteristics for Three Designs Based
on Isomite Cell Technology

	Note (1)	Note (1)	Note (2)
Output Power (watt at EOL)	0.360	0.360	0.500
Output Voltage (volt)	0.25-0.30	0.25-0.30	0.59
Collector O. D. (inch)	1	1	1
Cell Length (inches)	2	2	1.3
Cell Weight (grams)	156	130	153
Fuel	Pm_2O_3	PuO_2	PuO_2
Fuel Power Density (watts/cm ³)	1.8	2.0	2.5
Fuel Loading (watts at BOL)	12	8	15.5
Fuel Weight (grams)	44	20	40
Cell Efficiency (%)	4.2 (BOL)	4.4	3.2
Emitter Temperature (°F)	1382	1382	1742
Collector Temperature (°F)	752	752	896

NOTES:

1. Estimations by DWD for 0.360-watt cell capable of surviving penetrator impact.
2. Estimations by Sandia for 0.5-watt cell of the design shown in Figure B-4.

was made for these fuels for a 0.350-watt Isomite design. The PuO_2 offers some advantage in efficiency, but this may be offset by the more favorable safety characteristics of the shorter half-life promethium fuel.

The most difficult problem associated with the Isomite approach is the need to maintain the close spacing between the emitter and collector electrodes after high g impact of penetrator afterbody. The spacing is of the order of 0.001 to 0.0025 inch. A design approach which may overcome this problem is shown in Figure B-4. The basic Isomite design is altered to include ceramic supports at each end of the cell at the sacrifice of the active electrode surfaces at these ends. Because the impact loading will be in the axial direction, there will be little loading on the lateral walls. Electrode spacing is maintained in this latter design by sapphire balls instead of ceramic grains.

Environmental and Vehicle Interfaces -- Preliminary thermal analyses were performed to determine the problems associated with generator heat rejection and to better determine the feasibility of the two candidate generators in expected environmental conditions.

The thermal model used for these studies was based on using radiation from the 6-inch diameter back drag plate of the penetrator afterbody for the primary heat rejection mechanism. This choice was made after initial analyses indicated insignificant heat transfer through the Martian soil because of its low thermal conductivity. The back plate of the afterbody would normally be exposed to the atmosphere because of the probe design and is therefore available as a thermal radiator for removing waste heat.

A thermal analysis, using the thermal loadings from the designs of the previous section, indicates:

1. An Isomite generator, due to its high heat rejection temperature and small thermal loading, can satisfactorily operate within the afterbody section as it is now designed.

2. Battery and electronics can be maintained at suitable temperature by proper thermal separation from the generator.
3. The tubular module design, due to high thermal inventory, cannot maintain the heat rejection temperatures required for its operations. However, more detailed studies may reveal a means of rejecting sufficient heat to allow proper operation of a tubular module.

The high impact of the afterbody section of the penetrator imposes a severe shock environment on power supply components; however, appropriate use of energy absorbing materials such as crushable honeycomb can reduce the average g loading experienced by these components to 6500 g's for the hardest soil model. This is within the capability of the batteries, electronics, and the tubular model generator. It is felt that, with appropriate design changes, this is within the capability of an Isomite generator.

Summary -- Feasibility studies of the proposed generators for several power levels indicate that both generators could meet, with appropriate changes, system power requirements. Of the two, the Isomite cell is the most attractive design at this point because of its low thermal inventory, size, and weight. The tubular design, as indicated previously, poses some severe problems in the area of heat rejection. However, this design represents an alternative to the Isomite in the event the Isomite cannot be modified to survive impact loads. Both approaches would be carried forward in the early design until more detailed analyses could clearly establish which supply was to be used for the Sub-surface Water Analyzing Probe.

Solar Cells

Solar cells are an alternate primary source of power for the Viking penetrator. Solar arrays have been proven for space applications in earth orbiting systems and in the Surveyor moon lander missions. Data from

Surveyor missions [B-1] have shown that solar panels will survive the temperature extremes experienced on the lunar surface. The surveyor and other space missions have also shown that solar panels can be designed to withstand cosmic radiation and micrometeoroid flux with little degradation. A study of power supplies for a Mars hard lander [B-2] has indicated that solar arrays can withstand the impact shock anticipated for the afterbody of the penetrating vehicle proposed for Viking. This study reports on drops of a development lander capsule on a macadamized road at 115 feet per second and on laboratory tests of solar cell assemblies subjected to greater than 9000 g for 1 millisecond. The solar cells survived these shock environments.

