1978

The Biology Instrument for the Viking Mars Mission

Frederick S. Brown
Loyola Marymount University, fbrown@lmu.edu

H.E. Adelson
M.C. Chapman
O.W. Clausen
A.J. Cole

See next page for additional authors

Follow this and additional works at: https://digitalcommons.lmu.edu/systengg_fac

Part of the Systems Engineering Commons

Recommended Citation

This Article is brought to you for free and open access by the Systems Engineering at Digital Commons @ Loyola Marymount University and Loyola Law School. It has been accepted for inclusion in Systems Engineering Faculty Works by an authorized administrator of Digital Commons@Loyola Marymount University and Loyola Law School. For more information, please contact digitalcommons@lmu.edu.
The biology instrument for the Viking Mars mission


Applied Technology Division, TRW Defense and Space Systems Group, and One Space Park, Redondo Beach, California 90278

(Received 19 September 1977; in final form, 19 October 1977)

The United States has successfully sent two identical unmanned spacecraft, each consisting of a soft lander and an orbiter, to Mars in the 1975 launch opportunity. The project called Viking has placed both landers safely on the Martian surface. Each lander carries, along with several other scientific instruments, an instrument to search for living organisms in Martian surface material. This Viking biology instrument is the first device to be put on the surface of another planet to conduct life detection experiments.

The introduction

The project called Viking has placed both landers safely on the Martian surface. Each lander carries, along with several other scientific instruments, an instrument to search for living organisms in Martian surface material. This Viking biology instrument is the first device to be put on the surface of another planet to conduct life detection experiments.

The Viking biology instrument contains three separate biological experiments which analyze the Martian surface material for microorganisms by three different methods. These methods include the pyrolytic release experiment, the labeled release experiment, and the gas exchange experiment. The pyrolytic release experiment is designed to measure either photosynthetic or chemosynthetic fixation of carbon dioxide, or CO₂, into organic compounds. The labeled release experiment is designed to measure the fixation of carbon dioxide or carbon monoxide into organic matter. The gas exchange experiment is designed to measure the exchange of volatile carbon compounds from a radioactively labeled nutrient solution.

The instruments are called the pyrolytic release, labeled release, and gas exchange. The pyrolytic release experiment has the capability to measure the fixation of carbon dioxide or carbon monoxide into organic matter. The labeled release experiment detects metabolic processes by monitoring the production of volatile carbon compounds from a radioactively labeled nutrient mixture. The gas exchange experiment monitors the gas changes in the head space above a soil sample which is either incubated in a humid environment or supplied with a rich organic nutrient solution. Each experiment can analyze a soil sample as it is received from the surface or, as a control, analyze a soil which has been heated to above 160°C. Each instrument has the capability to receive four different soils dug from the Martian surface and perform a number of analysis cycles depending on the particular experiment. This paper describes in detail the design and operation of the three experiments and the supporting subsystems.

The 1960s saw a number of different experiments that were suggested for detection of extraterrestrial life based on various physical, chemical, and biological approaches. With the approval in 1969 of Viking as a landed Mars mission, the current three experiments along with a fourth, the light scattering experiment, were selected to be flown on a Viking mission in November 1969 by NASA after a review of proposals solicited from the scientific community at large. In addition to the scientists who developed these experiments, three additional scientists, not associated with one particular experiment, were also selected to form a science team. Table I presents the composition of the resulting Viking Biology Team. The fourth experiment, light scattering, was deleted from the instrument package midway through the development period after detailed engineering and planning studies indicated there was little chance that a four-experiment instrument could successfully be manufactured and launched.

The concepts for planetary life detection experiments have been seriously pursued and laboratory models of some of these concepts have been tested since the late 1950s and early 1960s. Throughout the 1960s several different experiments were suggested for detection of extraterrestrial life based on various physical, chemical, and biological approaches. With the approval in 1969 of Viking as a landed Mars mission, the current three experiments along with a fourth, the light scattering experiment, were selected to be flown on a Viking mission in November 1969 by NASA after a review of proposals solicited from the scientific community at large. In addition to the scientists who developed these experiments, three additional scientists, not associated with one particular experiment, were also selected to form a science team. Table I presents the composition of the resulting Viking Biology Team. The fourth experiment, light scattering, was deleted from the instrument package midway through the development period after detailed engineering and planning studies indicated there was little chance that a four-experiment instrument could successfully be manufactured and launched.

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

The biology instrument for the Viking Mars mission

Table I. NASA selected team for Viking active biology investigation.

<table>
<thead>
<tr>
<th>Name</th>
<th>Team Leader</th>
<th>Light Scattering</th>
<th>Porphyrin Release</th>
<th>Labeled Release</th>
<th>Gas Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. Klein</td>
<td>Team Leader (Ames)</td>
<td>Light Scattering</td>
<td>Porphyrin Release</td>
<td>Labeled Release</td>
<td>Gas Exchange</td>
</tr>
<tr>
<td>W. Vinograd (U. of Rochester, Ast.)</td>
<td>Team Leader</td>
<td>Light Scattering</td>
<td>Porphyrin Release</td>
<td>Labeled Release</td>
<td>Gas Exchange</td>
</tr>
<tr>
<td>H. Herweg (JPL, Cal Tech)</td>
<td>Team Leader</td>
<td>Light Scattering</td>
<td>Porphyrin Release</td>
<td>Labeled Release</td>
<td>Gas Exchange</td>
</tr>
<tr>
<td>G. Levin (Biospheres, Inc.)</td>
<td>Team Leader</td>
<td>Light Scattering</td>
<td>Porphyrin Release</td>
<td>Labeled Release</td>
<td>Gas Exchange</td>
</tr>
<tr>
<td>V. Oyama (Ames)</td>
<td>Team Leader</td>
<td>Light Scattering</td>
<td>Porphyrin Release</td>
<td>Labeled Release</td>
<td>Gas Exchange</td>
</tr>
<tr>
<td>A. Rich (MIT)</td>
<td>Team Leader</td>
<td>Light Scattering</td>
<td>Porphyrin Release</td>
<td>Labeled Release</td>
<td>Gas Exchange</td>
</tr>
<tr>
<td>J. Lederberg (Stanford)</td>
<td>Team Leader</td>
<td>Light Scattering</td>
<td>Porphyrin Release</td>
<td>Labeled Release</td>
<td>Gas Exchange</td>
</tr>
</tbody>
</table>

Prof. Vinograd died in an accident in 1973 while conducting Viking-related experiments in Antarctica.
tested within the temporal and fiscal constraints imposed by the mission.

Multiple experiments were chosen on the basis that no single life detection experiment would be adequate for the first landed mission to Mars. As a result, the experiments are based on different assumptions about the characteristics and function of any Martian biology. In general, the experiments range from incubation conditions which closely simulate those on Mars (the pyrolytic release experiment which adds no water and no nutrient compounds) through an intermediate environment (the labeled release experiment which moistens the soil with a nutrient of simple, dilute organic compounds in water) to rather earthlike conditions (the gas-exchange experiment which fits its wet mode partially to submerge the Martian soil in a rich and complex solution of salts and organic compounds). These experiments present a coordinated experimental system of environments for stimulating and measuring the manifestation of possible Martian soil organisms.

Development of the Viking biology instrument was begun in 1970 by TRW Systems, Redondo Beach, CA, under contract to Martin Marietta Corp., as the lander prime contractor, and continued for 3 years of design, fabrication, and test until delivery of the flight units in the spring of 1975. Three instruments (two flight instruments, and one spare) capable of conducting the landed mission and four test instruments were assembled. The two flight instruments are currently on the Martian surface and all three experiments in each instrument have operated successfully. Preliminary results from the biology experiment have been published and complete descriptions of the scientific data obtained on Mars will be the subject of subsequent papers.

II. INSTRUMENT SYSTEM DESCRIPTION

A single instrument of the complexity required to conduct the three active biology experiments has never before been assembled for space flight. The instrument's overall physical characteristics are given in Table II. The complexity of the instrument arises because of the large number of different functions which must be performed to conduct the biological analysis of the Martian surface material. Small amounts of soil are transported, tiny amounts of gases and liquids are metered, gas flows are controlled, 750°C temperatures are reached, and soil temperatures are held below those of the surrounding environment by thermoelectric cooling systems. Extremely lightweight and reusable test cells are used so that the minute quantities of gases in the incubation cells will not be lost. Two of the experiments utilize nuclear detector systems which detect picomole quantities of carbon-14 in the presence of a large radiation background from the radioisotope thermoelectric generators that power the Viking lander. A miniaturized gas chromatograph measures parts per million (ppm) concentrations of metabolic gases such as methane. Illumination simulating the spectrum, minus the ultraviolet, of the sun on Mars is provided by a miniaturized high-pressure xenon arc lamp. To conduct these operations the instrument contains 39 solenoid valves, 43 heaters, 4 thermoelectric coolers, 4 heat pipes and 3 types of thermal controllers, 4000 mechanical parts, and 1800 electronic parts. Because of the small passages and orifices (0.0076 cm) required by the small allowable physical size of the package, special steps were taken to prevent particle contamination or guard against its interference. The instrument was assembled under stringent "clean room" conditions and contains 11-μm pore-size filters to prevent particles from plugging critical flow restrictions.

The biology instrument resides along with other science instruments and electronic assemblies in the interior of the lander in a thermally controlled environment (−5°C to +27°C). All electric power is obtained from two radioisotope thermoelectric generators which have the capability of providing average power of about 300 W. Located directly above and mounted to the biology instrument is the soil sample processor and distributing assembly (SSPDA) (Fig. 1). This assembly protrudes upwards through the equipment mounting plate so that it can receive soil from the surface sample collector head. The collector head, mounted on the end of a 3.05-m furlable boom of the Viking lander (left photo of Fig. 1), has the capability of collecting material from a preselected site on the Martian surface. After collecting the sample, the boom retracts and deposits the soil sample in the top of the SSPDA. The soil is filtered through 1.5-mm screen at the top of the SSPDA to reduce the soil particle sizes to levels compatible with the biology instrument. A measured amount of soil, nominally 6 cm³, is then metered and delivered to the biology instrument.

The biology instrument's interfaces with the lander (as shown in Fig. 2) include the power control and distribution assembly which provides bus voltage to the instrument, the guidance and control and sequencing computer (GCSC) which provides clock signals and commands to the instrument, and the data acquisition and processing unit (DAPU) which, in turn, provides the data from the biology instrument for later transmission either to the orbiter or direct to earth. In addition to these electrical interfaces, the instrument is exposed to the Martian environment through the SSPDA. Waste gases and vapors are brought out of the lander through three gas and one vapor vent lines.

The three biology experiments have been integrated in one instrument sharing common support equipment. The biology instrument is packaged in two separate assemblies (Fig. 3), the mechanical subsystem (MSS) and the electrical subsystem (ESS), each of which is mounted directly to the lander equipment mounting plate. The MSS and ESS are connected by an electrical cable.

The ESS receives commands from the GCSC, uses those commands to control the individual experiments, and receives and processes the data for transmission to the data acquisition and processing unit. The control functions performed by the ESS involve timing and operating of all solenoid valves, nine proportionally controlled heaters, five electronic thermostats, and

---

### Table II. Biology instrument physical characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Volume</th>
<th>Power consumption</th>
<th>Data handling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>15.5 kg</td>
<td>0.027 m³</td>
<td>12 W</td>
<td>10,000 bits/sol</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td></td>
<td>180 W</td>
<td></td>
</tr>
<tr>
<td>Data generation</td>
<td></td>
<td></td>
<td>10,000 bits/sol</td>
<td></td>
</tr>
<tr>
<td>Capacity for surface samples</td>
<td>60,000 bits/sol</td>
<td>4 surface acquisitions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
tested within the temporal and fiscal constraints imposed by the mission.

Multiple experiments were chosen on the basis that no single life detection experiment would be adequate for the first landed mission to Mars. As a result, the experiments are based on different assumptions about the characteristics and function of any Martian biology. In general, the experiments range from incubation conditions which closely simulate those on Mars (the pyrolytic release experiment which misses the soil with a nutrient of simple, dilute organic compounds in water), to rather earthlike conditions (the gas-exchange experiment which in its wet mode partially submerges the Martian soil in a rich and complex solution of salts and organic compounds). These experiments present a coordinated experimental system of environments for stimulating and measuring the manifestation of possible Martian soil organisms.

Development of the Viking biology instrument was begun in 1970 by TRW Systems, Redondo Beach, CA, under contract to Martin Marietta Corp., as the lander prime contractor, and continued for 3 years of design, fabrication, and test until delivery of the flight units in the spring of 1975. Three instruments (two flight instruments, and one spare) capable of conducting the landed mission and four test instruments were assembled. The two flight instruments are currently on the Martian surface and all three experiments in each instrument have operated successfully. Preliminary results from the biology experiment have been published and complete descriptions of the scientific data obtained on Mars will be the subject of subsequent papers.

II. INSTRUMENT SYSTEM DESCRIPTION

A single instrument of the complexity required to conduct the three active biology experiments has never before been assembled for space flight. The instrument's overall physical characteristics are given in Table II. The complexity of the instrument arises because of the large number of different functions which must be performed to conduct the biological analysis of the Martian surface material. Small amounts of soil are transported, tiny amounts of gases and liquids are metered, gas flows are controlled, 750°C temperatures are reached, and soil temperatures are held below those of the surrounding environment by thermoelectric cooling systems. Extremely lightweight and resealable test cells are used so that the minute quantities of gases in the incubation cells will not be lost. Two of the experiments utilize nuclear detector systems which detect picomole quantities of carbon-14 in the presence of a large radiation background from the radioactive decay of the soil sample. The radioisotope thermoelectric generators that power the Viking lander. A miniaturized gas chromatograph measures parts per million (ppm) concentrations of metabolic gases such as methane. Illumination simulating the spectrum, minus the ultraviolet, of the sun on Mars is provided by a miniaturized high-pressure xenon arc lamp. To conduct these operations the instrument contains 39 solenoid valves, 43 heaters, 4 thermoelectric coolers, 4 heat pipes and 3 types of thermal controllers, 4000 mechanical parts, and 1800 electronic parts. Because of the small passages and orifices (0.0076 cm) required by the small allowable physical size of the package, special steps were taken to prevent particle contamination or guard against its interference. The instrument was assembled under stringent "clean room" conditions and contains 11-μm pore-size filters to prevent particles from plugging critical flow resistors.

The biology instrument resides along with other science instruments and electronic assemblies in the interior of the lander in a thermally controlled environment (−5 °C to +27 °C). All electric power is obtained from two radioisotope thermoelectric generators which have the capability of providing average power of about 30 W-

Located directly above and mounted to the biology instrument is the soil sample processor and distribution assembly (SSPDA) (tall, vertical column in right photo of Fig. 1). This assembly protrudes upwards through the equipment mounting plate so that it can receive soil from the surface sample collector head. The collector head, mounted on the end of a 3.05-m furlable boom of the Viking lander (left photo of Fig. 1), has the capability of collecting material from a preselected site on the Martian surface. After collecting the sample, the boom retracts and deposits the soil sample in the top of the SSPDA. The soil is filtered through 1.5-mm screens at the top of the SSPDA to reduce the soil particle sizes to levels compatible with the biology instrument. A measured amount of soil, nominally 6 cm³, is then metered and delivered to the biology instrument.

The biology instrument's interfaces with the lander (as shown in Fig. 2) include the power control and distribution assembly which provides bus voltage to the instrument, the guidance and control and sequencing computer (GCSC) which provides clock signals and commands to the instrument, and the data acquisition and processor assembly which provides the data from the biology instrument for later transmission either to the orbiter or direct to earth. In addition to these electrical interfaces, the instrument is exposed to the Martian environment through the SSPDA. Waste gases and vapors are brought out of the lander through three gas and one vapor vent lines.

The three biology experiments have been integrated in one instrument sharing common support equipment. The biology instrument is packaged in two separate assemblies (Fig. 3), the mechanical subsystem (MSS) and the electrical subsystem (ESS), each of which is mounted directly to the lander equipment mounting plate. The MSS and ESS are connected by an electrical cable.

The ESS receives commands from the GCSC, uses those commands to control the individual experiments, and receives and processes the data for transmission to the data acquisition and processing unit. The control functions performed by the ESS involve timing and operating of all solenoid valves, nine proportionally controlled heaters, five electronic thermostats, and

<table>
<thead>
<tr>
<th>II. Biology instrument physical characteristics.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight</strong></td>
</tr>
<tr>
<td><strong>Volume</strong></td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
</tr>
<tr>
<td><strong>Data acquisition</strong></td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
</tr>
<tr>
<td><strong>Capacity for surface samples</strong></td>
</tr>
</tbody>
</table>
The MSS also contains a soil distribution assembly (SDA) and the PR illumination assembly to form the MSS. Each of the modules is assembled and tested as a separate entity prior to integration into the lander.

The SDA is used to transport the soil sample to the head end of the chamber. The soil is obtained from the SDA and rotated to the incubation head end. The chamber is sealed and a CO\(_2\)/CO\(_2\) gas mixture is injected into the cell. An option exists to add a minute amount of water vapor to the chamber at this time. The lamp is turned on and the system allowed to incubate for 5 days. Organisms may assimilate carbon from the radioactive C and therefore become radioactive. After the incubation period, the incubation atmosphere is vented and the cell rotated to the pyrolysis head end. There the soil sample, which has been pyrolyzed by raising its temperature to 625°C, and the vaporized organics trapped in an organic vapor trap. These organics are then converted to CO\(_2\) by an "effluent to carrier gas" pump and counted by the separate nuclear detection system. The data are stored in the ESS and later transmitted to earth for analysis.

The MSS also contains a soil distribution assembly (SDA). The SDA receives 6 cm\(^3\) of soil from the soil sampler processor and distribution assembly. At the start of the experiment cycle, soil distribution is made to the three GEx, one of the entire lander with the biology instrument; two are placed upon it several unusual requirements. One of the requirements was satisfied by a double dry heat sterilization, one of the instrument alone, and then one of the entire lander with the biology instrument installed. The sterilization prior to installation into the Viking lander is unique to the biology instrument (as compared to the other lander instruments), because the biology instrument provides an environment where viable microorganisms are encouraged to metabolize and reproduce. Under these circumstances Earth microorganisms could be indistinguishable from Martian organisms that are present.

In the preinstallation sterilization, the instrument was heated to 120°C for 5 h in a dry nitrogen atmosphere. This heating of the instrument sterilizes the carbon from the radioactive C and therefore becomes radioactive. After the incubation period, the incubation atmosphere is vented and the cell rotated to the pyrolysis head end. There the soil sample, which has been pyrolyzed by raising its temperature to 625°C, and the vaporized organics trapped in an organic vapor trap. These organics are then converted to CO\(_2\) by an "effluent to carrier gas" pump and counted by the separate nuclear detection system. The data are stored in the ESS and later transmitted to earth for analysis.

After installation of the biology instrument in the Viking lander, handling precautions were taken to minimize any possible contamination of the hardware. After installation on the lander, the entire lander was encapsulated in a "bioshield" which was not opened until after launch and the spacecraft had left the Earth's atmosphere. While in the bioshield, the lander and biology instrument were heated to 120°C for 26 h in a dry nitrogen atmosphere at 1 bar. From the time of this sterilization onward, the biology instrument was protected by the bioshield except for inevitable leaks. The bioshield was designed to prevent Martian CO\(_2\) from contaminating the heliometer. Because of an automatic reset feature, the initial application of power automatically decontaminated the lander and biology instrument by dry heat.

Because the goal of the biology instrument is to detect indigenous life on Mars, there are two reasons for the sterilization of the instrument and the lander to significantly lower the biological contamination contained therein: (1) reduce the probability of the biology instrument detecting Martian CO\(_2\) when this instrument is not the case of temperature measurements, they are reduced and commands directing blocks of these activities to occur at appropriate times during the experiment cycle.

The MSS (Fig. 3) is designed as a modular concept. The three experiment modules, gas exchange (GE), labeled release (LR), and pyrolytic release (PR), are integrated with the common services module (CSM), the nuclear detection system, the soil distribution assembl (SDA), and the PR illumination assembly to form the MSS. Each of the modules is assembled and tested as a separate entity prior to integration into the lander.

The GEx is designed to incubate a soil sample in the presence of a rich nutrient. This experiment contains a soil delivery mode: one so sample and one soil dump cell mounted on a carousel permitting the use of anyone of the entire lander with the biology instrument; two are placed upon it several unusual requirements. One of the requirements was satisfied by a double dry heat sterilization, one of the instrument alone, and then one of the entire lander with the biology instrument installed. The sterilization prior to installation into the Viking lander is unique to the biology instrument (as compared to the other lander instruments), because the biology instrument provides an environment where viable microorganisms are encouraged to metabolize and reproduce. Under these circumstances Earth microorganisms could be indistinguishable from Martian organisms that are present.

In the preinstallation sterilization, the instrument was heated to 120°C for 5 h in a dry nitrogen atmosphere. This heating of the instrument sterilizes the carbon from the radioactive C and therefore becomes radioactive. After the incubation period, the incubation atmosphere is vented and the cell rotated to the pyrolysis head end. There the soil sample, which has been pyrolyzed by raising its temperature to 625°C, and the vaporized organics trapped in an organic vapor trap. These organics are then converted to CO\(_2\) by an "effluent to carrier gas" pump and counted by the separate nuclear detection system. The data are stored in the ESS and later transmitted to earth for analysis.

