GENERAL CONSTRAINTS ON THE VIKING BIOLOGY INVESTIGATION

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Abstract. The Viking biological investigation will be conducted in the face of a number of constraints. Problems are created because of the inherent engineering of the instrument, communication constraints and other factors.

It is the purpose of this paper to note some of the constraints within which the Viking biological experiments were conceived, designed, and manufactured; and within which the investigation will be carried out (Table I).

There is no doubt that what is being attempted in this study is extraordinary – in fact, unique – in the history of biology. In this investigation we will be attempting to conduct long-duration experiments, on the order of several months long, over a distance of over 200 million miles, entirely with automated equipment, and without the opportunity to deviate significantly from experiment strategies that were conceived almost 10 yr before the experiments will begin.

Certainly the most important limitation to the entire study is our incomplete information about the nature of Mars. While much information about Mars has been obtained in recent years, particularly through the use of spacecraft, large gaps in our knowledge remain. For example, we have no information about the chemical composition of the surface material of Mars. The information on the atmospheric constituents of that planet is incomplete. Only recently, as a result of data obtained by the Soviets on their Mars spacecraft, we learned that there is most likely an inert noble gas present, probably argon, in the Martian atmosphere in amounts of

TABLE I

Some constraints on Viking biology investigation

Science	Celestial mechanics	Engineering	Communications	Operations	Other
• Incomplete information about Mars • Limited number of approaches possible	• Schedule difficulties • Conjunction • Early termination of Lander B science • Affects on communication	• Because of Lander • Within Biology Instrument	• Restricted command capability • Long 'turnaround' time	• Competition with other science investigations • Mission sequence	• Landing sites • Sampling • Abbreviated test program

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the order of 35% of the atmosphere (Moroz, 1975). We do not know whether there are any nitrogen-containing compounds in the Martian atmosphere. Previous attempts to measure such compounds have failed to reveal any, and at the present time, we must assume that if there is nitrogen in the atmosphere of Mars, it must be present as a very minor constituent (Barth, 1974). The big question about which we should like to have more information revolves around water on Mars; there is evidence for bound water in the surface material (Houck *et al.*, 1973); there is also evidence suggesting water in the frozen ice caps at the poles (Murray and Malin, 1973), and there is evidence for occasional water clouds (Conrath *et al.*, 1973). There are also speculations that water exists as perma-frost beneath the surface of most of the planet (Masursky, 1973), but the fact remains that we would be in a much better position to plan biological investigations on the surface of Mars with a more thorough understanding of the water distribution on that planet.

With a relatively large number of unknowns regarding the local environmental conditions on the surface of Mars, the best 'search' strategy for life on Mars under these circumstances would entail either a large number of 'life detection' experiments based on differing assumptions about the nature of Martian biota, or an extremely sophisticated automated laboratory capable of making on-board decisions and proceeding from chemical analyses of the surface matter to detailed metabolic experiments (Reynolds and Klein, 1967).

There are a number of important ways in which celestial mechanics has placed rather severe limitations on the biology investigation (Table I). First of all, there are only limited opportunities to launch vehicles to Mars. Unlike launching to the moon, which can occur every month, we are in a position to launch to Mars only every 25 months. As a consequence, once a launch date has been selected, everything must be completed by the launch data since serious delay would necessitate a 'slip' of the launch by two years, thus adding a great deal to the cost of the mission. Without going into details, it is evident that *simply maintaining* a schedule for the design, manufacture, and testing of the Viking biological experiments became a dominating factor in the program, since all elements had to come together by the target launch date. Along the way, there were times when the Viking Biology Team* had to make hard choices between eliminating certain desirable items, or risking a costly delay to the mission.

Celestial mechanics also poses other difficulties. Thus, from about November 10 to December 19, 1976, Mars is occulted by the Sun, and therefore communications between the spacecraft and Earth must be suspended. This fact sets a termination date on the entire mission – that is, early November 1976 – despite the fact that the landers are designed to function for several years. Viking planners, however, are currently in the process of exploring possibilities for a so-called 'extended mission' in which the experiments could be resumed after this conjunction period, and continue through 1977 into 1978. But even if this becomes feasible, new difficulties would arise for the biological investigation. This involves the second lander. At *its*

* The team of scientists selected, in 1969, to conduct the biological investigation on the Viking spacecraft consisted of the author, Norman H. Horowitz (California Institute of Technology), Joshua Lederberg (Stanford University), Gilbert Levin (Biospherics Incorporated), Vance I. Oyama (NASA-Ames Research Center), Alexander Rich (Massachusetts Institute of Technology), and the late Prof. Wolf Vishniac (University of Rochester).