The primary advantage of a solar cell power supply is its ability to produce power without significantly increasing the temperature of the assembly and the adjacent Mars surface. Disadvantages of solar power systems include the unknown effects of dust and clouds in the Mars atmosphere.

The back plate of the afterbody of the penetrating vehicle provides an area suitable for mounting a solar array. This plate is 6 inches in diameter and, excluding a 1-inch diameter central area which is committed to the antenna mounting, is available for mounting solar cells. This is a surface area of 27 in^2 or 177 cm^2 . Assuming the use of photovoltaic silicon solar cells with an efficiency of about 10 percent and derating by two-thirds to account for packaging, impedance mismatch, and other factors, the power delivered by the solar array at normal incidence will be about 6.6 percent of the solar intensity at the Martian surface. For the available area,

$$P = (60 \text{ mW/cm}^2) (0.066) (177 \text{ cm}^2) = 700 \text{ mW}$$

Assume that the latitude for landing is such that an angle of 50 degrees from normal incidence at Martian noon exists.

$$P' = (700 \text{ mW}) (\cos 50^\circ) = 450 \text{ mW}$$

To account for the angle of incidence through the Martian day, assume the cosine law applies:

$$P'_{ave} = \frac{1}{\pi} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} P' \cos\theta d\theta = 288 \text{ mW}$$

Further, assume a Martian day of 10 hours out of a total of about 24 hours. Then, the average power available to supply the instruments and the rechargeable battery is

$$P_{ave} = \left(\frac{10}{24}\right) P'_{ave} = 120 \text{ mW}$$

This power, which is based on the mean solar intensity, will decrease by a factor of 0.83 at the Mars aphelion.

Factors which have not been included in the above power estimate include the effects of wind and dust in the Martian atmosphere and of dust settling on the face of the solar panel.

An average power of 120 milliwatts is adequate to charge the secondary battery and maintain the instrumentation and logic during the Viking mission.

Batteries

In power supply phases (1) and (2), batteries are required. The battery for the impact phase can be a one-shot component, for example, a thermal battery; the battery for the transmit phase is expected to be a rechargeable system (if the mission lifetime is to be greater than 18 days, the battery must be rechargeable). The most difficult design problems connected with the power

supply subsystem are those associated with the batteries. The problems arise in descending order of difficulty from

1. The prelaunch sterilization environment
2. The high-g impact shock deceleration
3. Low ambient temperatures

Several systems have been investigated, but none appears to presently meet all requirements. The planetary quarantine heat cycle is especially severe for battery systems. The following systems are discussed:

1. Thermal battery to supply power during the freefall and impact phase.
2. Nickel-cadmium sealed cell to be used, in conjunction with a radioisotope thermionic generator, or a solar cell array, to supply peak power loads.
3. A silver-oxide/zinc primary battery to supply several days of operation after landing.

1. Thermal Battery

Sandia has pioneered the development of thermal batteries for AEC applications since 1950; consequently, an extremely good selection of sizes, weights, power outputs, etc., can be shelf selected. These devices are inherently rugged battery designs; many of the existing designs can survive the expected 6500-g impact shock loads. The battery for Phase 1 (impact) will provide power to operate the system for 5 minutes prior to, during, and for a short time after impact to assure transmission of impact deceleration data. It must continue to deliver power through impact--not just be operable after impact. Recent tests [B-3] on thermal batteries for the penetrometer program showed only a 5 percent change in voltage (of approximately 1 to 2 milliseconds duration) during 2500-g hard target impacts.

