DESIGN AND FLIGHT OF THE
MARINER MARS 1969 INFRARED SPECTROMETERS

by
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Kenneth Herr, and R. Robert Brattain

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INTRODUCTION

This is a story about people, organizations, conflicts, and the development of a truly unique science experiment conducted on a NASA planetary mission. In 1969, NASA launched the Mariner 6 and 7 flyby missions to Mars, each with a scientific payload which included four instruments. One of these instruments was an Infrared Spectrometer, called IRS. The IRS instruments were unusual because they were built at the University of California at Berkeley (UCB) rather than at an established flight hardware facility. All the other instruments were built at established flight hardware facilities. This led to a fundamentally different approach by the IRS group in the design and development of their equipment.

The IRS Principal Investigator, Dr. George Pimentel, had IRS constructed at UCB under the direction of Dr. Kenneth Herr, who had been a graduate student of Pimentel’s. The Jet Propulsion Laboratory (JPL) was the Mariner Mars 1969 main contractor, and they had considerable control over many aspects of IRS quality assurance and flight environmental testing. The different desires and approaches of the two groups led to continual friction between them.

The story behind the development and flight of IRS addresses several questions which still affect spacecraft instrument development. First, how involved should the Principal Investigator or Co-Investigator be in the hands-on design and construction of the instrument they propose for flight, and in the equipment used for calibration, testing, and science backup measurements? Second, is pushing the state of the art for an instrument to obtain better data worth the risk of instrument failure? Finally, the story shows that the long term success of an instrument team depends as much on effective communication with NASA as it does technical expertise.

The instrument. IRS measured the infrared wavelength region from 1.8 to 14.4 µm in approximately 1400 discrete measurements with a spectral resolution of 1% [Herr et al., 1972]. In the lab, IRS operated in a special environmental chamber which simulated the spaceflight environment by providing a hard vacuum and walls cooled to liquid nitrogen temperatures. That environment provided the means for the instrument to cool via its radiator plate as it would in space, and allowed the IRS team to operate and calibrate IRS under simulated flight conditions. IRS could not operate unmodified outside its environmental chamber. For calibration, IRS viewed a blackbody target in the chamber which filled its field of view, and IRS and the
blackbody temperature were varied to give different calibration curves. The IRS group operated their instruments within the chambers for several hundred hours to obtain the desired testing and calibration data.

For science support, the IRS group constructed a multiple reflection cell to measure gases at path lengths up to 2 kilometers [Horn and Pimentel, 1971]. The cell allowed the temperature, pressure, and path length of the gases to be varied, and this provided the means to measure gases at Mars ambient conditions. The group made these measurements with a Beckman IR-9 or the backup flight IRS in its environmental chamber. They also used IRS in a second environmental chamber to measure minerals and ices which they felt might be present on Mars. Measuring lab spectra with the same type of instrument flown to Mars allowed direct comparisons between their lab and Mars data.

**Data loss and recovery.** Even after 30 years the IRS data set remains unique, and is still actively used for Mars research, which likely makes it the oldest planetary data set in current use. However, the unfortunate loss of most of the IRS data set has long hampered research with the data. In the late 1970’s the entire IRS data set in digital form was lost to the planetary science community, but Dr. Terry Martin (JPL) restored a partial version around 1984. However, his data set lacked most of the IRS calibration spectra and all the lab spectra. We recently located the original 7-track IRS data tapes at UC Berkeley, and are restoring the complete data set from these tapes. We plan to calibrate the Mars and lab spectra in wavelength and intensity, and then archive them.

**IRS CONCEPT AND MARINER PROPOSAL**

Pimentel and Herr conceived and developed their variable interference filter spectrometer at UC Berkeley. They proposed IRS for the Mariner Mars 1969 flight and were accepted. Initially, Pimentel did not fully realize how large and complex their project would grow.

In 1963, Dr. George Pimentel was a professor of physical chemistry at the University of California at Berkeley (UCB), and Kenneth Herr was a fourth year graduate student of Pimentel’s (Figure 1). As physical chemists, both Pimentel and Herr worked in a discipline where building lab instruments in-house was common. Consequently, both had hands-on experience building instruments, and they thought in terms of hands-on involvement in instrument design and
Herr and Pimentel recorded their idea for an infrared Variable Interference Filter spectrometer in October 1963 [Pimentel and Herr, 1963]. Pimentel then applied for a NASA grant to develop their idea to the breadboard stage, and NASA accepted their proposal around January 1964.

Pimentel told Herr that he would have to finish his thesis before he could become the project director. This motivated Herr to write his thesis in about six weeks, after which he became project director when the NASA grant commenced in March 1964. This early work focused on radiative cooling studies and on developing methods to fabricate a variable interference filter. During this early period of development, the Berkeley group remained small, employing approximately five people full-time [Herr and Pimentel, 1967], and Pimentel managed them much as he would graduate students or post-docs.

Figure 1. Ken Herr (IRS Co-Investigator, at left) and George Pimentel (IRS Principal Investigator) discuss IRS in Pimentel’s office at UC Berkeley. Behind Pimentel are plots of IRS test spectra.
In early 1966, Pimentel and Herr proposed IRS for the Mariner Mars 1969 flybys, with Pimentel as the IRS Principal Investigator (PI) and Herr the Co-Investigator (Co-I). They wanted to study Mars’ atmosphere, surface and polar cap, and obtain topographic measurements and limb spectra.

In May 1966, NASA accepted their proposal, with JPL as the Mariner Mars 1969 main contractor. Pimentel then opened contract negotiations with JPL with a budget proposal for $785,000, an amount which JPL found so absurdly small that they refused to consider it. At the request of Pimentel, R. Robert Brattain, who came from Shell Research, signed on as IRS Project Manager, and he submitted a budget of $2,100,000. JPL found this a much more reasonable number [Brattain, pers. comm., 1997]. This shows Pimentel was not familiar with managing a project that large, and may not have fully appreciated how big the project would grow. Certainly he underestimated the amount of effort it would take to comply with JPL’s quality assurance and environmental testing requirements.

WHO WILL BUILD THE INSTRUMENT?

Pimentel wanted to build IRS at Berkeley because he felt this would give them better control over IRS design and allow more opportunities for innovation. This immediately raised concerns at JPL, who felt the Berkeley group lacked the experience needed to build successful flight hardware.

*JPL wants a contractor.* Mr. H. M. (Bud) Schurmeier (JPL Mariner Mars 1969 Project Manager) told Brattain that JPL had some question “as to whether we were experienced enough to build flight hardware; but he assured us that they were going to proceed on the basis that we would build the flight hardware...” [Brattain corr., 14 Sep 1966]. This element of doubt about the ability of the Berkeley group to produce a quality instrument remained throughout the project. All the other Mariner 1969 instruments were built at established flight hardware facilities.

