VOLUME 3, NUMBER 3

SETIQuest®

The Magazine of SETI and Bioastronomy

Viking and The Question of Life on Mars, Part 1

by Andrew J. LePage

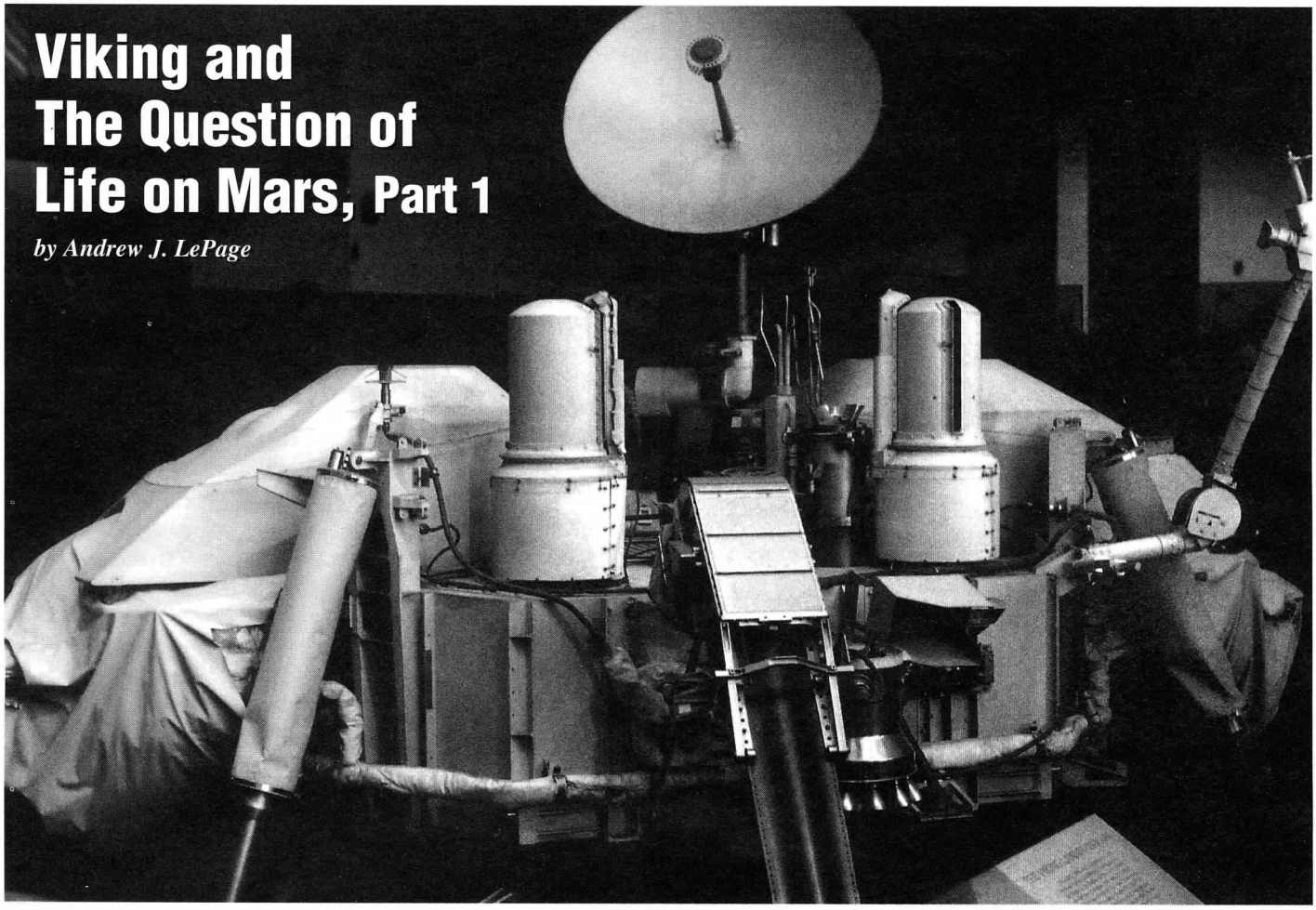

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Figure 1: *This engineering model is of the Viking lander currently on display at the Smithsonian's National Air and Space Museum in Washington, DC. The two Viking spacecraft which landed on Mars in 1976 made the first-ever successful landings on this planet and made the first in situ search for life on another planet. More than two decades since their landings, the question about life on Mars is still far from settled.*