In the existing designs, the pyrotechnic "match" used to liquify the electrolyte is destroyed by the sterilization heat cycle. The oxidizer reacts with the fuel at an accelerated rate without actually burning, so that, after 400 hours, the chemical agents are too depleted to react. This program will require we either develop an alternate chemical composition for the match that is less heat susceptible or else design another means of initiating the thermal battery. If adequate Lander power is available prior to release of the Subsurface Water Analyzing Probe, it may be possible to use an electro-thermal match which would completely solve the sterilization problem; the remainder of the thermal battery is unaffected by the 135°C temperature.

2. Nickel-Cadmium Cell

Since the transmitter requires 1.0 watt on only a 0.5-percent duty cycle, maximum utilization of the primary generator, irrespective of whether it is a radioisotope generator or solar cell array, suggests use of a secondary battery to accumulate the generator output during periods between transmissions. The most attractive of the various secondary cell designs from the stand points of voltage, recharge cycling, power to weight ratio, and wide field experience is the Ni-Cd cell.

Extensive experience has been gained at Sandia in successfully packaging these cells for several high-g impact applications. The batteries have been qualified for 10,000-g impact environments. Temperature control for the battery will be provided by using heat rejected from the generator.

Three volts were selected as battery voltage. This choice of two nickel-cadmium cells represents a good compromise between battery reliability and sufficient voltage input to the DC/DC converter for efficient operation.

To prevent battery overcharge and to provide current-voltage conditions conducive to efficient battery charge, circuitry will be included to limit generator voltage and current below that which could degrade battery performance. This circuitry will include, at a minimum, a shunt voltage regulator to limit voltage rise at end of charge.

The problem with existing designs is that the separators break down from the accelerated reaction with the electrolyte during the sterilization cycle. If NASA develops a sterilizable Ni-Cd cell in time for the Viking mission, we would hope to use their design. The other alternative is a lower efficiency cell with ceramic separators. Development on this cell will be carried out by the battery development group at Sandia.

3. Silver-Oxide/Zinc

This battery could be used in the event that a radioisotope-fueled supply or solar cell array and associated secondary battery power supply subsystem were found to be impractical. A 1-inch diameter, 3-inch long battery would be adequate to provide power during landing and for 18 days afterwards. The battery would have to be sterilized before injection of the electrolyte. The electrolyte and cells would be isolated during the heat cycling; then the cell could be activated.

A small radioisotope heater would have to be incorporated in the power supply to maintain the battery temperature between 10° and 40°C after the landing on Mars. Sandia has not certified a Silver-Oxide/Zinc cell for high-g impact loads. Therefore, some development work would be required to improve shock survivability and to insure hermetic sealing of the cells.

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APPENDIX C

INSTRUMENTATION

General

The instrumentation system, shown by block diagram in Figure C-1, provides for measurement of deceleration upon penetration of the surface, measurement of temperature and humidity beneath the surface and near the surface, and a measurement of the water content of the effluents from a soil sample which has been weighed and then heated to 200°C. Data are sampled by a commutator, converted to 6-bit binary form, and transmitted as serial PCM signals over a 100-milliwatt, 20 MHz radio frequency link to the Lander. On the Lander, a receiver detects the transmitted signals, demodulates them, and stores them in a 8-kilobit temporary store until the data can be read into the Lander data storage or data transmission system.

Sensors

Acceleration

Acceleration will be measured by a unit similar to the Endevco Model 2261 piezoresistive bridge accelerometer. The device will measure peaks up to 10,000 g's and has a resonant frequency of 30 KHz. Output of the DC-excited gauge will be amplified by a low-power differential operational amplifier and fed through a gate to the A/D converter. Power for all systems during the phase from penetrator release from the Lander to several minutes after impact will be obtained from a small thermal battery. During this

Figure C-1. Viking Lander Subsurface Water Analyzing Probe

phase, the A/D converter will be driven at the maximum clock rate of 28,820 Hz. Upon command from the timer, the transmitter, A/D converter, commutator, clock, and scaler power buses are switched from the thermal battery to the long-term power system; the accelerometer circuitry is switched off, and the bit rate is reduced to 14 bits per second.