Furthermore, Raymond Heacock (JPL Mariner Mars 1969 Representative) told Brattain that “JPL has found in the past that a group or organization tends to underestimate the value of certain reliability and quality assurance activities the first time that they fabricate flight hardware” [Brattain corr., 10 Apr 1967]. This indicates JPL may have felt the need to be more watchful with the inexperienced Berkeley group in these areas.
Berkeley and a contractor? Brattain felt Berkeley should build the IRS prototype, but then have a contractor construct the flight instruments under the close supervision of Pimentel and Herr. He told Pimentel, “I sincerely believe that I would be improving your and Ken [Herr’s] chances of sending a successful instrument to Mars if I could convince you to set up a tight organization to supervise the fabrication of the instruments by an outside contractor” [Brattain corr., 30 May 1967]. He felt this would free up their time, and so allow the efforts of the IRS group to “be devoted to those phases of the project [for] which you and the group are uniquely equipped rather than being burdened by those phases of the project for which other organizations are equally or better equipped” [Brattain corr., 30 May 1967].

Brattain left the project around June 1967, when he felt he had completed the main budget and management setup work for the project [Brattain pers. comm., 1997]. He left Pimentel with words that proved prophetic, and that describe how instruments are currently constructed:

“It is pointless at this time to develop in a university a capability for fabricating flight hardware, even if you believe from a philosophical standpoint that it is proper for universities to fabricate flight hardware. The reason that it is pointless is that we are quite close to the time when no experimenter will be allowed to build his own flight instruments. ... This does not mean that the role of the Principal Investigator will disappear but it does mean that he will become the person who suggests an experiment, conceives the instrument to obtain the necessary data, and interprets the data that are returned from the mission, but he will not be the person that fabricates the flight models of the instruments that obtain these data” [Brattain corr., 10 Apr 1967].

UC Berkeley. Nonetheless, after some consideration, Pimentel and Herr chose to build IRS at UC Berkeley. Producing the instrument they wanted would require extraordinary levels of innovation, and their desire to measure data with very high signal-to-noise ratio would have a considerable influence on the design of IRS [Hughes and Herr, 1973]. For example, it led them to the extraordinary decision to use active cryogenic cooling for the long wavelength detector to achieve their desired sensitivity, even though there was no precedence for this on a planetary flight. They took a great risk in this approach; the safe route would use established hardware and a contractor, and accept measurements made at a lower signal-to-noise ratio (lower sensitivity).
But they accepted the greater risk of failure in exchange for the potential of obtaining a more informative data set.

After completing contract negotiations with JPL, Pimentel and Herr hired more people, and their numbers expanded within a year from approximately 12 to 36 people, counting everyone from Pimentel down to technicians and secretaries [Pimentel, 1966; Herr et al., 1967].

Herr managed the daily operations of the project, while Pimentel handled correspondence with NASA. The UCB Chemistry Machine Shop did most of the machine work on IRS, with some of the work also done at the UCB Space Science Laboratory (SSL) machine shop. Technicians at the SSL constructed and assembled the IRS electronics (Figure 2). Outside contractors manufactured most of the parts for IRS, such as the 10” telescope mirror, the cryostat, and the circular variable interference filter (CVIF). The IRS group designed and built a clean room at the SSL, where Herr assembled IRS from the manufactured parts, while Hughes assembled the gas cooling system (see Table 1).

Thus the contribution of the Berkeley group to the construction of IRS consisted of (1) designing IRS; (2) proposing and testing new instrument techniques, such as radiative cooling of the detector; (3) manufacturing and assembling the IRS framework and electronics; (4) overseeing the manufacture by contractors of other components; (5) the final assembly and calibration of IRS.
Figure 2: IRS control system. The bay on the left controlled the IRS environmental test chamber. The two center bays, called the IRS Bench Checkout Equipment, controlled IRS, and the 7 track tape drive is visible on the bottom left. The two shorter bays on the right controlled the IRS cooling gases.
### TABLE 1: Mariner IRS Project Lead Personnel. [IRS Org. Chart, 1968]

<table>
<thead>
<tr>
<th>Job title</th>
<th>Role</th>
<th>Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator</td>
<td>Conceived IRS Mars flight; Data interpretation</td>
<td>Dr. George C. Pimentel</td>
</tr>
<tr>
<td>Co-Investigator</td>
<td>IRS concept, design, assembly; Project leader; Data interpretation</td>
<td>Dr. Kenneth Carl Herr</td>
</tr>
<tr>
<td>Business Manager</td>
<td>Budget negotiations with JPL</td>
<td>Ross Robert Brattain</td>
</tr>
<tr>
<td>Assist. Project Manager</td>
<td>Liaison with outside machine shops</td>
<td>Maurice A. Carlson</td>
</tr>
<tr>
<td>Electronic Design Engineer</td>
<td>Electrical/electronic design (EE)</td>
<td>Dean A. Watson</td>
</tr>
<tr>
<td>Flight Hardware Engineer</td>
<td>Monochromator ; IRS operation and calibration.</td>
<td>Paul B. Forney</td>
</tr>
<tr>
<td>Flight Project Engineer</td>
<td>Cooling gas system design and assembly; Cryostat; Telescope.</td>
<td>John Lester (Les) Hughes</td>
</tr>
<tr>
<td>IRS System Engineer</td>
<td>Structural &amp; mechanical design</td>
<td>Dr. Robert H. Weitzmann</td>
</tr>
<tr>
<td>Technician</td>
<td>Data reduction and manipulation</td>
<td>Donald Kenneth Stone</td>
</tr>
<tr>
<td>Mechanical Fabrication</td>
<td>Machinist</td>
<td>W. W. (Andy) Anderson</td>
</tr>
<tr>
<td>Electronic Fabrication</td>
<td>Electrical/electronic fabrication (technician)</td>
<td>Wayne Moore</td>
</tr>
<tr>
<td>Data reduction</td>
<td>Optics ray tracing program; Early data reduction</td>
<td>James Holsworth</td>
</tr>
<tr>
<td>Engineering Rep.</td>
<td>Engineering liaison with JPL</td>
<td>George Thomas (Tom) Foster</td>
</tr>
<tr>
<td>Technician</td>
<td>Principal gopher</td>
<td>Mike Lowe</td>
</tr>
<tr>
<td>Draftsman</td>
<td>Drafting, artwork</td>
<td>Ted Denmark</td>
</tr>
<tr>
<td>Draftsman</td>
<td>Drafting, pictures</td>
<td>Don Renfro</td>
</tr>
<tr>
<td>Post-doc</td>
<td>Long path cell design and construction</td>
<td>Dr. Dieter Horn</td>
</tr>
<tr>
<td>Post-doc</td>
<td>Long path cell data collection and interpretation</td>
<td>Dr. Arthur Winer</td>
</tr>
<tr>
<td>Graduate student</td>
<td>Long path cell data collection and interpretation</td>
<td>Dr. John McAfee</td>
</tr>
</tbody>
</table>

### EARLY MANAGEMENT PROBLEMS

From the beginning, JPL was greatly concerned that Pimentel’s group lacked the expertise to manage such a large project, and they also strongly objected to his loose style of management. On the other hand, the IRS group saw the JPL approach as reliable but uninspired [Pimentel corr. 21 Aug 1968], and refused to adopt JPL’s management style. This caused a
running struggle between the two groups over how to manage the construction of IRS.