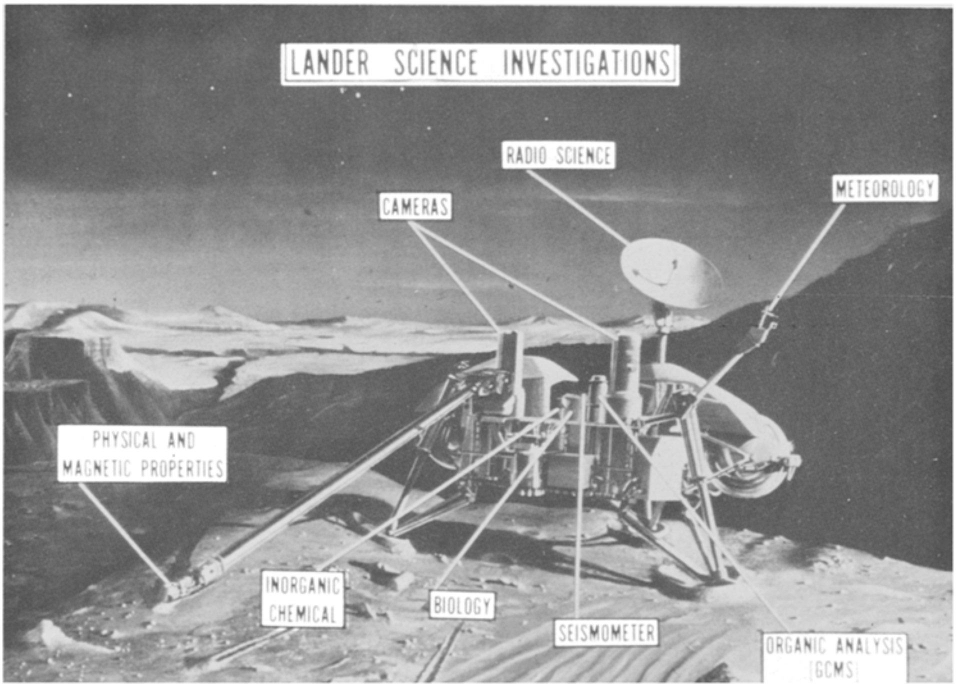

Fig. 1. Viking Lander showing position of several science instruments. The two broad, pyramid-shaped objects on top house the thermonuclear power sources.

landing site in the northern hemisphere, winter will become more intense after landing, and by late February or March 1977, that location is expected to become so cold that the thermal limits of the biology instrument will be exceeded.

Several major engineering constraints have also strongly influenced this investigation (Table I). These can be considered to fall into two categories. One arises because the biology instruments are inside of the landers, and the other is imposed by the design of the instrument itself.

In Figure 1, the Viking lander is shown. On the lander are two radioisotope thermal generators (RTG's) which will generate power for the landers. As a by-product, they will also generate a moderate amount of radioactivity – a background count of around 500 counts per minute at the two C^{14} detectors in the Biology instrument. This has necessitated very long counting periods for both of the experiments in which C^{14} counts are to be measured in order to obtain acceptable statistics. Clearly, small changes in counting rates will be difficult to evaluate.

Because the Biology instrument is inside the lander, the thermal control of the experiments is cumbersome. The Biology instrument is mounted to a plate on the lander into which a large amount of energy is dissipated, both from other experiments and from the RTG's themselves. At times, during the expected diurnal cycle on Mars, this plate will become much warmer than the incubation cells. Therefore, despite the fact that temperatures outside of the landers will never get above freezing at either of the two sites selected for landing, the incubation cells will actually have to be *cooled* by thermoelectric coolers incorporated in the biology instrument