As I sat in front of the television during this past Fourth of July watching news coverage of the Mars Pathfinder landing, I experienced a strange combination of déjà vu and nostalgia. Almost 21 years ago to the day I dragged myself out of bed early to watch live coverage of the landing of the Viking 1. Being 14 years old and a bit of a night owl even then, this was quite difficult for me but I felt it was worth the effort. Along with millions of other television viewers, I got to see the first images returned from the surface of Mars in near-real time. I was also very aware of this spacecraft's primary mission and NASA's reputation at that time for getting definitive answers. I felt certain that before I started my freshman year of high school in six weeks, a centuries-old mystery would be solved and we would know for certain if Mars harbored life.

More than two decades later on a sunny Independence Day morning, I sat in front of the television once again to watch another unmanned landing on Mars. Thankfully for me, the coverage did not start until ten o'clock in the morning and Mars Pathfinder's landing and its first pictures from Mars would not come in until a more reasonable hour—late at night. But as I look back to the Viking mission and its search for life on the Red Planet, I do not have the sense that it definitively resolved this important question.

While the current scientific mindset is that Viking found Mars to be lifeless, this conclusion seems to be far too sweeping for such a limited experiment. Even now there seem to be too many loose ends and many doubts remain in my mind. The

SETIQuest®
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VOLUME 3, NUMBER 3

Editorial and Business Offices:
SETIQuest
Helmers Publishing, Inc.
174 Concord Street
Peterborough, NH 03458-0874
(603) 924-9631 • Fax (603) 924-7408
http://www.setiquest.com

SETIQuest Magazine (ISSN 1077-6605) is published quarterly by Helmers Publishing, Inc. The U.S. subscription rate is $39.00 (includes surface mail delivery). For air-mail shipping to Canada & Mexico, add $9; all other countries, add $17. Back issues are available for $12.00 each: Canada/Mexico, add $1.25 per issue shipping; all other countries, add $3 per issue shipping. Checks must be drawn on a U.S. bank. MasterCard, VISA, and American Express accepted.

announcement one year ago of the discovery of possible signs of fossils in the Martian meteorite ALH84001, while itself far from conclusive, only fuels these feelings. Unfortunately Mars Pathfinder and the other missions to Mars currently planned by NASA and the world's other space agencies likely will not be able to resolve the question of extant life on Mars anytime soon.

So for now all we have is data returned by the two Viking landers. In many of today's books on space exploration and the search for extraterrestrial life, Viking's first-of-its-kind search for life on another planet at best receives only a brief summary and the misleadingly definitive statement that it found Mars to be totally lifeless. As I dug deep into my archives to research the subject in detail, I found much written about Viking and its results during the mid- to late-1970s. But actual information on follow-up laboratory experiments that are needed to prove researchers' theories and explanations for what Viking found is rare and scattered thinly throughout the scientific literature of more than two decades since the landing. In this article I review the design and capabilities of Viking's life-detection experiments. I will discuss the generally accepted explanations for what they found and review some of the alternative explanations and questions that persist 21 years after this historic mission.

The Viking Program's Beginning

The Viking program officially began on February 8, 1969, when NASA administrator Thomas Paine signed the project approval documents. Its predecessor, the Voyager program (not to be confused with the spacecraft of the same name that successfully explored the outer planets between 1979 and 1989), proved to be an overly ambitious and expensive project that called for a series of complex landers to be launched to Venus and Mars on Saturn V moon rockets. When this project was finally scuttled in the summer of 1967, a series of proposals developed by NASA's Langley Research Center took an early lead as a relatively low-cost replacement for Voyager. One family of proposals, the Titan Mars 1973 missions, called for a pair of lander-carrying orbiters to be sent to Mars during the 1973 mission opportunity using a Titan III-class launch vehicle (1).