After installation of the biology instrument in the Viking lander, handling precautions were taken to minimize any possible contamination of the hardware. After installation on the lander, the entire lander was encapsulated in a "bioshield" which was not opened until after launch and the spacecraft had left the Earth's atmosphere. While in the bioshield, the lander and biology instrument were heated to 120°C for 26 h in a dry nitrogen atmosphere at 1 bar. From the time of this sterilization onward, the biology instrument was protected by the bioshield except for inevitable leaks. The bioshield was designed to prevent Martian CO\(_2\) from contaminating the heliometer. Because of an automatic reset feature, the initial application of power automatically decontaminated the lander and biology instrument by dry heat.

Because the goal of the biology instrument is to detect indigenous life on Mars, there are two reasons for the sterilization of the instrument and the lander to significantly lower the biological contamination contained therein: (1) reduce the probability of the biology instrument detecting Martian CO\(_2\) when this instrument is not the case of temperature measurements, they are reduced and commands directing blocks of these activities to occur at appropriate times during the experiment cycle.

The MSS (Fig. 3) is designed as a modular concept. The three experiment modules, gas exchange (GE), labeled release (LR), and pyrolytic release (PR), are integrated with the common services module (CSM), the nuclear detection system, the soil distribution assembl (SDA), and the PR illumination assembly to form the MSS. Each of the modules is assembled and tested as a separate entity prior to integration into the lander.

The GEx is designed to incubate a soil sample in the presence of a rich nutrient. This experiment contains a soil delivery mode: one so sample and one soil dump cell mounted on a carousel permitting the use of anyone of the entire lander with the biology instrument; two are placed upon it several unusual requirements. One of the requirements was satisfied by a double dry heat sterilization, one of the instrument alone, and then one of the entire lander with the biology instrument installed. The sterilization prior to installation into the Viking lander is unique to the biology instrument (as compared to the other lander instruments), because the biology instrument provides an environment where viable microorganisms are encouraged to metabolize and reproduce. Under these circumstances Earth microorganisms could be indistinguishable from Martian organisms that are present.

In the preinstallation sterilization, the instrument was heated to 120°C for 5 h in a dry nitrogen atmosphere. This heating of the instrument sterilizes the carbon from the radioactive C and therefore becomes radioactive. After the incubation period, the incubation atmosphere is vented and the cell rotated to the pyrolysis head end. There the soil sample, which has been pyrolyzed by raising its temperature to 625°C, and the vaporized organics trapped in an organic vapor trap. These organics are then converted to CO\(_2\) by an "effluent to carrier gas" pump and counted by the separate nuclear detection system. The data are stored in the ESS and later transmitted to earth for analysis.

After installation of the biology instrument in the Viking lander, handling precautions were taken to minimize any possible contamination of the hardware. After installation on the lander, the entire lander was encapsulated in a "bioshield" which was not opened until after launch and the spacecraft had left the Earth's atmosphere. While in the bioshield, the lander and biology instrument were heated to 120°C for 26 h in a dry nitrogen atmosphere at 1 bar. From the time of this sterilization onward, the biology instrument was protected by the bioshield except for inevitable leaks. The bioshield was designed to prevent Martian CO\(_2\) from contaminating the heliometer. Because of an automatic reset feature, the initial application of power automatically decontaminated the lander and biology instrument by dry heat.
power switching for eight mechanical thermostats in the MSS. The ESS receives the individual experiment sensor outputs and temperature outputs and processes those outputs for storage. If the data are analog, as is the case with peristaltic measurement in the gas sample, they are amplified, commutated, and processed with a dual slope analog-to-digital converter, identified, and then stored in a high-density magnetic memory. Digital data such as the °C outputs and commands are identified and stored in the memory. The sequence control of the MSS is provided with three read only memory (ROM) sequencers which perform timing and control functions as directed by the commands from the GCSC. The individual sequence functions of the instrument are stored in a single sequence function memory. The GCSC commands directing blocks of these activities to occur at appropriate times during the experiment cycle.

The MSS (Fig. 3) is designed as a modular concept. The three experiment modules, gas exchange (GE), labeled release (LR), and pyrolytic release (PR) are integrated with the common services module (CSM), the nuclear detection system, the soil distribution assembly (SDA), and the PR illumination assembly to form the MSS. Each of the modules is assembled and tested as a separate entity prior to integration into the MSS assembly.

The GE module is designed to incubate a soil sample in the presence of a rich nutrient. This experiment contains a single test cell and three soil dump cells mounted on a carousel. In addition, simulated Martian sunlight is provided by a xenon lamp. A sample of soil is received from the SDA and rotated to the incubation head end. The chamber is sealed and a CO2 gas mixture is injected into the cell. An option exists to add a minute amount of water vapor to the chamber at this time. The lamp is turned on and the system allowed to incubate for 5 days. Organisms may assimilate carbon from the radioactive gas and therefore become radioactively labeled. After the incubation period, the incubation atmosphere is vented and the cell rotated to the pyrolysis head end. There the soil sample, which has been radioactively labeled, is pyrolyzed by raising its temperature to 625 °C, and the pyrolyzed organics trapped in an organic vapor trap. These organics are then converted to CO2 by an "effluent" heating of the trap and counted by the separate clear detection system for the duration of incubation.

The LR experiment is designed to trap any organics in a charcoal filter, and expels the gas to the atmosphere established. A small quantity of aqueous nutrient solution is added to the soil, and an oxic incubation of the soil is started. After 200 days of incubation on Viking Lander [1], this experiment provides an environment where viable microorganisms are encouraged to metabolize and reproduce. Under these circumstances Earth microorganisms could be indistinguishable from Martian organisms that exist.

In the preinstallation sterilization, the instrument was heated to 120°C for 54 h in a dry nitrogen atmosphere. This experiment provides an environment where viable microorganisms are encouraged to metabolize and reproduce. Under these circumstances Earth microorganisms could be indistinguishable from Martian organisms that exist.

During installation of the biology instrument in the Viking lander, handling precautions were taken to minimize any possible contamination of the hardware. After installation on the lander, the entire lander was encapsulated in a "bioshield" which was not opened until after launch and the spacecraft had left the Earth's atmosphere. The bioshield, the lander and the biology instrument were heated to 12°C for 26 h in a dry nitrogen atmosphere at 1 bar. From the time of this sterilization onward, the biology instrument was protected by the shield which also contained the experiment cellNever again exposed to the airborne microflora of the earth's atmosphere.

The results from the two biology instruments on Mars are consistent with insufficient viable Earth organisms to contaminate the biology experiments. The gas exchange experiment which is most earthlike in its incubation conditions has shown no evidence of gas exchange from the soil samples over the equivalent of much as 200 days of incubation on Viking Lander 1 [1]. This experiment provides an environment of 10^-12°C, a 2 x 10^-3 saturation ratio, a nutrient rich in amino acids, carbohydrates and salts, and pressure averaging about 200-600 mbars. Under these conditions Earth microorganisms would be expected to metabolize and reproduce. The lack of detectable evidence supports there being very few, if any, viable Earth microbes contaminating the biology instrument.

IV. PREPARATIONS FOR SURFACE OPERATIONS

After launch and during the voyage to Mars, the biology instrument was basically dormant. The only active elements are two mechanical thermostatically controlled thermostats which maintain the LR and GE standard gas temperatures, each contained in a sealed glass ampoule, above freezing.

During this phase of the mission all solidoloid valves are open except for two valves on the vents. The stored helium is retained in a hermetically sealed container, as are the 14C/12C, CO2/CO, LR and GE experiments. The container containing LR is connected to the Martian atmosphere by a xenon lamp. A small sample of soil is re­

## Figure 3 (Viking biology instrument)

The Viking biology instrument is designed to incubate a Martian soil sample in the presence of a radioactive labeled (a)CO2 atmosphere. This experiment contains one test cell and three soil dump cells mounted on a carousel. In addition, simulated Martian sunlight is provided by a xenon lamp. A sample of soil is received from the SDA and rotated to the incubation head end. As in the presence of a radioactively labeled (14C) carbon nutrients which might serve as substrates for indigenous life on Mars, there are two reasons for soil sterilization. The first reason is to significantly lower the biological contamination contained therein: (1) reduce the probability of the biology instrument becoming contaminated, and (2) reduce the probability of the Viking mission contaminating Mars with Earth organisms to less than one in ten thousand.

While the rationale for these requirements is obvious, the responsibility to assure that any detected life responses are from Martian and not Earth organisms is overwhelming.

These requirements were satisfied by a double dry heat sterilization, one of the instrument alone, and then one of the entire lander with the biology instrument installed. The sterilization prior to installation into the Viking lander is unique to the biology instrument (as compared to the other lander instruments), because the biology instrument provides an environment where viable microorganisms are encouraged to metabolize and reproduce. Under these circumstances Earth microorganisms could be indistinguishable from Martian organisms that exist.

In the preinstallation sterilization, the instrument was heated to 120°C for 54 h in a dry nitrogen atmosphere. This experiment provides an environment where viable microorganisms are encouraged to metabolize and reproduce. Under these circumstances Earth microorganisms could be indistinguishable from Martian organisms that exist.

During installation of the biology instrument in the Viking lander, handling precautions were taken to minimize any possible contamination of the hardware. After installation on the lander, the entire lander was encapsulated in a "bioshield" which was not opened until after launch and the spacecraft had left the Earth's atmosphere. The bioshield, the lander and the biology instrument were heated to 12°C for 26 h in a dry nitrogen atmosphere at 1 bar. From the time of this sterilization onward, the biology instrument was protected by the shield which also contained the experiment cellNever again exposed to the airborne microflora of the earth's atmosphere.

The results from the two biology instruments on Mars are consistent with insufficient viable Earth organisms to contaminate the biology experiments. The gas exchange experiment which is most earthlike in its incubation conditions has shown no evidence of gas exchange from the soil samples over the equivalent of much as 200 days of incubation on Viking Lander 1 [1]. This experiment provides an environment of 10^-12°C, a 2 x 10^-3 saturation ratio, a nutrient rich in amino acids, carbohydrates and salts, and pressure averaging about 200-600 mbars. Under these conditions Earth microorganisms would be expected to metabolize and reproduce. The lack of detectable evidence supports there being very few, if any, viable Earth microbes contaminating the biology instrument.
The sequence of operations starts with the application of a command to the instrument. This operation automatically closes all instrument solenoid valves, opens the valves on the vent lines, and powers the instrument to allows for 100 min to allow the instrument to stabilize thermally. A. Labeled release experiment concept

1. Nutrient supply and injection system

The nutrient supply and injection system is designed to deliver the nutrient to the soil. The nutrient is delivered to the soil in a reproducible manner by a series of bleeds and injections. After each injection, the nutrient is allowed to soak into the soil for a specified period of time. The nutrient is delivered to the soil through a series of bleeds and injections, with each injection being 0.12 cm$^3$ of nutrient. The nutrient is delivered to the soil at a rate of 1.7 cm$^3$ per injection.

2. Test cell system

The test cell is a stainless steel cylinder of 3.25-cm$^3$ volume with a rotating slider. The nutrient is delivered to the soil through a series of bleeds and injections. After each injection, the nutrient is allowed to soak into the soil for a specified period of time. The nutrient is delivered to the soil through a series of bleeds and injections, with each injection being 0.12 cm$^3$ of nutrient. The nutrient is delivered to the soil at a rate of 1.7 cm$^3$ per injection.

3. Test cell assembly

The test cell assembly is designed to deliver the nutrient to the soil. The nutrient is delivered to the soil through a series of bleeds and injections. After each injection, the nutrient is allowed to soak into the soil for a specified period of time. The nutrient is delivered to the soil through a series of bleeds and injections, with each injection being 0.12 cm$^3$ of nutrient. The nutrient is delivered to the soil at a rate of 1.7 cm$^3$ per injection.
The sequence of operations starts with the application of the sample to the instrument. The operation automatically closes all instrument solenoid valves, opens the valves on the vent lines, and powers the instrument and heaters. Since this operation may have been quite cold, all valve operations which would involve pressure are delayed for 100 min to allow the instrument to stabilize thermally before any automatic operation is attempted. At this time, one drive operation of the instrument's motors to their initial positions in preparation for actual cell rotations or soil distribution operations is performed.

The following operations involve the accessing of the instrument's stored gases and the GEx column rejuvenation sequence. A command is given to the instrument to operate the thermal isolation valves (TIVs), which seal the GCS, etc. These valves are one-shot devices that contain oil sealed in a bellows which drives a plunger as heat is applied. When commanded, the heaters come on, expand the oil and drive a plunger through a stainless steel disc that seals the stored gases from the usage areas.

Gas rejuvenation of the GEx chromatographic column packing material is accomplished by flowing carbon dioxide and oxygen in helium through the columns. The devices that contain oil sealed in a bellows which drives a plunger as heat is applied when commanded, the heaters come on, expand the oil and drive a plunger through a stainless steel disc that seals the stored gases from the usage areas.

FIG. 4. Exploded view of the labeled release experiment module assembly. For clarity the liquid and gas lines which purge the test cell and supply the nutrient are not shown.

During the experiments and as dumps for excess soil thereafter, the cells are set on a Geneva wheel mechanism that is lowered to permit cell rotation and raised to the cells against the head end.

A dual channel solid state beta radiation detector (described in Sec. VIII C) measures the carbon-14 gases in the space above the soil. A complex of heaters is used to sterilize the soil, as required, prevent water condensation, and heat the beta detector to remove adsorbed carbon-14 material at experiment completion.

The experiment operations are listed in Table III. The experiment operation in terms of the functions of the components is described below.

V. LABELED RELEASE EXPERIMENT

A. Labeled release experiment concept

The labeled release (LR) experiment detects biological activity in a soil by measuring the evolution of gaseous products from simple organic compounds by microbial activity. The terrestrial organisms metabolize carbon-based nutrients to gaseous products such as CO₂ and CH₄. In the LR experiment a soil experiment is used which is prepared from compounds containing radioactive carbon (¹⁴C). The organisms in the soil can then assimilate the compounds and give off carbon gases. The radioactive gases will be radioactive and so can be detected. The gases are measured in a detector sensitive to ¹⁴C beta radiation from the metabolized labeled gasses.

For the Viking biology instrument the LR experiment uses a small volume of nutrient compared to the soil volume (1:5 ratio). The rationale for not completely wetting the soil is to provide a moist environment (versus the arid environment which is simulated, and the gas exchange experiment, which is primarily very wet) and create a moisture gradient in the soil to allow the metabolized ¹⁴C carbon to diffuse through the soil (from the lines to assure the bulk composition being injected is that of the ampoule). Thus, for an active cycle of 6 bleeds and two injections, the maximum usage is 1.7 cm³.

Adding nutrient to the soil in the test cell is accomplished by filling a closed cavity, under a pressure of 45 cm of water, with nutrient (1.7 cm³) and then opening it to the lower pressure test cell through a line terminating in a nozzle directly above the soil sample. In order to prevent boiling of the nutrient upon injection in the test cell, the pressure above the soil, it is necessary to admit helium to the test cell to raise the total pressure above the vapor pressure of the nutrient (≈45 cm of water) and thus bring the pressure in the cell to 60-70 mbars versus the water vapor pressure of 12.3 mbars at 10°C.

B. LR experiment implementation

Figure 4 is an exploded view of the LR module. The essential parts of the experiment are described below.

1. Nutrient supply and injection system

The nutrient supply function has the capability of transporting the nutrient from Earth to Mars in a sterilized manner. Once on the Martian surface the nutrient must be delivered to the soil in a reproducible manner while maintaining sterility.

The nutrient formulation (Table IV) was determined by G. Levin and was supplied to TRW by Biospherics, Inc. (Rockville, MD) as a deaerated solution in 25-cm³ vials.

About 6.5 cm³ of nutrient is required to perform four complete LR experiments on each instrument. To allow an excess, about 8 cm³ of nutrient was placed in a Pyrex glass ampoule (Fig. 6) for each instrument. Ampoules were filled by the following procedure designed to minimize the possibility of microbial contamination. The empty ampoules were cleaned with filtered isopropanol followed by distilled water to insure no toxic material was present. Then wrapped in aluminum foil and sterilized by autoclaving for 15 min. The ampoules were then filled with the carbon-14 labeled nutrient in a special apparatus which was assembled from autoclaved components in a laminar flow bench (class 100). The filling apparatus allows the nutrient to be placed in the ampoule under an atmosphere of helium to keep it from being exposed to a 0.6-μm membrane filter. The filled ampoule is sealed at 134 mbars total pressure by melting the glass fill tube. Confirmation that the ampoule and its fill-port seal are leak free is made by testing for helium leakage from the ampoule under vacuum. The sealed ampoule and nutrient are sterilized in aluminum foil by heating to 175°C for 45 min.

Approximately 7 cm³ of the total 8 cm³ nutrient in the ampoule is available for injection; there is a loss of about 1.0-1.5 cm³ from retention in the reservoir and lines and from nutrient degassing. The volume of nutrient delivered per injection is determined to be 0.12 cm³ maximum for a bleed discarding sufficient nutrient from the lines to assure the bulk composition being injected is that of the ampoule. Thus, for an active cycle of six bleeds and two injections, the maximum usage is 1.7 cm³.
contains the nutrient injection port, an opening to the tube connecting the detector and cell, and an opening to a vent valve S-52. The test cell itself has no heaters or temperature sensing equipment attached. Measurement of cell temperature and cell heating is provided by sensors and heaters in the head end.

Table II. Summary of the primary operations of the labeled release experiment.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ampoule breakage</td>
<td>At initialization</td>
</tr>
<tr>
<td>2. Nutrient degassing</td>
<td>At initialization</td>
</tr>
<tr>
<td>3. Soil loaded to cell</td>
<td>Start of each experiment cycle</td>
</tr>
</tbody>
</table>
| 4. Nutrient in ampoule      | Ampoule is punctured at the top and bottom by pistons which pierce break-disks set in reinforced glass rings at each end of the ampoule. The pistons are driven by 9.2-bar helium which, when valve S-46 (Fig. 5) from the high-pressure helium regulator is opened. This lower piston is equipped with a flow path that allows nutrient to flow from the reservoir to a nutrient line that connects the reservoir to valve S-59 at the head end assembly. Following the puncture of the ampoule, the high-pressure helium serves to drive the nutrient from the reservoir to the head end. The initial helium is vented off the detector or detector line. Above 15°C environment the detector assumes ambient temperature. The detector is not controlled by the thermoelectric coolers and its temperature can rise above 27°C. The detectors have been tested at the component level and found to be essentially noise free up to 50°C allowing them to operate satisfactorily without cooling. The soil in a control experiment must be heat sterilized to destroy any organisms initially present in the soil. The sterilization method was heating at 160°C or greater for 3 h. The LR cell heater is located at the head end flange and serves to heat the head end and the test cell through the flange coupling. Experimental data show that heating the head end flange to about 190°C results in a nominal heating at the test cell bottom of 160°C. The LR head end is also heated to maintain the sterility of head end parts. In this case the head end flange heater is used as the main heating element. The LR detectors are heated during the sterilization cycle to prevent condensation of any outgassed material on the detector. Heaters on the detector mounting plate raise the detector body temperature to 110°C.

C. LR experimental operation

During the initial sequence conducted after landing on Mars, one of the first operations to be performed in the LR experiment is breakage of the nutrient ampoule. The ampoule is punctured at the top and bottom by pistons which pierce break-disks set in reinforced glass rings at each end of the ampoule. The pistons are driven by 9.2-bar helium which, when valve S-46 (Fig. 5) from the high-pressure helium regulator is opened. This lower piston is equipped with a flow path that allows nutrient to flow from the reservoir to a nutrient line that connects the reservoir to valve S-59 at the head end assembly. Following the puncture of the ampoule, the high-pressure helium serves to drive the nutrient from the reservoir to the head end. The initial helium is vented off the detector or detector line. Above 15°C environment the detector assumes ambient temperature. The detector is not controlled by the thermoelectric coolers and its temperature can rise above 27°C. The detectors have been tested at the component level and found to be essentially noise free up to 50°C allowing them to operate satisfactorily without cooling. The soil in a control experiment must be heat sterilized to destroy any organisms initially present in the soil. The sterilization method was heating at 160°C or greater for 3 h. The LR cell heater is located at the head end flange and serves to heat the head end and the test cell through the flange coupling. Experimental data show that heating the head end flange to about 190°C results in a nominal heating at the test cell bottom of 160°C. The LR head end is also heated to maintain the sterility of head end parts. In this case the head end flange heater is used as the main heating element. The LR detectors are heated during the sterilization cycle to prevent condensation of any outgassed material on the detector. Heaters on the detector mounting plate raise the detector body temperature to 110°C.

The central section of the LR module properly is heated by the module enclosure heaters. These are 9.2 heater modules that maintain the test cell temperature at a minimum operating temperature of 8°C to 10°C. These heaters also serve to maintain the temperatures of lines and the nutrient in the reservoir. At temperatures above 15°C the thermometer coolers are activated that maintain the cell temperature below 25°C.