Temperature

Silicon resistors (Sensistors) in resistance bridges will be used to sense temperature at the soil sampler location in the probe and at one location in the afterbody. This element will operate over the range -100° to $+30^{\circ}\text{C}$ with a resolution of $\pm 3^{\circ}\text{C}$. Bridge outputs will be amplified by low-power differential operational amplifiers whose outputs will be fed to the commutator for subsequent A/D conversion.

Water

Sandia Laboratories pioneered the development of the aluminum oxide hygrometer ([C-1 through C-5] and U.S. Patent* No. 3075385) and has extensive laboratory and field experience with these elements. In view of the low temperature extremes ($\sim -100^{\circ}\text{C}$) and the extremely low water vapor pressures ($3 - 7 \times 10^{-4}$ millibar) expected on Mars, the aluminum oxide hygrometer would appear to be the only sensor element suitable for water vapor measurements in the Subsurface Water Analyzing Probe.

The sensor consists of an aluminum strip which is anodized by a special process to provide a porous oxide layer. A very thin coating of gold is evaporated over this structure. The aluminum base and the gold layer form the two electrodes of what is essentially an aluminum oxide capacitor.

Water vapor is rapidly transported through the gold layer and equilibrates on the pore walls in a manner functionally related to the vapor pressure of water in the atmosphere surrounding the sensor.

*U. S. AEC patent by Sandia Corporation, dated 29 January 1963 (inventor C. M. Stover).

The number of water molecules adsorbed on the oxide structure determines the complex conductivity of the pore wall. Each value of pore wall resistance provides a distinct value of electrical impedance which in turn is a direct measure of the water vapor pressure.

The sensor is placed in one leg of an AC bridge (1 KHz) which measures its complex impedance and hence the amount of water adsorbed by the aluminum oxide layer in the element. A calibration chart made for that element under similar test conditions (pressure, temperature, humidity and equilibration times) can give accuracies of ± 2 percent for temperatures above 0°C and ± 5 percent for temperatures near -100°C . The standard sensor probe will measure water vapor from Dew/Frost Points of $+20^{\circ}$ to -110°C at 1 atmosphere pressure. This range represents a change in moisture from $20,000 \mu\text{g H}_2\text{O/liter}$ to about $0.001 \mu\text{g H}_2\text{O/liter}$. This latter range of sensitivities of the sensor is the most meaningful since it defines the limits of the hygrometer performance independent of the atmosphere.

The aluminum oxide humidity element, when sealed in a vial of low humidity gas, has survived the high temperature sterilization environment specified by NASA. The probe must be kept in a known humidity gas during the temperature cycling to preserve the presterilization calibration. In this experiment, the sensors would be kept in this stable environment during pre-flight, launch, and interplanetary flight to insure their calibration on arrival at Mars. The Al_2O_3 sensor has no significant temperature or pressure coefficient over the entire dynamic range. It is unaffected by large concentrations of nearly all gases, including carbon dioxide, nitrogen dioxide, ozone, and carbon monoxide. Operation is affected by the presence of ammonia, methanol, and certain primary amines (ammonia-derived compounds).

With temperature known, the sensor can measure relative humidities from 55 to less than 0.0001 percent at $+30^{\circ}\text{C}$ and from 10 to 100 percent at -84°C .

Baseline data for soil water content will be obtained by heating a measured mass of soil and letting it outgas into a known volume and then measuring the dew point of the liberated water vapor in the chamber. The configuration of the components for this experiment is shown in Figure C-2.

Immediately after the penetrating vehicle has come to rest beneath the Martian surface, a small port in the side of the vehicle will be opened and a small explosive charge mounted on the wall of the penetrating vehicle near this port will detonate to loosen soil and drive it into the port. Experiments made to test this scheme have demonstrated that a 50-milligram charge will dislodge compacted soil and drive several hundred milligrams into a 0.2-inch diameter port. A tissue-paper barrier was placed over the port to prevent premature sampling. The barrier was broken when the soil was driven into the port by the overpressure of the explosive. To avoid altering the water content of the Martian soil, or producing combustion byproducts which might interfere with the operation of the aluminum oxide hygrometer elements, the explosive used (metallic azides) will not evolve water or ammonia as a reaction product.