Despite its more modest design, Viking was still a very advanced and complex spacecraft in its final incarnation. To minimize risk and development costs, the orbiter simply consisted of an enlarged version of the Mariner-class spacecraft bus used earlier to explore Venus and Mars. With this cost-savings measure, the bulk of the development effort and budget could be poured into the lander and its instrumentation. While it borrowed heavily from previous studies done for Voyager, as well as the successful Surveyor program that sent landers to the Moon, much work remained to be done. Within a year of the project's official start, the proposed launch date was pushed back to the summer of 1975 to ease budget demands and give more time to design and build the lander and its suite of cutting-edge technology instruments (1).

Viking's Instruments

Almost since the beginning of the Space Age, NASA and the scientific community had been developing life-detection techniques that could be used on Mars. With a total science payload of 32 kilograms for each Viking lander, only a select few of these proposals could be accommodated. Based on their weight,

development costs, and likelihood of detecting what biologists thought Martian life would be like, five experiments were finally chosen by the end of 1969 to fly to Mars (1). The total weight of these instruments was about 15 kilograms or almost half of the landers' total instrument payload.

Probably the most important instrument to investigate the biology of Mars was the Gas Chromatograph–Mass Spectrometer (GCMS) which was developed by the California Institute of Technology's Jet Propulsion Laboratory and built by Litton Industries. The dual purpose of the GCMS was to analyze the chemical composition of the Martian atmosphere and soil (2). The heart of the instrument was the mass spectrometer, which first ionized the gas sample it was to examine, then separated and measured the atomic mass-to-charge ratio (m/e) of the resulting ions by electromagnetic means. Since the ion fragments of every compound have a unique m/e spectrum or fingerprint, the mass and identity of the original compounds contained in the sample can usually be uniquely identified. Because it had to analyze both low atomic mass atmospheric gases and heavier organic compounds, the mass spectrometer's design was optimized to measure the m/e of ion fragments in the 11.5 to 215 range with a resolution of about one part in 200 (3). Gases as light as methane (with an atomic mass of 16) to organic compounds containing as many as 10 carbon atoms could be detected by the mass spectrometer. Hydrogen and helium could not be measured by the mass spectrometer but a similar instrument in the landers' Entry Science package housed in the aeroshell could, so there was no major loss to science by this engineering compromise (2).

For atmospheric analysis, the gas sample was first passed through a chemical filter to remove all of the carbon monoxide and carbon dioxide it contained. These gases constitute about 90 percent of the atmosphere and their removal allowed a more sensitive measurement of the interesting minor atmospheric components such as oxygen, nitrogen, argon, and krypton. The presence of certain gases in nonequilibrium concentrations could also serve as an independent indicator of biological activity on Mars. Nonequilibrium amounts of methane in our atmosphere are the result of biological activity and the same should be true for other planets with highly active biospheres. The finite absorption capabilities of the chemical filter limited the number of filtered atmospheric gas samples to a total of 60 (3). Unfiltered analyses were also possible so that the measurement could be made of the major atmospheric components and water vapor.

Since the mass spectrometer can only handle gases, the analysis of solid soil samples presented some difficulties. In a terrestrial laboratory, a soil sample would normally have its organic compounds removed using wet chemical methods followed by solvent extraction and various forms of chemical separation. Miniaturizing such a complicated process with the technology available around 1970 within the budget, weight, and volume constraints imposed on the GCMS was not possible (3). The simplest and most reliable method available to liberate any organic compounds in the sample was through thermal volatilization. With this technique, the soil sample is first heated so that its organic compounds would vaporize. Because of the fragility of some organic compounds, this process could damage some of the compounds that were originally in the sample. Still, it is possible to determine the identity of the original parent molecule in cases of thermal degradation.