The beta detector is equipped with a heater that cycles on and off at 15°C and off at 19°C, thus maintaining the detector temperature at a level above that of the cell. This temperature differential is important to guarantee that water will not be condensed (changing the effective dissolved nutrient concentration at the cell in the detector or detector line. Above 15°C environment the detector assumes ambient temperature. The detector is not controlled by the thermoelectric coolers and its temperature can rise above 27°C. The detectors have been tested at the component level and found to be essentially noise free up to 50°C allowing them to operate satisfactorily without cooling. The soil in a control experiment must be heat sterilized to destroy any organisms initially present in the soil. The sterilization method was heating at 160°C or greater for 3 h. The LR cell heater is located at the head end flange and serves to heat the head end and the test cell through the flange coupling. Experimental data show that heating the head end flange to about 190°C results in a nominal heating at the test cell bottom of 160°C. The LR head end is also heated to maintain the sterility of head end parts. In this case the head end flange heater is used as the main heating element. The LR detectors are heated during the sterilization cycle to prevent condensation of any outgassed material on the detector. Heaters on the detector mounting plate raise the detector body temperature to 110°C.
contains the nutrient injection port, an opening to the detector assembly consists of a 46-cm length of 0.64-cm stainless tubing connecting the head end to the detectors, the detectors consisting of two silicon diffusion-junction semiconductor elements positioned to monitor the trapped volume of 2.4 cm³ between them and associated electronics.

In any experiment the gases evolved as a result of the nutrient being dropped into the soil diffuse from the test cell down the 46-cm tube to the detector. The time for diffusion to establish 95% of equilibrium was determined to be 15 min.

The actual gases sampled by the detector chips are those in the 2.4-cm³ volume between the detectors. The total volume of the cell plus tubing and detector was 8.95 cm³, of which 8.60 cm³ was head space when 0.5 cm³ of soil was added with 50% solid volume. The detector counting efficiency is 10.9% for the gas directly in the detector volume. These combined to give an overall system efficiency of 3% for detection of carbon-14 over the entire head space.

The output of the two detector elements is normally summed electronically, and the total output accumulated by a register. However, if one detector fails, the data from the other detector can be accumulated separately.

4. Module thermal control

The central section of the LR module proper is heated by the module enclosure heaters. These are 9-W heaters that maintain the test cell temperature at its minimum operating temperature of 8°-10°C. These heaters also serve to maintain the temperatures of lines and the nutrient in the reservoir. At temperatures above 15°C thermoelectric coolers are activated that maintain the cell temperature below 25°C.

The beta detector is equipped with a heater that cycles on at 15°C and off at 19°C, thus maintaining the detector temperature at a level above that of the cell. This temperature differential is important to guarantee that water will not be condensed (changing the effective dissolved nutrient concentration at the soil in the detector or detector line. Above 15°C environment the detector assumes ambient temperature.

The detector is not controlled by the thermoelectric coolers and its temperature can rise above 27°C. The detectors have been tested at the component level and found to be essentially noise free up to 50°C allowing them to operate satisfactorily without cooling.

The soil in a control experiment must be heat sterilized to destroy any organisms initially present in the soil. The sterilization method was heating at 160°C or greater for 3 h. The LR cell heater is located at the head end flange and serves to heat the head end and the test cell through the flange coupling. Experimental data show that heating the head end flange to about 190°C results in a nominal heating at the test cell bottom of 160°C. The LR head end is also heated to maintain the sterility of head end parts. In this case the head end flange heater is used as the main heating element.

The LR detectors are heated during the sterilization cycle to prevent condensation of any outgassed material on the detector. Heaters on the detector mounting plate raise the detector body temperature to 110°C.

C. LR experimental operation

During the initial sequence conducted after landing on Mars, one of the first operations to be performed in the LR experiment is breakage of the nutrient ampoule. The ampoule is punctured at the top and bottom by pistons which pierce break-disks set in reinforced glass rings at each end of the ampoule. The pistons are driven by 9.2-bar helium when valve S-46 (Fig. 5) from the high-pressure helium regulator is opened. This lower piston is equipped with a flow path that allows nutrient to flow from the reservoir to a nutrient line that connects the reservoir to valve S-59 at the head end assembly.

Following the puncture of the ampoule, the high-pressure helium serves to drive the nutrient from the reservoir to the head end. The initial helium is vented from the reservoir during the nutrient degassing (see below). Each time an injection of nutrient is required, S-46 is opened and the reservoir pressurized. Following the initial pressurization the 9.2-bar helium remains above the nutrient (Fig. 5). While injection of nutrient does not significantly deplete the helium pressure, the reservoir is repressurized prior to each injection sequence as a safeguard against possible leakage.

The LR nutrient is labeled with carbon-14, and undergoes time-dependent radiolytic decomposition. This decomposition is normally a slow process and the nutrient components are stable for long periods. However, upon heating the rate of thermal decomposition increases, producing a considerable radioactive background due to the production of volatile material. This background will appear as carbon-14 in the beta detector at a level above that of the cell. This temperature differential is important to guarantee that water will not be condensed (changing the effective dissolved nutrient concentration at the soil in the detector or detector line. Above 15°C environment the detector assumes ambient temperature.

The detector is not controlled by the thermoelectric coolers and its temperature can rise above 27°C. The detectors have been tested at the component level and found to be essentially noise free up to 50°C allowing them to operate satisfactorily without cooling.

The soil in a control experiment must be heat sterilized to destroy any organisms initially present in the soil. The sterilization method was heating at 160°C or greater for 3 h. The LR cell heater is located at the head end flange and serves to heat the head end and the test cell through the flange coupling. Experimental data show that heating the head end flange to about 190°C results in a nominal heating at the test cell bottom of 160°C. The LR head end is also heated to maintain the sterility of head end parts. In this case the head end flange heater is used as the main heating element.

The LR detectors are heated during the sterilization cycle to prevent condensation of any outgassed material on the detector. Heaters on the detector mounting plate raise the detector body temperature to 110°C.
To remove the radioactive gases helium is bubbled through the nutrient. This occurs immediately following the ampoule breakage 2-3 days after landing on the Martian surface. The high-pressure helium in the reservoir is first vented through S-47 (Fig. 5). Helium at 1.2 bars is then flowed through the nutrient through S-47 and S-59.

The flow is 2 std cm³/min controlled by restrictor FR-4. A second restrictor, FR-3, at the reservoir creates a back pressure in the reservoir of about 200 mbars to control the flow of helium and maintain the pressure above the water boiling point. The flow continues for 5 h, corresponding to a flow of 600 std cm³ of helium. This background radioactive gas to a level that does not contribute significantly to the instrumental background. The amount of water lost from the nutrient during degassing is less than 0.1 cm³. The nutrient is degassed only once. Valve S-47 is not used again. This guards against possible nutrient microbial contamination from Martian organisms residing in the vent system.

Nutrient is injected onto the soil by filling the cavity formed by valves S-44, S-45, S-59, and S-61 (Fig. 5) using the nutrient utilizing valve S-59. The cavity is first filled with 1.26 kg cm² helium through valve S-61 to prevent the high-pressure nutrient from forcing open a valve due to its high volume effect. A line-bleeding operation to provide unheated nutrient is performed on one soil sample to increase the available nutrient at the head end system is then cleaned using the cell detector-giving a drop to one half the normal value in each case. Seventeen nutrient injections have been performed and carbon-14 release data recorded for a total of 8650 h following those injections. For each experiment, background detector data was recorded from the time of soil receipt until the first nutrient injection.

D. LR experiment sequence

The major elements of one cycle of the experiment are receipt of soil, detector background determination, initial and additional nutrient injections, experiment termination in preparation for the next experiment and the optional sterilization of the soil for a control analysis. A block diagram of the sequence steps is presented in Fig. 5. One sterilization option is presented as a branch to the primary sequence. Each major sequence function consists of the activities listed under the functional blocks. A test was performed on Earth according to the sequence outlined in Fig. 7 using an instrument nearly identical to the ones landed on Mars. In order to simulate the rate of carbon-14 release immediately after injection, the number of counts accumulated by the detector is recorded every 4 min for 2 h and then every 16 min for the remainder of the experiment cycle.

More than one nutrient injection (0.12 cm³) can be conducted on one soil sample. The nutrient is injected at a selected time within the incubation sequence. The nutrient is delivered to the soil by the detector-giving a drop to one half the normal value in each case. The data are presented in cpm and can be converted to dpm using an overall detector efficiency of 3%. The dips in the otherwise well-behaved data are caused by purposely exercising the instrument's capability to use only one of the two sensing elements in the carbon-14 detector—giving a drop to one half the normal value in each case.

The two biology instruments have successfully executed 8 sequences on the Martian surface. Table V lists those sequences and gives the time for the major events in each sequence. Nutrient injections have been performed and carbon-14 release data recorded for a total of 8650 h following those injections. For each experiment, background detector data was recorded from the time of soil receipt until the first nutrient injection.

The data interpretation has been discussed elsewhere. 6,7

VI. PYROLYTIC RELEASE EXPERIMENT

A. Experiment concept

The pyrolytic release (PR) experiment is designed to search for life on the basis of a common property of living organisms, namely that they incorporate CO₂ into higher organic compounds. 8,9 In particular, this experiment is designed to detect carbon assimilation by organisms in Martian soil under conditions altered as little as possible from the natural Martian environment.

In order to detect the incorporation of either CO₂ or CO into the carbon-14 detectors but to the addition of water vapor and/or simulated sunlight, and both as of these are present on Mars, this capability is part of the experimental hardware. However, the ultraviolet component of the sun's light is removed to eliminate the possibility of nonbiological formation of organic compounds. 10-14 The Martian soil is exposed to these conditions of sunlight.
 sterilizations heat the nutrient and the radioactive gas generated must be removed before the next experiment.

To remove the radioactive gases helium is bubbled through the nutrient. This occurs immediately following the anaerobic breakup 2-3 days after landing on the Martian surface. The high-pressure helium in the reservoir is first vented through S-47 (Fig. 5). Helium at 1.2 bars is then flowed through the nutrient through S-41 and S-59.

The flow is 2 std cm/min controlled by restrictor FR-4. A second restrictor, FR-3, at the reservoir creates a back pressure in the reservoir of about 200 mbars to control the flow of helium and maintain the pressure above the water boiling point. The flow continues for 5 h, corresponding to a flow of 600 std cm/min of helium. Tests have shown that this flow rate is adequate. A line-bleeding operation to provide unheated helium is flowed through the system to carry the adsorbed radioactive gases. The vent heaters are turned on 30 min prior to cleaning. This temperature is used during all of the next experiment and the optional sterilization of the soil for a control plot. The difference between the two is that the active plot continues its rise for a longer period and reaches a significantly higher value. The difference of 1.5 orders of magnitude at the highest level in each case is ascribed to biological activity in the test soil.

The data are presented in cpm and can be converted to dpm using an overall detector efficiency of 3%. Any number of well-behaved data are caused by purposely exercising the instrument's capability to use only one of the two sensing elements in the carbon-14 detector—giving a drop to one half the normal value in each case.

The two biology instruments have successfully executed 8 sequences on the Martian surface. Table V lists these sequences and gives the time for the major events in each. Seven nutrient injections have been performed and carbon-14 data recorded for a total of 6560 h following those injections. For each experiment in Table VII, background detector data was recorded from the time of soil receipt until the first nutrient injection. The data interrelation has been discussed elsewhere.

VI. PYROLYTIC RELEASE EXPERIMENT

A. Experiment concept

The pyrolytic release (PR) experiment is designed to search for life on the basis of a common property of living organisms, namely, that they incorporate CO or CO into higher organic compounds. In particular, this experiment is designed to detect carbon assimilation by organisms in Martian soil under conditions altered as little as possible from the natural Martian environment.

In order to detect the incorporation of either CO or CO into higher organic compounds, the detector is placed in an environment of CO and/or simulated sunlight, and as both of these are present on Mars, this capability is part of the experimental hardware. However, the ultraviolet components of the sunlight are removed to eliminate the possibility of nonbiological formation of organic compounds. The Martian soil is exposed to these conditions...
Material in the soil is volatized by the pyrolysis and is condensed in the trap and is collected in a solid-state counter where helium carrier gas where it condenses. Any residual $^{14}C$ is counted based on a prior calibration.

The amount of radioactive organic material contained in the organic material in the soil is detected by the beta decay of the $^{14}C$ atoms (see Sec. VI C 2).

The amount of radioactive organic material contained in the soil is detected by the beta decay of the $^{14}C$ atoms. This amount is measured after the soil is pyrolyzed in a stream of helium gas. The organic material is volatized by the pyrolysis and is transported into an organic vapor trap (OVT) by helium carrier gas where it condenses. Any residual $^{14}CO_2$ and $^{14}CO$ from the incubation atmosphere or the soil residing in the cell.

Table V. Labeled release experiment summary of Mars surface operations. Each experiment sequence is described by the Viking mission time for start and stop and the experiment identifying characteristics. Soils are the number of Mars days elapsed since landing. Soil 0 is July 20, 1976 for Lander I and September 3, 1976 for Lander 2.

<table>
<thead>
<tr>
<th>Experiment description</th>
<th>Soil received, soil sterilization regime</th>
<th>Nutrient injections, number, End experiment, soil</th>
<th>Lander 1</th>
<th>Lander 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>8</td>
<td>None</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Control</td>
<td>24</td>
<td>3 h, 160°C</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Extended, active</td>
<td>38</td>
<td>None</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>Double nutrient, active</td>
<td>250</td>
<td>None</td>
<td>306</td>
<td>306</td>
</tr>
<tr>
<td>Lander 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>8</td>
<td>None</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Low temperature control</td>
<td>28</td>
<td>3 h, 50°C</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Active, subrock soil</td>
<td>51</td>
<td>None</td>
<td>141</td>
<td>141</td>
</tr>
<tr>
<td>Low temperature control repeat</td>
<td>145</td>
<td>3 h, 50°C</td>
<td>171</td>
<td>171</td>
</tr>
<tr>
<td>High soil ratio, active</td>
<td>None</td>
<td>None</td>
<td>260</td>
<td>260</td>
</tr>
</tbody>
</table>

Table V continued...

The PR experiment provides a method of determining if carbon assimilating microorganisms exist in the Martian soil without subjecting them to abnormal Martian conditions. The Martian soil is exposed to no conditions or environments which are different from usual Mars conditions except a higher temperature for the incubation.

B. PR experiment implementation

A metered amount of soil (0.25 cm$^3$) is dropped into a selected PR test cell by the SDA. The pyrolysis experiment contains a carousel that holds three test cells and three dump cells (Fig. 9). Each of these test cells can be indexed under the soil loader port. This design allows test cells to receive a calibrated soil sample and the dump cells can be used to empty the soil hopper in preparation for the arrival of a new soil. Once loaded, the incubation cell is moved through 180$^\circ$ (by three steps of a six position Geneva mechanism) to the incubation station. This operation places a dump cell under the load port so that soil can be emptied from the metering cavity into the cell. It also places a clean dump cell under the pyrolysis head end so that presol analysis procedures can be performed at the pyrolysis station. At the end of the soil incubation, the soil is moved to the pyrolysis station for the pyrolysis of the soil, after which the carousel is again rotated so that the clean dump cell is replaced under the pyrolysis head end. This operation provides a soil-free flow path for the final determination of the level of radioactive organic material at the pyrolysis position.

Prior to the start of another experiment, the carousel is again rotated so that a new test cell is placed under the soil loading port and the same experimental sequence is repeated. The experimental sequence is arranged so that the dump cells that receive soil are not used under the pyrolysis head end for pre- and final analysis procedures.

The flow diagram for the pyrolytic experiment is shown in Fig. 10. The first operations occur at the incubation station, which contains all the systems that are required to perform a natural Martian soil incubation. Each of these systems is physically con-

Fig. 10. Pyrolysis release experiment module flow diagram. The module contains three test cells which receive soil and are one at a time at the incubation head end and the pyrolysis head end in that order. The gases and water vapor flow through the lines in the directions indicated to carry out the incubation and analysis cycle operations.
The trap and is collected in a solid-state counter where helium carrier gas where it condenses. Any residual sections where the count rate is one-half the normal rate are caused by purposely recording only one of the two halves of the beta detector.

It is transported into an organic vapor trap (OVT) by pyrolyzed in a stream of helium gas. The organic matter including the newly synthesized radioactive material is dropped as sequestered prior to exposure to the incubation gases. Sterilized a control except that a sample of the same soil is known to have carbon assimilating microorganisms exist in the Martian soil without subjecting them to abnormal Martian conditions. The Martian soil is exposed to no sterilization and analysis cycle operations. Prior to the start of another experiment, the carousel is again rotated so that a new test cell is placed under the soil loading port and the same experimental sequence is repeated. The experimental sequence is arranged so that the dump cells that receive soil are not used under the pyrolysis head end for pre- and final analysis procedures.

The flow diagram for the pyrolytic experiment is shown in Fig. 10. The first operations occur at the incubation station, which contains all the systems that are required to perform a natural Martian soil incubation. Each of these systems is physically con-

Table V. Labeled release experiment summary of Mars surface operations. Each experiment sequence is described by the Viking mission time for start and stop and the experiment identifying characteristics. Sol 0 is July 20, 1976 for Lander 1 and September 3, 1976 for Lander 2.

<table>
<thead>
<tr>
<th>Experiment sequence</th>
<th>Soil received, soil sterilization regime</th>
<th>Nutrient injections, number</th>
<th>End experiment, soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lander 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>8 None</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>Control</td>
<td>24 3 h, 160°C</td>
<td>2</td>
<td>37</td>
</tr>
<tr>
<td>Extended active</td>
<td>38 None</td>
<td>2</td>
<td>89</td>
</tr>
<tr>
<td>Double nutrient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>230 None</td>
<td>2</td>
<td>306</td>
</tr>
<tr>
<td>Control</td>
<td>8 None</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>Low temperature</td>
<td>28 3 h, 50°C</td>
<td>2</td>
<td>48</td>
</tr>
<tr>
<td>Active, tartrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>51 None</td>
<td>2</td>
<td>141</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control, repeat</td>
<td>28 3 h, 50°C</td>
<td>2</td>
<td>48</td>
</tr>
<tr>
<td>High soil, active</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>145 3 h, 50°C</td>
<td>2</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>None*</td>
<td>1</td>
<td>260</td>
</tr>
</tbody>
</table>

* Experiment sequence begins on Soil 225 with previously dumped soil residing in the cell.

Fig. 8. Labeled release experiment active and sterilized soil carbon-14 release from test of flightline instrument. Each of the two experiment sequences consists of a background segment, two nutrient injections, and carbon-14 gas purge and subsequent background. The data sections where the count rate is one-half the normal rate are caused by purposely recording only one of the two halves of the beta detector.

Fig. 9. Exploded view of the pyrolytic release experiment module assembly. For clarity the liquid and gas lines which supply the helium flow, CO/CO incubation gas and water vapor are not shown.

Fig. 10. Pyrolysis release experiment module flow diagram. The module contains three test cells which receive soil and are at a time at the incubation head end and the pyrolysis head end in that order. The gases and water vapor flow through the lines in the directions indicated to carry out the incubation and analysis cycle operations.

cells can be indexed under the soil loader port. This design allows test cells to receive a calibrated soil sample and the dump cells can be used to empty the soil hopper in preparation for the arrival of a new soil. Once loaded, the incubation cell is moved through 180° (by three steps of a six position Geneva mechanism) to the incubation station. This operation places a dump cell under the load port so that soil can be emptied from the metering cavity into the cell. It also places a clean dump cell under the pyrolysis head end so that pressurization procedures can be performed at the pyrolysis station. At the end of the soil incubation, the soil is moved to the pyrolysis station for the pyrolysis of the soil, after which the carousel is again rotated so that the clean dump cell is replaced under the pyrolysis head end. This operation provides a soil-free flow path for the final determination of the level of radioactive organic material at the pyrolysis position.
nected to the incubation cell via the incubation head end assembly. The incubation volume formed when the cell is sealed end to mated leaktight by compressing the test cell containing soil against an elastomeric seal in the incubation head end. A controlled amount of CO$_2$ and CO (tracer gases) is injected into the cell by initially allowing the incubation gases to flow from a reservoir into a calibrated volume. The gas is expanded from this volume into the incubation cell by opening valve S-12 that connects the cell to the instrument vent line VI.

The incubation cell is then moved to its second position, the pyrolysis station. Here the pyrolysis head end and the test cell form a programmable pyrolysis oven. This contains an organic vapor trap. The trap is a temperature programmable 25-cm-long, 0.3-cm-diam stainless steel tube containing a mixture of Chromosorb P and copper oxide. The Chromosorb provides a large surface area for trapping organic condensation products and the copper oxide, when heated above 500 °C, oxidizes the organics to oxides of carbon. The helium gas exiting the trap can be either directed into an instrument vent line VI or into a solid-state radiation detector assembly. The sample temperature is measured with a programmable detector assembly which contains an isolable spherical 6-cm$^3$ holding chamber and an isolable 1-cm$^3$ cylindrical detector volume. Both the end faces of the cylinder are composed of solid-state silicon beta detectors. The exit line from the detector cylinder goes to vent line VI.

C. Experiment operation

Operation of the experiment is described below through a detailed description of the construction, purpose, and function of each of the critical components.