The soil will be collected on a platform supported by springs. Motion of the platform drives a coil in the field of a permanent magnet. The mass of the soil sample will be determined by pulsing the coil to initiate motion and by observing the frequency of oscillation of the spring-mass system.

A spring-mass system similar to that described for determining the mass of soil collected has been developed by Sandia Laboratories for use in geophones implanted by penetrating vehicles. Many of these systems have been successfully used, and the ability of these instruments to survive the shock of emplacement by a penetrating vehicle has been established.

When the mass of the soil sample has been determined, the entry port will be closed, and a pellet of Iron-Potassium perchlorate heat powder in the platform supporting the soil will be ignited to heat the soil to about 200°C.

Figure C-2. Soil Moisture Gauge

This heat powder, which delivers 220 calories per gram, is essentially gas free (1 - 3 milliliter of gas at STP); thus the combustion cell can be sealed to prevent the escape of any combustion byproducts. This heating will liberate water absorbed in the soil, but will not release chemically-bound water.

The quantity of water liberated from the soil will be determined by measuring the dew point in the chamber into which the water is liberated. This measurement is made by the standard technique of optically determining the point at which condensation on a reflecting surface occurs to diffuse light and measuring the corresponding temperature of the specular reflector. When the soil sample is heated, the reflecting surface will also be heated and its temperature will be monitored. This reflecting surface will be located to provide a thermal conducting path to the outside of the vehicle higher than that of the remainder of the chamber components. In particular, the heated platform supporting the soil will be thermally isolated from the remainder of the chamber to keep the soil sample temperature elevated while the mirror is cooled through the dew point temperature. The low temperature of the soil in which the penetrating vehicle is embedded will make it possible to cool the reflecting surface from the initially heated temperature to about -60°C . Determination of a dew point in this range of temperature will provide measurements of soil water content ranging from about 0.1 gram of water per gram of soil to less than 10^{-5} gram of water per gram of soil. The behavior of the dew point as a function of soil water content is shown in Figure C-3.

The initial temperature of the penetrating vehicle, and therefore the soil sample chamber, could be below the dew point of the water liberated from the soil sample. The initial temperature of the chamber will depend upon the temperature of the vehicle when it is ejected from the lander, the heat generated by the penetrating vehicle, and the heat radiated from the platform on which the soil sample is heated. To reduce condensation on the chamber walls before the dew point is measured, all components within the chamber, except the dew point instrument and the platform on which soil is collected, will either be constructed of Teflon or coated with Teflon. Teflon has no attraction for

Figure C-3. Graph of Soil Water Content versus Dew Point (assuming $20 \text{ cm}^3/g_{soil}$ for the volume into which soil water is evaporated)

water molecules, and it has been observed that an atmosphere saturated with water vapor does not condense on Teflon.

Probe Electronics

Clock

A multivibrator oscillator and binary countdown chain provide the basic timing for all digital circuits and programming functions. The frequency of 28,820 Hz was selected for the following reasons:

1. For measurement of the deceleration profile, a sampling rate of about 4,000 samples per second is required. Using an 8-bit data word (including word sync), the bit-rate would then be about 32,000 bits per second.
2. A transmitting interval of once-every-eight hours for the 90-day mission was selected. The binary divisor of this time period near 32,000 Hz is approximately 28,820 Hz. This frequency was therefore selected.

Scaler outputs are taken at 896 Hz, 112 Hz, 14 Hz, 1.75 Hz, 0.88 Hz, 18 sec, 2 hr, and 8 hr for various functions.

Commutator

The commutator is active for the low-frequency measurements only. It scans the two temperature sensors and two humidity sensors and provides the appropriate output to the A/D converter. The accelerometer and soil sampler outputs bypass the commutated gates and go through analog gates.

Analog-to-Digital Converter (A/D Converter)

A six-bit A/D converter was selected as a compromise between data resolution and converter complexity. The converter is of the successive approximation type. Digitizing rate is 3,602 6-bit conversions per second

during the impact phase and 1.75 6-bit conversions per second during readout of temperature and humidity data.

Serializer

This unit converts the parallel-output digitized data to a serial PCM bit train. It is programmed to inject the 8-bit counter data from the soil sampler into the serial bit stream at the selected time.

