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Viking Lander: Creating the Science Teams

Designing and fabricating the Viking lander was a difficult task. Engineers at JPL could draw on their experiences with Mariner systems as they worked on the orbiter, but the lander team was tackling a new field. The men in California completed the orbiter with relatively few technical difficulties; but the contractors at Martin Marietta in Denver, breaking much new technological ground, encountered many problems. The lander was far more complex than NASA's previous unmanned lander, the lunar Surveyor, and Viking's goals were more ambitious. Viking was twice as heavy as Surveyor; it had two cameras for stereophotography and a complement of very sophisticated scientific instruments, and it was destined to land on a planet far more distant than Earth's own moon. The Viking lander represented a series of clever inventions in answer to specific problems. While this inventiveness can be seen clearly in the creation and fabrication of the biology instrument and the gas chromatograph-mass spectrometer, the NASA-contractor team also developed a host of other new solutions to meet new technological demands.

As with the orbiter, the first priorities of the Viking managers in dealing with the lander were establishing spacecraft specifications, selecting an organization to build it, and forming key teams to do the work—industrial, managerial, and scientific teams. Team-building began months before the official approval of the Viking program when Jim Martin at Langley Research Center selected some of his top people from the Lunar Orbiter team. For deputy project manager Martin selected Israel Taback, spacecraft manager for Lunar Orbiter. Iz, as he was called by his colleagues, had joined the Langley staff in 1942 as a mechanical engineer on graduation from Cooper Union Engineering School. He successively headed the instrument calibration laboratory—a group developing aircraft flight instruments—and the navigation and communications branch at the Langley center. Gerald A. Soffen, Viking project scientist, once noted that while Taback might have looked like a tailor among the engineers and managers, he was the wizard behind the Viking lander. If any one man could be awarded the title "father of the lander," it was Taback.[1]

During the summer and fall of 1968, Taback supervised the progress of the contractors studying various technological approaches for landing on Mars. General Electric was investigating hard-landers; McDonnell Douglas Astronautics was examining soft-landers; the Boeing Company was studying propulsion and landing systems; and Hughes Aircraft was looking into low-cost landers, support modules, and mission reliability. In Denver, the Martin Marietta Corporation was winding up a study of direct versus out-of-orbit entry for the lander.[2] These early studies helped define the shape and size a Mars lander would have for a Titan-launched mission. They also drew attention to subjects that would require special handling. Taback and his associates at Langley worked constantly with the contractors so that their latest ideas for alternative approaches to lander design could be debated and evaluated in NASA circles.

As Taback's people and the contractors worked on general approaches to lander design, Jim Martin took steps to begin definition of the science payload. In August 1968, he established a science instrument working group under the chairmanship of G. Calvin Broome. Broome, who had joined Langley in June 1962, was manager of the photographic subsystem of Lunar Orbiter, overseeing design, fabrication, testing, and operation of the instrument that would photograph the lunar surface. Just 30 years old in the summer of 1968, Cal Broome was given a major responsibility for Viking. His working group, a subdivision of the Mission Design Steering Committee, would oversee all the preliminary planning for the scientific payloads for the orbiter and lander. Essential to its work was an understanding of the interactions among the various lander experiments, especially the interfaces among the surface sampler, biological instrument, and gas chromatograph-mass spectrometer experiments being proposed for the mission.[3]

With the definition of the lander and science hardware taking shape, Jim Martin needed a project scientist. He first took measure of Gerald Soffen during a 1967 briefing, when Soffen, a senior scientist at JPL, described his abbreviated microscope as a possible life detector. The scientist impressed Martin with his technical competence and his enthusiasm for Mars exploration. Jerry Soffen, 42 years old in 1968, was one of the early members of the exobiology community. After receiving his Ph.D. from Princeton University in 1960, he had been a U.S. Public Health Service fellow at the New York University School of Medicine. Shortly after he joined the JPL staff, he took part in devising instruments for detecting life on Mars, in the science planning for Mariner B, and in the development of automated biology laboratories. Before the demise of Voyager, Soffen had been deputy project scientist for that endeavor. With this background, he had the necessary stature in the scientific community that Martin was sure would be needed by the project scientist of a 1973 Mars landing mission.[4]

In August 1968, Edgar M. Cortright, Langley director, asked JPL Director William H. Pickering to assign five JPL staff members to the

Virginia center for six to nine months of temporary duty. Of those requested, four had taken part in capsule systems advanced development activities at JPL. The fifth was Soffen. Pickering and his managers were unhappy about this request. At that time, Langley and JPL were competing over Mars mission proposals, and it did not seem to be in JPL's best interests to send its specialists to help the competition. Pickering told Cortright that if Langley wanted Soffen, then Soffen would have to resign his position and join the civil service staff at Langley. Soffen recalled that he felt like a pawn in a game of planetary chess. Cortright could not promise that the Langley proposal for a 1973 Mars mission would be approved, and if it were not, Soffen could find himself a solitary scientist awash in a sea of engineers in Tidewater Virginia. If he stayed at JPL, he would be able to keep alive his vital contacts with other space scientists, but he might also miss the opportunity to lead the first landed scientific investigations of Mars. Cortright ultimately persuaded Pickering to agree to Soffen's temporary assignment to the Langley Mars 73 planning project, but only after an appeal to John Naugle at NASA Headquarters.[5]

Reflecting on his decision to move from California, Soffen commented that morale and leadership also affected his desire to make the change. In the months immediately following the termination of Voyager, the planners at JPL were in turmoil. At Langley, the situation was different. Cortright and Martin wanted their 1973 project to become a reality, and Martin especially pursued this goal with single-minded zeal. If sheer will and determination could make something happen, then Langley would be the center that landed spacecraft on Mars. Appreciating this aggressive spirit, Soffen forced the issue of his being detailed to Langley by purchasing a house in Hampton, Virginia. In the face of a determined Soffen and a solid front in the NASA management, Pickering had to let Soffen go east.[6]

A Team of Scientists

Setting up the science instrument working group and appointing a project scientist* were part of Langley's strategy to gain an early definition of the scientific aspects of the landed mission. Prospective industrial contractors would, in turn, have a reasonably good understanding of the problems in building the lander and incorporating the scientific instruments into it. During the second half of 1968, Jim Martin, Jerry Soffen, and A. Thomas Young began talking to scientists. Tom Young would have a very difficult assignment as science integration manager; he would often be surrounded by the conflicting demands of Martin, project engineers, contractor engineers, and oft-complaining scientists. Another 30-year-old, a mechanical engineer with a second degree in aeronautical engineering, Young was a native Virginian and a graduate of the University of Virginia.

*At NASA Headquarters, Soffen's counterpart was Milton A. Mitz, program scientist. On 28 December 1970, Mitz left Viking to join NASA's Grand Tour Project, and Richard S. Young became Viking program scientist.

He had joined Langley in 1961 and managed the mission-definition phase of the Lunar Orbiter project.[7]

Together, Young, Martin, and Soffen went in search of science team members for a 1973 mission. At the outset, it appeared that NASA Headquarters preferred that Langley deal with "inside" scientists; that is, persons already receiving support from the Office of Space Science and Applications. But the managers at Langley wanted to cast their net as widely as possible.[8] Their philosophy was outlined in a document, "Selection Criteria for Team Membership," circulated by Jerry Soffen in early December 1968. It began, "Rarely are scientists assembled in loosely bound organization and asked to perform and make intelligent compromises." As a rule, they act as individuals with considerable control over their own research efforts. For the Mars lander project, a group of scientists would have to work "in concert" to select the best plans for developing instruments that might be used several years later. In addition to projecting the wisest technological approach, the science team would have to handle "engineering problems, financial problems, political pressure, not to speak of scientific unknowns. The quality of brilliance is likely to be in more abundance than wisdom and certainly more than experience." An "*absolute prerequisite*" for membership on the science team was "*complementarity to other members of the team*." The guidelines also noted that usually scientists were identified with a speciality. For this team, however, persons with scientific breadth and an ability to cooperate with others would be more important assets. Strictly discipline-oriented persons would be a liability.

"The most difficult candidates to evaluate are likely to be the new or unknown faces." Some of the newcomers might be "well-meaning-but-not-too-useful" scientists who were attracted to the project because they believed that "the space program might be a nice lark for awhile." Others would not understand that participation in a spaceflight project required a minimum commitment of five years. The burden of ferreting out the good scientists rested with Soffen and his colleagues at Langley and NASA Headquarters. The guidelines cautioned, "An unknown name should not mean that the candidate is relegated to a second rate position." But the NASA managers could not afford to accept an only candidate for a position either, hoping he would "work out." Obviously, "the time for bringing up doubts is during selection not after the choice" was made, when dismissal would be difficult, awkward, and embarrassing.

While "scientists do not like to make decisions any more than other people," someone would have to be the "General" when science and democracy failed to resolve problems. It was, therefore, important for Soffen and his associates to consider which of the scientist candidates would make good leaders. Team leaders certainly had to be good communicators, with their teammates and with other members of the project. One last thing had to be kept in mind during the search: Teams "should not be too large. Five are a democracy, six an assembly, and more than eight lead ultimately to confusion and are often uncontrolled."[9]

The need for three basic lander science teams had been identified by December 1968—imaging, organic analysis, and life detection. The scientists on the imaging team would represent the most mixed set of disciplines, since the goals for that experiment were so broad. Each field of inquiry anticipated some useful information from lander photography. "The biologist has hope of finding something interesting. The geologist expects clues to the surface characteristics. The mineralogist could make some deductions about the surface composition." Cartographers, geographers, and engineers working on landing maneuvers and planning future spacecraft for Mars would all have an interest in the images from the landers' cameras. While most of the specialists who wanted to be included on the imaging team were more interested in the information the system would obtain than the development of the instrument itself, some would have definite suggestions about the technology. To translate these suggestions into specifications that the contractors could use in building hardware, a very talented instrument engineer would also have to be assigned to the team so that Langley's plans for a facsimile camera on the lander could be realized. The name for the camera was borrowed from the technique in telegraphy in which a picture is divided into a grid of small squares. The brightness of each square is converted into an electrical signal, and a sequence of such signals transmitted to a receiving station. The sequence is converted into an equivalent array of light and dark shades, and a "facsimile" of the original picture is produced on a photographic film. In 1968, the facsimile camera for aerospace applications was a relatively new tool, and the imaging science team would have to learn many new lessons in the development of that instrument for Viking.[10]

It was generally agreed that the imaging team leader would need to be familiar with facsimile camera technology, experienced in photo interpretation, and well versed in other major aspects of the mission. He would need a geologist colleague who was a "field scientist familiar with a wide variety of terrain and experienced in interpreting photos." And that geologist would have to be acquainted with the major theories on the formation of Mars. A biologist for this team would be difficult to find according to Soffen. There just was not a large group of "first rate field biologists from which to choose," and of these only a small number were interested in exobiology. Interpreting the images from the standpoint of mineralogy and inorganic chemistry might be done by a geologist, biologist, or related specialist. Analyzing the effects of the braking rockets on the landing zone—called site alteration—might require additional expertise, depending on the mode of terminal descent chosen. Obviously there would be more to Martian imagery than just taking pictures. The photographs would provide many important clues to scientists, and the system would likely be the eyes of the landed spacecraft, relaying important messages to Earth-bound engineers.

For the organic analysis team, five different specialties were required—organic chemistry, gas chromatography, mass spectroscopy, inorganic chemistry, and meteorology. The organic chemist in the group must be a specialist in pyrolysis, since "the central theme of the experiment is the reconstruction of the organic [compounds] from the analysis of the end products of thermal degradation." For pure compounds, this analytical work can be very complex. For mixtures of compounds, the task is exceedingly difficult. "For mixtures in which soil inorganics have been added, the experiment is . . . !!" Since gas chromatography was a science in which the technology was "changing every day," the specialist for this experiment would have to be abreast of those changes. This expertise was especially important because the information provided by gas chromatography would help other specialists understand the makeup of compounds they encountered in other experiments.