1. Incubation system

Test cells. The six cells mounted on the PR carousel are all made of 316 stainless steel. Three of these cells are used as test cells which have an internal volume of 2.6 cm$^3$, while the other three are dump cells and have an internal volume of 2.95 cm$^3$. The total incubation system volume, which is composed of the test cell and the incubation head end volume of 4.13 cm$^3$. Each test cell has an integral heater and a temperature sensor which provide five temperature set points. The first set point is $85^\circ$ to $10^\circ$ C which is used to heat the soil prior to sterilization. The second set point is $115^\circ$ to $10^\circ$ C which is used to heat the soil after the incubation to remove the gases adsorbed on the soil during incubation. This heating is carried out with the cell exit valve, S-12, open which allows any water in the soil to evaporate. This ensures that when a sterilization temperature is reached the pyrolysis products from the cell and carries them into the detector cylinder goes to vent line VI.

Water reservoir. The PR water reservoir has a total volume of 2 cm$^3$ and is loaded with a nominal 0.5 ml of water. Prior to sealing on Earth, a thorough degassing of the water by repeated freeze-evacuate-thaw cycles was performed to remove any trace of air. Then it was sealed with an isolation valve until punctured on Mars during the initialization procedure. Once the instrument receives power, the reservoir and associated valves and tubing are maintained at $30^\circ$ C at all times. This ensures that the reservoir is always hotter than the test cell which produces a pressure differential between the reservoir and the test cell. The water vapor injection into the incubation cell is initiated by opening valve S-7. The amount of water vapor injected is controlled by a flow restrictor and the time period that S-7 is open which can be varied in multiples of 1 min. A 1-min injection was used which provides sufficient water vapor to saturate the test cell atmosphere when the cell is at about 24°C.

Lamp. The incubation head end (Fig. 9) contains a quartz window through which simulated Martian solar illumination can irradiate the soil in the test cell. This artificial sunlight is provided by a xenon arc lamp (Fig. 11) assembled with a spectral range and distribution that is very similar to Martian sunlight (Fig. 12). The system requirement was that the artificial light must approximate Martian solar radiation in intensity and spectral distribution so that it is necessary to provide a spherical 6-cm$^3$ holding chamber and an isolable 1-cm$^3$ cylindrical detector volume. Both the end faces of the cylinder are composed of solid-state silicon beta detectors. The exit line from the detector cylinder goes to vent line VI.

2. Analysis system

Organic vapor trap. The OVT is essentially a high-surface-area condensation trap coupled with high-temperature oxidation capability. It is a 1.5-cm$^3$ stainless-steel tube, about 25 cm long and 0.25 cm i.d. A Calrod heater runs axially through the tube that is packed with Chromosorb P coated with 25% by weight of copper oxide. The ends of the tube are capped with stainless steel frits which permit the flow of gas but which retain the packing material. The packed stainless steel tube is surrounded by a 0.6-cm-thick outer gold-plated tube to reduce radiation losses. The inner tube has a platinum resistance sensor mounted at a point midway from either end. This sensor provides housekeeping parameters for heater control. The OVT has two temperature set points of $120^\circ$ to $10^\circ$ C and $625^\circ$ to $25^\circ$ C.

The packing material in the OVT provides a large surface area for the condensation of organic material. However, this packing material is the major adsorber of the radioactive oxides of carbon released from the soil during pyrolysis. This adsorbed gas is the major source of error in the experiment as it is impossible to remove completely.
nected to the incubation cell via the incubation head end assembly. The incubation volume formed when the cell is sealed and made leak tight by compressing the test cell containing soil against an elastomeric seal in the incubation head end. A controlled evacuated incubation cell is open to gas flow from a reservoir into a calibrated volume. The gases are expanded from this volume into the incubation cell which contains the soil and the normal Martian atmosphere. If humidification of the incubation cell is required, the valve between the water vapor reservoir and the incubation cell is opened to allow gases to flow from a reservoir into a calibrated volume.

At the end of the incubation period, the incubation gases are allowed to diffuse out of the incubation cell by opening valve S-12 that connects the cell to instrument vent line VI. The incubation cell is then moved to its second position, the pyrolysis station. Here the pyrolysis head end and the test cell form a programmable pyrolysis oven that is constantly purged with a 1.5-cm/min helium gas flow. This helium carrier gas flow removes the pyrolysis products generated in the test cell and carries them through an organic vapor trap. The trap is a temperature programmable 25-cm-long, 0.3-cm-diameter stainless steel tube containing a packed bed of Chromosorb P and copper oxide. The Chromosorb provides a large surface area for trapping organic condensation products and the copper oxide, when heated above 500 °C, oxidizes the organic compounds to carbon dioxide.

The helium gas entering the trap can be either directed into an instrument vent line (VI) or into a solid-state radiation detector assembly. The radiation detector assembly is any programmable detector assembly that contains an isolable spherical 6-cm jacket and a spherical 0.28-cm cylindrical detector. This detector contains three cells of 316 stainless steel, 4.13 cm², 5.54 cm², and 4.13 cm², respectively. The 5.54 cm² cell has an integral heater and a temperature sensor which provide five temperature set points. The first set point is 85 °C ± 10 °C which is used to heat the soil prior to sterilization. The next two set points are 115 °C ± 10 °C which is used to heat the soil after the incubation to the temperature of sterilization. The fourth set point is 200 °C ± 10 °C which is used to heat the soil during pyrolysis. This heater is carried out with the cell exit valve, S-12, open which allows any water in the soil to evaporate. This ensures that any water in the soil is removed upon sterilization. The final pyrolysis step is performed at 400 °C with S-12 closed, the pressure produced by superheated water vapor does not overcome the pneumatic helium pressure that holds the cell closed. The third set point of 200 °C ± 10 °C is to sterilize the soil with dry heat. The fourth set point is 400 °C ± 10 °C which is used during soil pyrolysis.

During the incubation, the cell temperature is kept within a predetermined range by automatic operation of the heating and thermal electric coolers. At the end of the incubation period, the incubation gases are allowed to diffuse out of the incubation cell by opening valve S-12 that connects the cell to instrument vent line VI.

The incubation cell is then moved to its second position, the pyrolysis station. Here the pyrolysis head end and the test cell form a programmable pyrolysis oven that is constantly purged with a 1.5-cm/min helium gas flow. This helium carrier gas flow removes the pyrolysis products generated in the test cell and carries them through an organic vapor trap. The trap is a temperature programmable 25-cm-long, 0.3-cm-diameter stainless steel tube containing a packed bed of Chromosorb P and copper oxide. The Chromosorb provides a large surface area for trapping organic condensation products and the copper oxide, when heated above 500 °C, oxidizes the organic compounds to carbon dioxide.

The helium gas entering the trap can be either directed into an instrument vent line (VI) or into a solid-state radiation detector assembly. The radiation detector assembly is any programmable detector assembly that contains an isolable spherical 6-cm jacket and a spherical 0.28-cm cylindrical detector. This detector contains three cells of 316 stainless steel, 4.13 cm², 5.54 cm², and 4.13 cm², respectively. The 5.54 cm² cell has an integral heater and a temperature sensor which provide five temperature set points. The first set point is 85 °C ± 10 °C which is used to heat the soil prior to sterilization. The next two set points are 115 °C ± 10 °C which is used to heat the soil after the incubation to the temperature of sterilization. The fourth set point is 200 °C ± 10 °C which is used to heat the soil during pyrolysis. This heater is carried out with the cell exit valve, S-12, open which allows any water in the soil to evaporate. This ensures that any water in the soil is removed upon sterilization. The final pyrolysis step is performed at 400 °C with S-12 closed, the pressure produced by superheated water vapor does not overcome the pneumatic helium pressure that holds the cell closed. The third set point of 200 °C ± 10 °C is to sterilize the soil with dry heat. The fourth set point is 400 °C ± 10 °C which is used during soil pyrolysis.

During the incubation, the cell temperature is kept within a predetermined range by automatic operation of the heating and thermal electric coolers. At the end of the incubation period, the incubation gases are allowed to diffuse out of the incubation cell by opening valve S-12 that connects the cell to instrument vent line VI.

1. Incubation System

Test cells. The six cells mounted on the PR carousel are all made of 316 stainless steel. Three of these cells are used as test cells which have an internal volume of 2.6 cm³, while the other three are dump cells and have an internal volume of 2.95 cm³. The total incubation system volume, which is composed of the test cell and the incubation head end volume, is 4.13 cm³. Each test cell contains the soil and the normal Martian atmosphere. If humidification of the incubation cell is required, the valve between the water vapor reservoir and the incubation cell is opened to allow gases to flow from a reservoir into a calibrated volume. The gases are expanded from this volume into the incubation cell which contains the soil and the normal Martian atmosphere. If humidification of the incubation cell is required, the valve between the water vapor reservoir and the incubation cell is opened to allow gases to flow from a reservoir into a calibrated volume.
to distinguish this gas from the organics that are converted to oxides of carbon during the subsequent elution heating of the OVT. Therefore, a substantial design and laboratory effort was made to reduce the risk of the loss of some organics which will not be adsorbed to a minimum. All metal surfaces were thoroughly cleaned and all interior materials were selected for their low oxide of carbon adsorption coefficients. During pyrolysis, the OVT is heated to 120°C to reduce adsorption of these gases with the associated risk of the loss of some organics which will not condense out on the OVT at this elevated temperature. These procedures produce an OVT adsorption level of only one part in ten thousand (1:10⁴). This value was an average obtained for measurements carried out on six flight quality traps. This means that if a soil pyrolysis produces a count of 10⁶ dpm, the resultant organic peak will produce ~10⁴ dpm from OVT adsorption of oxide of carbon gases that were released during pyrolysis. During the elution cycle, the OVT is heated to 625°C in a period of 90 s. A temperature above 300°C was required for capillary oxide to act as a strong adsorbing agent. Temperatures much higher than 625°C cause a deterioration of the packing material which increases the adsorption of the oxide of carbon gases. The fast rate of heating of the OVT produces a count of 10⁶ dpm, the reaction heating of the OVT. Therefore, a substantial decrease in the temperature of this gas from the organics that are condensing in the holding chamber is placed in the detector volume for counting. Under these circumstances, the counting efficiency for the first peak is 25.6% (average for six flight detector assemblies). In order to reduce the adsorption of the oxides of carbon in the detector chamber, the interior of the chamber is gold plated and each silicon detector chip is brazed directly onto the detector chamber. As adsorption is a function of both the level of radioactivity to which the material is exposed and the time of exposure, care is taken to minimize the counting period of any large volume of radioactivity. The pyrolysis peak is counted for only 1.61 min count periods and is then vented. The detector assembly is equipped with a heater (H-22) which can heat and maintain the detector assembly at (109 ± 5)°C. In the normal sequence, the detector is heated for 120 min at (109 ± 5)°C after the pyrolysis count period, to ensure a high efficiency for desorption of the oxides of carbon from the system.

3. Experiment data

Data counting requirements. The PR criterion for detection of radioactive activity in a soil sample is based on the comparative size of the organic (second) 14C peak from an “active” and from a sterilized soil sample. The peak is determined by trapping the effluent from a 625°C heating of the OVT in the detector chamber and counting the resultant radioactive oxides of carbon for many hours. In order to monitor the movement of carbon-14 material in the experiment, several additional but separate radioactive counting periods are required during the experiment. These additional count periods provide information on the PR system "background" processes that could influence the size of the second peak. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]

The background count rate is dependent on several processes, but the largest contributor to this background count is produced by secondary electrons resulting from neutron emission from the plutonium in the radiosotope thermoelectric generators (RTG) that power the landers. Detectors placed directly under the pyrolysis cell head end and line to the OVT made of metallic oil sample. The organic peak is determined by monitoring the movement of carbon-14 material in the experiment. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]

The background count rate is dependent on several processes, but the largest contributor to this background count is produced by secondary electrons resulting from neutron emission from the plutonium in the radiosotope thermoelectric generators (RTG) that power the landers. Detectors placed directly under the pyrolysis cell head end and line to the OVT made of metallic oil sample. The organic peak is determined by monitoring the movement of carbon-14 material in the experiment. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]

The background count rate is dependent on several processes, but the largest contributor to this background count is produced by secondary electrons resulting from neutron emission from the plutonium in the radiosotope thermoelectric generators (RTG) that power the landers. Detectors placed directly under the pyrolysis cell head end and line to the OVT made of metallic oil sample. The organic peak is determined by monitoring the movement of carbon-14 material in the experiment. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]

The background count rate is dependent on several processes, but the largest contributor to this background count is produced by secondary electrons resulting from neutron emission from the plutonium in the radiosotope thermoelectric generators (RTG) that power the landers. Detectors placed directly under the pyrolysis cell head end and line to the OVT made of metallic oil sample. The organic peak is determined by monitoring the movement of carbon-14 material in the experiment. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]

The background count rate is dependent on several processes, but the largest contributor to this background count is produced by secondary electrons resulting from neutron emission from the plutonium in the radiosotope thermoelectric generators (RTG) that power the landers. Detectors placed directly under the pyrolysis cell head end and line to the OVT made of metallic oil sample. The organic peak is determined by monitoring the movement of carbon-14 material in the experiment. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]

The background count rate is dependent on several processes, but the largest contributor to this background count is produced by secondary electrons resulting from neutron emission from the plutonium in the radiosotope thermoelectric generators (RTG) that power the landers. Detectors placed directly under the pyrolysis cell head end and line to the OVT made of metallic oil sample. The organic peak is determined by monitoring the movement of carbon-14 material in the experiment. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]

The background count rate is dependent on several processes, but the largest contributor to this background count is produced by secondary electrons resulting from neutron emission from the plutonium in the radiosotope thermoelectric generators (RTG) that power the landers. Detectors placed directly under the pyrolysis cell head end and line to the OVT made of metallic oil sample. The organic peak is determined by monitoring the movement of carbon-14 material in the experiment. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]

The background count rate is dependent on several processes, but the largest contributor to this background count is produced by secondary electrons resulting from neutron emission from the plutonium in the radiosotope thermoelectric generators (RTG) that power the landers. Detectors placed directly under the pyrolysis cell head end and line to the OVT made of metallic oil sample. The organic peak is determined by monitoring the movement of carbon-14 material in the experiment. The interpretation of the experiment data requires that the second peak count can determine 100 dpm of 14C as a 3σ increase above background, or it will need to be counted for a time period equal to

\[
T = \frac{\sigma \times \text{background count rate}}{\text{detector counting efficiency}}
\]
to distinguish this gas from the organics that are converted to oxides of carbon during the subsequent elution heating of the OVT. Therefore, a substantial design and laboratory effort was made to reduce the adsorbed count to a minimum. All metal surfaces were thoroughly cleaned and all interior materials were selected for their low oxide of carbon adsorption coefficients. During pyrolysis, the OVT is heated to 120 °C to reduce adsorption of these gases with the associated risk of the loss of some organics which will not condense out on the OVT at this elevated temperature. These procedures produce an OVT adsorption level of only one part in ten thousand (1 : 10,000). This value was an average obtained for measurements carried out on six flight quality traps. This means that if a soil pyrolysis produces a count of 10^4 dpm, the resultant organic peak will produce ~10^2 dpm from OVT adsorption of oxide of carbon gases that were released during pyrolysis.

During the elution cycle, the OVT is heated to 625 °C in a period of 90 s. A temperature above 500 °C was required for cupric oxide to act as a strong oxidizing agent. Temperatures much higher than 625 °C cause a deterioration of the packing material which increases the adsorption of the oxide of carbon gases. The fast rate of temperature increase produces a maximum in organic oxidation products. Also it minimizes the amount of carrier gas required to transport the products into the detector.

**Pyrolysis head end.** The temperature requirements of the pyrolysis cell head end and line to the OVT made the design of a vacuum full system impossible. To obtain the required condensation it is necessary to keep the head end and line at approximately 200 °C during pyrolysis. However, the head end seal should not exceed its maximum specified temperature of 265 °C when the pyrolysis test cell is compressed against this seal to 625 °C. The selected heater for H-22 (Fig. 10) is a metallic sheath desorbed with the H-22 AA heater. The line junction between the head end and H-22 AA is maintained at the required temperature by a coating of aluminized Kapton secured with gold tape. This heater is a part of the PR module. The thermal environment provided by the lander and the instrument is supplemented by a variety of heaters and coolers. The normal operational temperature of the PR module is maintained by heater H-11 PM, which is positioned on the stainless steel can surrounding the module.

The temperature of the incubation head end as the instrument warms during the Martian incubation head end (Fig. 13). These coolers dissipate the heat generated when the lamp is on and cool the head end as the instrument warms during the Martian day. Under simulated "warm" (versus cold or hot) Martian conditions, the incubation head end temperature range is 0 °C to 15 °C while the instrument undergoes a -5 °C to 25 °C temperature variation. This ensures that any water present in the cell does not freeze and cosmically and gaseous radiations and radioactive decay processes. The 238Pu-238Th (MgTh) alloys used in the construction of several lander science instruments including biology. These additional radiation sources were expected to provide an increase of the background count rate. Hence the uncertainty in the background due to increased radiation with RTG fuel age and impurity level, a count period of 1.8 h minimum was selected to provide a statistical margin. In order to assess the constancy of the count rate, this count period needed to be divided into a number of subintervals so that a quadratic test could be performed. The length of each individual count interval was 16 min. Therefore, the 8-h count period produces 30 subintervals of counting and based on statistical considerations, allows a squared interpretation of the data to be made.

Another possible source of error in the second peak count rate is associated with the effect of temperature on the silicon detectors. The detector noise (N) due to these thermal effects is equal to \( N = (N_0 + N_x + N_y) \), where \( N_0 \) is the detector noise in keV, \( N_x \) at 20 °C, and \( N_y \) is the electronic system noise in keV FWHM. This detector noise varies in a manner described by \( N = A + B/T \), where \( A \) and \( B \) are constants.

**Data counting requirements**. The PR detector consists of two silicon diffused junction semiconductor chips that are arranged to efficiently monitor a trapped volume between them. The function of the detector is to measure the number of beta particles produced in the trapped volume from the decay of 14C which has a mean energy of 155 keV. This measurement has to be performed on Mars in the presence of a highly stable, low-energy radiation from the radioisotope thermoelectric generators on the lander and a flux of high-energy cosmic rays. The thickness of the detectors and electronic discrimination circuitry is preferentially optimized to detect the 14C beta particles. The output of the two detectors is normally summed electronically and the total output accumulated in a register. However, if one detector fails or becomes electrically noisy, the other detector can be commanded to operate separately.

The detector assembly is equipped with a heater (H-23) which can heat and maintain the detector assembly at (109 ± 5) °C. In the normal sequence, the detector is heated for 120 min at (109 ± 5) °C after the pyrolysis count period, to ensure a high efficiency for adsorption of the oxides of carbon from the system.

**3. Experiment data**

**Detector**. The detector consists of two silicon diffused junction semiconductor chips that are arranged to efficiently monitor a trapped volume between them. The function of the detector is to measure the number of beta particles produced in the trapped volume from the decay of 14C which has a mean energy of 155 keV. This measurement has to be performed on Mars in the presence of a highly stable, low-energy radiation from the radioisotope thermoelectric generators on the lander and a flux of high-energy cosmic rays. The thickness of the detectors and electronic discrimination circuitry is preferentially optimized to detect the 14C beta particles. The output of the two detectors is normally summed electronically and the total output accumulated in a register. However, if one detector fails or becomes electrically noisy, the other detector can be commanded to operate separately.

The detector trapped volume is 1.4 cm³ and the detector system has an overall counting efficiency of 10.94%. This volume was selected for efficient counting of the oxides of carbon produced during the OVT heating cycle. The pyrolysis cycle produces approximately five times as much gas as the elution cycle but it normally contains several orders of magnitude more radioactivity. As the pyrolysis count is not as important as the elution count, it does not need to be counted as accurately. In order to obtain an adequate estimate of the radioactivity produced in the pyrolysis cycle, a 14C peak is usually identified with the magnetic field of the detector assembly to trap the entire first peak. Only 20% of the total volume of the gases at equilibrium in the holding chamber is placed in the detector volume for counting. Under these circumstances, the counting efficiency for the first peak is 2.64% (average for six flight detector assemblies). In order to account for the adsorption of the oxides of carbon in the detector chamber, the interior of the chamber is gold plated and each silicon detector chip is brazed directly onto the detector chamber. As adsorption is a function of both length of each individual oxidation period to which the material is exposed and the time of exposure, care is taken to minimize the counting period of any large amount of radioactivity. The pyrolysis peak is counted for only 16 min count periods and is then vetoed.

The detector assembly is equipped with a heater (H-23) which can heat and maintain the detector assembly at (109 ± 5) °C. In the normal sequence, the detector is heated for 120 min at (109 ± 5) °C after the pyrolysis count period, to ensure a high efficiency for adsorption of the oxides of carbon from the system.
to a count of 264 cpm. Assuming equal counting times for the background count (1360 cpm) and the first peak count, the minimum counting time ($t$) can be obtained to determine a 3σ difference between signal and background.

$$t = \frac{\sigma}{2 \times \text{Signal}} + \frac{\sigma}{2 \times \text{Background}}$$

where $t$ is in minutes, $\sigma$ is 3, and Background and desired detectable Signal are in counts per minute.