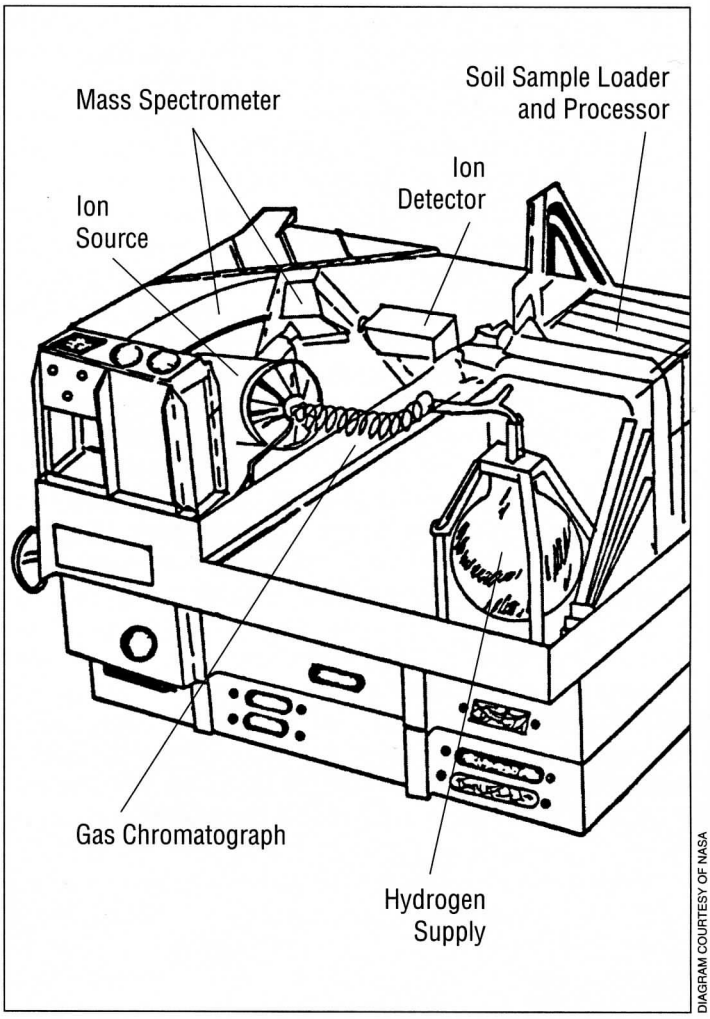


Figure 2: *This diagram shows the major components of Viking's Gas Chromatograph–Mass Spectrometer. The instrument was designed to determine the composition of the Martian atmosphere and search for organic compounds in the soil. Unfortunately the red dust that covers the surface of Mars is totally devoid of any organic molecules.*

In the procedure finally adopted, a 100-milligram soil sample secured by the lander's sampling arm would first be ground and passed through a 0.3-millimeter sieve, then deposited into one of three miniature electric ovens located in a motorized holder. Each ceramic oven had a chamber that was two millimeters in diameter and 19 millimeters long. The sample was heated to 50, 200, 350, or 500 degrees C to drive off its volatile organic compounds. The pyrolysis temperature, which would be reached in one to eight seconds, could be chosen from a preprogrammed sequence or commanded directly from Earth. Any organic compounds generated by the sample during the 30-second heating process were swept away by a two to three cubic centimeter puff of isotopically pure carbon dioxide labeled with carbon-13. This was done to distinguish the purge gas from any carbon dioxide released by the sample (primarily the carbon-12 isotope that dominates the carbon normally found in our solar system). After leaving the test cell, the gas was mixed with a stream of hydrogen carrier gas (3).

Instead of proceeding directly to the mass spectrometer for analysis, the gas sample first passed through the gas chromato-

graph (GC), which consisted of a two-meter-long column packed with a liquid-modified organic adsorbent consisting of 60- to 80-mesh Tenax-GC coated with polymetaphenoxylene (3). The gas chromatograph column allowed the quick passage of water vapor and carbon dioxide through the system while delaying the passage of the more interesting organic compounds. The length of the delay was dependent on the compounds' adsorptive properties. This lessened the load on the mass spectrometer further downstream and allowed for the differentiation of organic compounds with similar m/e spectra but differing chemical structures and properties.