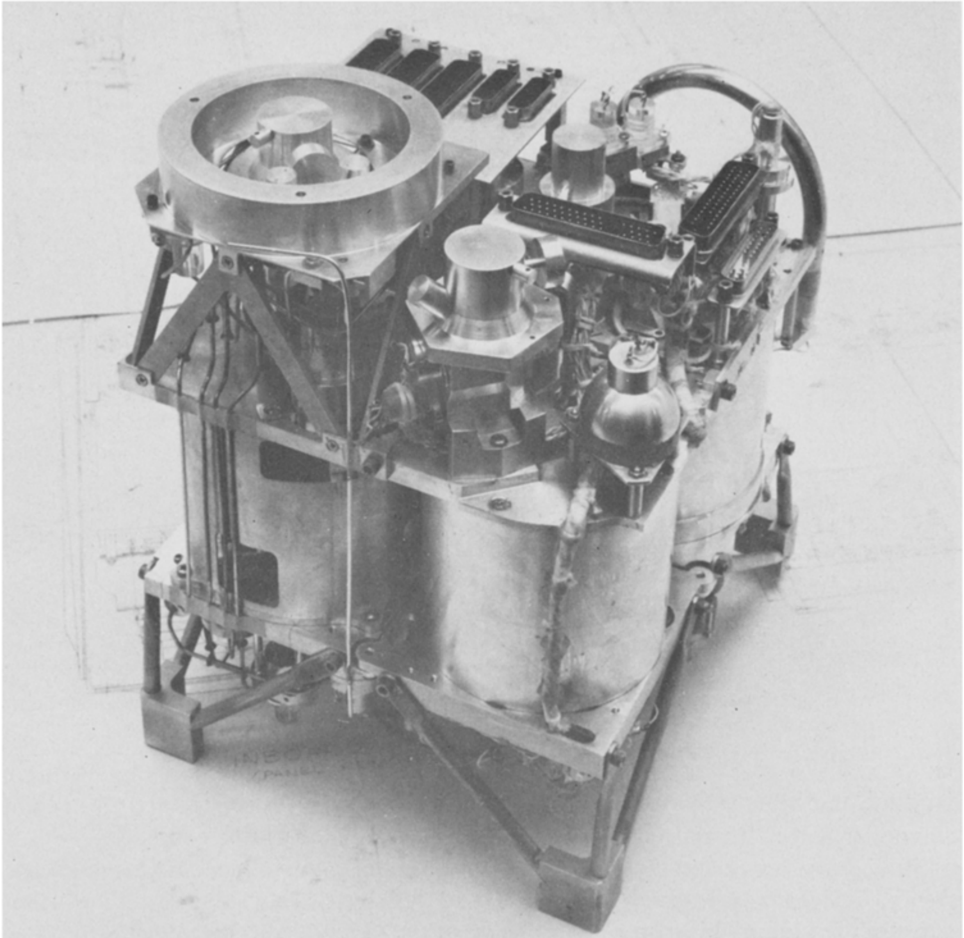

Fig. 2. Flight-like biology instrument with side panels removed.

in order to maintain incubation temperatures of around 15 °C. Incubation at temperatures equal to Martian ambient temperatures is out of the question for two of the three experiments, since these contain liquids, and freezing of liquid-containing lines would damage the instrument.

Constraints imposed by the design of the Biology instrument itself are numerous. To a large extent, the engineering of the experiments was hampered by having to fit the three experiments and supporting electronics into the volume initially allotted for them. Similar restrictions in the total weight required the engineers* to use lighter materials than had ordinarily been used in spacecraft up to that time. These were often more difficult to shape and to work with. For example, very tiny valves had to be designed and manufactured. These were not only more difficult to make, but the resultant products had higher leak rates than larger valves would have

* The instrument was designed and manufactured by TRW Systems Group, Redondo Beach, California. Details can be obtained in TRW Rept. No. 201020-6003-RU-100, August 1975.

given. The very dense packaging (shown in Figure 2), necessitated by these restrictions on volume and weight, ultimately led to a design which meant that individual parts within the instrument were very difficult to get to. If anything went wrong – for example, during some test procedure – this often required a major disassembly, consuming weeks of effort just to get to the affected part. This complexity, is no small matter. In the summer of 1974, there were up to 570 people working full-time on the Biology instrument.

In the category of communications constraints (Table I), the first point to emphasize is that the kind of adaptability to react to data that biologists are accustomed to will not be feasible in this mission. To begin with, the Biology instrument has long sequences already programmed into it. Changes in the initial program will have to be commanded, but such ground commands will be permitted only once every few days during the mission. Of course, the other Viking investigations (Soffen and Young, 1972), will also need to be commanded from time to time. Therefore, since the total available period of time for commands on any one day will be limited to about 45 min, it is clear that very severe limits will be placed on exercising the inherent capabilities of the Biology instrument. Changes in the 'nominal' (i.e., pre-planned) sequence will be difficult to implement.