Solving Eq. (2) yields a time of 0.395 min. Therefore, based on this calculation, a 1-min count should easily determine the amount of carbon-14 produced during the soil pyrolysis to more than a 3σ difference between background counts and 10^6 dpm plus background counts. In order to obtain a reasonable $t$-value exponent interpretation of the count and to provide a contingency against spurious system noise, the data period was increased to 16-minute count periods.

D. Experiment sequence

At the start of the first experiment cycle, the heaters and thermoelectric (TE) coolers are activated, and the incubation cell is allowed to temperature stabilize. The background counts are recorded against a system noise, the data period was in

During the incubation period, the pyrolysis station had been purged with the Martian atmosphere to equilibrate the hardware surfaces, especially the OVT, with CO and CO$_2$. At the start of the soil incubation, during the time the soil is raised to its initial temperature of 120°C, any CO$_2$ and CO$_2$ system equilibration occurs.

If the experiment is to be an incubation of a sterilized soil, then once the cell has been sealed under the incubation head end, the cell is raised to a temperature of 85°C to remove any water vapor with the vent line valve S-12 open. The S-12 is closed and the cell is raised to 180°C for 3 h to sterilize the soil. The incubation head end is kept at a minimum temperature of 120°C during this operation. Once the heaters are turned off, the cell cools to the temperature of the local environment and then radioactive incubation gas is added. The remainder of the experiment is performed in exactly the same manner as an active experiment.

In Fig. 14 the incubation sequence is shown in block diagram form. During the time that the soil is incubating at the incubation station, the analysis part of the experiment is preparing for the soil pyrolysis, and both stations are operating in parallel.
During the incubation period, the pyrolysis station is heated and the holding chamber is placed in the Martian atmosphere to equilibrate the hardware surfaces, especially the OVT, with CO and CO₂. At the start of the soil incubation, the pyrolysis station is kept closed and the OVT is heated to 625°C. After the temperature of the OVT has reached 625°C, the OVT is vented to air and the pyrolysis station is heated to 625°C. The radioactive gases in the detector and holding chamber are oxidized to CO₂ by the CuO in the OVT. The CO₂ gas is released from the soil early in the pyrolysis process. The detector, containing a high proportion of the gas, is heated to 625°C and the detector is vented to Martian pressure (open S-1, open and close S-8). Opening S-9 then fills the detector with the holding chamber contents. The gas is then counted as the first peak (nonbiogenic). After 5 days of incubation, the detector is vented and a second peak is counted. The second peak is the result of adsorbed CO gas and is used as a baseline for the first peak. The amount of CO₂ released from the soil is calculated by subtracting the second peak from the first peak.

The pyrolysis station is then vented to air and the pyrolysis station is heated to 625°C. The radioactive gases in the detector and holding chamber are oxidized to CO₂ by the CuO in the OVT. The CO₂ gas is released from the soil early in the pyrolysis process. The detector, containing a high proportion of the gas, is heated to 625°C and the detector is vented to Martian pressure (open S-1, open and close S-8). Opening S-9 then fills the detector with the holding chamber contents. The gas is then counted as the first peak (nonbiogenic). After 5 days of incubation, the detector is vented and a second peak is counted. The second peak is the result of adsorbed CO gas and is used as a baseline for the first peak. The amount of CO₂ released from the soil is calculated by subtracting the second peak from the first peak.
cease the experiment is performed with no added water or only water vapor added. Earth soil microorganisms do not assimilate detectable carbon under these dry (by Earth standards) environmental conditions. Therefore, the Earth test of the instrument under Martian conditions was conducted using a soil specifically compounded to give an active response. The soil sample used on the active cycle only was prepared by mixing 10% of a preincubated soil with the standard Aiken soil and sterilized for 3 h at 180 °C after the primary mission. The primary mission is that period over which the instrument was designed to operate. The last two sequences on Lander 2 were performed properly but the two in the extended mission did not. An interpretation of the Lander 2 instrument's helium consumption in the extended mission has indicated that one valve (S-11) stuck in the open position and precluded collection by pressurization of the carbon-14 material in the beta detector volume for the sequences after the primary mission.

VII. GAS EXCHANGE EXPERIMENT

A. Experiment concept

The gas exchange experiment (GEX) for the detection of biological activity in soil is based on the measurement of changes in the concentration of gases in the headspace over the soil (in an enclosed cell) caused by metabolism and growth of microorganisms. The experiment, devised by experimenters V. I. Oyama and co-experimenters B. Berdahl and G. Carle, is based on a common characteristic of life on earth in which all organisms produce and/or consume various gases such as H₂, N₂, O₂, CH₄, and CO₂. In the GEX experiment, the metabolism and growth of the microorganisms are stimulated either by humidifying the soil or contacting the soil with an aqueous solution containing a variety of nutrients and growth factors. The changes in gas composition are measured by periodically analyzing the headspace composition by gas chromatography. The patterns of gas composition change with time produced by organisms in terrestrial soils are markedly different from changes caused by nonbiological phenomena.

Preliminary results from Mars operation have been presented elsewhere. The soil sample is delivered to the test cell and sealed gastight. Incubation gas and nutrient solution are added to the test cell and the temperature controlled above freezing but below 27°C. Gas analyses are periodically made of the cell headspace. At selected intervals the nutrient and incubation gas are replaced with fresh solution and gas. The soil can be thoroughly dried if a second soil is to be added to the single test cell. When desired the soil cell and cell can be heated to sterilize the soil for a control experiment.

The basic design of the GEX experiment is shown in Fig. 15. The major components of the GEX module assembly are described below. The single test cell of 8.7-cm³ volume and dump cell both mounted at opposing positions on a carousel and Geneva wheel rotates to the soil load port and to the head end when lowered by a vertical actuator assembly.

The head end assembly provides the cell seal, inlets for gas and nutrient, and valve S-19A to prevent condensation of water in the line between the head end and the gas chromatographic analysis assembly.}

The reservoir assembly contains the nutrient ampoule. This assembly is also equipped with two pistons that are actuated with high pressure helium to puncture the ends of the ampoule.

A gas chromatographic analysis assembly (GCAA) is used to analyze the cell headspace and is composed of a gas sample valve, a pair of matched 7.6-m by 0.1-cm i.d. columns packed with 100-120 mesh Porapak Q, and a thermistor thermal conductivity detector.

A gas reservoir contains a He/Kr/CO₂ mixture used as the incubation gas. A gas reservoir (physically located on the labeled release experiment module) provides a gas mixture (He/CO₂/CO₂) used to pretreat the columns after they have been exposed to space vacuum during the interplanetary voyage.
The test conditions are the same as those described for the LR experiment in Sec. V D. A sample, which returned interpretable scientific data, was tested on the active cycle only. This sample was prepared by mixing sterile subrocks with a soil specifically built into the soil before it was tested in the instrument. The purpose of this is to cause the experiment to be performed with no added water so that a positive response of several hundred dpm is non biological phenomena. The experiment, devised by experimenter V. I. Oyama and co-experimenters B. Berdahl and G. Carle, is based on a common characteristic of life on earth in which all organisms produce and/or consume various gases such as H2, N2, O2, CH4, and CO2. In the GEx experiment, the metabolism and growth of microorganisms is measured by rapidly analyzing the headspace composition by gas chromatography. The patterns of gas composition change with time produced by organisms in terrestrial soils are markedly different from changes caused by nonbiological phenomena. Table VII. Nine experiment sequences were conducted which returned interpretable scientific data. On Lander 1 the PR experiment performed the maximum number of sequences (six) as allowed by the capacity of the test cells and the usable helium. On Lander 2 the three sequences in the primary mission proved useful data but the two in the extended mission did not. Interpretation of the Lander 2 instrument's helium consumption in the extended mission has indicated that one valve (S-11) stuck in the open position and precipitated collection by passivation of the carbon-14 material in the beta detector volume for the sequences after the primary mission.

VII. GAS EXCHANGE EXPERIMENT

A. Experiment concept

The gas exchange experiment (GEX) is for the detection of biological activity in soil is based on the measurement of changes in the concentration of gases in the headspace over the soil (in an enclosed cell) caused by metabolism and growth of microorganisms. The experiment, devised by experimenter V. I. Oyama and co-experimenters B. Berdahl and G. Carle, is based on a common characteristic of life on earth in which all organisms produce and/or consume various gases such as H2, N2, O2, CH4, and CO2. In the GEx experiment, the metabolism and growth of microorganisms is measured by rapidly analyzing the headspace composition by gas chromatography. The patterns of gas composition change with time produced by organisms in terrestrial soils are markedly different from changes caused by nonbiological phenomena.

Preliminary results from Mars operation have been presented elsewhere.16,17

Table VII. Pyrolytic release experiment summary of Mars surface operations. Each experiment sequence is described by the Viking mission status for start time, incubation and final data collection period mediate (geological peak) and the experiment identifying characteristics. Soils are a mixture of Mars dusts described since landing. Soils are a mixture of Mars dusts described since landing. Soils are a mixture of Mars dusts described since landing. Soils are a mixture of Mars dusts described since landing. Soils are a mixture of Mars dusts described since landing.

<table>
<thead>
<tr>
<th>Experiment description</th>
<th>Received soil</th>
<th>Sterilized or heat soil</th>
<th>Add water vapor</th>
<th>Begin 5 soil incubation</th>
<th>Collect biological peak, dpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lander 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface sample-active, light</td>
<td>8</td>
<td>27 (18°C)</td>
<td>No</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>Residual soil-control, light</td>
<td>24</td>
<td>27 (18°C)</td>
<td>No</td>
<td>27</td>
<td>54</td>
</tr>
<tr>
<td>Surface sample-control, light</td>
<td>36</td>
<td>27 (18°C)</td>
<td>No</td>
<td>91</td>
<td>98</td>
</tr>
<tr>
<td>Residual soil-water vapor and heat</td>
<td>160</td>
<td>160 (80°C)</td>
<td>Yes</td>
<td>160</td>
<td>167</td>
</tr>
<tr>
<td>Residual soil-active, light</td>
<td>230</td>
<td>160 (80°C)</td>
<td>Yes</td>
<td>230</td>
<td>227</td>
</tr>
<tr>
<td>Lander 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface sample-active, dark</td>
<td>8</td>
<td></td>
<td>No</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Surface sample-active, light</td>
<td>31</td>
<td></td>
<td>No</td>
<td>28</td>
<td>37</td>
</tr>
<tr>
<td>Residual soil-active, light</td>
<td>145</td>
<td></td>
<td>No</td>
<td>51</td>
<td>59</td>
</tr>
<tr>
<td>Surface sample-active, light</td>
<td>177</td>
<td>145 (85°C)</td>
<td>No</td>
<td>177</td>
<td>186</td>
</tr>
</tbody>
</table>

B. Experiment implementation

The soil sample is delivered to the test cell and sealed gas tight. Incubation gas and nutrient solution are added to the test cell and the temperature controlled above freezing but below 27°C. Gas analyses are periodically made of the cell headspace. At selected intervals the nutrient and incubation gas are replaced with fresh solution and gas. The soil can be thoroughly dried if a second soil is to be added to the single test cell. When desired the soil cell can be heated to sterilize the soil for a control experiment.

The basic design of the GEX experiment is shown in Fig. 15. The major components of the GEX module are described below.

The single test cell of 8.7-cm³ volume and dump cell both mounted at opposing positions on a carousel and Geneva wheel rotates to the soil load port and to the head end and lowered by a vertical actuator assembly. The head end assembly provides the cell seal, inlets for gas and nutrient, and valve S-19A to prevent condensation of water in the line between the head end and the gas chromatographic analysis instrument. The reservoir assembly contains the nutrient ampoule. This assembly is also equipped with two pistons that are actuated with high pressure helium to puncture the ends of the ampoule.

A gas chromatographic analysis assembly (GCAA) is used to analyze the cell headspace and is composed of a gas sample valve, a pair of matched 7.6-m by 0.1-cm i.d. columns packed with 100-120 mesh Porapak Q, and a thermistor thermal conductivity detector.

A gas reservoir contains a He/Kr/CO2 mixture used as the incubation gas. A gas reservoir (physically located on the labeled release experiment module) provides a gas mixture (He/O2/CO2) used to pretreat the columns after they have been exposed to space vacuum during the interplanetary voyage. Heaters are used to sterilize or dry the soil in the cell, if necessary, sterilize portions of the nutrient system, control the temperature of the cell, nutrient system, and lines exposed to water, and provide constant GCAA.
The lower part of the GEx module contains the gas chromatographic analysis assembly (GCAA) and the nutrient reservoir. The GCAA is a specialized gas chromatograph for the analysis of gases of biological interest. The basic requirements of the analysis system are listed in Table VIII.

| Gases separated | H₂, N₂, O₂, CH₄, Kr, CO₂ (CO and Ar are 99.999 % pure) |
| Resolution | 99% between peaks of 70 nM of N₂ and 7 nM of O₂ |
| Sample size | 10 μL |
| Sensitivity | Minimum detectable quantities in nM: H₂: 10, CH₄: 0.5, N₂: 0.25, O₂: 0.3, CO₂: 1.0 |
| Precision | 5% between 40 and 400 limits the minimum detectable quantity |
| Carrier gas purity | 99.999 % |
| Data sampling rate | Constant throughput chromatogram |

1. Chromatographic analysis system

The gas sampling system contains the largest deviation from typical laboratory operation. The usual laboratory gas sampling system is a six- or eight-port rotary gas sample valve. Pneumatic and electrical actuators are available for these valves. However, these devices had the drawbacks of being bulky and heavy. The flight system used a manifold of the mini-

**Table VIII. Gas chromatograph analysis requirements.**

- **Gases separated**: H₂, N₂, O₂, CH₄, Kr, CO₂ (CO and Ar are 99.999 % pure).
- **Resolution**: 99% between peaks of 70 nM of N₂ and 7 nM of O₂.
- **Sample size**: 10 μL.
- **Sensitivity**: Minimum detectable quantities in nM: H₂: 10, CH₄: 0.5, N₂: 0.25, O₂: 0.3, CO₂: 1.0.
- **Precision**: 5% between 40 and 400 limits the minimum detectable quantity.
- **Carrier gas purity**: 99.999 %.
- **Data sampling rate**: Constant throughput chromatogram.

---

**Fig. 16.** Gas exchange experiment module flow diagram. The module contains one test cell which receives soil and seeds at the head end. The components for contacting the soil incubation are shown in the lower portion of the diagram, and the lines, valves, columns, and detector of the gas chromatograph are in the upper portion.

A cross section of the GEx test cell and head end is shown in Fig. 17. The cell consists of two stainless steel cups with a total volume of 8.7 cm³. The inner cup receives the soil sample and has a bottom consisting of a 10-μm (nominal) pore size sintered stainless steel frit. The inner cup also has six small sintered stainless steel frits above the soil level to allow gases to equilibrate between the inner cell and the outer cell body. The nutrient is conducted to the bottom of the outer cell from the head end by a small stainless steel tube so that the nutrient does not contact the inner cup bottom frit (and hence the soil) until somewhat more than 1 cm³ of nutrient has been added. The inner cup is positioned such that when the nominal full amount of nutrient (2.5 cm³) has been added, the soil is not completely submerged, and is in contact with the bulk of the nutrient in the cell. The large excess of nutrient in the outer cell body acts as a reservoir to dilute metabolic products generated by any soil organisms which might otherwise interfere with continued growth and metabolism. When only humidification of the cell is desired, approximately 0.5 cm³ of nutrient is added by a 1-ml injection at a nominal flowrate of 0.5 cm³/min. The connections to the test cell are the cell drain line (0.32 cm o.d. Teflon tube), drain valve leads, and cell heater and sensor electrical leads. These lines are connected from the cell to the rest of the module via a trailing lead assembly. The trailing lead assembly contains a lead port and thermoelectric cooler, the cell seal, and a Kapton film heater. The drain line and valve are required so that the cell can be drained when desired prior to adding fresh nutrient or prior to drying the cell without opening the cell. The drain line leads to a sump and charcoal trap assembly which allows evaporation of water but retains organic compounds which might otherwise give false responses in the molecular analysis (gas chromatograph-mass spectrometer) experiments.

The head end assembly contains all of the lines which were not required to be connected to the cell itself. The lines leading into the cell via the head end are the nutrient line coming from valve S-22, the line providing incubation gas (from valves S-24 and S-25) and low pressure (1.2 bars) helium (from valve S-23), and the line leading to the gas chromatographic analysis assembly (GCAA). This line is closed at the head end with valve S-19A to prevent water from condensing in the line during the diurnal temperature variations. The placement of the GCAA with respect to the head end was determined by volume utilization requirements and the modularized design of the overall instrument. The head end also contains the heat pipe termination from the thermoelectric cooler, the cell seal, and a Kapton film heater which is used for the control heating. The nutrient valve block is heated to sterilization temperatures with a separate heater. Thermal control of the cell during incubation is achieved by heating with the module (can) heater mounted on the module structure or by cooling with the thermoelectric cooler and heat pipe as required. The cell temperature requirement during incubation is greater than 5°C and less than 27°C. For the control (sterilization heating), the head end and cell body are simultaneously heated to insure that no cold spots are present. The control heating requirement is 140°C minimum for the cell and head end. The nutrient line is heated during the control sterilization to 120°C minimum near the valve block. The valve block and surrounding area are heated to an average 130°C prior to all but the first nutrient injections.

---

**Fig. 17.** Cross section of the gas exchange experiment test cell showing the location of the soil in the suspended inner cup, and the nutrient volume which is filled from beneath the soil cup. The bottom of the cup is fitted stainless steel to allow the nutrient to reach the soil. Gas samples are taken by the gas chromatograph from the head-space above the soil.

**Fig. 18.** Gas exchange experiment gas chromatograph analysis assembly. The assembly consists of a gas sampling system, two gas chromatograph columns, and a thermal conductivity detector.
The gas chromatographic analysis assembly (GCAA) is a specialized gas chromatograph for the analysis of gases of biological interest. The basic requirements of the analysis system are listed in Table VIII.

The GCAA is basically a conversion to flight hardware of the chromatographic system used in the laboratory. The GCAA (Fig. 18) is 9 cm square by 6 cm high and consists of a gas sampling system, a pair of matched porous polymer head chromatographic columns, and a thermistor thermal conductivity detector. A 400 psi (27 bar) He tank and regulators in the common services module (discussed under common support elements). The detector data processing is carried out in the electronic subassembly (ESS).

The gas sampling system contains the largest deviation from typical laboratory operation. The usual laboratory gas sampling system is a six- or eight-port rotary gas sample valve. Pneumatic and electrical actuators are available for these valves. However, these devices had the drawbacks of being bulky and heavy. The flight system used a manifold of the mini-module (can) header mounted on the module structure or by cooling with the thermoelectric cooler and heat pipe as required. The cell temperature requirement during incubation is greater than 5°C and less than 27°C. For the control (sterilization heating), the head end and cell body are simultaneously heated to ensure that no cold spots are present. The control heating requirement is 140°C minimum for the cell and head end. The nutrient line is heated during the control sterilization to 120°C minimum near the valve block. The valve block and surrounding area are heated to an average 130°C prior to all but the first nutrient injections.

### Chromatographic analysis system

1. **Gas chromatography**

The lower part of the GEX module contains the gas chromatographic analysis assembly (GCAA) and the nutrient reservoir. The GCAA is a specialized gas chromatograph for the analysis of gases of biological interest. The basic requirements of the analysis system are listed in Table VIII.

The GCAA is basically a conversion to flight hardware of the chromatographic system used in the laboratory. The GCAA (Fig. 18) is 9 cm square by 6 cm high and consists of a gas sampling system, a pair of matched porous polymer head chromatographic columns, and a thermistor thermal conductivity detector. A 400 psi (27 bar) He tank and regulators in the common services module (discussed under common support elements). The detector data processing is carried out in the electronic subassembly (ESS).

The gas sampling system contains the largest deviation from typical laboratory operation. The usual laboratory gas sampling system is a six- or eight-port rotary gas sample valve. Pneumatic and electrical actuators are available for these valves. However, these devices had the drawbacks of being bulky and heavy. The flight system used a manifold of the mini-module (can) header mounted on the module structure or by cooling with the thermoelectric cooler and heat pipe as required. The cell temperature requirement during incubation is greater than 5°C and less than 27°C. For the control (sterilization heating), the head end and cell body are simultaneously heated to ensure that no cold spots are present. The control heating requirement is 140°C minimum for the cell and head end. The nutrient line is heated during the control sterilization to 120°C minimum near the valve block. The valve block and surrounding area are heated to an average 130°C prior to all but the first nutrient injections.

### Chromatographic analysis system

1. **Gas chromatography**

The lower part of the GEX module contains the gas chromatographic analysis assembly (GCAA) and the nutrient reservoir. The GCAA is a specialized gas chromatograph for the analysis of gases of biological interest. The basic requirements of the analysis system are listed in Table VIII.

The GCAA is basically a conversion to flight hardware of the chromatographic system used in the laboratory. The GCAA (Fig. 18) is 9 cm square by 6 cm high and consists of a gas sampling system, a pair of matched porous polymer head chromatographic columns, and a thermistor thermal conductivity detector. A 400 psi (27 bar) He tank and regulators in the common services module (discussed under common support elements). The detector data processing is carried out in the electronic subassembly (ESS).