Beyond the gas chromatograph was an effluent divider that diverted and vented any excess gas, especially water vapor and carbon dioxide, through a series of restrictor valves and vents. This would prevent components further downstream from becoming overloaded and permanently damaged by the large amounts of gas that a heated sample could generate. From here the gas sample continued on to the hydrogen separator which consisted of 60-centimeter-long silver-palladium alloy tube that was porous only to hydrogen. This device would remove all but 0.5 parts per million of the hydrogen carrier gas from the sample stream by electrochemical means and would lessen the burden on the mass spectrometer ion pump (3).

The resulting effluent was then monitored by the mass spectrometer which repetitively scanned the entire m/e spectrum every ten seconds. During each scan the mass spectrometer produced a 3840-sample m/e spectrum that was first converted to a logarithmic scale then encoded to 9 bits (i.e., 512 levels). During a typical measurement run, 17 megabits of data would be generated (3). Originally this raw data was to be analyzed on the lander and only the most interesting results would be transmitted back to Earth. With the availability of a high-capacity tape recorder on the lander and an increase in the data transmission rate from 4 to 16 kilobits per second, it became possible for the raw data to be transmitted directly to Earth. Once in the hands of investigators, they could perform a much more thorough data reduction and analysis than would otherwise be possible on the lander (2).

Ground testing of the GCMS using Antarctic soil samples indicated that it was capable of detecting and differentiating between a huge variety of organic compounds at levels from parts per million to parts per billion or better (3,4). Even if the other biological experiments failed to detect any life that might be present due to faulty assumptions of its preferred conditions, the sensitivity of the GCMS allowed the detection and analysis of its constituent organic compounds. Because the GCMS was optimized for the detection of organic compounds, its ability to analyze volatile-bearing minerals was greatly reduced. The procedure used by the Viking GCMS typically called for rapid heating of 350 to 500 degrees C. Reliable pyrolytic analysis of water- or carbon-bearing minerals requires much slower heating to temperatures as high as 1000 degrees C (5). As a result, the GCMS could offer little data to constrain the proportions of hydrated minerals or carbonates that might exist on the Martian surface.

The Biology Instrument Package

The original Viking lander biology package, built by the Applied Technology Division of TRW Defense and Space Systems Group, was to consist of four separate miniaturized life-detection experiments packaged to fit within a volume of only a single cubic foot (about 0.03 cubic meters) (1). Each biological test sample obtained from the Martian surface using the lander's remote sampling arm was delivered to the package's processing and delivery assembly. The sample then passed through a 1.5-millimeter screen and was subsequently split and gravity fed into the test cells of the various experiments. Each experiment analyzed a 0.25 to 1 cubic centimeter sample of loosely packed surface material. Ultimately each experiment was built with the ability to perform tests on four samples. In order to avoid terrestrial contaminants, the instrument was assembled under clean-room conditions and was heat sterilized in dry nitrogen for 57 hours at 120 degrees C (6). After installation, the lander was encased in a protective bioshell and was itself heat sterilized for 40 hours at 112 degrees C. This procedure reduced the risk of biological contamination to less than one chance in 10,000 (2).

All of the biological experiments made the assumption that Martian organisms used gaseous or liquid organic nutrients supplied by the instrument to yield products that could be detected over the lifetime of the test. The first experiment, originally called the carbon assimilation experiment but later known as the Pyrolytic Release (PR), was performed under the most Mars-like conditions. This experiment assumed that Martian life would make use of common gases in the atmosphere to produce organic compounds via photosynthesis or some other form of autotrophism much as organisms on the Earth do (2).