The data generated by the Biology instrument will be transmitted to the central lander computer, and then during an approximately 20 minute period each day, the lander will communicate this data up to the orbiter, which will later transmit the data back to Earth over a period of 2–3 h each day. The socalled 'uplink' and 'downlink' aspects of the mission thus occur only for limited periods of time. It also turns out that it will require a minimum of two days, and probably very much longer than that, to react to any unanticipated data in the form of new commands to the Biology instrument.

Many other limitations are derived from the operational aspects of the mission. For example, in referring to 'mission sequence' (Table I), the extremely full schedule of events as the mission proceeds, should be emphasized. All of the experiments, as well as all of the necessary 'housekeeping' (engineering) measurements, are scheduled on an extremely full 'time line.' A perturbation of any one experiment, necessitating changes in this schedule, can and probably will affect all the other experiments. For example, if one of the biological experiments should yield data indicating a presumptive positive response after 4 days of incubation, and if the Biology Team wished to proceed immediately to run a control experiment on that experiment, this would not be possible. To perform an 'unscheduled' control experiment would complicate the mission sequence to such an extent that a delay of about 2 weeks is anticipated under this circumstance.

Concerning the landing sites, it should be noted that although these were very carefully chosen on the basis of what is known about Mars at present, it is obvious that with only two small areas to sample, the biological investigation is only slightly better than a random sampling of Mars. Such an approach essentially assumes a model of Mars that has life uniformly distributed over the planet's surface, but clearly other less homogeneous models are also tenable. Furthermore, the area available for sampling will be restricted to a small region immediately adjacent to each lander (about 80 square feet). If the cameras on board the lander were to show some object or area of interest more than about 100 in. away from the spacecraft, we would be powerless to obtain samples for analysis!

Finally, one other major constraint on this investigation must be mentioned. This has to do with the testing program that has gone into the development of the Biology instrument. In this regard, it should be noted that the actual flight instruments are the last of a series of Biology instruments that began to come off the assembly line some 2 yr ago. It was the precursor instruments that were to be extensively tested, both for engineering and scientific validation, in order to give the Biology Team the confidence that the flight instruments would perform reliably. The flight instruments, of course, could not be tested with soil samples since this would have necessitated a major disassembly just to clean up the instruments prior to flight. On Table II is summarized the nature of the tests that were supposed to be performed on the various completed instruments, including the flight instruments, and also those tests that were actually performed. In this regard, there are a few points that should be noted. First of all, in the face of schedule and fiscal constraints it was not possible to complete all of the tests that were originally felt to be desirable. Specific deviations from the test program included the following: no Biology instrument was subjected to extensive engineering stresses, such as vibration and shock

TABLE II

Viking biology instrument tests

	Tests on instrument alone						Tests on instrument on lander					
					Science						Science	
Unit	Thermal	Vibration	Shock tests	Electrical	with gases	with soil	Thermal	Vibration	Electrical	Systems	with gases	wi so
Design verification instrument	• √			• √	• √	• +						
Qualification test instruments (2)	• +	• +	• +	• +	• √(1)	• +(1)						
Lander test instrument	• √	• √		• √		+	• √	• √	• √	• √	• √	(•
Flight instruments (2)	• √	• √		• √	o				• √			
Flight 'spare' instrument	• √	• √		• √	o							

• In test plans, 1972.
(•) Proposed but not accepted, 1972.
√ Test successfully carried out.
\+ Portion of test successful.
o Several gas chromatograms taken as part of other tests.

tests, and *then* subjected to science tests using terrestrial soils; no Biology instrument was put into a lander and then subjected to a complete 'end-to-end' test in which terrestrial soil was scooped up and then analyzed; while tests with terrestrial soils were attempted on several precursor instruments, in no case did a single instrument perform all three of the Biology experiments acceptably. That is to say, different instruments performed one or more of the Biology experiments, but were not completely successful. With more time available, the Biology Team would have preferred to have a more complete demonstration of the scientific integrity of the instrument. Nevertheless, the Team did, after careful consideration of all of the test data, accept the final flight instruments and recommended that they be included in the final science payload at launch.

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