Brattain warned Pimentel that JPL would object to his loose style of management, saying “JPL believes in and operates on the basis of a tight organizational structure” [Brattain corr., 14 May 1967]. Brattain proved correct, as JPL doggedly tried to impose their management style onto the IRS group for the next four years. JPL managers felt very strongly that building successful flight hardware for the extremely unforgiving spaceflight environment required well documented lines of authority, strict job descriptions, and rigid timelines. Lack of these elements in the IRS management caused JPL great concern over the ability of the IRS group to produce a successful instrument.

On the other hand, the IRS group felt JPL had remarkable engineers overseen by a rigid management which allowed them to use well understood techniques to produce steady but unexciting results. In contrast, Pimentel and Herr wanted to assemble an enthusiastic crew who would throw themselves into the project and thrive on little top-down management. This was more important to them than experience, and as a result, none of the people they hired had experience building flight hardware. They believed their method would release the same creative energy that a university project typically taps into, and that IRS required this approach to bring a new type of instrument from contract start in early 1967 to flight in early 1969.

JPL demanded the Berkeley group tighten their management structure, which the IRS group saw as an attempt by JPL to control their project. This led to a series of contentious meetings and correspondence between JPL managers and Pimentel’s group.

Brattain later wrote that the clash had its roots in the fact that Pimentel “started from the position that of course the instruments would be built in-house, that they knew how to do it and there was no need for what JPL called ‘management.’” George [Pimentel] had a record of conceiving and constructing instruments to do as yet unheard of research, and did not see that building 8 copies of an instrument that he and Ken [Herr] had conceived was any different. ... To him JPL was a rigid structure of engineers who did not appreciate the power of a creative group such as the ones which George consistently built. To JPL George was a scientist who didn’t appreciate the demands of building instruments to fly in space. Both of them were correct” [per. corr. Brattain, 10 Sep 1997].

JPL proved correct on some points, as Pimentel’s loose management style caused some
confusion early on within the expanding IRS ranks. Some of the IRS group remember problems at this stage, but others do not. Brattain did implement some standard management methods in parts ordering, inventory, quality assurance, and document control. This pleased JPL and reduced the disorganization which some of the IRS group felt.

The Berkeley crew had valid points as well. Their group was much smaller than JPL was familiar with, and such a small group required less overhead. Their approach used a few well-qualified people for each task, and this reduced their need for such tight control. It also gave them greater flexibility and allowed more time for building and testing rather than planning and writing.

COMMUNICATING WITH JPL ENGINEERS

The Berkeley team wanted to tap into JPL’s engineering expertise, but early in the project this proved troublesome. JPL management may have been reluctant to hand over design information since their heritage was building and flying hardware, and not in teaching others how to do so. On the other hand, Pimentel’s experience lay in the academic world, which takes the free exchange of ideas more for granted. The two groups worked to bridge this gap, and then together they produced a better instrument than either could have alone.

In August 1966, Pimentel wrote to JPL and requested information on gold plating, cold-welding problems, and which motors to use in space applications. He said their questions on those issues had gone unanswered for about a month, and that “we have begun to wonder if these facts are considered proprietary by JPL so you might be reluctant to tell us the art of these techniques. If so, please tell us that so we don’t depend on you for help here” [Pimentel corr., 4 Aug 1966a].

Resolving the problem. In late August 1966, Herr contacted JPL to schedule a vibration test (Figure 3), and expected some guidance in which tests IRS would need and in how to proceed. Instead, the JPL contact could provide him no information on the test, but rather was only interested in having the correct paperwork filled out. Herr said the management “response to our readiness for vibration tests was apparently not enthusiastic cooperation.” However, once he got through the management layer, “fortunately the attitudes of the engineers who actually conducted the test...were entirely helpful” [Herr corr., 26 Aug 1966].
During the vibration test, a JPL engineer asked Herr to meet with other engineers to discuss some calculations. Herr wrote that during these discussions, one engineer “was explaining the...calculations in a helpful and cooperative manner and seemed about to give me a Xerox copy of them so I could study them at my leisure and use them as a point of reference in our own calculations of this matter. To my astonishment, Dr. [Gail] Despain interrupted to say that these calculations could not be given to us since they had not been cleared for transmittal to Berkeley. I found this such a discouraging operational rule that I left....

“Later in the day, Dr. Despain contacted me again and explained this rather unusual incident. He stated that an order from the [JPL] Director’s office forced him to transmit all material to our group at Berkeley through the Contract Negotiator. ... It was also indicated that this order...was the reason why we had not received information in writing in reply to our numerous requests for assistance. ... I now feel that I understand why our communications...have been so one-sided and fruitless over the last two months. As I have said to you in the past, these engineers have always seemed eager to help us whenever we have met with them” [Herr corr., 26 Aug 1966].

Brattain discussed the problem with Schurmeier (JPL MM ‘69 Project Manager), who then worked to open the lines of communication. He told Brattain “that instructions had been given to the [JPL] technical group to furnish us all information of value to us without hesitation and without waiting for any prior approval” [Brattain corr., 14 Sep 1966].

As a result, communications on an engineering level improved until it was no longer a problem. JPL then provided Berkeley with a great deal of engineering expertise for details such as how to obtain flight qualified parts, how to flight qualify parts, and vibration testing. They also warned them of potentially devastating problems such as cold welding and hydrogen embrittlement. Without the warning and subsequent fix, embrittlement could have caused a rupture of the IRS high pressure H₂ gas tank, which would likely have destroyed the spacecraft. Cold welding of the IRS filter gear train could have caused the IRS gears to weld in place during the transit to Mars.
**Figure 3:** Vibration testing of IRS at JPL. In the white coats (left to right) are Paul Forney (IRS engineer and scientist), Les Hughes (IRS and cooling system engineer), and Ken Herr (IRS Co-Investigator). IRS sits on the vibration table just in front of Hughes, as they mount the cooling bottles to IRS in preparation for the test. Visible are the white IRS radiator with its gold-plated “fence” and the IRS telescope. The two spheres that Hughes is mounting would hold the N\textsubscript{2} and H\textsubscript{2} gases for the two stage Joule-Thompson cryostat. For safety the gas bottles remained empty for this test.

However, in some engineering areas the IRS group remained ahead of JPL, such as building a logarithmic amplifier for the IRS electronics. Dean Watson (IRS electrical engineer) designed this to give IRS a non-linear response and so lower the digitization noise and thus increase the signal-to-noise ratio. JPL objected to the log amp, saying they felt it added an unnecessary layer of complexity. But in the end, it worked, and it is part of the reason the IRS spectra are such high quality.