At the start of the Pyrolytic Release experiment, a 0.25 cubic centimeter soil sample was sealed in one of four test cells with a volume of four cubic centimeters. Next, 0.02 cubic centimeters of gas consisting of 92 percent carbon dioxide and 8 percent carbon monoxide that had been "tagged" with radioactive carbon-14 was added to the test cell (7). The tracer gas had a total radioactivity of 22 microcuries and its addition resulted in a modest 2.2 millibar increase in pressure above the ambient Martian surface pressure of about 6 or 7 millibars. If Martian organisms used the carbon-carrying gases in the chamber, the carbon-14 would be incorporated into the organic compounds they produced. The sample could be provided with simulated sunlight using a xenon lamp at an illumination level 20 percent of Mars' maximum surface daylight intensity to promote photosynthesis. This light source was equipped with a filter to remove ultraviolet light with wavelengths shorter than 320 nanometers. It was felt that these wavelengths could either kill any Martian organisms (giving a false negative experiment result) or unintentionally produce organic compounds through nonbiological photocatalytic reactions (which would produce a false positive result). Water vapor could also be added to the test cell in 80-microgram increments on command (7).

After an incubation period of 120 hours at a nominal temperature of about 10 degrees C, the sample was heated to 120 degrees C to drive off the residual tracer gas. Finally the sample was pyrolyzed at about 635 degrees C to drive off any organic compounds that had been formed by the assimilation of the tracer gas. The evolved gases were then flushed with helium through a column packed with a hot mixture of 75 percent Chromosorb-P (a form of diatomaceous earth) and 25 percent cupric oxide (7). This mixture allowed the unused tracer gas to pass through while absorbing any organic compounds heavier than methane. After the unused gas obtained from the purge

cycle was analyzed, the column was heated to 640 degrees C so that any organic compounds it adsorbed were released and oxidized into carbon dioxide via reactions with the cupric oxide.

The gases from both the purge and the pyrolysis stages were monitored for the presence of the radioactive carbon-14 tracer using a β particle detector. The first wave of purged gas was referred to as peak 1 and served as an indicator of unreacted tracer gas (7). The second wave of gas from the pyrolysis of the sample was known as peak 2. The size of peak 2 determined the extent to which any organisms in the sample had assimilated the tracer gas. As a control, the Pyrolytic Release experiment could be repeated with a portion of the original soil sample that was heat sterilized for three hours at 175 degrees C (7). According to the protocols established before the mission, the presence of peak 2 in the first experiment followed by none in the sterilized control run indicated the presence of living organisms in the soil sample.

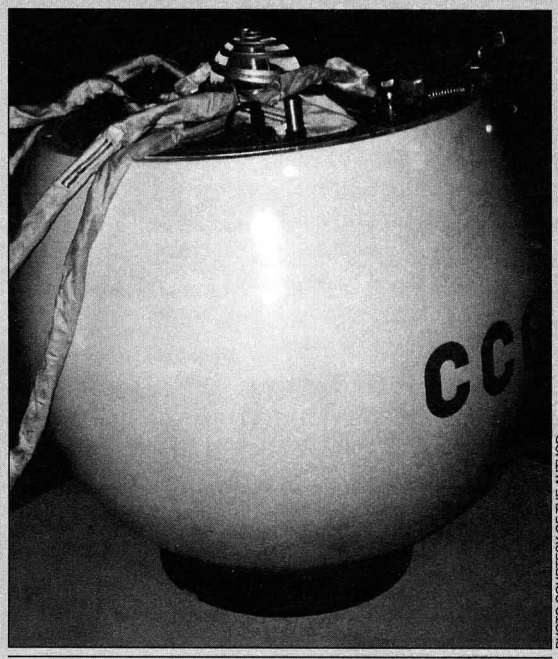
The prototype for the second experiment was known as Gulliver, named after Jonathan Swift's fictional traveler to strange places. The essential elements of Gulliver were retained and incorporated into Viking's Labeled Release experiment (1). Biologist Gilbert Levin started work on this experiment in 1959. Within just seven years its hardware development had advanced to the point where it was the leading contender to fly to Mars (8). The Labeled Release experiment was conducted under slightly less Martian conditions than Pyrolytic Release, but used similar principles. In this experiment, a soil sample was placed into one of four test cells and then injected with an aqueous solution containing "labeled" glycine, DL-alanine, sodium formate, DL-sodium lactate, and calcium glycolate. These nutrients were labeled by having some of their normal carbon-12 atoms replaced with radioactive carbon-14 so that they could be tracked (2). The wetted sample was allowed to incubate in the dark for about eight days at a nominal temperature of 10 degrees C with an atmospheric pressure slightly higher than normal for the Martian surface.