The gas sampling system contains the largest deviation from typical laboratory operation. The usual laboratory gas sampling system is a six- or eight-port rotary gas sample valve. Pneumatic and electrical actuators are available for these valves. However, these devices had the drawbacks of being bulky and heavy. The flight system used a manifold of the mini-module (can) header mounted on the module structure or by cooling with the thermoelectric cooler and heat pipe as required. The cell temperature requirement during incubation is greater than 5°C and less than 27°C. For the control (sterilization heating), the head end and cell body are simultaneously heated to ensure that no cold spots are present. The control heating requirement is 140°C minimum for the cell and head end. The nutrient line is heated during the control sterilization to 120°C minimum near the valve block. The valve block and surrounding area are heated to an average 130°C prior to all but the first nutrient injections.

### Chromatographic analysis system

1. **Gas chromatography**

The lower part of the GEX module contains the gas chromatographic analysis assembly (GCAA) and the nutrient reservoir. The GCAA is a specialized gas chromatograph for the analysis of gases of biological interest. The basic requirements of the analysis system are listed in Table VIII.

The GCAA is basically a conversion to flight hardware of the chromatographic system used in the laboratory. The GCAA (Fig. 18) is 9 cm square by 6 cm high and consists of a gas sampling system, a pair of matched porous polymer head chromatographic columns, and a thermistor thermal conductivity detector. A 400 psi (27 bar) He tank and regulators in the common services module (discussed under common support elements). The detector data processing is carried out in the electronic subassembly (ESS).

The gas sampling system contains the largest deviation from typical laboratory operation. The usual laboratory gas sampling system is a six- or eight-port rotary gas sample valve. Pneumatic and electrical actuators are available for these valves. However, these devices had the drawbacks of being bulky and heavy. The flight system used a manifold of the mini-module (can) header mounted on the module structure or by cooling with the thermoelectric cooler and heat pipe as required. The cell temperature requirement during incubation is greater than 5°C and less than 27°C. For the control (sterilization heating), the head end and cell body are simultaneously heated to ensure that no cold spots are present. The control heating requirement is 140°C minimum for the cell and head end. The nutrient line is heated during the control sterilization to 120°C minimum near the valve block. The valve block and surrounding area are heated to an average 130°C prior to all but the first nutrient injections.
of the column assembly (and detector) is not required to be thick. The column heater is a film type applied to the interior of the mandrel, and is proportionally controlled between the column plug and the solder joint during use. The pneumatic connectors between the columns and control valves) for flow restriction of the instruments and shipment to Kennedy Space Center for installation into their respective Landers. The pneumatic connectors between the columns and control valves were used rather than a trapped volume. This restrictor was intended to seal the ampoule containing Ne/He gas above the nutrient when exposed to space vacuum. The nutrient was prepared at NASA's Ames Research Center under the direction of the GEX experiment scientist, V. I. Oyama, and provided to TRW for loading into the flight ampoules. All equipment used in loading which could contaminate the nutrient with microparticles was autoclaved prior to use. The ampoule loading operations were conducted in a glove jar under an atmosphere of flowing helium. The nutrient was contained in ampoules of 15 cm (13.5 cm3) minimum delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles. The nutrient system

The GEX nutrient is a complex aqueous solution whose composition is shown in Table IX. It is intended to provide essentially all factors which stimulate and sustain growth of various types of microorganisms withstanding the rigors of space flight. The nutrient is contained in a Pyrex glass ampoule similar to that used in the LR experiment except that the GEX ampoule is somewhat larger. The amount of nutrient in the ampoule is sufficient to supply an 80 cm2, 1 cm thick (15 cm3, 13.5 cm3 min delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles.

The nutrient was prepared at NASA's Ames Research Center under the direction of the GEX experiment scientist, V. I. Oyama, and provided to TRW for loading into the flight ampoules. All equipment used in loading which could contaminate the nutrient with microparticles was autoclaved prior to use. The ampoule loading operations were conducted in a glove jar under an atmosphere of flowing helium. The nutrient was contained in ampoules of 15 cm (13.5 cm3) minimum delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles. The nutrient was prepared at NASA's Ames Research Center under the direction of the GEX experiment scientist, V. I. Oyama, and provided to TRW for loading into the flight ampoules. All equipment used in loading which could contaminate the nutrient with microparticles was autoclaved prior to use. The ampoule loading operations were conducted in a glove jar under an atmosphere of flowing helium. The nutrient was contained in ampoules of 15 cm (13.5 cm3) minimum delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles. The nutrient was prepared at NASA's Ames Research Center under the direction of the GEX experiment scientist, V. I. Oyama, and provided to TRW for loading into the flight ampoules. All equipment used in loading which could contaminate the nutrient with microparticles was autoclaved prior to use. The ampoule loading operations were conducted in a glove jar under an atmosphere of flowing helium. The nutrient was contained in ampoules of 15 cm (13.5 cm3) minimum delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles. The nutrient was prepared at NASA's Ames Research Center under the direction of the GEX experiment scientist, V. I. Oyama, and provided to TRW for loading into the flight ampoules. All equipment used in loading which could contaminate the nutrient with microparticles was autoclaved prior to use. The ampoule loading operations were conducted in a glove jar under an atmosphere of flowing helium. The nutrient was contained in ampoules of 15 cm (13.5 cm3) minimum delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles. The nutrient was prepared at NASA's Ames Research Center under the direction of the GEX experiment scientist, V. I. Oyama, and provided to TRW for loading into the flight ampoules. All equipment used in loading which could contaminate the nutrient with microparticles was autoclaved prior to use. The ampoule loading operations were conducted in a glove jar under an atmosphere of flowing helium. The nutrient was contained in ampoules of 15 cm (13.5 cm3) minimum delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles. The nutrient was prepared at NASA's Ames Research Center under the direction of the GEX experiment scientist, V. I. Oyama, and provided to TRW for loading into the flight ampoules. All equipment used in loading which could contaminate the nutrient with microparticles was autoclaved prior to use. The ampoule loading operations were conducted in a glove jar under an atmosphere of flowing helium. The nutrient was contained in ampoules of 15 cm (13.5 cm3) minimum delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles. The nutrient was prepared at NASA's Ames Research Center under the direction of the GEX experiment scientist, V. I. Oyama, and provided to TRW for loading into the flight ampoules. All equipment used in loading which could contaminate the nutrient with microparticles was autoclaved prior to use. The ampoule loading operations were conducted in a glove jar under an atmosphere of flowing helium. The nutrient was contained in ampoules of 15 cm (13.5 cm3) minimum delivered volume) as compared to the maximum of 12 cm3 required for four experiment cycles.
of the column assembly (and detector) is not required because the amount of convection heat loss is small between the column plug and the solder joint during interplanetary cruise with the GCAA, it had this function. The column heater is a film type applied to the external surfaces of the ampoule to provide constant temperature circuit are greater stability. Furthermore, the detector can be operated for testing purposes in any environment and without the necessity of an earth airlock with any possibility of thermal stress on the beads.

The control of the thermometer is accomplished by the GEX low-level electronics (LLE) which is located in the electronic subsystem (ESS). The GEX LLE also provides for periodic reset of the baseline condition, and can change the output signal from the bridge so that the signal will match the input requirements of the analog to digital converter (A/D). The A/D is designed for positive only signals with a range of 5 mV (size of the smallest bit of the A/D) to 5 V, while the voltage range of interest from the detector bridge circuit is 0.005 to 50 mV. A range-switching amplifier with gains of either 100 or 1000 is used to bridge out 10,000 to 1000. In addition, the LLE amplifies the stability of negative signals, the output is offset from zero to 0.5 V at gain of 1000 and 0.05 V at gain of 100. The range of switching allows a total dynamic range of 10,000 to 5000. The low-flow rate used for the liquid interface of interest within the likely range of gas composition changes.

2. Nutrient system

The GEX nutrient is a complex aqueous solution whose composition is shown in Table IX. It is intended to provide essentially all factors which stimulate and sustain growth of various types of microorganisms without having to address any special types. The nutrient is contained in a Pyrex glass ampoule similar to that used in the LR experiment except that the GEX ampoule is somewhat larger. The amount of nutrient in the nutrient ampoules was 15 ml (13.5 cm x 13.5 cm x 13.5 cm) delivered volume as compared to the maximum of 12 cm³ required for four experiment cycles.

The nutrient was prepared at NASA Ames Research Center under the direction of the defeated nutrients. The nutrient solution can be adapted to any special needs. The nutrient was autoclaved prior to use. The ampoule loading operations were conducted in a glove jacket under an atmosphere of flowing helium. The nutrient was degassed by heating in a water bath and is contained in the Pyrex glass ampoule. The gas above the nutrient in the filled ampoule was analyzed to contain less than 1000 ppm air. The filled ampoule containing Ne/He gas above the nutrient was sealed by standard glass blower technique. The external surfaces of the ampoule were cleared to remove adsorbed helium prior to checking for helium leakage with a mass spectrometer leak detector. The helium was stored in 125 °C for 45 to 55 min and stored prior to installation into the GEX. Neon was sealed for the addition to the ampoule to act as a nutrient delivery diagnostic. Nutrient delivered in the test cell outgases dissolved neon which is then detected in the chromatographic analysis. A sealed ampoule present for the external leak check of the sealed ampoule.

The nutrient ampoules were inserted aseptically into the flight ampoule. All equipment used in loading which was added late in the design of the instrument and was not intended to seal the columns during interplanetary cruise. The nutrient ampoules were inserted aseptically into the flight ampoule. All equipment used in loading which was added late in the design of the instrument and was not intended to seal the columns during interplanetary cruise.

The column pretreatment (rejuvenation) gas reservoir was added late in the design of the instrument and is physically located on the LR module. The initial design of the GCAA, it had been intended to seal the columns during interplanetary cruise with the GCAA valves to prevent exposure to space vacuum. Later, during the development program it was determined that leaving these valves sealed for about 1 year was unnecessary because the pressure of valve sealing. Laboratory testing indicated that exposure of the columns to space vacuum resulted in certain reversible adsorption phenomena which caused partial loss of the sample in the initial chromatograms after vacuum exposure. Testing also indicated that the problem could be corrected by exposing the columns to a CO₂/O₂ gas mixture in a He cabinet. To the extent of the columns for analysis. Preliminary testing with accelerated exposure at elevated temperatures and long-term vacuum exposure tests verified the efficiency of this rejuvenation process.

C. GEX experiment operation

Because the biology sequencer is addressable, a high degree of flexibility in experiment operation through commands from Earth is possible. However, the ex-
and S-21 are closed and S-20 reopened. The sample is actually occurred.

The cell head space in the O. II-cm loop volume with a the sample column with S-15 closed. This sample is between S-18 and S-19 and the gas between S-19 and S-18 closed, sampling of the cell head space is carried S-18. This is done twice and the second time S-18 re- space gas (including the gas in the line between S-19 and does meet it closely enough to allow accurate recon­struction of the sampled data. The peak shapes produced by the GEx experiment are close approximations to a Gaussian profile and Gaussian peaks have suitable characteristics for reconstruction because of rapid convergence (due to the exponential factor) in both the time and frequency domains.

In the case of an ideal Gaussian distribution, a sampling interval equal to the standard deviation of the Gaussian in the time domain is adequate for accurate peak reconstruction. In the case of the GEx experiment, the sampling interval is 1 s, which means that peaks with full-width at half-maximum greater than 2.36 s cannot be reconstructed with better than 1% accuracy. The GEx peak widths vary from approximately 3 s (H2 and N2) to 15 s (CO2), which easily satisfies the requirement. There are a number of other factors involved in the flight hardware system. Baseline drift does not interfere with the reconstruction process of experimentally chromatograms since any sampling rate adequate to model the response of the analyte. For the sake of clarity, in S-18 closed, sampling of the cell head space is carried out by opening S-19. The reason the He/Kr/CO2 in­ indicator is that the helium acts as a pressurant so that the cell pressure will always be significantly higher than Martian ambient pressure. After S-19 and S-19A have been opened 1 min, they are closed and S-18 is opened for 1 min. The loop fill and venting is repeated and a final third loop fill is made. This traps a representative sample of the cell head space in the 0.1-cm loop volume with a total consumption of approximately 0.5 cm head space gas (including the gas in the line between S-19 and S-19A) which is vented prior to the next analysis.

After the sampling procedure is complete, valve S-21 is opened to pressurize the loop, and 1 min later valve S-20 is closed simultaneously with the opening of valve S-17 to sweep the sample into the active column. When the test cell but also on the total cell pressure. The response depends not only on the component partial pressure in the test cell but also on the total cell pressure. The magnitude of the effect was insignificant at test cell pressures in the range of 1 bar, but at pressures in the 100-millibar range (which is the lower end of the nominal test cell pressure range) the response was as much as 20% lower than predicted. This effect is thought to be caused by excessive restriction in the sample loop outlet restrictor assembly which prevents complete venting of He from the sample loop and line from the cell to the GCAA during the loop and line pressurization and venting which normally precedes sample acquisition (conducted to prevent any carryover of sample trapped in the line from one analysis to the next). This effect has been corrected for actual mission operations by the use of data obtained during instrument diagnostic testing and sequence changes to maintain the cell at somewhat higher than usual pressures (usually above 600 mbars). Since the incubation gas contains Kr as an internal standard, this pressure dependent effect has little impact on measuring changes in gas concentra­ tion in the cell in those samples that are referenced to the Kr peak. The correction is of importance only when absolute quantities are desired, as in determining the amount of O2 evolved from the soil after humidification.

Independent of the above effects, the results must also be corrected for the amount of gas removed from the cell by each analysis. The fractional amount removed per sample depends on the actual head space volume in the cell which in turn depends on the amount of soil and nutrient present in the cell. Typical

1. A pressure dependence was found at the instrument level that did not exist during the GCAA component tests. This pressure dependence is such that the response depends not only on the component partial pressure in the test cell but also on the total cell pressure. The magnitude of the effect was insignificant at test cell pressures in the range of 1 bar, but at pressures in the 100-millibar range (which is the lower end of the nominal test cell pressure range) the response was as much as 20% lower than predicted. This effect is thought to be caused by excessive restriction in the sample loop outlet restrictor assembly which prevents complete venting of He from the sample loop and line from the cell to the GCAA during the loop and line pressurization and venting which normally precedes sample acquisition (conducted to prevent any carryover of sample trapped in the line from one analysis to the next). This effect has been corrected for actual mission operations by the use of data obtained during instrument diagnostic testing and sequence changes to maintain the cell at somewhat higher than usual pressures (usually above 600 mbars). Since the incubation gas contains Kr as an internal standard, this pressure dependent effect has little impact on measuring changes in gas concentra­ tion in the cell in those samples that are referenced to the Kr peak. The correction is of importance only when absolute quantities are desired, as in determining the amount of O2 evolved from the soil after humidification.

Independent of the above effects, the results must also be corrected for the amount of gas removed from the cell by each analysis. The fractional amount removed per sample depends on the actual head space volume in the cell which in turn depends on the amount of soil and nutrient present in the cell. Typical
ﮭ٨١ ٢-٨-٠، ٢-٢٢ ٩٧٧٨

The details of a chromatographic analysis of the test cell gas are as follows. First, the column and detectors are heated to their operating temperatures prior to initiating a carrier gas flow. Time of day constraints on the analysis insure that it is conducted when the environment is cool enough to allow proper control of the temperatures. Before sampling the cell head space, the gas in the sample loop between S-18 and S-19 and the gas between S-19 and S-19A are removed by pressurizing the volume with 9.2-bar psi helium from S-21 and venting through S-18. This is done twice and the second time S-18 remains open for 1 min to assure that proper venting of the sample loop with S-18 closed, sampling of the cell head space is carried out by opening S-19. The reason the He/kr/CO₂ mix is closed between S-18 and S-19 closed, sampling of the cell head space is carried out by opening S-19. The reason the He/kr/CO₂ mix is closed between S-18 and S-19 is that the helium acts as a pressurant so that the cell pressure will always be significantly higher than Martian ambient pressure. After S-19 and S-19A have been open 1 min, they are closed and S-20 is opened for 1 min. The loop fill and venting is repeated and a final third loop fill is made. This traps a representative sample of the column head space in the 0.11-cm³ loop volume with a total gas volume of approximately 0.5 cm³ of head space gas (including the gas in the line between S-19 and S-19A which is vented prior to the next analysis). After the sampling procedure is complete, valve S-21 is opened to pressurize the loop, and 1 min later valve S-20 is closed simultaneously with the opening of valve S-17 to sweep the column into the isochromatogram. When 8.2 s (using a special timing circuit) later S-17 and S-21 are closed and S-20 reopened. The sample is swept through the column where it is separated into the individual components which are detected by the thermal conductivity detector. The loop is pressurized with 9.2-bar He prior to opening valve S-21 to minimize any high-pressure column spike due to S-17 which would occur if S-17 was opened with high pressure in the column and low pressure in the loop. The applied detector signal from the GEx low-level electronics is sampled once per second during the 16-mi chromatogram producing 960 data points which are transferred to the Lander memory for transmission to Earth. The chromatogram is then reconstructed by computer from the received data points.

It is known that a signal can be reconstructed with zero error from samples taken at a continuous rate equal to 2.5 s provided that no frequency components exist at a frequency higher than 0.5 (the Nyquist frequency). While this requirement is not completely satisfied by the biological instrument chromatographic data, the method do meet it closely enough to allow accurate reconstruction of the sampled data. The peak shapes produced by the GEx experiment are close approximations to a Gaussian profile and Gaussian peaks have suitable characteristics for reconstruction because of rapid converge (due to the exponential factor) in both the time and frequency domains.

In the case of an ideal Gaussian distribution, a sampling interval equal to the standard deviation of the Gaussian in the time domain is adequate for accurate peak reconstruction. In the case of the GEx experiment, the sampling interval is 1 s, which means that peaks with full-width at half-maximum greater than 2.36 can be reconstructed with better than 1% accuracy. The GEx peak widths vary from approximately 3 s (H₂ and N₂) to 15 s (CO₂) which easily satisfies the requirement.

A side effect of the sampling interval is that there are a number of other factors involved in the flight hardware system. Baseline drift does not interfere with the reconstruction process of experimental chromatograms since any sampling rate adequate to satisfy the Nyquist rate will suffice. Baseline noise is not well characterized because the noise bandwidth is large in comparison with the Nyquist frequency. However, reconstruction of the baseline noise is not at all important in the chromatographic data. Peak tailing effects do not interfere since they tend to increase the effective peak time constant. Column overloading can cause distorted peaks with a rapidly rising leading edge which is not well reconstructed. This effect is relatively small and does not occur in the normal range of peak heights observed with the GEx experiment.

Figure 19 shows a chromatogram from above a Martian soil sample. It is constructed from once per second data. The data shown here is the first gas analysis taken from above the Martian soil after exposure to water vapor (Lander 1, 97, July 29, 1976).

\[ \text{Fig. 19. Chromatogram reconstructed from once per second data. The data shown here is the first gas analysis taken from above the Martian soil after exposure to water vapor (Lander 1, 97, July 29, 1976).} \]
values are 6.5% removal per analysis for a humidified cycle and 9.8% per analysis for a nominal case with 2.5 cm\(^2\) of nutrient injected. Again, the internal standard Kr peak is used to provide the correction.

While the instrument was not designed with the intent to conduct Martian atmospheric analyses as one of the design criteria, there are in fact several ways by which an atmospheric sample can be acquired and analyzed. One simple method is to open valve S-18 for a period long enough (several hours are used in practice) to attain equilibrium between the loop volume and the atmosphere. When the valve is opened, the pressure rises to about 150 millibars at this point. Later in the incubation cycle, the soil is humidified for a time with only 0.5% of nutrient added. The test cell pressure is adjusted to 1.2 bars with the low-pressure He supply to maintain it at a constant pressure.

The deep soil chemistry cycle was performed properly but no useful data were obtained due to the low Martian atmospheric pressure and the small volume of the sample loop. A redesigned system based on the GEx GCAA has been developed specifically for atmospheric analyses on the Pioneer Venus large probe scheduled for launch in 1978.

**D. GEx experiment sequence**

For the primary mode of test cell analyses, the spacing of analyses is such that they are usually carried out at intervals of one day immediately after nutrient injection to monitor any rapid initial changes. Then the spacing is increased with increasing incubation time since any gas changes occurring later in the incubation usually have a slower rate. This spacing provides adequate monitoring for gas changes while minimizing the number of analyses required. A total of 52 gas analyses was run on Lander 1 and 57 on Lander 2 (Table X).

A block diagram presentation of the major elements of the GEx sequence is shown in Fig. 20. In the first incubation cycle, the soil is humidified for a time with only 0.5% of nutrient added. The test cell pressure is about 150 millibars at this point. Later in the first incubation cycle, 2 cm\(^3\) of nutrient is added to start a typical "active" cycle incubation with the nutrient in contact with the soil and the cell pressure rises to approximately 200 millibars. On the second and all subsequent nutrient injections, the nutrient valve block and line from the soil valve to the head end are heated to approximately 145°C for 3 h to prevent any Martian microorganisms, if present, from migrating through the valve and possibly contaminating the nutrient in the reservoir.