The best results occurred when the IRS and JPL groups complemented each other. For example, Ken Herr designed a novel and simple mount for the IRS radiator which provided excellent thermal isolation [Herr *et al.*, 1972]. Meanwhile, JPL engineers told the IRS group
about the superior properties of a special radiator paint, called Cat-A-Lac White. In combination this created a radiator with better thermal isolation (from Herr’s mount) coupled with superior radiative performance (from JPL’s knowledge of radiative paint). Improved radiator performance allowed improved instrument sensitivity. Thus at the engineering level, the IRS-JPL relationship was frequently symbiotic, and together they built a better instrument than either could have alone.

COMMUNICATING WITH JPL MANAGEMENT

Although the two groups worked out their differences at the engineering level, tensions remained high in management throughout the project. JPL felt Berkeley’s disregard for documentation and JPL's quality assurance methods would jeopardize the instrument, while Berkeley felt their time was better spent in building and testing rather than in writing and planning. The two groups never resolved this problem.

Although the Berkeley group found JPL engineers very helpful, they still resisted JPL’s attempts to impose many quality assurance and instrument documentation procedures. JPL management initially saw this failure as a communications problem, so they recommended that “UCB should supply a full time resident engineer at JPL as the Experimenter’s representative. The primary purpose served by this resident will be to convey details of JPL experience in a variety of design and system areas to Berkeley in such a way that UCB develops a direct appreciation of the validity of Laboratory project recommendations” [IRS Prelim. Design Rev., 1967]. Berkeley then provided a resident engineer to JPL, but this failed to give the IRS group a “direct appreciation” of JPL management recommendations for more documentation.

The problem simmered, as JPL continued to feel heavy documentation was a cornerstone of building successful flight hardware, while the IRS group continued to resist assimilation. The issue came to a head at a JPL-IRS meeting convened in February 1968 to discuss the IRS Handling Document. The IRS group brought a fake Handling Document to show as a joke before presenting their real document. The fake document had a picture of a scruffy-looking person holding IRS, and a placard on the wall in the background read “Convert existing rooms into clean rooms!” This picture was followed by blank pages with fingerprints on them.
When the IRS group showed their fake document, the JPL person who headed the meeting became so incensed that it made a continuation of the meeting impossible. The barbs hurled back and forth were sharp and became personal. The IRS group apparently had no malicious intent behind their joke, and the strength of the JPL reaction surprised them.

The event demonstrates the IRS group never truly understood how seriously JPL management held documentation. This was clearly not an area where one could make jokes. It also made it clear to JPL management that even when they coerced the IRS group into producing these documents, the IRS group did not take them very seriously.

The exchange led Dr. Samuel Silver (Director of the UCB SSL) to write to Dr. William Pickering (Director of the JPL) that “I think that the difficulties have been largely due to the differences in temperament between faculty people and engineering management people.... The unfortunate thing is that these differences soon build up to a point where anything that is said--whether in a serious or joking vein--becomes suspect, and so we often in this process begin to overlook the positive side of the relationship.

“As I talked with the members of the group here, I soon found that there is a distinct appreciation of the role of JPL...and the help that JPL has given the group.... Regrettably, in the exchange that took place between the people this recognition of JPL’s contribution became submerged in the rest of the talk...” [Silver corr., 19 Mar 1968].

GETTING READY FOR SCIENCE

In tandem with the construction of IRS, the Berkeley group prepared for science interpretation of their data. By the end of their project, they had produced an unusually complete laboratory measurement program. They measured lunar and planetary spectra with a prototype wedge interference filter spectrometer at Lick Observatory (Figure 4), and constructed a unique 2 km long path cell to measure IRS gas spectra at Mars’ ambient temperature and pressure. They began preparations to use the spare flight qualified IRS to measure lab spectra of minerals and ices thought to be present on Mars. After the twin Mariner launches, they collected the spare IRS from JPL and started their lab work.

They constructed all their equipment with funds under the IRS contract. Two million
dollars thus bought the development, construction, and calibration of two operational but non-flight qualified IRS spectrometers, three flight qualified IRS spectrometers with cryogenic cooling, a 2km long path cell, two environmental chambers, ground support equipment, and the supporting lab calibration and scientific measurements, and data interpretation. Table 2 lists the equipment built under the IRS contract.

**Lick Observations.** In 1967, the IRS group used a single channel prototype IRS to measure high quality lunar and planetary thermal spectra (8 - 14 µm) from the Lick Observatory in California (Table 3) [Herr and Pimentel, 1967]. This spectrometer, called V.A.G.G. II, used a circular variable interference filter with 1.8% resolution, and a detector cooled to liquid He temperature. This gave them “real” data to see how well the design concept worked.

**Testing and calibration.** To test and calibrate the instruments, the UC Berkeley Chemistry machine shop built an environmental chamber for IRS which held a vacuum of <2×10⁻⁶ torr (Figure 5). They coated its interior with high emissivity paint and installed a liquid nitrogen jacket to cool the walls to 77ºK. The chamber allowed the group to operate and calibrate IRS in conditions simulating those of deep space. From within the chamber, IRS could view a blackbody calibration target which filled its field of view, and IRS and the blackbody temperature were varied to give different calibration curves.
Figure 4: A predecessor to IRS: MAGG II. It had a 10” telescope and a single detector. The long cylinder rising from the center of the instrument is the detector’s cryostat.
**TABLE 2: Instruments and major equipment.** The IRS group built seven instruments, two environmental chambers, a 2 km long path cell, supporting Bench Checkout Equipment, and a Calibration Test Unit. They designed, built, and tested this equipment, including the long path cell and environmental chambers, under the IRS contract, with a final cost overrun of 2%.

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Use</th>
<th>Fate</th>
<th>Operational</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>Structural Test Model</td>
<td>Spacecraft vibration tests</td>
<td>Left at JPL; possibly lost</td>
<td>No</td>
</tr>
<tr>
<td>102</td>
<td>Thermal Test Model</td>
<td>Spacecraft thermal tests</td>
<td>On spacecraft mockup in LASP at University of CO</td>
<td>No</td>
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<td>103</td>
<td>Engineering Model</td>
<td>Proof of concept</td>
<td>At UC Berkeley</td>
<td>Yes</td>
</tr>
<tr>
<td>104</td>
<td>Proof Test Model</td>
<td>Final design testing</td>
<td>Left at UC Berkeley, now at LPI</td>
<td>Yes</td>
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<tr>
<td>105</td>
<td>Flight A</td>
<td>Flight model</td>
<td>Flew on Mariner 6</td>
<td>Yes</td>
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<tr>
<td>106</td>
<td>Flight B</td>
<td>Flight model</td>
<td>Flew on Mariner 7</td>
<td>Yes</td>
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<tr>
<td>107</td>
<td>Flight C</td>
<td>Flight model</td>
<td>Post-encounter lab work; left at UC Berkeley; later lost at Berkeley</td>
<td>Yes</td>
</tr>
<tr>
<td>101-109</td>
<td>Gas system</td>
<td>Cryo. gases</td>
<td>105, 109 flew; some at Berkeley</td>
<td>—</td>
</tr>
<tr>
<td>—</td>
<td>2ft. diameter</td>
<td>IRS testing or mineral measurements</td>
<td>Maybe shipped to Aerospace Corp. in 1979; later lost.</td>
<td>—</td>
</tr>
<tr>
<td>—</td>
<td>Environmental Chamber</td>
<td>IRS testing or coupled to long path cell.</td>
<td>Maybe shipped to Aerospace Corp in 1979; later lost.</td>
<td>—</td>
</tr>
<tr>
<td>—</td>
<td>3ft. diameter</td>
<td>IRS testing or coupled to long path cell.</td>
<td>Maybe shipped to Aerospace Corp in 1979; later lost.</td>
<td>—</td>
</tr>
<tr>
<td>—</td>
<td>Long Path Cell</td>
<td>Gas spectra measurements</td>
<td>Shipped to Aerospace Corp 1979; scrapped around 1990.</td>
<td>—</td>
</tr>
</tbody>
</table>