The gas in the chamber was then monitored over time using a β particle detector. The presence of any radioactive carbon dioxide or other volatiles would imply that organisms were metabolizing the labeled nutrients. By measuring the amounts of tagged gases generated by the sample as a function of time, information on the reproduction rate and physiological state of

THE SOVIET UNION'S MARS MISSIONS AND THE SEARCH FOR LIFE

NASA has not been alone in its pursuit of Mars. Before the Viking missions, the Soviet Union had an aggressive Mars exploration program that was far more ambitious than the American missions in the 1960s and early 1970s. The launch of the Mars 1 probe on November 1, 1962, and Zond 2 on November 30, 1964, were the only Mars probe attempts of the 1960s officially acknowledged by the Soviet Union.

Mars 1 and Zond 2 were to perform a photographic flyby of Mars and the former was equipped with a spectro-reflexometer to search for the signature of organic compounds on the Martian surface (11). Obviously Soviet scientists were just as interested in the search for life on Mars as their American counterparts. Both of these spacecraft succumbed to equipment failures during the long cruise to Mars and were unable to complete their missions. But for years there were rumors of numerous unacknowledged attempts (11).



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Shown here is a mockup of the first probe to successfully land on Venus, Venera 7. The Soviet Mars landers built in the 1960s likely shared its simple robust design.

Only after the fall of the Soviet Union did the true extent of their Mars exploration program become known to the West. According to this new information, the Soviets were attempting to launch spacecraft not only to fly by Mars but also to land on its surface and search for signs of life more than a dozen years before the launch of Viking. A lander and another flyby probe were to accompany the ill-fated Mars 1 probe in 1962 but they failed to leave Earth orbit due to a malfunction in these probes' escape stages (12). Some as yet unspecified problems prevented the launch of lander-laden probes to accompany Zond 2 to Mars in 1964.

While the design of these landers has yet to be disclosed, they are believed to have been one-meter diameter spheroids weighing about 250 to 300 kilograms (13). They would have looked similar to the Soviet's Venus landers, such as Venera 7 pictured here, that were launched during this same period. These early Mars landers likely carried rudimentary instruments to obtain basic data on the Martian environment. According to one account, one of these early landers was to carry a simple instrument to search for life on Mars (14). Before this probe was launched, however, a check of weight budgets showed that it was slightly overweight. Officials decided to remove the life-detection instrument and test it on the barren steppes 10 kilometers outside of the launch site at the Baikonour Cosmodrome. The instrument failed the test and it was removed from the ill-fated lander.

A result of the successful flyby of Mariner 4 in 1965 was the discovery that the Martian atmosphere had a surface pressure of only six millibars (15) as opposed to the earlier accepted estimate of 85 millibars (16). With this revelation, the first generation Soviet Mars landers became obsolete since they could not safely land with such a thin atmosphere. The Soviets abandoned any further Mars missions with this design and set about building a much larger and more advanced lander. This effort culminated with the launch of the Mars 2 and 3 landers in 1971 and Mars 6 and 7 in 1973. None of these attempts was entirely successful and none carried any life-detection experiments because of the complexity of the task (17). The search for life on Mars was left to the two Viking landers launched in 1975.

the microorganisms could be obtained (2). In case the experiment produced a positive signal, the Labeled Release process could be repeated with a sample that had been heat sterilized for three hours at 160 degrees C.