After a period of incubation (whose duration is controlled from Earth), the cell is drained by pressurizing the cell to 1.2 bars with the low-pressure He supply and then opening drain valve S-27 for 1 min. This pressurization is repeated and S-27 is closed. Fresh incubation gas and nutrient are injected, starting another incubation cycle. The basic GEx concept is the repeated incubation of one soil sample in order to provide opportunity for a growth response to occur and to help differentiate between biological and purely chemical responses. The system does have the capability of taking a second soil sample on top of the first in the single test cell if desired. The nutrient system was designed for four complete incubation cycles with the nominal amount of deliverable nutrient being about 13.5 cm\(^3\) as compared to the amount used in one incubation cycle of 2.5 ± 0.5 cm\(^3\). If desired, a control incubation can be performed by first drying the soil and cell with flowing He while heating the cell and then sterilizing the soil by heating the closed cell at 150°C for 3 h. After cooling the cell and purging, soil gas and nutrient are added, and the incubation and gas analyses conducted as before. A summary of the sequence as run on both Landers on Mars is given in Table IX.

The cell must be dried prior to opening the test cell to acquire the first soil sample of that as described. If the soil is not fully dry on cell opening, exposing the contents to Martian pressure, it could erupt because of rapid water volatilization and soil particles deposited on the cell seal could cause sufficient leakage to prevent subsequent successful incubation gas retention. The soil drying can be performed by either heating the cell in a He purge flow, or by maintaining incubation temperature while leaving the drain valve open a sufficient length of time (after an initial purge to remove the bulk of the nutrient).

Whenever nutrient is drained from the cell it is decontaminated in a variety of different ways. The common services module where it is slowly evaporated through a charcoal trap. In this manner the nutrient organic matter is retained in the sump or held on the charcoal to prevent organic contamination of the soil yet to be acquired from the surface and analyzed by the molecular analysis (GCMS) instrument. A test of the GEx experiment performance was conducted on Earth utilizing a complete instrument whose configuration was very nearly like the instruments now on Mars. The GEx results for that test which consisted of one humidified cycle, the wet mode, and one sterilized soil wet mode are given in Fig. 21. Evidence for biological activity is not seen until after simulated Martian day 22 when CO\(_2\) and N\(_2\) are seen to increase and H\(_2\) appears after the instrument has been exposed to room temperature for 7 days for repair. The conclusion that the gas changes are due to biological activity is reinforced by the dramatic CO\(_2\) and H\(_2\) increase in the third wet mode cycle. Final confirmation of biological activity is made in the sterilized soil mode where the previous vigorous gas evolution ceases. The soil used in this test was the Alken soil described in Sec. V D.

Each point in the graph of Fig. 21 represents the results of one gas analysis performed on the gases above the incubating soil. Only one krypton point is given at the beginning of each new mode because the krypton
values are 6.5% removal per analysis for a humidified sample and 8.8% per analysis for a nominal case with 2.5 cm$^3$ of nutrient injected. Again, the internal standard Kr peak is used to provide the correction.

While the instrument was not designed with the intent to conduct Martian atmospheric analyses as one of the design criteria, there are in fact several ways by which an atmospheric sample can be acquired and analyzed. One simple method is to open valve S-18 for a period long enough (several hours are used in practice) to obtain equilibrium between the loop volume and the atmosphere as if the diffusor. Valve S-18 is then closed, and the GCAA warmed and column flow established and the sample injected. The system is sufficiently sensitive that N$_2$ and O$_2$ can be detected down to approximately 0.25% for N$_2$ and 0.5% for O$_2$ despite the low Martian atmospheric pressure and the small volume of the sample loop. A redesigned system based on the GEX GCAA has been developed specifically for atmospheric analyses on the Pioneer Venus large probe scheduled for launch in 1978.

D. GEX experiment sequence

For the primary mode of test cell analyses, the spacing of analyses is such that they are usually carried out at intervals of one day immediately after nutrient injection to monitor any rapid initial changes. Then the spacing is increased with increasing incubation time since any gas changes occurring later in the incubation usually have a slower rate. This spacing provides adequate monitoring for gas changes while minimizing the number of analyses required. A total of 52 gas analyses was run on Lander 1 and 57 on Lander 2 (Table X).

A block diagram presentation of the major elements of the GEX sequence is shown in Fig. 20. In the first incubation cycle, the soil is humidified for a time with only 0.5 cm$^3$ of nutrient added. The test cell pressure is about 150 millibars at this point. Later in the first incubation cycle an additional 2 cm$^3$ of nutrient is added to start a typical “active” cycle incubation with the nutrient in contact with the soil and the cell pressure rises to about 200 millibars. On the second and subsequent nutrient injections, the nutrient valve block and line from the valve to the heat end are heated to approximately 145°C for 3 to 6 prevent any Martian microorganisms, if present, from migrating through the valve and possibly contaminating the nutrient in the reservoir. After a period of incubation (whose duration is controlled from Earth), the cell is drained by pressurizing the cell to 1.2 bars with the low-pressure He supply.

<table>
<thead>
<tr>
<th>Experiment description</th>
<th>Soil received, cm$^3$</th>
<th>Heat soil to 145°C, cm$^3$</th>
<th>Begin experiment cycle, cm$^3$</th>
<th>Drain cell, cm$^3$</th>
<th>No. of gas analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lander 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extended active incubation</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>9</td>
<td>29</td>
<td>68</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Wet mode #1</td>
<td>29</td>
<td>68</td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Wet mode #2</td>
<td>68</td>
<td>103</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #3</td>
<td>90</td>
<td>216</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen release test</td>
<td>230</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>312</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>271</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep acquisition soil chemistry</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>271</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil dried</td>
<td>271</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lander 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface soil active</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #1</td>
<td>17</td>
<td>36</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #2</td>
<td>17</td>
<td>36</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedrock soil active</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #1</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #2</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedrock soil active</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen release test</td>
<td>255</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>377</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>178</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #1</td>
<td>178</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #2</td>
<td>178</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>178</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil dried</td>
<td>178</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lander 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface soil active</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #1</td>
<td>17</td>
<td>36</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #2</td>
<td>17</td>
<td>36</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedrock soil active</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #1</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet mode #2</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedrock soil active</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry mode</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid mode</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The cell must also be dried prior to opening the test cell to acquire a second soil sample of that as described. If the cell is not fully dry on cell opening, exposing the contents to Martian pressure, it could erupt because of rapid water volatilization and soil particles deposited on the cell seal could cause sufficient leakage to prevent subsequent successful incubation gas retention. The soil drying can be performed by either heating the cell in a He purge flow, or by maintaining incubation temperature while leaving the drain valve open a sufficient length of time (after an initial purge to remove the bulk of the nutrient).

Whenever nutrient is drained from the cell it is deposited in a sample collection module from the soil to be acquired from the surface and analyzed by the molecular analysis (GCMS) instrument. A test of the GEX experiment performance was conducted on Earth utilizing a complete instrument whose configuration was very nearly like the instrument now on Mars. The GEX results for that test which consisted of a humid mode, a dry mode, and one sterilized soil wet mode are given in Fig. 21. Evidence for biological activity is not seen until after simulated Martian day 22 when CO$_2$ and N$_2$ are seen to increase and H$_2$ appears after the instrument has been exposed to room temperature for 7 days for repair. The conclusion that the gas changes are due to biological activity is reinforced by the dramatic CO$_2$ and H$_2$ increase in the third wet mode cycle. Final confirmation of biological activity is made in the sterilized soil mode, where the previous vigorous gas evolution ceases. The soil used in this test was the Aiken soil described in Sec. V D.

Each point in the graph of Fig. 21 represents the results of one gas analysis performed on the gases above the incubating soil. Only one krypton point is given at the beginning of each new mode because the krypton
which meters out small soil samples to the three experiment modules, along with the common services module which supplies power, heaters, and limit switching heater controllers, thermal isolation valve drivers, xenon-valve driver matrix, a four-phase stepper motor controller, and a heater prgorimeter.

Some electronics are located in the MSS in order to reduce susceptibility to generation of EMI. This includes the low level circuitry for the "C" detectors, two electronic thermostat heater controllers, and the starting circuitry for the xenon lamp.

A. Electronic subsystem description

1. Power distribution and conditioning

The power conditioning is performed in the A1 slice. The instrument receives power from three buses on the Lander. They are:

(a) Bio operate. This power bus supplies the primary power for the instrument. It is turned on after landing and provides for all power, except for the cruise/down-mode heaters and the thermo-electric coolers and has a voltage range of 24–37 V.

(b) Bio thermal. This power bus is applied to the instrument after launch and is used exclusively for temperature control of items that must be controlled when bio operate power is not available.

(c) Bio emergency. This bus will be turned on only in case there is a Lander power drop-out during the landed mission. The bus provides a power pulse which is used to close off the common services helium system and disable the power supply to the thermo-electric coolers.

The circuits are the primary power supply, the current limit, protective power supply, and the xenon lamp power supply. This slice also contains the magnetic core circuit, a precise timer, the xenon lamp driver, and the two electronic thermostat (bang-bang limit switching heater controllers). The heater controllers, which are located in the A1 slice for packaging convenience, are discussed in the heater control section. The remaining A1 slice circuits are discussed below.

Primary power supply. The primary power supply consists of a switching regulator and a 20-kHz power converter. The switching regulator produces a regulated +5 V from the bio operate bus. Its frequency of operation is determined by the load demand of the system and can rise to a maximum of 100 kHz to reduce the size of the switching regulator. The switching regulator takes its feedback from a separate winding on the converter. This feedback system is able to maintain constant flux in the output transformer of the converter.

The 20-kHz converter uses a two-transistor oscillator-based output power amplifier. The output of the oscillator is directly proportional to the +5 V output from the switching regulator. The output transformer of the switching regulator is the winding which provides drive for a square-wave power amplifier. This latter circuit uses the +5-V output from the switching regulator as a power source, and provides three sets of output voltages: one set of four voltages has a floating return and is used within the ESS, and a separate +5-V output which is the control voltage for the regulator.

Master reset. The master reset logic (MROI) is used throughout the ESS to initialize the system. This logic signal is generated by a voltage comparator which senses the +5-V output of the primary power supply and thus the MROI reset signal is produced whenever bio operate power is present. This signal resets all of the logic and causes all the system switches and latching relays to go to a known state.

In-situ operation. When the lander bus, a 2A1 transistor is in series with the bio operate line to reduce filter in-rush current during the initial power turn-off. The circuit uses the MROI reset signal to short the resistor with a latching relay contact 100 ms after power is applied. When the bio operate bus is removed, the relay is reset so that the 2A1 transistor will be in the correct state when the power is reapplied. A special relay driver, powered by the bio thermal bus is triggered by a phototransistor in an optical coupler which responds to a light signal generated by a "voltage-going-down" circuit on the bio operate line.

Illumination control power supply. The illumination control power supply takes power from the bio operate bus and provides power to the xenon lamp in the PR illuminator assembly. The lamp is part of the pyrolytic release instrument and provides simulated sunlight for photosynthetic incubation. In this circuit, a variable-frequency-chopper regulator controls the current drawn by the lamp. The control circuit error amplifier also accepts the lamp voltage as an input and adjusts the error signal so that the lamp current level such that lamp power is nominally constant (within 5%) over the entire operating range.

Lamp ignition is accomplished by supplying a voltage of 110 V or 17.5–80 V to the lamp while the lamp supply is also attempting to draw high current through the lamp. This sustains lamp ignition and the
VIII. COMMON SUPPORT ELEMENTS

The Biology Instrument is packaged in two as-
semblies: the electrical subsystem (ESS) and the me-
chanical subsystem (MSS). The MSS contains the three ex-
periments previously described and common support ele-
ments for the experiments. All elements of the MSS oc-
cupy a space of less than 16 500 cm³ (19.8 × 27.7 × 30.0 cm³). The contents of this small package include:
- 8 experiment test cells, 4 geared stepper motors, 6 thermally actuated isolation valves, 56 catching solenoid valves, 5 supplies of nutrients or special gases, 1 regulated helium supply, 2 nuclear detection subsystems, 1 dual column gas chromatograph, 1 soil distributor assembly, 1 xenon arc lamp, 4 heater ele-
ments, 4 thermoelectric coolers and heat pipes, 1 high-
pressure pure helium gas supply, and 3 Geneva drive mechanisms for the test cell carousel. Additionally, there are traps, ramps, plumbing, wiring, and all other elements needed to implement the three biological experiments. The MSS is physically arranged as a group of se-
parable and interchangeble assemblies, each of which were assembled and tested independently. These major assemblies consist of the following:

1. Three experiment modules (labeled release, pyrolytic release, and gas exchange);
2. A common services module (CSM);
3. A soil distribution assembly (SDA);
4. An interface module that attaches to the Viking Lander (the upper mounting plate assembly);
5. A pyrolytic release illuminator assembly (xenon lamp);
6. A nuclear detector module with its electronics.

After each of the above major assemblies have been tested, they are integrated to form a complete MSS. Because of the similarity of thermal control requirements, the experiment modules are grouped together along with the common services module which supplies pressurized pure gas to the experiment modules. The SDA, which meters out small soil samples to the three experiments, is suspended from the interface module (the upper mounting plate assembly) by an array of thin titanium struts that provide thermal isolation and struc-
tural support.

The interface module includes the illuminator as-
sembly which contains a xenon arc lamp to illuminate the soil in the PR experiment test cell, and a series of thermoelectric cooler modules to maintain experiment illumination temperature in the case of a "hot" landing site. The addition of the detector module completes this part of the mechanical assembly.

The ESS provides the power conditioning, data handling/conversion and storage, and the electrical and elec-
tromechanical control. A functional block diagram of the ESS is shown in Fig. 22. As can be seen from the figure, the ESS is made up of six major subsystems: the electrical subsystem, the control/monitoring and limit switching heater controllers, thermal isolation valve drivers, xenon valve driver matrix, a four-phase stepper motor controller, and a heater preregulator.

Some electronics are located in the MSS in order to reduce susceptibility to generation of TEM. This in-
cludes the low level circuitry for the 14C detectors, two electronic thermostat heater controllers, and the steering circuitry for the xenon lamp.

A. Electronic subsystem description

1. Power distribution and conditioning

The power conditioning is performed in the A1 slice. The instrument receives power from three buses on the Lander. They are:

- (1) Bio operate: This power bus supplied the primary power for the instrument. It is turned on after landing and provides for all power, except for the cruise/land-
mode heaters and the thermo-electric coolers and has a voltage range of 24–37 V.
- (2) Bio thermal: This power bus is applied to the instrument after launch and is used exclusively for temperature control of items that must be controlled when bio operate power is not available.
- (3) Bio emergency: This bus will be turned on only in case there is a Lander power drop-out during the loaded mission. The bus provides a power pulse which is used to close off the common services helium system and disable the power supply to the thermo-electric coolers.

The circuits are the primary power supply, the current brush limiter, thermoelectric power supply, and the xenon lamp power supply. This slice also contains the master control circuit, the stepper motor and latch controller, and two electronic thermostat modules (bang-bang limit switching heater controllers). The heater controllers, which are located in the A1 slice only for packaging convenience, are discussed in the thermal control section.

The remaining A1 slice circuits are discussed below.

Primary power supply. The primary power supply consists of a switching regulator and a 20-KHz power converter. The switching regulator produces a regulated +5 V from the bio operate bus. Its frequency of opera-
tion is determined by the load demand of the system and can rise to 100 kHz to maintain +5-V power the converter. The switching regulator takes its feedback from a separate winding on the converter. This feedback control is a square-wave power amplifier. This latter circuit uses the +5-V output from the switching regulator as a power source, and provides three sets of output voltages: one set of four voltages has a floating return and is used within the ESS, and a separate +5-V output which is the control voltage for the preregulator.

Master reset. The master reset logic (MR01) is used throughout the ESS to initialize the system. This logic is generated by an electronics circuit which senses the +5-V output of the primary power supply and thus the MR01 reset signal is produced whenever bio operate power is applied to the instrument. This signal resets all of the logic and causes all the system supplies and latching relays to go to a known state.

In case there is a Lander power drop-out during the loaded mission, a 24-V power bus, a 24-V resistor is in series with the bio operate line to reduce filter in-rush current during the initial power turn-off. The circuit uses the MR01 reset signal to short the resistor with a latching relay contact 100 ms after power is applied. When the bio operate bus is re-
moved, the relay is reset so that the 24-V resistor will be in the circuit when power is reapplied. A special relay driver, powered by the bio thermal bus is triggered by a photoelectric-optical switch which responds to light pulse generated by a "voltage-going-down" circuit on the bio operator line.

Illumination control power supply. The illumination control power supply takes power from the bio operate bus and provides power amplification to drive lamp in the PR illuminator assembly. The lamp is part of the pyrolytic release experiment and provides simulated Martian sunlight for photosynthetic incubation. In this circuit, a variable-frequency-chopper regulator controls the current drawn by the lamp. The control circuit error amplifier also accepts the lamp voltage as an input and generates a control signal whose duty cycle is such that lamp power is nominally constant (within 5%) over the entire operating range.

Lamp ignition is accomplished by supplying a voltage of 117 V at 7.5–8.0 kHz to the lamp while the lamp supply is also attempting to draw high current through the lamp. This sustains lamp ignition and the
lump voltage and current then drop to low steady state values. A "lump on" signal is generated during normal lump operation for use within the logic circuits and for telemetry. Should the lump extinguish inadvertently, bursts of eight lumps per second pulses are applied at 30 ms intervals until it restarts.

Thermoelectric cooler power supply. The thermoelectric circuitry controls the operation of the Peltier effect coolers when the main MCP is powered through the PZT cells during the hot portion of the Martian sol. The four coolers are operated in series by one control circuit. Temperature sensing is accomplished by a single thermistor, located on the GE-X FET end. The temperature of the Peltier element is measured by the control circuit and temperature controller. The temperature controller then modulates the power supply to maintain the desired temperature in the MSS.

The control logic for the thermoelectric controller enables or disables the circuit on command from the Lander. Coolers that are not called upon are driven into a noninterference basis. The circuits within this slice are sequenced to use the common circuits within the ESS on a noninterference basis with the other data requested by the sequencers. The sequencers are controlled by commands from the command processor. After the memory receives its data from two sources. The first is a parity bit for the 16-bit command word, and is not used, or one as required to achieve odd parity. For the commands which provide access to one or another of the memory circuitry, a special "flag" bit is used to identify the effect of some sequencer commands, and bits 11-18 contain a sequencer address of a subroutine which is being called into execution. The pattern of bits 10-11 is sent to the sequencer for its reference module sequencer when the appropriate command signals are decoded from the command subfield. A separate flag bit at the top of the command header is used to notify the biology instrument when it is to expect this address.

The biology instrument is supplied with a stable 288-kHz clock from the Lander. The instrument uses this clock to derive all of its internal timing, since no higher clock rate than the 288 kHz is required by the instrument, all timing clocks are produced by synchronous division of the Lander clock. The master clock generator produces 14 separate clock lines for the master control function, and a master clock, output FET switch is controlled by the output of the master clock generator. The master clock generator is used to control the pulse width modulation circuits of the th".

Figure 23: Electrical subsystem simplified sequencer flow diagram

Command or when the memory is three quarters full. In read mode, the memory first generates a pseudo-random synchronization word and instrument ID for Lander data and frame data (frame number and number of words in memory) and then transmits the memory contents (first in, first out) to the Lander (DAPU). When empty, the memory reverts to the standby mode. In standby mode, a counter within the data select control function continually scans the write-cycle request lines and read-cycle lines looking for results.

The operation and composition of the three sequencers is similar, each using microprogramming for operational control. The microprogramming is performed with the use of 256 x 10 MOS read-only memories (ROMs). The GEXs and LR sequencers use three ROMs and the PR sequencer uses four. The ROMs for each sequencer are parallel addressed and thus provide 256 discrete program steps (words). Each program step provides 30 bits of information (40 bits for PR), which when decoded are used to control the internal operation of the sequence and provide event signals to the instrument. Events are command signals produced by the sequencers which cause valve operation, heater switching, etc. Each program step is subdivided into two microinstructions. The first is 10 bits long (one ROM output) and is used directly to provide time information for the sequencer. This instruction determines the time interval between successive events and has a range of 1-1024 min. The second microinstruction of each program step contains both control and event information as described below. This instruction contains 20 bits of information (30 bits for PR) and is decoded to produce the required signals.

A simplified signal flow diagram of one of the experiment sequencer is shown in Fig. 23. The sequencer operation is initiated with the receipt of an access command from the command processor. The command is 9 bits long with 8 bits being the ROM address, and the ninth being a "flag." The command is parallel loaded into the ROM address register thus providing access to any subroutines that may be stored within the ROMs. The sequencer control circuitry is then activated and the address register is incremented by one count and time counter is reset to zero. The outputs of the event ROMs are then decoded and strobed to produce the event and control signals. If a sequencer disable signal is decoded, the sequencer immediately shuts down. When the sequencer is disabled, it remains dormant until a new access command is received. If the event word (second microinstruction) does not contain a disable command, the information it contains is decoded and these events are sent to the system. After the events are initiated, the timer counter is incremented by 1 bit and a delay occurs, typically 1 min. The 1-min delay is the period of the 1 ppm (100 ms) clock the sequencer uses for its time base. After the delay, the output of the time ROM (first microinstruction) is compared with contents of the time counter. If they are not the same, the time counter is incremented by 1 min and the 1-min delay occurs. The time comparison loop cycles until the output of the time ROM matches the time counter content. When this occurs, the sequencer sends an event signal to the next event to occur. The sequencer proceeds to increment the address register and continues to process the next instruction. The sequencer will continue to operate in this manner until it finishes the subroutine and disables itself, or is commanded by the Lander to stop or change subroutines. Each sequencer also has a data subroutine which it calls on for data retrieval stored within the ROMs.