**TABLE 3: IRS Lick Observations.** [Herr and Pimentel, 1967]

<table>
<thead>
<tr>
<th>Date</th>
<th>Work done at Lick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 1966</td>
<td>Daytime use of telescope to explore IRS coupling, logistics, etc.</td>
</tr>
<tr>
<td>29-30 Dec 66</td>
<td>First night-time viewing. Could not achieve adequate IRS-telescope coupling.</td>
</tr>
<tr>
<td>Jan 67</td>
<td>Recorded acceptable Moon spectra, but needed improved chopper.</td>
</tr>
<tr>
<td>18-19 Feb 67</td>
<td>Recorded best Moon spectra.</td>
</tr>
<tr>
<td>28-29 Mar 67</td>
<td>Snowed out.</td>
</tr>
<tr>
<td>18-19 Apr 67</td>
<td>Snowed out.</td>
</tr>
<tr>
<td>20-21 May 67</td>
<td>Measured Mars, Moon, Venus, and Jupiter spectra</td>
</tr>
</tbody>
</table>
Figure 5: **Large environmental test chamber.** Shown in the UCB Chemistry Department machine shop. The large environmental chamber is on the right, still under construction. The large cylinder in the middle of the picture would become the inner wall of the chamber.

**Long path cell.** Conrath *et al.* [1973], who worked with 1971 Mariner 9 IRIS spectral data, recognized the need to record CO$_2$ lab spectra under Martian temperature, pressure, and CO$_2$ path conditions to verify theoretical parameters used for modeling CO$_2$ absorptions. Accordingly, they listed lack of such spectra as one of the main sources of error in modeling the atmospheric temperature profiles and surface pressures from their IRIS data. They wrote, “laboratory CO$_2$ data, not now available, should be recorded under Martian temperature, pressure, and CO$_2$ path conditions to verify the theoretical CO$_2$ parameters for the Martian application.”

Pimentel foresaw this problem, and so as part of the IRS contract he had a multiple reflection long path cell built to measure gases under Mars’ conditions [Horn and Pimentel, 1971]. He brought in a post-doc, Dieter Horn, in January 1968 to supervise its development and
construction. This unique cell allowed measurement through path lengths up to 2 km, which permitted IRS to measure gases held at temperatures and pressures expected at Mars.

IRS made these measurements from an environmental chamber coupled to the long path cell. Thus the Berkeley group measured gas spectra with an instrument identical to the ones which flew to Mars, while it operated under simulated space conditions, and viewed gases held at Mars’ temperature and pressure. Even now, no other data set like this exists. They also used a Beckman IR-9 to obtain higher spectral resolution long path cell data.

**Mineralogy.** To interpret the Mars surface mineralogy, the Berkeley group modified an environmental chamber so that IRS could view mineral samples from within the chamber without an intervening window. The chamber also held the samples under vacuum, and an external liquid bath controlled the sample temperature. They enlisted the help of an SSL geologist, Dr. Joseph O’Connor, to provide minerals for their study. This data set provides the only spectra of Mars’ analog rocks and minerals measured under controlled conditions with an instrument identical to the ones flown to Mars.

**LAST MINUTE PROBLEMS**

Communications problems between JPL and Berkeley remained throughout the project, as did distracting conflicts. Also, a novel last minute problem illustrated an advantage to a small IRS crew.

**Communications.** In January 1968, John Naugle (NASA Assoc. Admin. for Space & Sci. Appl.) told Pimentel that NASA had placed IRS on their critical list because the IRS Proof Test Model (PTM) had “a more serious projected schedule than any other science instrument,” and that “there is a very real risk that your experiment will not fly” [Naugle corr., 5 Jan 1968]. However, the vidicon camera PTM still retained problems at this point, and it was delivered almost a month later than the IRS PTM [JPL, 1970; Pimentel corr., 5 Jan 1968].

Pimentel responded to Naugle, “In all candor, let me state that I believe the ultimate reason you were brought to writing your letter is not really connected to technical problems in our instrument. We are again encountering the abrasive recurrence of the perennial and understandable difficulty JPL has in accommodating its rather rigid management procedures to
an individualistic, independent and highly competent University research group. They would be much more comfortable with a more submissive organization producing an instrument of far less capability and correspondingly fewer problems to be solved” [Pimentel corr., 16 Jan 1968].

The fact that the IRS PTM was having neither more nor greater problems than the vidicon PTM and yet was still placed on the critical list shows the depth of the communications problems between JPL/NASA and Berkeley. Clearly NASA felt the IRS project was in more danger than the other instruments. Perhaps JPL simply had faith that their experienced vidicon engineers would work through their last minute problems and produce yet another successful instrument, but doubted the IRS group could work the same miracle.

_Distracting conflicts._ In the midst of such serious problems, the Berkeley crew remained feisty, and their antics continued to cause distracting conflicts with JPL. For example, they proudly placed one decal and one embossed UC Berkeley Seal on each IRS, but JPL refused to accept delivery unless Berkeley removed them. This caused a flurry of letters between Pimentel and JPL, but Schurmeier (JPL MM ‘69 Project Manager) finally told Pimentel to remove the seals [Schurmeier corr., 22 Nov 1968]. The IRS group removed the decal, but would not remove the embossed seal on the grounds that doing so would damage IRS. They compromised by painting over the seal in November 1968 with Cat-A-Lac White, the same paint used on the IRS radiator. This left the embossed seal still readable, but technically covered.

_Frostbitten._ Soon after they arrived at Cape Kennedy in December 1968 to prepare for the February and March 1969 launches, the IRS group set up their small environmental chamber for IRS inside their trailer (Figure 6). Before placing IRS inside, they planned to run the chamber empty, so they drew it down to a vacuum and filled its cooling jacket with liquid nitrogen (LN₂). NASA had provided them an unexpectedly large quantity of LN₂ for this purpose: they had parked a fully loaded eighteen wheeler tank just outside.
Figure 6: Testing IRS at Cape Kennedy. The IRS group took their small environmental chamber to Cape Kennedy and placed it in their trailer. Kenneth Herr (left) and Paul Forney load IRS for testing. IRS appears upside down, with the radiator fence at bottom, and the telescope faces into the chamber. After loading IRS, they closed the chamber door (visible to the left), began drawing the chamber down to a hard vacuum, and then filled the chamber’s jacket with LN$_2$, thus simulating the spaceflight environment.