Next was the Gas Exchange experiment. The conditions under which it operated were significantly less Mars-like than those in either the Pyrolytic Release or Labeled Release experiments. A one cubic centimeter sample was placed into a single, dark, 8.7 cubic centimeter test cell with an atmosphere of 91.65 percent helium, 5.51 percent krypton, and 2.84 percent carbon dioxide at a pressure of about 200 millibars and a nominal temperature of about 10 degrees C (9). The Gas Exchange experiment had three different modes of operation: The Humid Mode introduced 0.5 cubic centimeters of a nutrient solution rich in organic compounds and inorganic salts into the test cell with minimal wetting of the soil sample. In the Wet Mode, two cubic centimeters of nutrients were added to the soil sample to be tested. Finally there was the Dry Mode where no nutrient solution was added. The relatively high atmospheric pressure under which the Gas Exchange experiment was conducted was needed in part to prevent the nutrient solution from instantly vaporizing under ambient Martian surface conditions. Because of the relatively large amounts of rich nutrients added by the Gas Exchange experiment, it was popularly known as the "chicken soup" experiment (1).

After a suitable incubation period, a portion of the gas in the test cells was removed for analysis by a gas chromatograph. This gas chromatograph was independent of the GCMS in keeping with the mission's design philosophy that a failure in any one of the lander's instruments should not jeopardize any other experiment (1). Much simpler than the GCMS, the Gas Exchange experiment's gas chromatograph could measure the abundance of hydrogen, neon, nitrogen, and argon or carbon monoxide, nitrous oxide, methane, krypton, carbon monoxide, nitric oxide, and hydrogen sulfide (9). The krypton added to the test cell's atmosphere served as a calibration standard for this instrument. The changes with time in the composition of the gases in the test cell could indicate the presence of life and give hints about its metabolism. Methane and carbon dioxide are frequent byproducts of terrestrial organisms growing in a dark oxygenless environment and it was hoped that Martian life would behave similarly. The single Gas Exchange experiment's test cell was purged and dried between experiments with helium gas and then could be repeated with a sterilized control sample that was heated to 145 degrees C for 3.5 hours (9).

The fourth and final experiment in the original suite of biological instruments was the light-scattering experiment. It was also popularly known as the Wolf Trap after its developer, Wolf Vishniac (1). Vishniac developed the original Wolf Trap between 1958 and 1960 to demonstrate for the first time the feasibility of remote, automatic life detection. Promising early results led to the subsequent development of more complex breadboard models during the 1960s under the auspices of NASA (8). Like the Gulliver experiment, this experiment's advanced state of development made it an early contender to fly to Mars.

In this experiment, which had the least Mars-like conditions, the sample was placed directly into a nutrient-rich solution. If microorganisms were present, they would grow and multiply in the solution making it cloudy over time. Any change in the light-scattering properties of the nutrient medium was detected by a simple light sensor (1). Early versions of the Wolf Trap also measured the pH of the solution over time as an independent check on microorganism growth and metabolism (8). Early trials with samples from Antarctica and other locales indicated that this system was incredibly sensitive and was capable of detecting the presence of as few as 1000 microorganisms after incubation. This high sensitivity was a definite asset if Martian microorganisms possessed a rather sluggish reproduction rate.

Taken together, these original four experiments were able to test for the presence of life under a wide variety of environmental conditions (10). The Pyrolytic Release experiment operated under almost Mars-like conditions. Except for the addition of modest quantities of nutrients, the Labeled Release experiment was also performed using conditions that might conceivably be found in favorable oases on the Martian surface. The Gas Exchange and Wolf Trap experiments both operated under conditions that have not existed on Mars for millions if not billions of years. While they were both designed under the assumption of a more Earth-like or "Lowellian" (see *SETIQuest* Vol. 3, No. 2, p. 14) conditions on the Martian surface, the designers felt that they were best suited for the detection of dormant life forms or spores that were waiting for the return of conditions more amenable for life (at least by terrestrial standards). Given the limits of the then-available technology and development budget, it was the best set of tests that biologists could fly on Viking.

***Part 2 of this article will appear in the next issue of* SETIQuest.**

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