The heart of the entire organic investigation was an unusual sensor called a mass spectrometer. This instrument would examine the vapors produced by Martian soil compounds when heated. The vapors would be drawn into the gas chromatograph, which would separate the vapors into their individual components. The components would then be drawn into the mass spectrometer to be ionized (given an electrical charge) and analyzed to identify the constituent components. Profiles for each compound would be converted into digital form and sent to Earth. Results of the organic chemistry analysis would give scientists insights into compounds that might have been produced by any life forms on Mars and identify any organic material that might be present or might be generated at the Martian surface by purely chemical means.[11] The biological experiments were all predicated on the detection of active life processes, but the organic chemistry investigation would determine if any organisms had existed in the past or if the right organic compounds were present for the evolution of life in the future. As a cross-check on the life detectors, the organic chemistry experiment was all-important.

In addition to the analysis of organic compounds, there would also be a need to examine inorganic compounds found at the landing site. Because many of these inorganics are found in volatile form (ammonia, carbon dioxide, carbon monoxide, nitrogen dioxide, nitric oxide, sulfur dioxide, hydrogen sulfide) and appear only as gases in the atmosphere, a scientist would be included on the organic analysis team who was "familiar with such outgassing" and the composition of "juvenile" and secondary planetary atmospheres. A meteorologist could also add to the examination of these atmospheric elements as he studied the dynamics of Martian weather.

Finally, the major instrument planned for the lander was an integrated series of life-detection experiments. By 1968, after several frustrating years of experimenting with sample collectors for Voyager, exobiologists agreed that a Martian biology investigation instrument should have a common source for sample acquisition and analysis if evaluation of the results from the individual elements was to have scientific validity. Because the biology investigation was to be an integrated experiment, Soffen expected several kinds of specialists to be on the biology team. "But more important than the specialties, there should be a good mixture of different attitudes and experiences," since this complex of experiments would undoubtedly be "the most controversial of the payload." For example, the variations on a growth-detection instrument were apparently limitless, so the biology team would have to select the best concepts and then "be willing to defend them as the most reasonable thing to be done." Four kinds of biology expertise were sought for the Viking lander biology team:

> A *microbiologist* is the essential ingredient, one familiar with soil growth conditions and the problems of demonstrating viable organisms from natural soil.
>
> A *photosynthesis specialist*. Since part of the experiment is likely to be done in the light, searching for the photosynthetic reaction, it is important that someone familiar with these conditions be included.
>
> A *cellular physiologist-biochemist*. This is usually the same individual as the microbiologist, but in addition it is desirable to find a specialist familiar with intermediary metabolism and the internal biochemistry of organisms. . . .
>
> One versed strongly in *biological theory*, evolution, genesis, chemical de nova synthesis, genetics. This theoretical job is likely to give the very fabric to the biological goals of the mission. An appropriate person could become the [team leader].

Soffen and his colleagues believed that an engineer with a particularly strong background in developing miniaturized systems would also be an asset to the biology group in the design of the life-detection experiments.[12]

To expedite the development of the lander science instruments, the new Viking Project Office, in concert with the program scientist's staff at NASA Headquarters, organized the science activities into three phases—preparation, implementation, and data analysis. The preparation period would extend from October 1968 to December 1969, culminating in the selection of the Viking scientific investigators for the flight. Implementation would run from December 1969 through the final preparations for launch. The analysis phase would begin with the collection of the first data and end with the shutdown of each of the instruments. Only the lander investigations were identified as requiring a preparation phase, because the Viking managers expected that series of experiments to be more difficult to develop than the orbiter instruments. Orbiter investigators also would be chosen later than lander experimenters.

Associate Administrator for Space Science and Applications John Naugle officially began selecting investigators for the preparation phase 27 September 1968. Although the "solicitation for participation" did not name any specific mission or guarantee the participants in the early phase a place on the flight team, Naugle, program scientist Milton Mitz, and Soffen realized that those chosen in the fall of 1968 to help define the scientific payload for the lander would have an inside track toward selection as investigators for Viking. And everyone—managers and scientists—recognized that the development of an atmospheric probe-lander and the scientific instruments for a Mars lander would "require a long lead time." Considering also the highly integrated payload, the interdisciplinary nature of some of the proposed instruments, and the basic complexity of the lander design, NASA had no choice but to bring scientists into the planning phase at the very earliest point, even if this later made objective selection of the flight team scientists more difficult.[13]

The flight team investigators would be responsible for developing the functional specifications for the instruments and for providing direct guidance in all aspects of instrument design and construction. Including scientists in all stages of experiment definition, design, development, fabrication, testing, and operation was an attempt to preclude a problem that had plagued many of NASA's programs: the conflict between the builders of scientific instruments and the users of the data collected from them. Outside the arena of spaceflight, scientists have traditionally built or at least closely monitored the construction of their own experimental apparatus. Indeed, scientists were often judged by their peers on how well they executed the design of their hardware. With the shift from experiments on the laboratory bench to instruments that had to be integrated into the multiplicity of spacecraft systems, a rift grew between the persons who conceived the experiments and analyzed the results and those who actually built the hardware. An exobiologist might conceptualize an investigation and even build a bench prototype, but any elements of an integrated biology instrument would likely be built by a contractor specializing in the design and fabrication of flight hardware. This new division of labor did not often please the scientists, especially when engineers took an "I know how to do it better than you" stance. To avoid this problem in Viking, Naugle and the other NASA managers wanted the scientists working with the project from the very beginning.[14]

On 11 February 1969, after the headquarters' Space Science and Applications Steering Committee had evaluated the many proposals sent them by potential investigators, Jim Martin sent letters to 38 scientists, inviting them to participate in the preparation phase of project planning. While some familiar names were among the scientists, many were also newcomers to space science. Soffen's objective of incorporating new talent into the teams had been realized. All the invitees accepted, and their first meetings at the Langley Research Center were the inaugural sessions of the Viking science instrument team, 19–20 February, and the Science Steering Group, 21 February.[15] These meetings gave the scientists an overview of the entire project, introducing them to current activities, the project's methods of operation, and the schedule. Scientific objectives were discussed with respect to the existing knowledge of Mars and the investigations planned for Mariner 1969 and Mariner 1970 spacecraft. The scientists were also briefed on their responsibilities and the manner in which the teams and the

Science Steering Group would function. Mission design, engineering facts of life ("engineering constraints"), and hardware design (lander, orbiter, and scientific instruments) were summarized, as well.[16] On 25 February, NASA Headquarters officially announced the selected preliminary Viking science team members.[17] The list was a long one, and the number of teams had grown to eight (see app. D).

During the next six months, each science team planned instrument development. At the February Science Steering Group meeting, Jim Martin had told the team leaders that their science definitions should clearly state the scientific values of the instruments and the definitions "should be so complete that they may be used as a guide in preparing preliminary specifications for spacecraft design." The scientists were responsible for defining their potential hardware needs.[18] Viking planners had initially agreed to include a "science definition" in "Mission Definition No. 2," but that official statement of Viking science objectives promised to be too lengthy.[19] Only the essential data would appear in the mission definition, while the more detailed information would be included in a reference work, "Viking Lander Science Instrument Teams Report." Lander contractors would use both documents as sources of information about the proposed instruments and a guide to scientific rationale as they determined how to increase the scientific capabilities of the lander.[20]

Potential scientific investigators received the "Announcement of Flight Opportunity for Viking 1973" in early August 1969. This package of materials, which included the instrument teams' reports and the mission definition, would guide scientists who wished to work on one of the suggested experiments or who wanted to propose alternative versions of existing experiment proposals or additional experiments.[21] (See app. D for an excerpt from one of the science reports.) Concurrent with the final revisions of the science instrument reports, the Science Steering Group recommended at its July meeting that the weight of Viking lander science instrumentation be targeted at 41 kilograms rather than the original 32 kilograms. The extra weight would permit consideration of a number of important additional goals that had been identified as desirable if a larger payload was possible.[22]

With the completion of three major documents—the "Viking Lander Science Instrument Teams Report," "Viking Mission Definition No. 2," and the "Science Management Plan"—the science instrument team's work was essentially completed. The next step was the reception and evaluation of the science proposals in response to the flight opportunity announcement. More than 300 persons had attended the two day pre-proposal briefing for Viking science. By the 20 October deadline, NASA had received 150 proposals. Since 5 of these were considered dual proposals and 10 presented additional instrument options that had to be studied, the total number of items to be evaluated reached 165. They were divided into nine groups.

Table 36
Viking Science Proposals

Lander		Orbiter	
Experiments	Number of Proposals	Experiments	Number of Proposals
Imaging	14	Imaging	17
Molecular analysis	19	Proposals for experiments requiring additional instruments	27
Active biology	13	Radio science	27
Meteorology	11		
Entry science	15		
Proposals for experiments requiring additional instruments	22		

As part of the evaluation process, Mike Mitz, program scientist at headquarters, made these proposals available to the four subcommittees of the Space Science and Applications Steering Committee—Planetary Biology, Planetary Atmospheres, Planetology, and Particles and Fields. Each proposal was reviewed by at least one subcommittee. The steering committee recommended 12 experiments and 61 scientists to John Naugle, who concurred on 15 December (see app. D and table 37). Of the 8 lander experiments, 6 had been proposed during the preparation phase of the lander work; 2 were new investigations suggested by outside scientists, and 1 of the major instruments proposed for the lander during the early planning phase, the ultraviolet photometer, would not be flown.[23]

In the course of selecting the scientific experiments for Viking, Jim Martin expressed some reservations to Ed Cortright: "The proposed science payload represents an escalation in science objectives which is likely to lead to cost increases beyond those estimated in our assessment." His concern was especially strong for the experiments not previously examined by science instrument teams. Cost problems could be generated by the entry-science retarding-potential analyzer, the lander-science physical properties investigations, or the magnetic properties experiment. "These additions, when coupled with the problems of using the [gas chromatograph–mass spectrometer] to measure water and adding a gas exchange investigation to the biology instrument, add up to a potential overrun. . . ." Martin was also worried about some of the scientists chosen for the work. He told Cortright that lessons they should have learned over the course of the preceding year were not being implemented. "Specifically, the Biology Team has the same group of men who demonstrated an inability or unwillingness to work together, the [Molecular Analysis] Team has two members only interested

Table 37
Key Dates in Assessment of Viking Science Proposals

11-12 Sept. 1969	Pre-proposal briefing for potential experimenters.
20 Oct. 1969	Proposals due at NASA Headquarters.
23 Oct. 1969	Copies of proposals due at Langley and JPL; meeting held at Langley to discuss proposals.
3-4 Nov. 1969	First Space Science and Applications Steering Committee (SSASC) subcommittee meetings to initiate evaluation process, Goddard Space Flight Center.
7-8 Nov. 1969	Review of science proposals at Langley.
12-14 Nov. 1969	Second subcommittee meetings, Goddard.
17 Nov. 1969	Viking Project Office assessments of proposals due at NASA Headquarters.
18-20 Nov. 1969	Definition of science payload by Headquarters Planetary Program Office.
21 Nov. 1969	Tentative payload presentation to D. P. Hearth, director, Planetary Program Office.
26 Nov. 1969	Planetary Program Office recommendations made to SSASC.
3 Dec. 1969	Recommendations presented to SSASC in writing.
8 Dec. 1969	Oral presentation to SSASC.
15 Dec. 1969	Selection of Viking science payload by John E. Naugle, associate administrator for space science and applications, based on SSASC recommendations.

in water detection who will interfere with achievement of the team's primary objective, and the Entry Team has the same two members who have demonstrated many times an inability to work together."[24]

Martin had good reason to be worried about possible cost escalations. On 3 September, Don Hearth's Planetary Program Office held a Viking science review with Langley personnel, Office of Space Science and Applications program chiefs, and Dr. Henry J. Smith, deputy associate administrator for space science. The objective was to establish weight- and cost-limit goals for Viking science activities. Later decisions about overall Viking costs and flight instruments could be made using these guidelines. Some of the more significant decisions reached at the 3 September review were on reduction of the lander science instruments' total weight, development of backup instruments for the gas chromatograph-mass spectrometer and the biology instrument, and specific dollar limits on science spending.