The IRS group left the empty chamber running overnight. Unfortunately, someone had knocked over the mercury cutoff switch for the LN$_2$. Hundreds of gallons of LN$_2$ freeflowed out of the top of the chamber into the trailer, freezing the trailer and all its contents. When the IRS group returned, they could see from a distance that something disturbing had occurred, because the entire trailer was white with frost. Inside the trailer, water condensed on the frozen equipment, including the ground support equipment electronics, causing significant damage. However, the flight instruments remained safely stored in their airtight cases, unaffected.

Here the small size of the IRS group proved beneficial: rather than spending time filling
out forms and forming committees, they put their energies into working night and day to clean up the mess, and then simply resolved never to leave any equipment running unattended.

**MARINER FLIGHT AND MARS ENCOUNTER**

Just prior to the Mariner 6 encounter, JPL lost contact with Mariner 7, and they felt the most likely cause was a rupture of one of the IRS gas tanks. The IRS group felt that JPL was too quick and certain in blaming IRS, and that JPL did so because they always doubted IRS’ reliability.

*IRS explosion?* Mariners 6 and 7 launched flawlessly on February 25 and March 27, 1969. However, about a day prior to the Mariner 6 arrival at Mars, JPL suddenly lost contact with Mariner 7 (Table 4 lists encounter events). The IRS group was in the control room at JPL, and they heard about the problem as word got around informally. Meanwhile, a JPL group met privately to discuss the signal loss, and then returned with a list of possible causes. They placed a rupture of the IRS cooling tank at the top of their list, but they also considered a battery explosion a remote possibility.

About 12 hours before the Mariner 6 encounter, JPL regained a stable Mariner 7 signal. Then the Mariner 6 encounter occurred, and during its encounter the IRS-6 active cooling system failed. This may have heightened JPL’s concerns for a possible failure of the IRS cooling on Mariner 7. Following the Mariner 6 encounter, JPL had four days to investigate the cause of the Mariner 7 signal loss before its encounter. IRS invariably remained at the top of their list, and they debated whether they would activate it for the Mariner 7 encounter. JPL finally decided to activate it because they felt that even if the IRS cooling tank had caused the problem, activating IRS would not worsen it. They told the Berkeley group a few hours before the Mariner 7 encounter that they would activate their instrument.

JPL activated IRS about 30 minutes before the Mariner 7 encounter, and when the cooling worked, it proved IRS had not caused Mariner 7’s problems. An excited and relieved IRS group raised a quite a commotion in the control room, jumping on top of each other, and especially on Les Hughes, their IRS cooling system engineer.
**TABLE B.4: Encounter events.** [Encounter times from JPL, 1970.]

<table>
<thead>
<tr>
<th>Flight</th>
<th>Time (PDT)</th>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mariner 7</td>
<td>3:11pm</td>
<td>29 Jul 69</td>
<td>Communications lost(^a)</td>
</tr>
<tr>
<td>Mariner 6</td>
<td>10:17pm</td>
<td>30 Jul 69</td>
<td>Closest approach(^b)</td>
</tr>
<tr>
<td>Mariner 6</td>
<td>10:00am</td>
<td>2 Aug 69</td>
<td>Press conference</td>
</tr>
<tr>
<td>Mariner 7</td>
<td>10:00pm</td>
<td>4 Aug 69</td>
<td>Closest approach(^b)</td>
</tr>
<tr>
<td>Mariner 7</td>
<td>10:00am</td>
<td>7 Aug 69</td>
<td>Press conference</td>
</tr>
</tbody>
</table>

\(^a\) JPL lost and regained communications three times over the following 13 hours.
\(^b\) The close encounter phase of the flyby lasted about 30 minutes for each spacecraft.

JPL later decided a battery explosion caused the problem with Mariner 7 [JPL, 1970]. Hughes later determined a plug in the gas line leading from the nitrogen tank to the cryostat caused the IRS-6 active cooling failure. Solder flux had plugged the cryostat in an IRS-6 test run just before launch, and after replacing the cryostat, they did not have time to put IRS-6 through vibration tests before launch. When the cooling failed during encounter, they theorized contaminants had jarred loose during launch and caused the plug [Hughes and Herr, 1972]. The possibility of the cryostat plugging had concerned them for some time, but it did not have the potential to cause a catastrophic failure. The IRS group resented the immediate conclusion by JPL that IRS had caused the Mariner 7 problem, and felt JPL did not seriously consider other possibilities until after the successful operation of IRS conclusively ruled it out as the cause.

**FIRST SCIENCE RESULTS**

The IRS group presented first results at two press conferences held at JPL, each occurring approximately 48 hours after they received their encounter data. The IRS-6 results were quiet, but Pimentel and Herr produced some excitement at the press conference for Mariner 7.

After the Mariner 6 encounter, the IRS group returned to Berkeley, where they interpreted the short wavelength data (1.8 - 6 µm) returned by IRS-6. Since the long wavelength IRS-6 cooling failed, it returned no data from 6 - 14.4 µm. At the Mariner 6 press conference the following day, Pimentel reported IRS had measured CO\(_2\), CO, and water ice, and tentatively reported measuring water vapor [Mariner 6 Press Conf. Transcript, 1969].

After the Mariner 7 encounter, the IRS group also returned to Berkeley with plots of their
spectra. These spectra included a track which crossed the south polar cap edge and then continued deep into the polar cap. IRS spectra from the cap edge showed bands at 2.0, 3.0 and 3.3 µm (4900, 3300 and 3020 cm⁻¹). They knew CO₂ ice had a band at 2.0 µm, and this band appeared in all their polar cap spectra, indicating IRS measured CO₂ ice the entire time it viewed the cap. However, when moving from the cap edge toward the cap center, both the 3.0 and 3.3 µm bands disappeared. If CO₂ ice caused these two bands, then it somehow caused them at the cap edge but not farther into the cap.

To further complicate the issue, the IRS group could not find any reports in the literature of bands in CO₂ ice at 3.0 and 3.3 µm. Therefore, the disappearance of those two bands while IRS still viewed CO₂ ice, combined with the lack of reports of CO₂ ice bands at those wavelengths led the group to conclude that something which occurred only at the polar cap edge caused the two bands [Pimentel corr., 18 Jul 1972].

To investigate the puzzle in the few hours before the upcoming the Mariner 7 press conference, they spent the night measuring spectra. They were not yet set up to measure sprayed-on CO₂ ice in the lab, and so they measured it as a solid block. When they did this, they found no bands at 3.0 and 3.3 µm. On the other hand, their spectra of methane and ammonia gas showed bands at 3.0 and 3.3 µm. Therefore, less than 48 hours after receiving their data, they reported at the Mariner 7 press conference that IRS had measured methane and ammonia at the polar cap edge [Mar. 7 Press Conf. Transcript, 1969]. This created quite a stir because of its implications for life.