Timer

The timer uses appropriate outputs from the scaler to program the following functions:

1. Switch power buses from thermal battery to long-term supply.
Switch bit-rate from High to Low.
2. Turn transmitter on at selected intervals. Turn off after 18 seconds of transmission.
3. Activate and terminate soil sampling experiment.
 - a. Open port
 - b. Fire explosive charge
 - c. Pulse spring-balance motor coil
 - d. Initiate heat powder, close port
 - e. Energize light source
 - f. Turn off soil sampler system

Modulator

This unit converts the serial binary signals from the A/D converter to a bi-phase format and provides a signal of the proper amplitude to deviate the frequency-modulated transmitter.

Transmitter

A transmitter developed by Conic Corporation, San Diego, California, for a previous Sandia penetrometer project [C-6] will be used as a point of departure for transmitter procurement. The Conic Model CTM 400.25 operates

at approximately 20 MHz, is frequency-modulated, and provides 100 milliwatts for an input power of 0.88 watts. Size and weight are compatible with the proposed penetrating probe, and the unit will operate through impact levels of 7500 g, 1 millisecond. Further development will be required to meet temperature requirements of the Viking project. A short, flexible probe has been selected, on the basis of extensive field tests with instrumented probes, as the best antenna for the vehicle. At the selected frequency an efficient antenna would be too long to be considered for the Viking Lander. Antenna design can not be completed until the vehicle is completely defined. An efficiency of about -10 db is expected.

Lander Based Electronics

Receiver

An FM receiver will be employed to detect and demodulate the penetrator data signals. The unit will require about 12 cubic inches of space and about 100 milliwatts of power at 6 volts. A weight of 6 ounces is estimated.

Memory and Data Conditioner

The penetrator clock cannot be synchronized with the Lander instrumentation system. Data must therefore be treated as asynchronous. The acceleration profile will require temporary storage of approximately 8,000 bits of data. For this purpose, a MOS-FET register is proposed. Due to the power required by such devices (approximately 13 watts for 8,000 bits), it is proposed that the memory be energized by the receiver when data are received and that it be deactivated after readout by the Lander data system. The unit will require about 32 cubic inches of space and will weigh approximately 1 pound.

Electronic Components

Insofar as possible, components with well-established reliability histories will be employed. However, for most of the digital circuitry employed on the penetrator, the need for low-power devices has dictated the consideration of Complementary-Symmetry Metal-Oxide-Silicon (COS/MOS) devices which are relatively new. Such devices will be intensively tested and screened before being incorporated into the design of the instrumentation system.

REFERENCES

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APPENDIX D

DESIGN AND QUALIFICATION TESTING

General

This appendix, unlike Appendices A, B, and C which gave detailed information on a part of the experimental equipment, is intended to describe the general nature of the test program which will be established, first, to aid in the design of the experiment, secondly, to ascertain its expected likelihood of successful operation, and finally, to interpret the data gathered.

Sandia Laboratories facilities and experience developed over the years for weapon systems and research and development testing will be put to extensive use on this project. Sandia has the capability of simulating in the laboratory nearly every type of environment this experiment will be exposed to. In addition, field tests will be conducted on Sandia's Tonopah Test Range, on DOD ranges, and at other remote sites as required to yield terradynamic and aerodynamic development data and other system qualification information for test environments that cannot be adequately simulated in the laboratory.

Environmental testing will be an integral part of the development program for components and subassemblies of the Subsurface Water Analyzing Probe experiment. During development of components such as the instrumentation system and the humidity sensors, our environmental test facilities will be utilized to demonstrate the ability of all the components to meet the test requirements specified for the Viking Lander [D-1] and to survive those environments unique to the subsurface water detection experiment. Special test emphasis will be placed on the sterilization temperature cycle and on

the mechanical shock associated with the penetrating vehicle; these environments are expected to be the most difficult for the system to survive.

Radioisotope Generators

The radioisotope thermoelectric generator will be tested and qualified according to agreements between the AEC and NASA which apply to all radioisotope generators supplied for NASA, including those on the Viking Lander.