As a result of the early fall meeting, the science planners reverted to the 32-kilogram limit on science instruments, dropping the 41-kilogram proposal made by the Science Steering Group. The major difference between the two weight packages was the addition of a separate mass spectrometer for determining lower atmosphere constituents. Hearth's view was that the additional scientific information they could obtain with that instrument could not be justified when they considered its cost. He believed that the first gas chromatograph-mass spectrometer measurements after touchdown would be sufficient. Weights and costs of the 32-kilogram science payload for the lander were summarized in September 1969 (table 38).

Table 38
Estimates for Lander Payload, September 1969

Item	Weight (kg)	Cost (millions)
Entry science	4.1	$ 4.1
Imaging	5.0	6.2
Biology	5.4	11.3
Gas chromatograph-mass spectrometer	10.4	8.5
Meteorology	2.3	3.0
Water	1.1	1.8
Seismometry	.9	2.0
Ultraviolet photometry	.5	0.7
Total for instruments	29.7	37.6
Integration and test	2.0	5.8
Total	31.7	$43.4

Cost of the lander instruments was expected to be about $1.36 million per kilogram. The orbiter experiments were projected to cost about $0.56 million per kilogram. Overall costs were broken down as in table 39.

Table 39
Viking Science Cost Projections, September 1969

Item	Cost (millions)
Lander science	$43.4
Orbiter science	32.0
Support of science teams	13.3
JPL support of GCMS development	5.6
Ames support of biology instrument development	2.1
Total	$96.4

With an additional 10 percent for contingencies, Hearth established a firm ceiling of $107.5 million for the total Viking science package.[25]

Looking at Hearth's estimate in December, Martin believed that they were selecting too many members for the experiment teams. "The total number of team members and participating scientists has increased beyond our budgeted estimates and considerably beyond what the [project office] believes is required to achieve the mission objectives." The budget called for 55 scientists; 61 had been selected. Martin would have been happy with fewer than 40. (By flight time, the number of science team members would grow to 80.) Although Don Hearth's Planetary Science Office had told all the scientists that the payload selection was tentative pending negotiation of a contract for each instrument and an individual contract for each scientist, Martin personally believed that it would be extremely difficult for NASA to drop any scientist or investigation. The "pressure will be on to consider an increase of a few million [dollars] as acceptable; it will come out of our contingency allowance and avoids unpleasantness between [the Office of Space Science and Applications] and the science community."

Martin feared that in a few years when all these reasons for the increased expenditures had been forgotten, he and the Viking Project Office would be held responsible for not properly managing their funds. With only $102 million set aside for total project contingency costs (a small amount compared to other major NASA projects) and the "tight funding environment" that everyone expected to face for several years, it appeared to Martin that "a prudent manager must hold the line against escalation in all areas of the project today." Since he saw considerable cost uncertainty associated with the science instruments, Martin would be especially cautious in this area.[26] Many of his concerns did become problems in the future. There was friction among the members of the biology team, and the costs of the biology instrument and the gas chromatograph-mass spectrometer rose sharply. Most of these difficulties emerged after the January 1970 schedule change from a 1973 to a 1975 launch.

Reservations aside, NASA appeared to be well on its way to organizing a Mars lander mission. In encouraging Joshua Lederberg to work with the biology team, Richard S. Young, chief of exobiology, Office of Space Science and Applications, had written that many details of the biology experiment still needed resolving. Young sought Lederberg's advice on NASA's "method of operation" as much as on "the science involved in these missions." Looking back over the long road since the early 1960s when exobiology was a very new field, Young noted, "The science hasn't changed much since the 'Westex' days [see chapter 3], but we are finally trying to organize in the best way as to achieve some of the 'old' objectives." Young and his colleagues wanted "to make this thing work . . . within the constraints imposed" on them by the administration and Congress.[27] They would need the help of many parties to reach their goal.

SELECTING A CONTRACTOR

Selection of a contractor to build the lander and to supervise integration of the lander and orbiter and integration of the spacecraft and launch vehicle paralleled in time the selection of the scientific experiments. On 28 February 1969, Langley Research Center issued a request for proposals on the design and fabrication of the lander and project integration. In addition to the 20 firms directly solicited for this procurement, 12 others requested and were sent copies of the proposal package. Technical and managerial proposals were submitted to NASA by the Boeing Company, McDonnell Douglas Corporation, and Martin Marietta Corporation. All three companies had conducted studies earlier for Jim Martin's Titan Mars 1973 team. In the process, they had developed an enthusiasm for and an expertise in the design of Mars landers.

In April the Source Evaluation Board began with an appraisal of the written proposals and visited the production facilities of each of the three potential builders, where members of the board spoke at length with company representatives. As Administrator Thomas O. Paine noted in his report on the contractor selection process, the board furnished written questions to each firm before its visit. The companies were advised that the questions covered deficiencies and omissions as well as proposal ambiguities and that they were being given an opportunity to support, clarify, correct, or make revisions. After the visits, the board made its final rankings in May 1969.

Martin Marietta received the highest overall final rating; its cost proposal was between those of the other two bidders. The Denver-based division's technical proposal was well organized, according to the judges on the board; its strong points were "outstanding mission analysis and plans for maximum science return, the communications system, the terminal descent radar analysis, a common deorbit and descent engine, and landing gear design." Weak points included "the power system design and uncertain subsonic stability of the aerodynamic configuration." NASA specialists believed these to be "readily correctable" problems, and Martin Marietta suggested that the inflatable-balloon decelerator (ballute) and parachute combination, which had been proposed for slowing and stabilizing the lander once it was separated from its aeroshell, be replaced by a more conventional parachute.

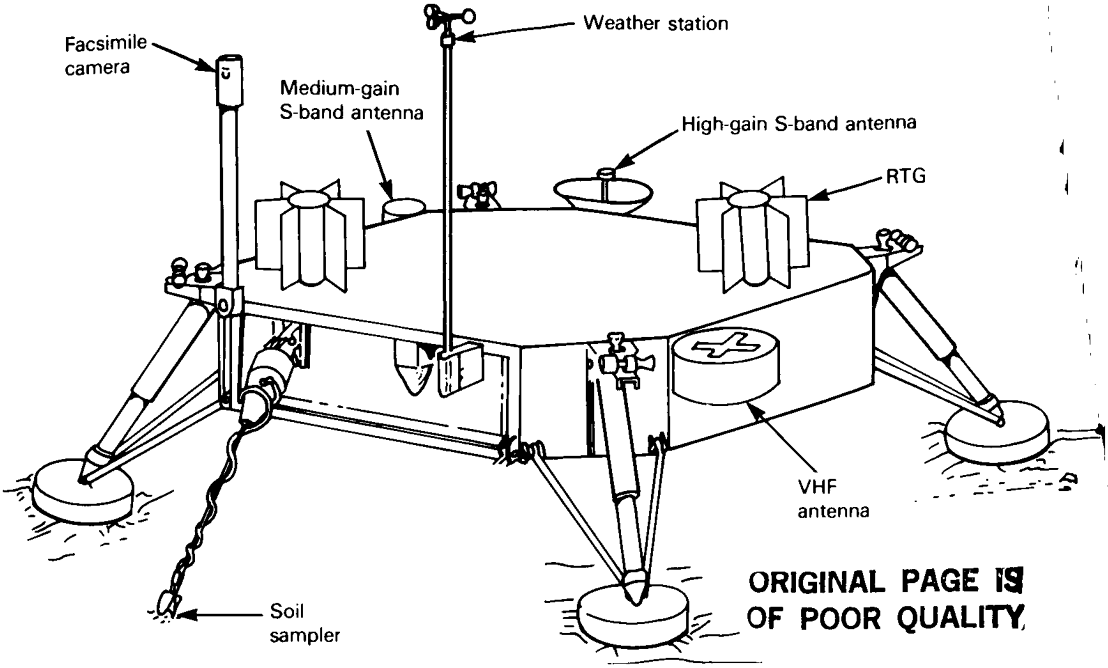
Boeing received the second highest overall ranking and offered the lowest cost. Boeing's proposal contained "a well-conceived mechanical design, a redundant and flexible communications system, and an excellent plan for launch and flight operations." Proposal weaknesses centered on a method suggested for dealing with the scientific instruments and the investigators, the power system design, and deorbit propulsion. The latter two areas would require "major proposal revisions," according to the source board. Boeing had planned to join forces with General Electric and Hughes Aircraft Company—GE as the subcontractor for entry, power, data handling, and attitude control systems; Hughes as the subcontractor for terminal landing subsystems, terminal guidance and control, terminal propulsion, and landing gear. While the combination of these three companies offered much "specialized experience" and while the Boeing-GE-Hughes team plan was well organized, NASA officials thought there were "potential management and operational problems" in this arrangement.[28]

McDonnell Douglas, with the highest cost estimate, was ranked third. Technical weaknesses outweighed the strengths of its proposal. And the potential strength of its management team was outweighed by its decentralized facilities, which were not as well suited for Viking as those at Martin Marietta or Boeing.

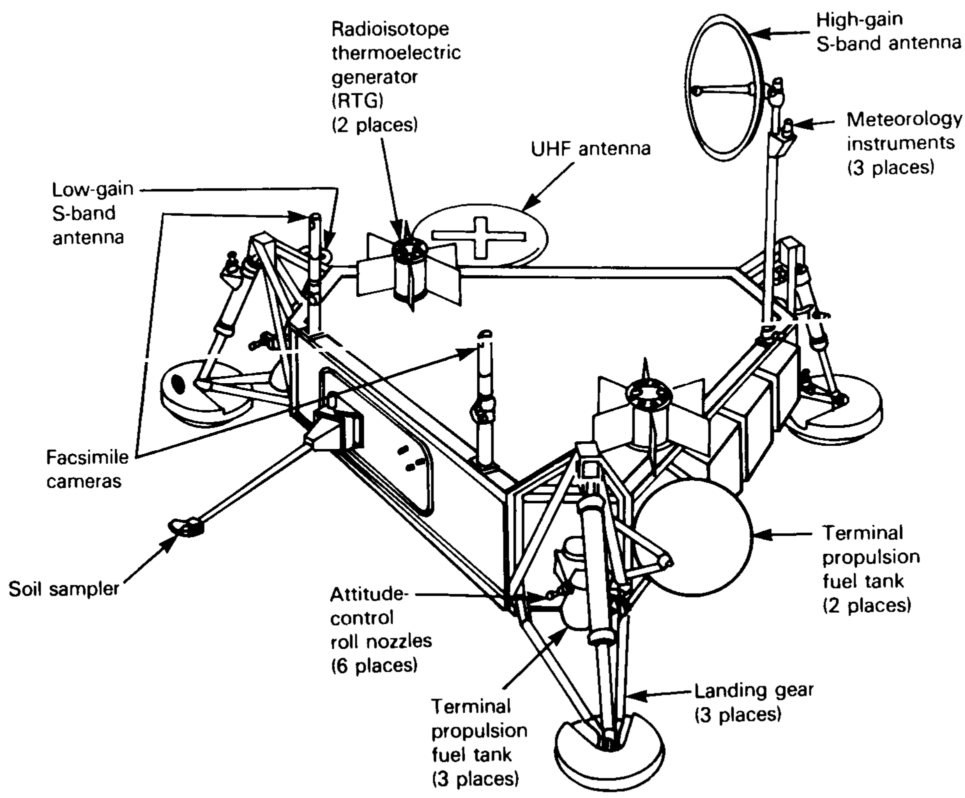
Following the Source Evaluation Board presentations, Paine met with a few key NASA employees to obtain their views on the board's findings. Administrator Paine, Associate Administrator Homer E. Newell, and NASA General Counsel Paul G. Dembling subsequently met and agreed to award the contract to Martin Marietta.[29] Paine explained that his choice for the lander contractor was influenced by the fact that the firm had "applicable company experience, technical capability and the most outstanding facilities . . . which are specially tailored to Viking requirements." Martin Marietta's participation in early Voyager activities and its decision to maintain a team effort with more than 100 persons during the 1967-1969 period had "established a strong and highly motivated" group from the top management down through the working personnel.[30]

On 29 May 1969, Paine announced that NASA planned to award a cost-plus-incentive-fee/award-fee contract for $280 million.[31] The lander system as proposed by the contractor was technically evaluated by the engineers at Langley to identify changes that should be made before the formal contract negotiations between NASA and Martin Marietta began. These alterations were documented in a "shopping list" of 18 items over which Langley and the new contractor negotiated. With the changes, the contract figure totaled $299.1 million in the contract approved by Paine 20 October. Martin Marietta's fee was targeted at $14.52 million, but the incentive provision permitted the company to earn more money if the contract was concluded at less than the projected cost of $299.1 million and it penalized the company for any cost overruns. For every dollar above the target, Martin Marietta would lose 15 cents from the fee, while any cost savings would bring an additional reward of 15 cents per dollar.[32]

The statement of work that accompanied the contract for "Viking lander system and project integration" was kept as general as practical so that the number of changes in the contract could be kept to a minimum. Other large NASA projects like Gemini and Apollo had produced thousands of contract modifications. David B. Ahearn in the Langley Procurement Division sought from the beginning to produce a Viking contract that would ensure that the work was done properly but with a minimum of paperwork. During the life of the contract, the number of alterations made in that document numbered about 300.[33]



The Viking lander design went through a number of versions in 1968 and 1969. Above, one of the four-legged configurations presented at the Viking science instrument team's meeting 19–20 February 1968 was to be powered by radioisotope generator and battery. One not shown arrayed solar cells on the lander's flat top to provide power. Although RTGs posed heat problems, the Viking Project Office preferred them. Below, the three-legged September 1969 design added a second camera for stereophotography and moved the meteorology instrument to the high-gain antenna mast.