Over the next few weeks, the IRS group used the spare IRS in its environmental chamber with a newly constructed setup to measure CO₂ ice sprayed onto a target. They found absorptions at 3.0 and 3.3 µm also occur in CO₂ ice when it has lattice imperfections [Herr and Pimentel, 1969a]. Herr said when he saw the two absorptions, he thought “uh-oh!” He said he still distinctly remembers the uh-oh. Pimentel retracted the methane and ammonia interpretation at the NASA Headquarters press conference on 11 September 1969 [Astronautics, 1970].

Some have said that if the Berkeley group had shared their data with others in the hours between the encounter and press conference, then they could have avoided the missed identification. However, no one pointed out the correct identification of the bands to their group either during the Mariner 7 press conference or in the following days, which casts doubt on this
assumption. At any rate, it fell to the Berkeley group to provide the correct interpretation.

IRS DATA SET AND PUBLICATIONS

A long list of publications and science and hardware “firsts” from IRS shows the project was very productive. Further, the data set remains unique, and is still in use, which attests to its high quality. The IRS group published seven science articles and one Ph.D. thesis, three articles on the instrument and equipment, and a data format report. Other authors have produced numerous articles and abstracts using the IRS spectra.

Science firsts. Science firsts from the IRS group include: (1) detection of CO₂ ice clouds in Mars’ bright limb using the 4.3 μm CO₂ ice reflection spike [Herr and Pimentel, 1969b; Herr and Pimentel, 1970]; (2) measurement of lab gases at Mars ambient temperature and pressure, including CO₂, H₂O, NH₃, CH₄, O₃, N₂O, NO₂, NO, SO₂, OCS, C₃O₂, HCl, HBr, H₂S. These measurements used path lengths up to 2 km and temperature ranges from 120 to 300ºK. They combined their IRS lab and Mars data to define for Mars the upper limits of ten atmospheric gases. [Horn and Pimentel, 1971; Horn et al., 1972]; (3) measurement of Mars topography using the 2 μm CO₂ band. They used curves of growth from their long path cell measurements to interpret topography from this band, and so laid to rest long-standing speculation that Mars’ surface shows a strong correlation between albedo and elevation. They also showed that Hellas is a depression and that the eastern Valles Marineris region “appears to be a system of ridges and valleys” [Herr et al., 1970], a conclusion that was later borne out by the Mariner 9 photography; (4) measurement and identification of the 9 μm silicate band caused by suspended dust [Herr and Pimentel, 1969b; Herr et al., 1971]; (5) measurement of Mars water vapor at 6 μm [McAfee, 1974]; (6) recording first spectra of Mars’ night side; (7) measurement of CO₂ and water ice bands from the polar cap [Herr and Pimentel, 1969a; Pimentel et al., 1974]. Furthermore, they discovered that Mars south polar cap has a “collar” with characteristics which differ from the main cap [Herr and Pimentel, 1969a; Pimentel et al., 1974], and that the ice coverage is incomplete near the cap edge, and becomes more complete moving south [Pimentel and Herr, 1970].

Hardware firsts. Hardware firsts from IRS include: (1) the first spacecraft infrared
spectrometer, and the only CVIF spectrometer sent on an interplanetary flight; (2) first spacecraft instrument to use active cryogenic cooling of a detector (to 22ºK); (3) passive cooling of a detector to 175ºK, including development of a unique thermal mount which made this possible [Herr et al., 1972]; (4) long path cell which could provide path lengths up to 2.5 km, and provide a still-unique range of temperatures and pressures [Horn and Pimentel, 1971]; (5) large optics on a flight instrument (IRS used a 10” telescope).

**IRS data still unique.** Even after 30 years the IRS data set remains unique in the following ways: (1) it contains the only spacecraft spectra of Mars which cover both reflected light and thermal emission regions; (2) it is the only data set which contains both spectra of Mars and also Mars analog minerals, ices, and gases measured with identical instruments under controlled conditions; (3) it contains the only spectra of possible atmospheric gases measured at Mars ambient conditions; (4) it contains the only spacecraft coverage from 3 to 5 µm; (5) it contains the only spacecraft coverage from 5 to ~7.5 µm measured with good signal-to-noise ratio; (6) it can provide the only internally calibrated spacecraft spectra of the 3 µm hydrate band. Also of note are IRS polar cap, post-terminator, and limb scans.

**LOOKING BACK: WHO SHOULD HAVE DESIGNED IRS?**

The Berkeley group brought to the task innovation and the willingness to take risks, while JPL provided the requisite engineering expertise to flight qualify IRS. Given open lines of communication, the two groups together would have produced the best instrument. Also, the IRS story shows taking risks with flight instruments has both good and bad consequences.

**JPL.** JPL’s impressive level of engineering expertise proved vital to the IRS flight qualification. JPL taught the IRS group about flight hardware and vibration testing, and it was JPL who warned the IRS group about the dangers of cold welding and H₂ gas embrittling the IRS gas tanks.

However, despite their impressive level of experience with flight hardware, JPL lacked the willingness to accept some level of risk in order to increase scientific yield. They had learned the value of caution from their difficult experiences with the Ranger spacecraft [Koppes, 1982]. The most important issue to JPL management was a clearly defined success, and so given any
tradeoff, they invariably chose the safest route, even when it meant sacrificing scientific return. For example, if JPL had constructed IRS, they would not have used a log amplifier to increase the IRS signal-to-noise ratio, because they felt it added an undesirable layer of complexity. Furthermore, they would definitely not have flown the active cooling system. Not only did the cooling system carry extra risks with it, but also IRS could produce low quality spectra without the cooling. In a tradeoff between reliability and quality, JPL management preferred reliability.

Berkeley. The Berkeley group brought a small, dynamic team to the task whose greatest strength was their ability to try new things. For example, rather than accepting conventional wisdom in their choice of detectors, they first found the best type of detectors to cover the 2 to 14 µm range, and then went about figuring how to cool them to the desired operating temperatures. This approach had both good and bad consequences.

The failure of the active cooling on IRS-6 shows the dark side of the risk-taking route. If the IRS group had taken the low-risk approach, then they would have measured long wavelength data from IRS-6, and the JPL and IRS groups could have happily checked the “it worked perfectly” box on their press release. However, this would have required accepting spectra with low signal-to-noise ratio, and this the Berkeley group would not do, and here it cost them.

But the risky route paid off when IRS-7 put on a flawless performance. Its spectra still provide the highest signal-to-noise ratio thermal infrared data ever returned from Mars. Since substantial cooling remains a very difficult and necessary requirement to produce high signal-to-noise ratio thermal infrared data, IRS spectra will likely remain unique for some time. The IRS group’s dynamic approach produced data which likely holds the record for length of use of a planetary spacecraft data set. This is a consequence of their willingness to take risks.

Together. Thus JPL brought to the task the engineering ability and experience necessary to ensure the structural integrity of IRS, and they provided a cautionary break on the zealous IRS crew. On the other hand, the Berkeley group brought to the project the willingness to innovate and take risks. Given open lines of communication, these two groups should have had a nicely symbiotic relationship.
WHAT DOES THE STORY TELL?