This testing will be funded by the AEC.

Penetrating Vehicle

An experimental test program will be required to optimize the terradynamic and structural design of the probe vehicle. The following types of tests will be required:

1. Penetration tests of probe only: A portable air gun (available at Sandia) can be used to fire the probe into a variety of materials, including permafrost with various percentages of ice content. The tests will be both in natural earth targets and in man-made targets in the laboratory. In all cases, the probes will be instrumented to record deceleration during the penetration event. The objective of the tests will be to perfect the terradynamic and structural design of the probe. During these tests the emphasis will be on penetrating hard material.
2. Probe and tail section tests: The objectives of these tests will be to verify the performance of the system for paying out the umbilical line during penetration, and to optimize the structural design of the tail section so that it will deform at impact to absorb the maximum amount of energy while remaining sufficiently intact to protect the

electronics located in the tail section. The line pay-out tests will be in soft soil for maximum tail section/probe separation, and the structural tests of the afterbody will be in a moderately soft rock. The technique for testing these units will require development. One possible technique would be to air drop greatly overweight probes so that a free-fall impact velocity of 500 fps can be obtained in the earth's atmosphere. Another technique would be to shroud the penetrator to give the proper aerodynamic characteristics to the air drop configuration, and then just prior to impact discard the shroud and allow the penetrator to impact the soil and penetrate unhampered.

3. Complete systems tests: The recording equipment for the experiment will be installed in the penetrators for a series of full systems tests in a representative number of materials. In fact, there will normally be considerable overlapping or paralleling of the three basic types of field tests required. Therefore the complete systems tests will be more "proof" than developmental tests.

Tests on the penetrating probe and afterbody will be conducted in the wind tunnel to provide information about the stability of the vehicle in the Martian atmosphere. Data from these tests will be used for computer analyses of vehicle behavior. Past work on similar vehicles has resulted in thoroughly tested mathematical models for analyzing aerodynamic behavior.

Drop tests in the earth atmosphere will be conducted to determine the ability of the release mechanism to drop the vehicle at the proper attitude. These tests will also provide information on stability and the effects of wind loading, although interpretation may be difficult because of the large difference in the density of earth and Martian atmospheres.

Humidity Sensors

Extensive tests with the aluminum oxide hygrometers will be conducted to establish relationships between vapor phase humidity measurements and

soil water concentration for a wide range of soils. The humidity sensors for the Viking experiment will provide humidity data for soil near the surface where temperature variations are significant and for soil at a depth where the temperature and temperature changes are less and vary only seasonally. The soil moisture testing will establish the instrument response and humidity levels at various temperatures and soil water contents. These results will be used in the design stage to determine the appropriate range of sensitivity for the hygrometers and the associated monitoring circuitry.

Soil Sampler

Testing of this component for various soil conditions will be necessary to determine the choice and amount of the explosive charge required to efficiently dislodge and drive the soil sample into the chamber. The temperature required for heating the soil will have to be established experimentally to determine the proper amount of heat powder required to optimize the sensitivity of the instruments. The characteristics of the specular surface, its illumination, and the photocell sensitivity must also be determined experimentally for various soil water contents.

Testing in Support of Data Analysis

Data Transmitted from the Subsurface Water Detection Analyzing Probe experiment on Mars will include periodic water vapor concentration measurements. The interpretation of these data would be made by constructing a model soil for Mars based on the chemical and physical characteristics found by the Lander-based instrumentation and then by developing families of moisture sorption isotherms in the high altitude chambers at Sandia where the aspects of the Martian environment vital to humidity measurements could be simulated for extended periods of time (months).

During this test program, various soil compositions selected to be consistent with the observations of the Lander-based soil experiments will be analyzed with various water contents in an attempt to match the variations of observed water vapor concentration with temperature. It is hoped that tests attempting to duplicate these data in the laboratory will converge to a useful soil water model for Mars, which can then be used to quantitatively interpret the water vapor measurements from the experiment.

REFERENCE

- D-1. "Viking Project - Viking Description Presentation at Viking Preproposal Briefing, " NASA Document M73-115-0, September 1969.