Very early in the contract, a major modification, made necessary by the two-year launch-date slip, was negotiated between NASA and Martin Marietta. On 13 January 1970 following the administrator's unexpected announcement of the change in plans for Viking, the Langley Research Center Contracting Office notified the contractor to stop all work authorized under the contract. That week meetings at JPL, Martin Marietta, and Langley began reprogramming for the new game plan. Martin Marietta studied two possible alternatives for a 1975 launch (table 40).[34]

Table 40
Alternatives for 1975 Viking Launch

Option A: Viking 1973 Mission Slipped to 1975 Opportunity	Option B: Direct Entry Lander Mission in 1975
Orbiter-lander-Titan III-Centaur	Lander-relay module-Titan III-Centaur
1973 management and contractor team	1973 lander contractor to supply relay module
1973 science and scientists	1973 science and scientists
Type II trajectory	Type II trajectory
Use added time to minimize technical risk, optimize hardware use, minimize schedule risk, and minimize cost.	
FY 1969, 1970, 1971 funds held to $87.5 million.	
First priority in study	Second priority in study

By mid-February, the Viking Project Office authorized Martin Marietta to proceed with the first option and lifted the stop-work order. Through the end of fiscal 1971 (30June), only $87.427 million would be made available for the project, so Martin Marietta would not be able to hire as many persons as planned. Nor would it be able to increase employment levels as rapidly as it had hoped under the 1973 schedule. JPL also had to make changes in its manpower projections. Although Martin Marietta would employ a smaller total number during the life of the lander contract, those who did work on Viking would be employed for a longer time. As a consequence, the total cost of the lander grew by another $44 million (see also graphs in appendix C.)[35]

The immediately apparent increase caused by the shift from a 1973 to a 1975 launch was $141 million. While other factors would drive Viking costs

Table 41
Viking Cost Increases Because of Launch Delay

(in millions, as of June 1970)

Component		Viking 1973	Viking 1975 (as of June 1970)
Lander		$313	$360
Orbiter		202	257
Other		94	133
	Total	$609	$750

even higher, the economics of delaying the project two years to meet the political pressures on the fiscal 1971 budget were expensive for NASA and American taxpayers.

Scientists, Instruments, and Subcontractors

The Viking project stretchout also affected management of the scientific experiments for the Mars mission. Originally, the Viking Project Office had planned to negotiate contracts with the scientists and select instrument subcontractors during the first weeks of 1970, and most of the science teams had met in early January to review their plans. With the switch to a 1975 mission, that schedule had to be reevaluated and the activities reprogrammed. On 13 January the science teams, except those working on the biology instrument and the lander imaging system, were told to terminate their Viking activities.[36]

Jerry Soffen advised all of the scientists in late January that the Viking Project Office's main goal was to make the transition to a revised schedule as smooth as possible, while protecting against any unnecessary cost increases or further schedule delays. "During this transition period," Soffen hoped that the scientists would "not lose sight of the Viking objectives," and he reminded them that "scientific research has never been an easy way of life. We expect to find favorable aspects of this Viking deferment in the form of improvements in the investigations and the better use of Mariner 71 results."[37] The Viking Project Office worked out a procedure for keeping the science team leaders in the instrument definition process during the transition without having to include them in formal contract negotiations. After selection of a subcontractor to negotiate to build a science instrument and before negotiations began, a technical review would be held. Martin Marietta, the Viking Project Office, the science team, and the subcontractor (or "vendor") would thoroughly review the procurement drawing, especially where changes in specifications were required. The science team leader could participate in discussions leading to prenegotiation specification. Then, during negotiations, any additional changes would be coordinated with the team leader through the Viking office.[38]

For the scientists as a group, the next big gathering scheduled was the Viking science review in mid-April 1970. By that time, Martin Marietta had chosen Itek Corporation's Optical Systems Division to develop and build the lander camera system and was evaluating biology instrument proposals from Bendix Aerospace Systems Division and TRW Defense and Space Systems Group. JPL was in the process of evaluating a breadboard model of the gas chromatograph-mass spectrometer, and Martin Marietta's planning for the construction of the upper-atmospheric mass spectrometer breadboard was under way.[39]

For three days, 13-15 April, 42 scientists (about two-thirds of the total team membership) met with representatives from the project office and lander contractor. After receiving reports from the Viking managers the first morning, each team leader presented a 10- to 20-minute summary report on the status of his experiment that afternoon. On the 14th, a series of concurrent team meetings gave the scientists time to talk with their teammates and discuss matters of common interest with other teams. Later that day, a number of special science meetings took up investigative considerations affecting more than one team, such as site alteration, organic contamination, landing site characteristics, atmosphere. The final day of the gathering was given over to a session of the Science Steering Group. The scientists found all the meetings educational but agreed that the smaller "think" groups they had participated in the second day were particularly stimulating. Viking's schedule may have been stretched out, but nearly everyone agreed that much work would still have to be done by all to meet the 1975 launch date.[40]

The pace of work was moderately slow at first because of the limited money available, but in retrospect that may have been fortunate, because many technological problems lay ahead. Three scientific instruments—the ones given first priority for the dollars available—were particular problems: the gas chromatograph-mass spectrometer, the biology instrument, and the lander imaging system.* While the story of these instruments is a tale of amazing accomplishment, the facts also indicate that if Viking had flown in 1973 it probably would have been launched without the gas chromatograph-mass spectrometer and the biology instrument. Without those experiments, Viking would have been a vastly different mission. Those instruments were ready to fly in 1975, and the story of their design and fabrication deserves to be told. For the men and women who worked the extra hours, sweated out the successive problems, and reveled in personal

*Thomas A. Mutch has described the history of the lander cameras in *The Martian Landscape*, NASA SP-425 (Washington, 1978), pp. 3-31.

satisfaction when the experiments actually worked on the surface of Mars, it was "their" lander, "their" experiment, and "their" triumph.

Gas Chromatograph-Mass Spectrometer (GCMS)

Development of a GCMS prototype had initially been assigned to the Jet Propulsion Laboratory by Langley in August 1968. This responsibility remained with JPL when the Viking project was officially established. Before selecting a contractor to build the flight hardware, the California lab had the task of developing, fabricating, and testing a lightweight portable breadboard of the GCMS that could be used to carry out surface organic analysis by pyrolysis. Gas chromatography and mass spectrometry in the laboratory were one thing; shrinking the equipment to a size that could be placed on a spacecraft was another.[41] Requirements for such an instrument were not easy to meet for a laboratory model; restrictions put on the design to qualify it for spaceflight made it extremely difficult.

Pulverized Martian soil would be placed in the instrument and heated to temperatures up to 500°C. The gases given off would be carried into a gas column, a long tube packed with coated glass beads that would selectively delay the passage of gases according to their adsorptive qualities. The column would then be heated progressively to 200°C at a rate of 8.3°C per minute. Each level of temperature would release different organic molecules, separated into narrow family groupings. A palladium separator unit, porous only to hydrogen, would filter out that gas, leaving only the vaporized organic compounds, which would be drawn into the mass spectrometer to be ionized. The stream of ions would be focused in the electrostatic and magnetic sectors of the device. When the stream of focused ions struck the electron multiplier tube, generating electrical impulses, that activity would be amplified and recorded, producing a profile of each compound. Finally, the profiles would be converted into digital signals that could be transmitted to Earth.[42]

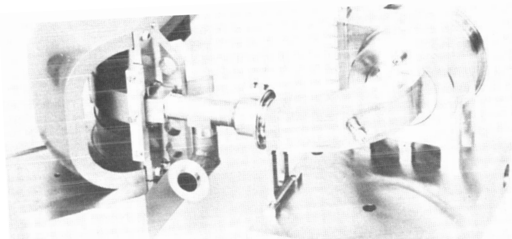
Although the GCMS was a complex piece of equipment, no one predicted the difficulties that JPL encountered in its development. At first, dollars and failure to agree on priority for the instrument's development were causes for delay. But by the summer of 1970, serious engineering and managerial problems were plaguing GCMS development.[43]

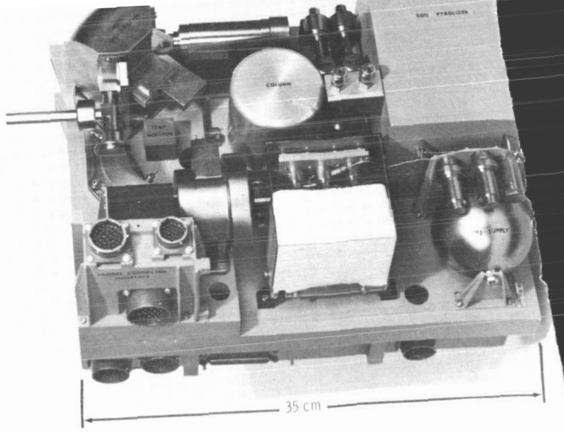
In September 1970, Cal Broome told Jim Martin that the GCMS, nominally under the purview of Henry Norris's Viking Orbiter Office, was a stepchild not getting proper supervision because of the decentralized management structure at the lab.[44] A five-day GCMS engineering model review, held 25-30 January 1971, was a disaster. Jack Van Ness told Langley Director Cortright that between 200 and 300 "request for action" forms resulted from the review; he anticipated that 100 to 150 of those items would be assigned to JPL for its attention. "It is expected that the major output of the review will be a critical reassessment of the requirements imposed upon the instrument and its subsystems, with an eye towards reductions in instrument complexity."[45] Two weeks later, Van Ness reported that JPL had taken steps to strengthen its managerial control. John J. Paulson, head of the GCMS project office, would henceforth report directly to Robert J. Parks, assistant laboratory director for flight projects. This shift put the GCMS on the same management plane as Mariner Mars 71 and Viking Orbiter. The Viking Project Office hoped this visibility would help solve some of the stepchild's troubles.[46]

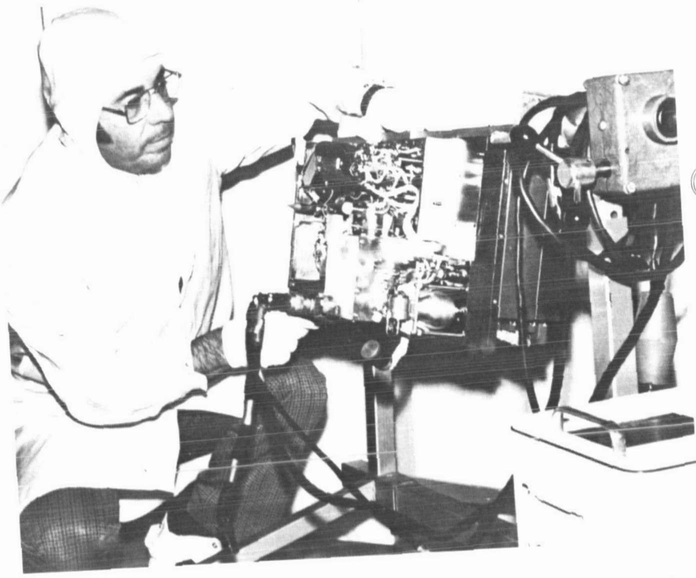
Jim Martin was not pleased. At a Science Steering Group meeting 2-3 March 1971, he indicated that funding increases, technical problems, and schedule slips had caused him and his colleagues considerable concern about the future of the GCMS. Although the recent management change at JPL was encouraging, the instrument's progress would be watched closely during the next few months. If progress was not satisfactory, Martin would have to consider an alternate or less ambitious design.[47] The project manager's attitude toward the GCMS difficulties was not enhanced by his unhappiness over the science subsystem preliminary design review at Martin Marietta on 1-2 March. The part of the PDR covering the science experiments integration laboratory (SEIL), to be built in Denver, was particularly unsatisfactory. Martin told the lander contractor that the SEIL PDR would be repeated and that no funds would be spent on equipment for that instrument until a satisfactory review had been held.[48] (The SEIL was canceled in July 1971; instruments tests would be performed on the system test bed lander at Martin Marietta.)