The IRS tale shows that there are advantages to having the PI or Co-I intimately involved in the design and construction of an instrument, and it shows the importance of access to a pool of engineering talent and experience such as JPL provided. It also demonstrates poor communications can derail even the best of programs.

**The good side.** JPL engineers had acquired an impressive level of engineering knowledge on flight hardware, and the IRS group drew heavily on their expertise to flight qualify IRS. JPL’s zealous approach toward documentation irritated the impatient Berkeley crew, but JPL had built an impressive track record for reliability.

On the other hand, constructing IRS at Berkeley (Figure 7) resulted in a scientist, rather than an engineer, knowing better than anyone the possibilities of IRS, and later, its capabilities and limitations. Since scientists rather than engineers will interpret the data, this gives an important advantage.

As spectroscopists and instrument builders, Pimentel and Herr understood which of their demands for IRS was most important, and so they understood what to push, and how much. Engineers would not have seen from the science side the relative importance of different trade-offs. Scientists who knew little about instruments would not have understood from the engineering side just how much of a problem different engineering issues were. Combining engineering knowledge of an instrument with science knowledge of the desired output gave the IRS group the ability to design an instrument tailored to the limits of technology.

Furthermore, as a result of their hands-on experience with instrument construction, when presented with a problem, Pimentel and Herr were not solely dependent on engineers to provide ideas for solutions, although they certainly relied on engineers for details. Their hands-on background allowed them to innovate and also provide an unusually complete testing, calibration, and laboratory science back-up program. Putting less time into managing and writing reports exasperated JPL, but it gave the IRS team more time for building and testing.
Figure 7: Assembling IRS. Ken Herr (IRS Co-Investigator) assembles IRS in the clean room at the UC Berkeley Space Science Lab. Although the radiator shown on top is black, it was painted with Cat-A-Lac white on the flight models and PTM. Herr assembled IRS, and Les Hughes assembled the gas cooling system.

Their direct approach also permitted an unusually small group to construct IRS, and the group’s small size required no middle management. Thus they could interact more easily, intimately, and quickly. This close interaction meant, for example, that it was not an anonymous electrical engineer who designed the IRS response, but rather one who saw the laboratory and knew the basics of spectroscopy. This gave him a better understanding of what the scientists needed, and allowed him the knowledge and access to propose innovative improvements for IRS. Such intimate involvement also gave each person a more personal stake in the results. This is shown by the reaction of Les Hughes, who felt personally responsible for the failure of the Mariner 6 IRS cooling, but also felt proud of the flawless performance of the Mariner 7 IRS [Hughes pers. comm., Sep 1997]. Also the reaction of one of the IRS machinists, Paul Duffy, who rated seeing their instrument launched almost as high as holding his firstborn.

Such a small, low inertia group has the ability to respond more quickly. When presented with a problem, they had no layers of management to sift through. Combined with a dynamic,
innovative leadership, such a small group can work miracles, and they did. It is important not to
overlook the fact that this group brought IRS from the design of a new instrument concept to a
spectacularly successful flight in four years, with a cryogenically cooled flourish, and a produced
data set that is still in use after 30 years.

The bad side. The story also shows that two such disparate groups as JPL and Berkeley
require a liaison such as Brattain who understands the mentality of both the engineering and
academic world. His presence during the early stages of the project helped stabilize the JPL-
Berkeley relationship. However, Brattain left early in the program, and the loss of his
perspective proved unfortunate. It was followed by continual and distracting feuding between
JPL and Berkeley which both groups intensely disliked, but which neither made a dedicated
effort to resolve.

This led to several very serious problems. First, it caused JPL to mistrust the IRS group
more than was warranted, since in the end Berkeley produced an exceptional instrument. Their
mistrust led JPL to keep the IRS group on a short leash, which wasted the time and energy of
both groups. Second, it caused the IRS group to mistrust JPL more than was warranted, since
JPL did help the IRS group in engineering their instrument to meet the demands of space flight.
The amazing part of the story is that both groups attacked their engineering and science problems
with ferocity, innovation, and sometimes brilliance, yet neither seemed to recognize the
overriding importance of resolving the conflict.

Had there been another IRS flight, relations would likely have improved with time.
Raymond Heacock was the JPL Mariner Mars 1969 Representative, and he also dealt with many
other flights and investigators. He emphasized that investigators become easier to deal with after
repeated flights, because with time they realize JPL is there to help, not to interfere [Heacock
pers. comm., 11 Sep 1997]. Pimentel also later recognized the need for a better interface with
JPL, and wrote in a later proposal that Berkeley’s “more complete perspective of such a project”
would lead them to include a project manager “to mesh more comfortably with the JPL interface”
[Pimentel and Herr, 1972]. But by then it was too late: although they proposed for at least six
other flights, NASA never accepted another proposal from Pimentel’s group. The IRS crew
slowly broke up, until no one from Pimentel’s group remained in planetary exploration.
Acknowledgments
This story draws heavily from the memories of the people involved, and we thank Don Stone, Les Hughes, Dean Watson, Arthur Winer, John McAfee, Ray Heacock, John Casani, Hugh Kieffer, and Bruce Murray, who generously gave of their time to help complete the story. Thanks to the UC Bancroft Library for preserving the Pimentel collection and director Peter Hanff for considerable help accessing the collection; to the UC Berkeley Chemistry Department for faithfully storing the IRS data tapes for 25 years and then releasing them for this work; to Texaco for generously having the tapes read; to Oil Data Inc. and Ovation Data for not laughing too hysterically at Texaco’s request to read Mars data; and to Don Stone (The Aerospace Corporation) and Brian Fessler (LPI) for decoding the data. A special thanks to Allan Treiman and Scott Murchie for their faith in allowing a geophysics student to head off on such an odd tangent, and to LPI, Aerospace, and Texaco for funding this work.

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IRS in the large environmental test chamber.
Layout of IRS optical train
Internal layout of IRS, in same orientation as the previous optical print.
IRS on its mount for the large environmental test chamber
Ken Herr, IRS Co-I, shown with an IRS. The Joule-Thompson cryostat is visible as the tube in the near, upper part of IRS, and the telescope to the left, and the radiator fence is underneath.
Picture from the fake IRS handling document. It says in the background, "convert existing rooms into clean rooms!", and at the bottom, "Pig-Pen Project Manager." Pig-Pen was a rock singer, and he is "holding" an IRS, which was superposed onto the poster image.
All three builders of the only thermal infrared spectrometers ever sent to Mars, when they met in June 1999 at the Lunar and Planetary Institute. It is the first, and will perhaps be the only time, that all three have met:

Kenneth C. Herr (1969 Mariner Mars 6/7 Infrared Spectrometer, IRS)
Rudolf A. Hanel (1971 Mariner Mars 9 Infrared Interferometer Spectrometer, IRIS)
Philip R. Christensen (1997 Global Surveyor Thermal Emission Spectrometer, TES)

(this image is in color)