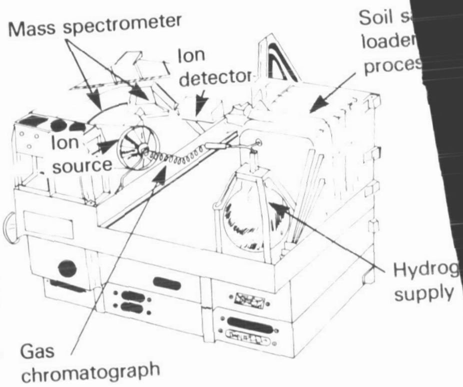
On 18 March, the GCMS engineering breadboard was operated for the first time as a completely automated soil-organic-analysis instrument. Several problems of the kind usually associated with first tries were encountered, but everyone in the Viking Project Office interested in the development of the GCMS considered it a major step forward.[49] Meanwhile, an ad hoc GCMS requirements review panel, established by Martin after the unsuccessful engineering model review in January, met to discuss possible ways of simplifying the design.* Preliminary results of the ad hoc panel's study were presented at the June 1971 Science Steering Group meeting. Martin noted several discouraging facts at this session: by this date the start of GCMS science testing had slipped by six months (from early 1971 to October 1971); after four years of work the breadboard was just ready; and the GCMS was now getting too heavy. Originally projected to weigh about 9.5 kilograms, the GCMS was weighing in at about 14.5 kilograms. The ad hoc panel presented five GCMS design variants with weight projections between 11 and 14 kilograms, but they requested and were given more time to study the science impact of these alternatives.[50]

*Panel members included Chairman H. B. Edwards, K. Biemann, T. Owen, R. S. Young, J. J. Paulson, and G. C. Broome.









The development model, top left, of the gas chromatograph–mass spectrometer was the first step toward spacecraft hardware. After a breadboard model, completed in October 1971 to perfect functioning of the instrument, designers worked on weight, size, and modifications to integrate it into the lander. The mockup, top right, is 35 centimeters wide. Finally, the flight GCMS is tested and prepared for its long journey through space to investigate Mars.

As the reconsideration of the GCMS continued, the Viking Project Office sponsored the first "Viking science symposium," structured to provide extended discussions of the chemical and biological premises on which two of the project's major investigations—biology and the molecular analysis experiment—were based. While much of the material presented was old information to seasoned Mars hands, for many of the attendees it was the first time they had been exposed to these scientific assumptions underlying the Martian search for life. In addition, several new interpretations of old phenomena or refined Mars data were presented for discussion. Alan Binder of the Illinois Institute of Technology's Research Institute suggested an alternative explanation for the so-called "wave of darkening." The most common reason given for this phenomenon had been an increase in atmospheric humidity as water sublimed from one polar cap and moved toward the other. New observations indicated that the wave, which progressed at a speed of 30 kilometers a day, might actually be a wave of brightening. Earth-based photometric measurements had compared dark areas to bright areas on the assumption that it was the bright areas that were unchanging. If the bright areas were getting brighter, then water or vegetation was not needed to explain the change. Instead, the explanation might be some simple mechanism, a dust storm, for example. Some microbe hunters who saw this as one more strike against the possibility of Martian water might not have been pleased, but the reasoning was more consistent with other investigations that indicated limited water on the Red Planet.[51]

Toby Owen of the State University of New York at Stony Brook and Michael McElroy of Harvard reported that *Mariner 6* and *7* had provided new clues about the composition of the planet's atmosphere. It was 95 percent carbon dioxide. Nitrogen probably existed in quantities less than 4 percent, and perhaps as little as 0.5 percent. Traces of carbon monoxide, molecular oxygen, ozone, and water vapor were likely. While these were not very encouraging comments for those who wanted to find life on Mars, Carl Sagan repeated his oft-given summary that the only way to make such a determination was to go there and check out the planet. Such an examination might not end all speculation, but it would certainly give them better data. To make that trip worth the effort, the GCMS and the biology instrument would have to work.

The problems encountered with the gas chromatograph-mass spectrometer were not made any better by renewed money problems. A special meeting held 19 September to discuss the budget led to some very bitter reactions by several scientists. Martin told those investigators that they would have to reduce their projected costs by a further $17 million to $22 million. Before the next discussion of the science budget reduction in early October, Jerry Soffen received some amazing letters in response to his comments about scientific priorities. There was a decided lander-versus-orbiter outlook among the scientists, and a dichotomy between the build-the-experiment-hardware-yourself group and the more theoretically oriented investigators.

Harold P. Klein, biology team leader, was among the first to write. He concluded that it was more important to get results from the lander than from the orbiter. "I say this for a number of reasons: by 1975, we will have had several missions to the planets—with flybys and orbiters, but no lander mission; we have learned a great deal about Mars from the Mariner series and there is no doubt that these have shaped our views of the planet, and that Mariner 9 should add immeasurably to this store of information." But there had never been a direct measurement made from or of the surface of Mars.

"What I am emphasizing is something which scientists recognize as first order science—i.e., it is generally easier to refine your techniques, and repeat your experiments with more sophisticated equipment than to start investigating in unknown territory." But Klein noted that "it is much more exciting to try something completely new and different—to do something first." He would be willing to sacrifice the orbiter imaging system rather than subtract anything from the landed group of experiments.

> On the lander, we are proposing a number of investigations—and while these will all be "first time" investigations, and therefore of great potential interest, it is obvious that some are concerned with answering really colossal questions and others are not. It is no surprise—at least to me—that there is a direct relationship between the magnitude of the scientific question being asked, and the complexity, uncertainty and, therefore, the expense involved in the equipment concerned with each investigation.

Klein would prune the orbiter science to only that needed to support the lander. While dropping the large imaging payload, he would maintain the atmospheric water detector and the infrared thermal mapping device. He hoped that no lander experiments would have to be eliminated, but if deletions were necessary the big experiments—the GCMS, the biology instrument, and lander imaging—must be preserved.[52]

Don L. Anderson, seismology team leader, was equally strong in his opinions. "First of all, I feel that Viking was poorly conceived from the beginning, and this, of course, was headquarters' fault." With that shot across the NASA bow, he continued:

> The way science was selected was ill-conceived, and headquarters was repeatedly warned that one does not decide what needs to be done and then try to find someone to do it. In the past, the scientists designed the experiments and, by and large, the instrument. The Viking scientists have little experimental experience and virtually no equipment experience. They were chosen because they expressed an interest in an area—not because of any demonstrated wisdom on the important problems of Mars or of the solar system. As a group they cannot provide you guidance in scientific policy matters of priority. As individuals they are ineffective, because of the system, in riding herd on their own experiments, particularly the costs.

Translated, the exobiologists might be asking the "colossal" questions, but it was Anderson and his colleagues who were doing experiments with which they had first-hand experience. They could create hardware and deliver it at a reasonable cost and on time. Anderson accepted, to a degree, that "one can argue that the first mission to Mars should have biological emphasis," but the realities were "that the biological and organic experiments were not ready when the payload was selected, are not ready now, and probably will not be ready in 1975." Anderson admitted that physical measurements, such as seismology, were relatively easy, but that complex experiments like the GCMS and the biology investigation were more difficult than anything NASA had ever flown. One could argue parenthetically that the molecular and biological investigations were closer to real laboratory science than anything ever done before in space. These experiments required more than data gathering; they demanded elaborate manipulations of sample materials in miniature laboratories. As he noted, such biological investigations as these were "not even routine measurements on the earth." They were "not ready to fly a biological mission to Mars. Even if the instruments are ready the chances are high that they will not work on Mars, and if they do, will give ambiguous results." This team leader represented one camp of scientists who wanted to make "straightforward" measurements; Klein and his associates preferred to pioneer a new "first order" science in space. There were strong arguments for both points of view, which did not make Soffen's or Martin's tasks any easier. The Viking Project Office managers had their hands full—with complicated and troublesome hardware, independent and troublesome scientists. A firm discipline would have to be applied to both.[53]

The issues raised in the September-October 1971 Science Steering Group meetings would not be resolved immediately. But the discussions led to several changes, as the minutes recorded:

> 1. Reduction of science team support—By deleting certain efforts of the scientists, holding fewer meetings, and supplying less assistance. . . . This will save $3 M[illion].
>
> 2. Reduction of the Molecular Analysis Investigation—Current technical problems with the GC/MS have resulted in substantial cost increase over the original estimate. Most team leaders agree to the importance of the investigation but feel that there should be a cost ceiling. By reducing the requirements and simplifying the instrument, it should be possible to assure technical feasibility and to bring the costs down to a level consis ʼt with the present project plans ($35 M). This involves a reduction ot the number of samples analyzed, deletion of direct [mass spectrometer] analysis and [deletion of a detector portion of the gas chromatograph]. The cost saving is $3.0 M.
>
> 3. Relaxation of the Biology Instrument Requirements—Two major requirements involving temperature control and waste management, and several minor ones, can be relaxed at considerable savings. . . . The total cost reduction of $2.0 M has been agreed upon.
>
> 4. Limitation of Viking Orbiter Science Mission Planning. . . . The saving is $1.0 M.
>
> 5. Reduction of Meteorology Investigation . . . to result in a "weather station" type experiment. . . . The saving would be $1.6 M.
>
> 6. Limitation of the Physical Properties Investigation to Current Baseline. . . . [The saving would be $0.15 M.]

7. Use of fixed masts for the Viking Lander Cameras. . . . The cost saving is $0.3 M.

8. End Mission B at the beginning of conjunction. . . . The savings are essentially in operations: $0.5M.[54]

These changes totaled up to a possible saving of $11.5 million. Decisions that were postponed at that meeting included eliminating photometric calibration of the orbiter camera ($1.6 million) and deleting the X-band radio ($1.1 million), the image-motion-compensation device for the orbiter camera ($0.4 million), the retarding-potential analyzer from the entry science experiment ($2.3 million), and deleting either the infrared thermal mapper ($3.3 million) or one of the biology experiments ($1.9 million). (Deletion of the orbiter imaging system was also seriously considered at this time. That proposal is described in chapter 9.)

Between October 1971 and March 1972, there were numerous conversations among Viking Project Office personnel members, JPL authorities, and the contractor, Litton Industries, about the fate of the GCMS. Jim Martin was not very happy with JPL's management of this activity, and he told the lab on several occasions that he wanted JPL to monitor the contract the way Martin Marietta was monitoring its science subcontracts. He did not want JPL trying to build the GCMS; that was Litton's responsibility. As early as October 1971, Martin was considering finding another organization to handle the GCMS contract, and the project office awarded Bendix Aerospace a contract to study the feasibility of using an organic analysis mass spectrometer (OAMS) in place of the GCMS. Similar in the information that it produced, the OAMS did not use a gas chromatograph. To demonstrate his concern, Jim Martin added the GCMS to the "Top Ten Problems" list on 26 October. "Specifically the problem is the systems design and program redefinition of a simplified GCMS." Shortly thereafter, Klaus Biemann and his colleagues of the molecular analysis science team requested that Alfred O. C. Nier, the entry science team leader, be added to their group because of his background in mass spectrometry.[55]

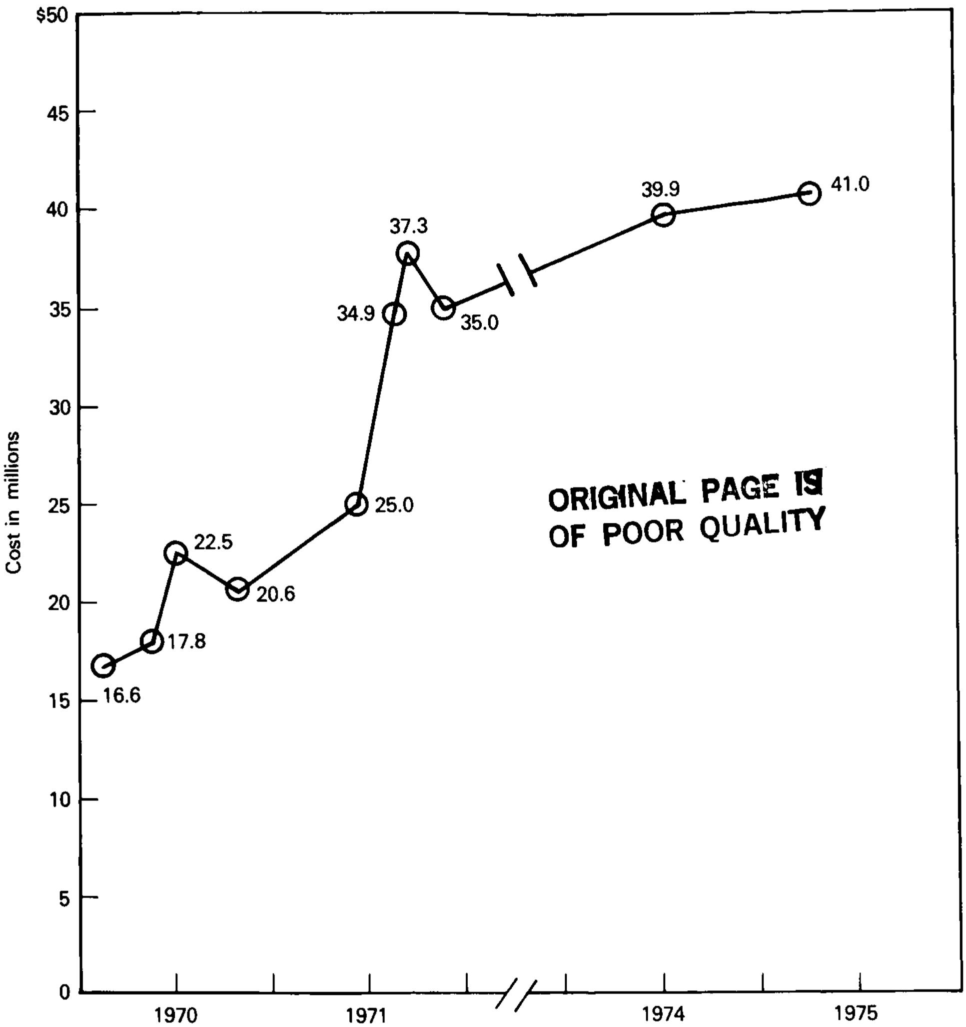
The addition of Nier to the GCMS activity was another blow to JPL. He had written to Jerry Soffen in September 1971: "While I regard a *properly* devised and managed GCMS experiment as one of the most important things we could do on Mars, the history of this endeavor leaves so much to be desired I really wonder whether it has not disqualified itself already." Nier thought that JPL's record in this area was "dismal." Nier also shared Don Anderson's complaint about the GCMS scientists' lack of experience in inventing and building instruments. He believed that it was "most unfortunate that in NASA's selection of the team some regard was not given to this factor in view of JPL's weakness in this very difficult area." By these statements, Nier did not mean to detract from the caliber of the individuals on the GCMS team, but he felt that it was necessary to underscore the nature of the problem facing the project managers.[56]

Continued troubles with development scheduling for the gas chromatograph-mass spectrometer and the lack of confidence among the scientists in JPL's ability to manage the instrument's development and fabrication led Martin to transfer the management of the GCMS instrument contract from JPL to his Viking Project Office at Langley. As a preparatory measure, he announced that effective 29 February 1972 Cal Broome, lander science instruments manager, would report directly to the Viking project manager. This shift was one more step to tighten control over the lander science payload and give those experiments the visibility that they seemed to require. Further—as a consequence of Klaus Biemann's presentation on the GCMS and the OAMS made at the February Science Steering Group meeting, in which Biemann had noted that each instrument had advantages and disadvantages that could not be directly compared—Martin decided in favor of continuing the development of a simplified version of the GCMS. His action was prompted primarily by the cost projections, which indicated that it would be cheaper, by about $7.5 million, to retain the GCMS and transfer management of the instrument to Langley. NASA Headquarters approved this recommendation on 10 March, and Martin appointed Joseph C. Moorman as the GCMS manager and J. B. Lovell as the Viking Project Office resident engineer at Litton Industries. Although the development and fabrication of the instrument was still far from ensured, at least a more responsive management-contractor structure had been established to deal with the problems that would emerge later.[57]

Viking Biology Instrument

Nearly everyone associated with the Viking project realized the Viking biology instrument was going to be a technical and scientific challenge, but no one was able to predict just how much time, energy, and dollars would be required by this complex scientific package. Devising a biology instrument that held three experiments in a container less than 0.0[illegible] cubic meter in volume and weighing about 15.5 kilograms was more of a chore than even the most pessimistic persons had believed. Certainly the TRW Systems Group personnel who won the Viking biology instrument subcontract in competition with Bendix Aerospace Systems Division did not expect its original estimated cost of the completed flight instruments and test articles to soar from $13.7 million to more than $59 million.[58] A box about the size of a gallon milk carton, the instrument contained some 40 000 parts, half of them transistors. In addition to tiny ovens to heat the samples were ampules containing nutrients, which were to be broken on command; bottled radioactive gases; geiger counters; some 50 valves; and a xenon lamp to duplicate the light of the sun. It was a complicated and sophisticated miniature laboratory.

The Viking biology instrument was originally conceived as essentially the integration of four individual life-detection schemes. According to



Gas chromatograph-mass spectrometer cost projections.

Loyal G. Goff, Viking Program Office, NASA Headquarters, "the transition from these early hardware models to an integrated, automated, and miniaturized flight unit capable of surviving all of the environmental conditions of sterilization, launch, cruise, and landing was a horrendous undertaking." These environmental requirements, with the performance specifications, demanded considerable examination and testing of the materials used in the biology instrument. The initial design concepts for the experiment were developed by Ball Brothers Research Corporation, Boulder, Colorado, and the Applied Technology Division of TRW Defense and Space Systems Group, Redondo Beach, California, under contracts managed by NASA's Ames Research Center.[59]

On 3 September 1970, when the TRW team was given the go-ahead by Martin Marietta, four direct biological tests had been selected for the instrument that could examine the Martian soil for traces of living organisms through the measurement of some aspect of the metabolic process. Three of the procedures could in principle detect "resting" metabolism, although all would be more reliable if growing organisms were present. The first experiment, originally called carbon assimilation but later known as pyrolytic release, would be performed with a minimum addition of external substances (that is, only radioactive carbon dioxide [$^{14}CO_2$], radioactive carbon monoxide [^{14}CO], and water vapor) to the samples. Experiment two, originally known as Gulliver and subsequently called labeled release, was to add extremely diluted solutions of labeled (carbon 14) organic matter to the Martian soil samples under conditions that barely moistened the samples. Experiment three, called the gas-exchange experiment, provided for adding greater amounts of organic materials and water to the samples. Because it was rich in nutrients, Jerry Soffen and others referred to this as the "chicken soup" experiment. The fourth experiment (subsequently eliminated) was the light-scattering experiment, or Wolf Trap as it was better known. Requiring the growth of organisms in the sample, this investigation provided the least Marslike environment because it would suspend the sample in an aqueous solution. But if microorganisms did grow, they would turn the liquid cloudy, and the light sensor would detect the change. Together, the four experiments represented a range from very dry to saturated solutions, and experimenters hoped they would provide a check on each other while giving Martian microbes a choice of environments in which to grow.[60]

The first year of work leading up to the preliminary design review was spent making a breadboard model for each of the experiments. The PDR, originally scheduled for July 1971, was postponed three months so that a number of changes could be made in the biology instrument design. In October, TRW submitted new "estimated cost at completion" figures to Martin Marietta; the cost had risen to $20.2 million. TRW had greatly underestimated the complexity of the task, which accounted for about half of the $6.5-million jump. The rest was due to modifications in the experiment definition.

The 4-6 October preliminary design review in Redondo Beach, California, disclosed a number of problem areas in the design and management of the Viking biology instrument. Rodney A. Mills, Walter Jakobowski's deputy, feared that Martin Marietta and TRW could both be blamed for poor management.[61] Of particular concern were the complexity of the waste management system, which would store the water and organic materials after they had been tested; the complicated nature of the sampling system; the increasing instrument weight, which would lead to higher costs; and the numerous elements that, should they fail, would render the whole instrument useless. On 1 July 1971, Jim Martin issued Viking project directive no. 6: "It is project policy that *no single malfunction shall cause the loss of data return from more than one scientific investigation.*"[62] Each of the biology experiments was considered to be one scientific investigation under this philosophy, and there were numerous "single point failures" that could terminate the data return from the instrument. At the October PDR, no single experiment stood out as a particular problem, but Martin, Broome, and their colleagues were worried about the overall complexity of the TRW design.[63]

During November and December 1971, TRW and Ames Research Center personnel under Harold Klein worked to simplify the biology instrument. Deleted from the design were the Martian gas pump, the onboard carbon dioxide gas system, one control chamber each for the gas-exchange and light-scattering experiments, and related valves, plumbing, and wiring. But it became apparent at a biology instrument review in late December that more drastic changes would have to be made. During the final days of January 1972, Martin concluded that one of the experiments would have to be eliminated to reduce the volume, weight, complexity, and cost of the package. Walt Jakobowski and Richard Young from NASA Headquarters met with representatives from the Viking Project Office, Martin Marietta, and TRW on 24-25 January to discuss ways to remedy the problems, especially cost, which had escalated to $33 million.[64]

That meeting was not a satisfactory one from Jakobowski and Martin's point of view. TRW was not able to suggest any acceptable engineering cost reduction items without removing two or more experiments. Additionally, all of TRW's cost reduction proposals had high-risk factors for scheduling, testing, or both. Martin Marietta personnel who had reviewed TRW's schedule and manpower figures were also unable to offer any alternatives. To find solutions to their problems, Martin formed an ad hoc panel for the examination of imposed and derived requirements on the Viking biology instrument under the chairmanship of Howard B. Edwards of Langley's Instrument Research Division. While that panel met to determine which, if any, of the scientific and engineering requirements could be relaxed or eliminated to reduce cost, weight, size, and complexity of the overall instrument, Klein, Joshua Lederberg, and Alex Rich, biology team members who were not affiliated with any particular experiment, met to discuss priorities for deleting one of the experiments.

Dropping an experiment was a painful experience for the men who made the recommendation and those who implemented it. By 13 March, NASA Headquarters had decided that the light-scattering experiment, the investigation based on the least Marslike premise, should be terminated. The men in Washington cited possible difficulties in interpreting results and a potential for further cost growth as reasons for their action. It was John Naugle's unhappy responsibility to tell Wolf Vishniac that his Wolf Trap would not be included in the Martian biology instrument. Noting that "this was one of the more difficult decisions" that he had had to make since joining NASA, Naugle told Vishniac that they had to "simplify the biology experiment—its history of growth in cost and complexity had forced this position." In deciding how to reduce costs, the managers at NASA had tried to consider both scientific and engineering factors:

> On the science side, we are assured that the deletion of the light scattering experiment, while undesirable, is the least damaging in terms of data lost. I won't go into detail here since you have talked at length with Drs. Lederberg and Rich on this subject. On the engineering side, it seems that the light scattering experiment might be considered one of the least complex in terms of number of parts and detail of design, but is one of the more difficult to actually build into a problem free device.

Following advice from all members of the biology team, Naugle stressed the desire that Vishniac continue to participate as a member of that group.[65]

Although the biology team seldom acted as a cohesive group, the decision to eliminate the light-scattering experiment did draw members together temporarily. As a group, they aired their dissatisfaction with the decision, the manner in which it was made, and the limited likelihood that it would reduce significantly the cost of the biology instrument. At a biology team meeting in March, Dick Young and Jerry Soffen were on the hot seat as they once again explained the need for cost reductions in an era of tight budgets. Klein, the team leader, wrote to Naugle on behalf of the whole group:

> Naturally, the Team is not very happy that the scope of the biological experiments was reduced. . . . This science reduction is all the more difficult to accept because it is not at all clear just what factors dictated this decision. Recent discussions with TRW . . . leave little doubt that no savings in weight or in volume will follow from the elimination of the light scattering experiment. . . . Whether, at this late date, any cost savings will accrue from the deletion is also problematical.

While stopping short of mutiny—and still promising to work hard—Klein said that the team wanted a better explanation of why Wolf Trap was dropped.[66]

Understandably, Wolf Vishniac was not happy with the decision. He criticized Lederberg and Rich for not being familiar with the development status of his experiment: "I am shocked to find that a judgment on the value of an experiment was based upon such complete ignorance on the present state of the instrument. . . ." Much of the discussion regarding Wolf Trap concerned "matters which have long ago been settled and solved." Some of the data the NASA managers had used in their decision-making process had been gathered by the Ames Research Center. Vishniac was told by persons at Ames that they had sent headquarters "some old reports which we had lying around." When the scientist asked why "old" material was used, he was given some surprising news: "It doesn't really matter, we have long ago decided that light scattering is to be eliminated." The more Vishniac investigated the elimination of his experiment, the more he was displeased.

He believed that there had been some anticipatory preparation for dropping Wolf Trap. And according to Vishniac, Lederberg and Rich were not really suited for or capable of making an informed decision. "Their aloofness from the team, their ignorance of the mechanical details and the apparent predisposition of Ames to leave out the light scattering experiment makes me question the value of their recommendation."[67]

In a compassionate review of the decision and the process by which it had been made, Naugle tried to allay Vishniac's frustration and anger. The associate administrator pointed out that something had to give, as the budget could not be increased. They had been forced to review and revise all of the Viking experiments on the orbiter and lander. If Lederberg and Rich had not participated in the examination of the biology instrument, someone entirely unfamiliar with the instrument and the search for life on Mars would have.

> We recognized that we were asking them to undertake a very difficult and personally distasteful job of reviewing four experiments which had originally been very carefully selected and had just recently been certified as complementary and an excellent payload for Viking, and recommending which of the four could be removed with the least impact on the overall biology experiment. They reluctantly agreed.
>
> In the guidelines we gave then we said the decision should be primarily made on the basis of the scientific merits of the experiments since there was no substantial engineering factor to use to select the experiments to be deleted. . . .
>
> Dr. Lederberg and Dr. Rich's recommendations were clear—that all four experiments should fly, but if one must be dropped, it should be the light scattering experiment. They also make it clear that although the experiment should be dropped, the experimenter (Dr. Vishniac) should not!

Naugle thought that the deletion would "contribute" in a very real way to the solution of their Viking payload problem. "I am assured that we will save at least two or three pounds [0.9-1.4 kilograms] by this action. This will be applied directly to the weight deficit already incurred by the biology package." Additionally, space would be saved for other biology requirements, at a saving of at least $2.3 million.[68] In the short run, the projected cost of the biology instrument did drop, but by the fall of 1973 the cost estimates would escalate wildly, leading to another major review of the biology package.

Wolf Vishniac faced other disappointments in the loss of his Mars experiment. While he continued to participate constructively in the biology team's work, he no longer had any NASA funds to support his research projects and personnel. Vishniac soon discovered that he would have to pay a high price for having gambled on spaceflight experiments. He had been the first person to receive exobiological research support from the agency, but now that the money was gone he discovered a hostility on the part of many scientists directed toward those who had accepted "space dollars." In spring 1973, Vishniac wrote to Soffen telling him that he could not attend a particular meeting. "I will do whatever is essential in the Viking Program but I simply must place my priorities on my university work. The consequences of my change in status in the Viking Team have been far-reaching as you know, not to say disastrous." He was finding it difficult to obtain support for laboratory research because of his work with the space agency. The National Institutes of Health had refused a grant application; "I was told unofficially that it received a low priority because I was 'NASAing' around." The National Science Foundation had decided not to renew a grant for Vishniac, partly because of his association with NASA. The exobiologist told Soffen that "it is essential that I recapture some sort of standing in the academic world and I must therefore limit my participation in Viking to essentials only."[69]

In 1973, Vishniac was still pursuing his research into the origins of life and the possibility of life on other worlds when he fell 150 meters to his death in Antarctica's Asgard Mountains. Searching for life in the dry valleys of that bitter cold and windswept region, Vishniac was attempting to prove that life forms could adapt to extremely hostile environments. Early in 1972, he had found microorganisms growing in what had previously been thought to be sterile dry valleys. This discovery by Vishniac and his graduate student assistant Stanley E. Mainzer, using a version of the Wolf Trap light-scattering instrument, was a bit of good news for the believers in life on other planets but a contradiction of the findings of Norman Horowitz and his colleagues Roy E. Cameron and Jerry S. Hubbard, who in five years of research had yet to detect any life forms in that barren land.

The dry valleys of South Victoria Land, Antarctica, with a few other ice-free areas on the perimeter of that continent, formed what was generally agreed to be the most extreme cold-desert region on Earth. The area was also the closest terrestrial analogy to the Martian environment. These valleys, which covered several thousand square kilometers, were cut off from the flow of glaciers out of the interior of the continent by the Transantarctic Mountains. Although the valleys were ice-free, their mean annual temperature was -20°C to -25°C, with atmospheric temperatures rising to just the 0°C mark at the height of the summer season. Liquid precipitation and water vapor were almost nonexistent, and the limited snowfall usually sublimed to the vapor phase without ever turning to liquid. It was in this region that Horowitz's colleagues discovered what was believed to be the only truly sterile soil on the face of Earth. From their research in the dry valleys, Horowitz and his associates concluded:

> These results have important implications for the Mars biological program. First, it is evident that the fear that terrestrial microorganisms carried to Mars could multiply and contaminate the planet is unfounded.

Scientists attend a Viking planning meeting at Langley Research Center in 1973. Left to right are Dr. William H. Michael, Jr., leader of the radio science team; Dr. Wolf Vishniac, assistant biology team leader; and Dr. Richard S. Young, Viking program scientist from NASA Headquarters in Washington.

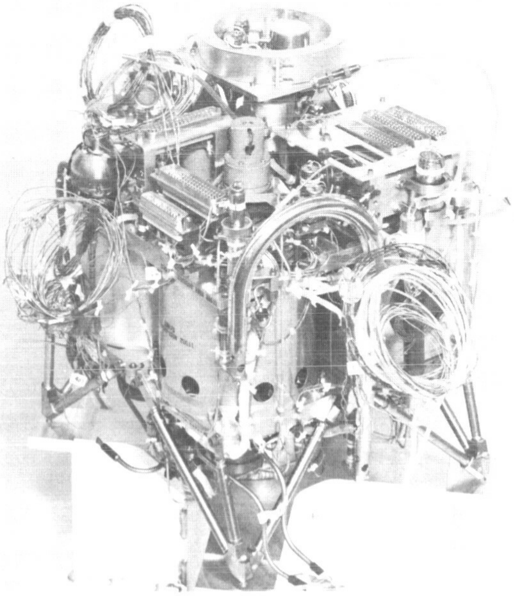
> The Antarctic desert is far more hospitable to terrestrial life than is Mars, particularly in regard to the abundance of water. In other respects, too—such as the ultraviolet flux at the surface—Mars is decidedly more hostile than the Antarctic.
>
> Second, Martian life, if any, must have evolved special means for obtaining and retaining water. . . . This has been known for some time. What is new in these findings is that even under severe selective pressure microbial life in the Antarctic has been unable to discover a comparable mechanism. To some this may suggest that life on Mars is an impossibility. In view of the very different histories of Mars and the dry valleys . . . we believe that such a conclusion is not justified.
>
> Finally, the Antarctic has provided us with a natural environment as much like Mars as we are likely to find on Earth. In this environment, the capacity of life as we know it to adapt and survive is pushed to the limit. The concentration of living things around the sources of water in the dry valleys and their rapid drying out in the most arid locales may be useful as a model of the distribution of the life we may, if we are lucky, find on Mars.[70]

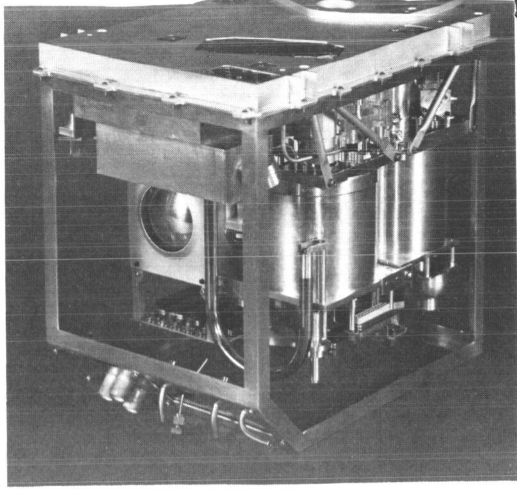
But in 1972, Vishniac detected microorganisms with Wolf Trap in exactly those regions that Horowitz had declared sterile. Life had found ways to survive in the inhospitable, Marslike dry valleys. In December 1973, Vishniac went back to Antarctica to learn more about these hardy microbes. He wanted to know where they obtained their life-sustaining water and nourishment. Alone on a steep slope in the dry valleys, Vishniac slipped, fell, and died.[71] Vishniac and his Wolf Trap life detector had been successful on Earth, but he would not see Viking go to Mars, and his instrument would not be applied to searching for elusive Martian microbes. A man who had done much to give exobiology legitimacy as a field of research was gone. The loss of Vishniac from the biology team was repeatedly felt in later years. He had been an arbiter and a man of good cheer. As the biology instrument continued to increase in cost and to raise more and more technological hurdles to be overcome, a man with his talents and humor was sorely needed.

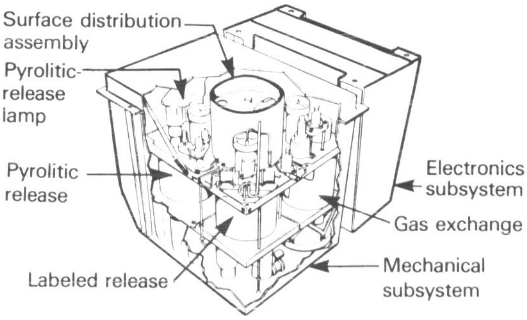
During the first half of 1973, work progressed on the design development units for the biology instrument and the gas chromatograph-mass spectrometer. Science tests for the biology instrument had begun in mid-December 1972, with biology team members participating in the trials of their experiments. GCMS testing began in early May. After the first round of testing, the Viking managers held a critical design review on 23-25 May for the biology instrument, and even though they discovered no major problems with the package, Martin Marietta and the Viking Project Office were less than pleased with the review. The GCMS critical design review in mid-July disclosed only three major concerns, which was encouraging news considering the problems that piece of hardware had caused earlier.

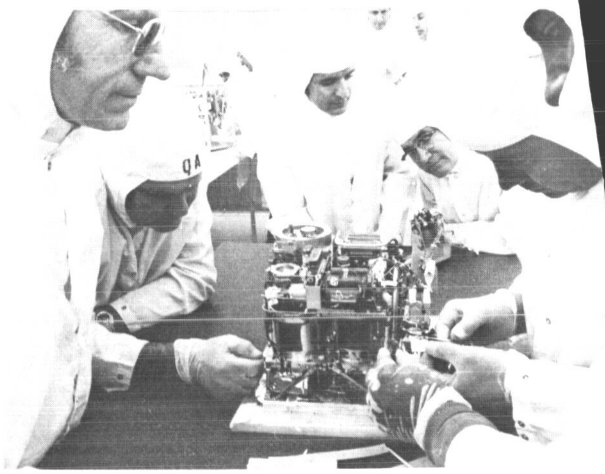
Unhappily, new trouble with the management of the biology instrument surfaced in mid-July. At a meeting held at TRW, Jim Martin learned that completion of the design development unit had slipped by three weeks and the projected delivery date of the proof test capsule unit was behind by five weeks. The problem, Martin found, was failure to plan ahead; TRW lacked the skilled manpower to assemble and check out these crucial units. As the July session went on, the discussion of the biology instrument came "unglued," according to Martin; he feared that the work at TRW was "out of control" with no credible schedule or cost plan.[72] By that autumn, the situation was even bleaker. On 15 October, Ed Cortright wrote to George Solomon, vice president and general manager at TRW. Cortright had been monitoring TRW's handling of the biology instrument problems with the intent of reporting to Hans Mark, director of Ames Research Center. His report was to give the center better data for judging prospective contractors—of which TRW was one—of experiment hardware for the Pioneer spacecraft scheduled to visit Venus. Cortright's report to Ames would not be favorable. He thought that TRW, Martin Marietta, and NASA had underestimated the complexity of the biology instrument task: "The original TRW proposed cost was grossly underestimated with the result that the current estimate at completion is $30.9 million, which is $18.4 million or 147 percent over the original estimate." Of that amount, $12.4 million was TRW's overrun; $6 million had been spent on redefining the experiments.

Cortright told Solomon that the TRW management had placed too much emphasis on the company's previous performance and had been reluctant to face the fact that the biology instrument was getting into serious trouble. "You are currently beset with a rash of technical problems









The development model of the Viking biology instrument's mechanical subsystem, top left, conveys some of the external complexity of the experiment. The mockup, top right, minus the essential electrical and plumbing connections exposes the hardware to view. At lower left, a diagram shows the biology instrument after deletion of the light-scattering experiment. At lower right, in final stages in 1975, the automated equivalent of a well-equipped biological laboratory makes up a package of less than 0.03 cubic meter to land on Mars.

which further threaten schedule and cost. It is clear that if the job were on schedule, there would be more time to adequately cope with the necessary fixes." Impressed with the steps Solomon had taken to strengthen management of the biology package, Cortright nevertheless believed that "heroic action" would be necessary to ensure "a successful experiment on the surface of Mars."[73] Two weeks later, after the schedule had slipped even further and the biology instrument had been put on Martin's Top Ten

Problems list, Cortright again wrote the general manager about the "potentially catastrophic" situation and sent a similar letter to Richard D. De Lauer, TRW Space Systems executive vice president. To De Lauer, Cortright bluntly said, "It is imperative that you bring to bear on these problems the most talented individuals you can find within your Company, and elsewhere, and quickly weld them into a problem solving team to get this job done. I know you have taken steps in this direction and I cannot fault individuals who are currently working the problems. However, I must believe that you have not yet applied your maximum effort, for which there is no longer any substitute."[74]

The problems at TRW were twofold. The engineering tasks imposed by the experiments were very difficult, and TRW's management of the project was poor. At very low temperatures, valves and seals failed, and other hardware difficulties surfaced as the initial pieces of equipment were tested. But most serious was the absence of a strong, driving manager at the California firm overseeing the work. In November 1973, production of the flight units was essentially stopped while the biology instrument was redesigned. But design quality and workmanship problems persisted, causing test failures and schedule difficulties. To meet the launch date, TRW was required to conduct design-development concurrently with qualification testing and fabrication of the flight units. By the first of February 1974, several independent analyses of the situation at TRW pointed to the possibility that the final flight units of the biology instrument would not be ready until July 1975. That would be very close to the scheduled launch dates (August and September) and too late for adequate preflight science testing.

Cal Broome, who had been appointed NASA biology instrument manager in December 1973, in a private note to Jim Martin on 7 February 1974, stated that his own view of the situation at the subcontractor's was that the "engineering organization, and, to a lesser extent, the manufacturing organization [at TRW], are running out of control." Furthermore, "The TRW engineering 'culture' simply cannot accept scheduling and discipline in connection with engineering problems." Broome was also worried that others would not share his opinion of TRW's failings and simply view his pessimistic outlook as a case of Broome having panicked again; but Hatch Wroton, the Martin Marietta resident engineer at TRW, and Dave Rogers, the JPL resident at TRW, had independently assessed the biology instrument's status and agreed with Broome's bleak prognosis.[75]

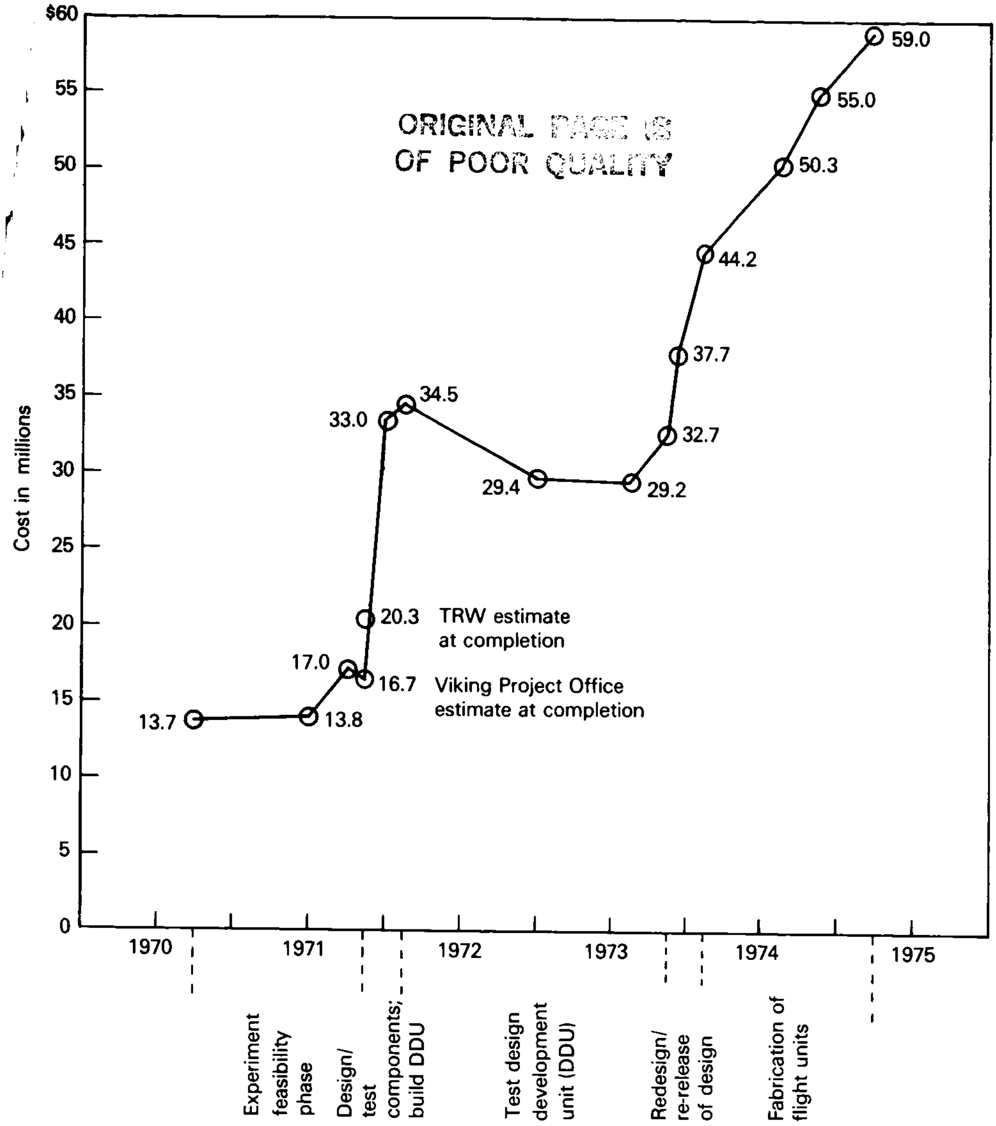
During the remaining months before the Viking launches, time lost in the schedule would be made up, only to be lost again when some new difficulty appeared. In July 1974, Martin had Walter O. Lowrie, lander manager at Martin Marietta, and Henry Norris, orbiter manager at JPL, study contingency plans for flights without the biology instrument and single flights of the Viking spacecraft in 1975, 1977, and 1979. Days later, progress on the instrument at TRW looked more promising, but by the end of the year, when the performance verification tests of the completed instruments were being conducted in Redondo Beach, new doubts about meeting the schedule plagued the Viking managers.[76]

The seesaw between failure and progress finally stopped in the early spring of 1975. On 7 March, Martin wrote to the three men who had seen the biology instrument through some of its most difficult moments—Eugene M. Noneman, TRW; Hatch Wroton, Martin Marietta; and Roy J. Duckett, Viking Project Office: "I was pleased today to be advised that Viking biology instrument S/N 106 is in its shipping box ready for delivery. I believe that you and your team members have achieved a very significant and important milestone. While there is still much work ahead of us, having a flightworthy biology instrument ready to ship to the Cape is a gratifying accomplishment." Martin extended his personal congratulations to every member of the team.[77] On 28 May, Cal Broome could at last recommend to Jim Martin that the GCMS and the biology instrument be removed from the Top Ten Problems list. Those had been the final items on the list of troubles. The hardware units were finally ready for shipment.

Table 42
Viking Biology Instrument Schedule, 1971–1975

Milestone	Original Contract Delivery Date	Actual Delivery Date	Delay in Months
Preliminary design review	July 1971	Oct. 1971	3
Critical design review	Aug. 1971	May 1973[a]	9
Design-development testing complete (S/N 001)	July 1971	Dec. 1973[b]	17
Qualification unit delivery/qualification testing complete (S/N 102)	Sept. 1973	Mar. 1975[c]	18
Proof-test capsule unit delivery (S/N 103)	June 1973	Nov. 1974	17
Flight unit-1 delivery S/N 105 on Viking lander capsule #1	Jan. 1974	Mar. 1975	14
Flight unit-2 delivery S/N 106 on Viking lander capsule #2	Apr. 1974	Mar. 1975	11
Flight unit-3 delivery (S/N 104)	July 1974	Apr. 1975	9
Spare flight unit	Added Dec. 1973[d]	Deleted Oct. 1974[e]	—

[a]Martin Marietta contended that a realistic CDR was not completed until Mar. 1974.
[b]Design development testing was completed on a nondeliverable unit; one of the deliverable units was canceled; the other deliverable unit's mechanical subassembly was simulated in system test bed testing.
[c]Qualification testing was different from original plans and not as comprehensive.
[d]This unit, not included in the original contract, was added in Dec. 1973.
[e]Unit deleted Oct. 1974 when requirement for spare lander was eliminated.



Biology instrument cost projections.

The cost in individual time and effort on these two items had been high; the dollar costs were equally great. By launch, the GCMS bill read $41 million, and the biology instrument had cost $59 million.[78]

There was, of course, more to the Viking lander science package than the gas chromatograph-mass spectrometer and the biology instrument. Each of the other instruments went through a similar series of problems met and problems solved. The GCMS and the biology instrument were unique because of the magnitude of the difficulties and the expense. With time, all problems with the instruments were resolved, and interaction among the scientists improved. Still, each team remained a collection of individuals, and among the teams only a loose confederation existed. Before the missions were flown, a stronger discipline would have to be forged. Operation of the orbiters and landers would be a complex task, and each sequential operation would have to be carefully planned and precisely executed. Jerry Soffen, Jim Martin, and Tom Young had many difficult tasks ahead of them, and one was establishing tighter control over the Viking scientists without stifling their inquisitiveness—exercising discipline so as to get maximum science return, but not in such a manner as to eliminate flexibility when scientific targets of opportunity appeared.

As the Viking science teams and their instruments matured, Jim Martin faced other technical problems with the lander, each of which had to be solved before the spacecraft could fly. Complexity and technological challenges abounded. Building Martian landing craft was genuinely hard work.