Temperature measuring resistor amplifier. Six temperature bridges, using platinum thermometer sensors, are monitored sequentially through analog EFT switches, amplified and sent to the A/D for processing. Selection of the desired bridge and temperature range is determined by input commands received from the sequencers. At the same time, the output EFT switch is activated to select the appropriate bridge signal to transfer it to the A/D converter.

The temperature range monitored is from 20°C to 70°C. The temperature ranges monitored are 20°C to 20°C for instrument temperature measurements and 500°C to 780°C for PR activities.
The temperature set point (+12°C) is a control signal which is used to accumulate the pulses produced by the instrument. The memory stack contains the 16-bit command word of the command holding register, which are then decoded and strobed to produce the event and control signals. The sequencer operation is initiated with the receipt of an access command from the command processor. The command is a 9-bit word with a high byte being the ROM address, and the ninth a "flag." The command is parallel loaded into the ROM address register thus providing access to any subroutine stored within the ROMs. The sequencer control circuitry is then activated and the address register is incremented by one count and time counter is reset to zero. The outputs of the event ROMs are then decoded and strobed to produce the event and control signals. If a sequencer disable signal is decoded, the sequencer immediately shuts down. When the sequencer is disabled, it remains dormant until a new access command is received. If the event word (second microinstruction) does not contain a disable command, the sequencer information it contains is decoded and sent to the A/D converter.

The temperature set point (+12°C) is a control signal which is used to accumulate the pulses produced by the instrument. If a sequencer disable signal is decoded, the sequencer immediately shuts down. When the sequencer is disabled, it remains dormant until a new access command is received. If the event word (second microinstruction) does not contain a disable command, the sequencer information it contains is decoded and sent to the A/D converter.
There are no temperatures to be monitored between 200° and 300°C; therefore, this range is bypassed. Special attention is given to the 60° and 110° C detectors, which are also monitored but need no amplification. These voltages are fed through the output analog switches to the A/D processing and are selected in the same way as the parallel data.

Test cell position monitor. The test cell position for each of the three experiments is detected by the use of optical sensing. In each experiment module in the mechanical assembly, the test cell can be rotated to as many as six positions by the use of a geared stepper motor coupled to a Geneva wheel. This Geneva wheel is mounted at the center of rotation on the test cell assembly.

The test cell position monitor (TCPM) uses light emitting diodes and phototransistors to detect the six positions of a Geneva wheel for each of the three experiments. Light from an LED which passes through a 1.32-mm hole in the Geneva wheel is detected by a phototransistor. The two elements are separated by 4.57 mm maximum. To read six positions, three LEDs and three phototransistors are used, and each position is binary coded to give a unique indication. The binary number 111 is not used for any position because a 000 would not be distinguishable from a solid part of the Geneva (i.e., no holes or slots to read through) and 111 is not distinguishable from a Geneva wheel slot. Each TCPM has three LEDs and three phototransistors, so that 9 bits of TCPM data are available.

GEX low-level electronics. The function of the GEX low-level electronics (LLE) circuit is to measure the difference in thermal conductivity between gases passing through detector cells at the ends of active and reference gas chromatograph columns and to make the information available to the analog-digital converter through the multiplexer.

A block diagram of the GEX LLE, Fig. 24, gives a representation of significant features. Inasmuch as the gas chromatograph (GC) is a "differential" device, balance between the active and reference sides is very important. The figure shows two thermistors at the input of a differential amplifier. Each thermistor operates in its own bridge circuit, powered by an operational amplifier, such that bead resistance is held constant. The output of the preamplifier differential op-amp amplifier is fed to a holding capacitor. When the output of the bridge circuit is equal, the holding capacitor retains its value, thus holding the output at the null reference from which the differential amplifier signal may now cease to vary.

Analog-to-digital converter. The instrument A/D converter uses dual-slope integrating techniques to achieve its required accuracy. The converter has a 10-bit resolution with an accuracy of ±0.1%. Since the instrument analog data change very slowly, aperture line was not used. This, together with integrating time constant was used to reduce noise errors.

When a conversion cycle starts, the converter first activates an offset correction loop to eliminate converter biases in the data. The input is applied to the integrator for a full 1024 pulse clock period. An accurate negative reference voltage is then applied to the integrator while a counter is accumulating 208 KHz clock pulses. When the integrator output crosses 0 V, the counter input is cut off and its contents are transferred to a shift register. The converter then adds 2 bits of identification to the 10-bit converted word and the 12-bit word is sent to the memory.

Mecahnical subsystem control. The valves, heaters, and motors in the MSS are controlled from the A3 slice. The MSS contains 6 thermal isolation valves, 39 latching solenoid valves, 4 stepper motors, and 43 heaters. The heaters are controlled either by mechanical thermostats, electronic thermostats, or proportional heater controllers. All heaters and solenoid valves run from raw bus voltage in order to reduce conversion efficiency losses. Power is supplied to the MSS as described below.

Valve control. The 39 latching solenoid valves are controlled by a 6 x 7 driver matrix. Since the valves run from raw power, the control voltages for the drivers were isolated. The drivers used in the matrix are relays which not only provide the required isolation but also hold the current flow to the valves to gate and unlatch them.

The circuit receives 100-m s pulse signals from the valve driver logic which operate nonlatching relays by applying 30 V power supply to the relay coils through hybrid drivers. The relays enable bus power to be applied to the valve coils. By energizing the proper two relays using two logic signals from the valve driver logic, one valve is selected through the 6 x 7 diode matrix. An auxiliary relay, whose state depends on a third logic signal, is used to establish whether the selected valve is to receive a voltage pulse in the open or close direction. One of the pair of matrix-selection logic signals is also used to enable the bus power relay driver. The pulse is gated by master clock pulse with duration of 50 ms, delayed 25 ms from the start of all the "100 ms" clock pulses. The result is that the bus relay is closed for 50 ms in the middle of the logic pulse. The voltage pulse from the valve driver controller determines the voltage pulse direction. This assures that the valve-select relay contacts are closed and settled before the present current is transmitted.

Motor control. The MSS control circuit operates the stepping motors for the soil distribution assembly (SDA) and three test cell positioning mechanisms (TCPM). The stepping motors are of the four-phase stepping type of which only one may be operational at any given time. This constraint permits much of the motor control circuitry to be shared by all of the motors resulting in substantial reduction in both power and control requirements.

Upon receipt of a command from the sequencer for the TCPM, the controller sets the stepping motor for the TCPM and, for the SDA, the controller turns on the appropriate motor power switch. It also generates a four-phase 20-Hz stepper sequence which, through driver switches, causes the motor to step in the appropriate direction. As the motor is stepping, the controller is constantly looking for two position feedback signals. The first signal allows the controller to act upon the second for the TCPM and, for the SDA, the controller determines the appropriate direction to reverse and then the motor direction to change. The second feedback signal causes the motor to stop and the controller to shut down. The position feedback signals are generated by optoelectronics in a manner similar to the TCPM monitor described earlier. A full motor rotation requires 12 s while a complete SDA cycle requires 24 s. The SDA has a second mode of operation in which the motor is sequentially stepped twice in one direction and twice in the other sense. This mode is used to provide a false indication in the voltage bus (24-37 V), the proportional heater controllers require a heater prereluctator. The prereluctator along with the other MSS components is described below.

Isolation valve driver. The isolation valve driver operates only once during the mission—during the landing initialization sequence to access the stored gas supplies. It is activated by a Landerr command and uses a counter and driver to sequentially apply +15 V to the system (bus) for 0.5 or 5 min, depending on the specific TIV thereby precharging the bus.

Heater prereluctator. The heater prereluctator works with the proportional controller to provide power to nine proportionally controlled heaters in the instrument. Power is supplied as a train of rectangular voltage pulses at a fixed frequency of 2 kHz. The duration of each pulse is a function of controlled temperature, heater temperature control, and the actual value of the voltage on the bus operate power line (between 24 and 37 V). The actual pulse duration is computed as a product of two ratios: the first is the duty cycle of ramp and gate signals generated by the heater prereleuctator as a function of bus voltage; the second ratio is the fraction of ramp time occupied by the heating pulse for each heater, as determined by its respective proportional controller from temperature sensing feedback.

The function of the prereleuctator is to make the maximum power taken from the bus nearly independent of bus voltage. With this accomplished, the loop gain requirements on the control circuits are minimized, peak power requirements are reduced, and the power requirements on heaters can be easily met by sizing of the heaters, based on constant power input.

The prereleuctor is accomplished by generating a ramp and an accurate comparison gate signal of constant amplitude and with a duty cycle such that a resistive load switched to the bus at the resulting duty cycle would draw the same current from the bus at 37 V. Available power to the same load at intermediate voltages is slightly less with a minimum of over 90% of end-point voltage at 30.5 V.

Heat control. The methods of heater control are used for thermal control. The simplest with mechanical thermostats. These thermostats are located in the MSS on the thermal isolation valves and are powered either from the bus or through latching relays within the ESS. The second method of control is with electronic thermostats. These "bang-bang" (limit switching) controllers use thermostats for temperature feedback and are used where mechanical thermostats will not fit or where tighter temperature control is required. The electronic thermostats are capable of controlling to ±1°C and are powered from the raw bus through latching relays. The instrument contains five electronic thermostats.

The use of the four accurate controllers are proportionally operated heater controllers. These controllers use pulse width modulation at 2 kHz from the heater prereluctator for proportional control of the heaters. The proportional controllers power the heaters directly from the bus.
There are no temperatures to be monitored between 200° and 300°C; therefore, this range is bypassed. Special calibration of the temperature control is necessary. GEs include the three test cells, GEx column and detector temperatures, and the PR organic vapor trap temperature.

Two thermistors mounted on the °C detectors also monitor these voltages and need no amplification. These voltages are fed through the output analog switches to the A/D processing and are selected in the same way as the phase feedbacks.

**Test cell position monitor.** The test cell position for each of the three experiments is detected by the use of optical sensing. In each experiment module in the mechanical subsystem control, the test cell can be rotated to as many as six positions by the use of a geared stepper motor coupled to a Geneva wheel. This Geneva wheel is monitored at the center of rotation on the test cell assembly.

The test cell position monitor (TCPM) uses light emitting diodes and phototransistors to detect the six positions of a Geneva wheel for each of the three experiments. Light from an LED which passes through a gas chromatograph (GC) is a "differential" device, applies the difference signal from the GCs output data to signal which gain setting is being used.

An integrating offset control is incorporated in the circuit. Upon receipt of a reset pulse, the switch is closed between the output of the reset driver and the holding capacitor. When this happens, the feedback circuit around the reset driver is all the rest of the circuit including the reset buffer, the summing amplifier, and the autoranging stage. The reset driver then charges the holding capacitor to that voltage at which the output voltage is equal to the offset reference (approximately 500 mV) regardless of the instantaneous value of the signal from the differential amplifier. On termination of the reset pulse, the reset switch is opened and the holding capacitor retains its value, thus holding the output at the last reference from which the differential amplifier signal may now cause it to vary.

**AID to analog-digital converter.** The instrument AID converter uses digital-to-analog techniques to achieve its required accuracy. The converter has a 10-bit resolution with an accuracy of ±0.1%. Since the instrument analog data change very slowly, aperture linearity was not considered a limiting factor at constant temperature conditions was used to reduce noise errors.

When a conversion cycle starts, the converter first activates an offset correction loop to eliminate converter biases in the data. The input is applied to the integrator for a full 1024 pulse clock period. An accurate negative reference voltage is then applied to the integrator while a counter is accumulating 208 KHz clock pulses. When the integrator output crosses 0 V, the counter input is cut off and its contents are transferred to a shift register. The converter then adds 2 bits of identification to the 10-bit converted word and the 12-bit word is sent to the memory.

**Mechanical subsystem control.** The valves, heaters, and motors in the MSS are controlled from the A3 slice. The MSS contains 6 thermal isolation valves, 39 latching solenoid valves, 4 stepper motors, and 43 heaters. The heaters are controlled either by mechanical thermostats, electronic thermostats, or proportional heater controllers. All heaters and solenoid valves run from raw bus voltage in order to reduce conversion efficiency losses. The VOC modulation described in the voltage bus (24-37 V), the proportional heater controllers require a heater preregulator. The preregulator along with the other MSS components are described below.

**VOC control.** The 39 latching solenoid valves are controlled by a 6 x 7 driver matrix. Since the valves run from raw power, the control voltages for the drivers were isolated. The drivers used in the matrix are relays which not only provide the required isolation but also allow bidirectional current flow to the valves to latch and unlatch them.

The circuit receives 100-ms pulse signals from the valve driver logic which operate nonlatching relays by applying 30-V power supply to the relay coils through hybrid drivers. The relays enable bus power to be applied to the valve coils. By energizing the proper two relays using two logic signals from the valve driver logic, one valve is selected through the 6 x 7 diode matrix. An auxiliary relay, whose state depends on a third logic signal, is used to establish whether the selected valve is to receive a voltage pulse in the OPEN or CLOSE direction. One of the pair of matrix-logic signals is also used to enable the bio bus pulse relay driver. The pulse is gated by master clock pulse with duration of 50 ms, delayed 25 ms from the start of all the "100 ms" clock pulses. The result is that the bio bus relay line is closed for 50 ms in the middle of the logic signal. The controller therefore determines the voltage pulse direction. This assures that the valve driver selects contacts are closed and settled before the current pulse is transmitted.

To control the control circuits operate the stepping motors for the soil distribution assembly (SDA) and three test cell positioning mechanisms (TCPM and, for the SDA, causes the step sequence to the desired position of which only one may be operational at any given time. This constraint permits much of the motor control circuitry to be shared by all of the motors resulting in smaller circuitry in both parts count and power requirements.

Upon receipt of a command from the sequencer for the transport command processor (for the SDA), the controller turns on the appropriate motor power switch. It also generates a four-phase 28-Hz stepper sequence which, through driver switches, causes the motor to step in the appropriate direction. As the motor is stepping, the controller is constantly looking for two position feedback signals. The first signal allows the controller to act upon the second for the TCPM and, for the SDA, causes the step sequence to reverse and thus the motor direction to change. The second feedback signal determines the motor to stop and the controller to shut down. The position feedback signals are generated by optoelectronics in a manner similar to the TCPM monitor described earlier. A full motor rotation on the TCPM requires 12 s while a complete SDA cycle requires 24 s. The SDA has a second mode of operation in which the motor is sequentially stepped twice in one direction and twice in the other sequence.

**Isolation valve driver.** The isolation valve driver operates only once during the mission—during the landing initialization sequence to access the stored gas supplies. It is activated by a Lander command and uses a counter and driver to sequentially apply +15 V to the system MSS for either 3 or 5 min, depending on the specific TIV the cycle to follow.

**Heater preregulator.** The heater preregulator works with the proportional controller to provide power to nine proportionally controlled heaters in the instrument. Power is supplied as a train of rectangular voltage pulses at a fixed frequency of 2KHz. The duration of each pulse is a function of controlled temperature, heater temperature command, and the actual value of the voltage on the bio operate power line (between 24 and 37 V). The actual pulse duration is computed as a product of two ratios: the first is the duty cycle of ramp and gate signals generated by the heater preregulator as a function of bus voltage; the second ratio is the fraction of ramp time occupied by the heating pulse for each heater, as determined by its respective proportional controller from temperature sensing feedback.

The function of the preregulator is to make the maximum power taken from the bus nearly independent of bus voltage. With this accomplished, the loop gain requirements on the control circuits are minimized, peak power demand is lowered, and the power requirements on heaters can be easily met by sizing of the heaters, based on constant power input.

The preregulation is accomplished by generating a ramp and an accurate gate signal of constant amplitude and with a duty cycle such that a resistive load switched to the bus at the resulting duty cycle would deliver the same power to the bus at 37 V. Available power to the load at intermediate voltages is slightly less with a minimum of over 92% of end-point values at 30.5 V.

**Heater control.** The methods of heater control are used for thermal control. The simplest with mechanical thermostats. These thermostats are located in the MSS on the thermal masses they are controlling and are powered either from the bus or through latching relays within the ESS. The second method of control is with electronic thermostats. These "bang-bang" (limit switching) controllers use thermostats for temperature feedback and are used where mechanical thermostats will not fit or where tighter temperature control is required. The electronic thermostats are capable of controlling to ±1°C and are powered from the raw bus through latching relays. The instrument contains five electronic thermostats. The initial and may be accurate controllers are proportional heater controllers. These controllers use pulse width modulation at 2 KHz from the heater preregulator to control the time that the proportional controllers power the heaters directly from the
In order to ignite the xenon lamp used in the PR experiment, the lamp must be ionized by high voltage applied to the xenon lamp. The high-voltage ionizing pulse is provided by a trigger transformer and driving circuit which are located in the actual lamp assembly. The output of the trigger transformer has a high-voltage capacitor in series with it. In parallel with the transformer and capacitor is a silicon controlled rectifier (SCR). The capacitor is normally trickle charged to ±200 V through a high-value resistor. When the lamp is to be ignited, a trigger pulse is sent from the lamp power supply through the SCR and dump the capacitor charge. This energy then flows through the transformer primary and causes a minimum of 7.5 kV to appear at the secondary winding and thus across the lamp electrodes.

In actual operation the voltage seldom rises above 5 kV since the xenon lamps ionize at that voltage and cause the secondary output voltage to collapse. Once the lamp is ionized, the lamp power supply sustains the arc by supplying the lamp with a constant 6.1 W of power at approximately 550 mA.

### B. Hydraulic and pneumatic systems

The multiplicity of flow and pressure requirements for the various liquids, vapors, and gases to and from the experiment modules led to the development of numerous components and assemblies utilizing commonality of designs and hardware. Requirements for low leakage (10⁻⁶ to 10⁻⁸ cm³/s) helium and nitrogen into pressure to 10.2 bar and two regulators downstream reduce the pressure to 9.2 ± 1.2 bar, respectively, above ambient. If for any reason pressure at either outlet rises above its regulator setting, pressure relief valves will limit the rise to a maximum of 11.2 and 1.9 bar, respectively.

**Instrument vents.** The common services module, in addition to containing the carrier gas supply (CGS), also is the central location for all the vent systems for the biology instrument. These vent systems include both gaseous and liquid systems. The three gas vent systems, which are shown on the schematic as V1, V3, and V4, are used to vent helium gas from the instrument. The vent system is used for venting of the PR detector, the vertical actuators, the gas chromatograph system and the high-pressure manifold. The V3 system was designed for minimum resistance within the biology instrument to minimize pressure drop between the PR cell system and the gas exchange gas sample loop.

All liquids from the biology instrument are vented through the V2 vent system. Key element of this system is the sump, which operates by heating the liquid in the sump to about 40°C and thereby converting it to water vapor prior to exhausting it to the Martian surface.

### 2. miniature latching solenoid valves

Control of gaseous, liquid, and vapor flow within the experiment is performed by 39 miniature latching solenoid valves distributed throughout the three experiment modules and the pulse whose signal is the solenoid module. Requires for low-power, low-weight, low-leakage, and high reliability led to the development of a miniature latching solenoid valve weighing less than 9 g (Fig. 26). The valve is operated by applying a 30-msec pulse at 28 V d.c. (nominal) to the coil of the miniature latching solenoid valve. The valve will latch open or closed, depending on polarity to the valve coil input. A summary of performance characteristics is presented in Table XI. Five configurations of this valve are used to match the thermal and operational requirements of the experiments: Basic valve with Viton E60C poppet, modified valve with ethylene propylene terpolymer (EPT) poppet, modified valve with Teflon poppet, diaphragm valve with EPT (diaphragm seal (vented)), and diaphragm valve with EPT (diaphragm seal (unvented)). The Viton valves are used...
In the experiment, the lamp must be ionized by high voltage system.

The discriminator produces a 100 mA pulse followed by a pulse shaping amplifier and an energy level discriminator.

When an electron emitted by a lattice disintegration leaves a high-energy exit and crosses a detection gap, the electric pulse ionizes the gas, creating a number of electrons and ions that travel to the electrodes.

To ignite the xenon lamp used in the PR lamp starting circuit for PR illuminator sub-systems, a trigger pulse is used to turn on the SCR and dump the capacitor charge.

Gas bottle pressure is contained by the thermal isolation vessel and is reduced to 100 bar at the output of the roughing regulator. Pressures downstream are limited to a maximum of 11.2 and 1.9 bar, respectively.

The multiplicity of flow and pressure requirements for the various liquids, vapors, and gases to and from the experiment modules led to the development of numerous components and assemblies utilizing commodity of designs and hardware. Requirements for low leakage (10⁻¹⁰ to 10⁻¹⁴ cm²/s) have been expressed as bottle pressure to 10.2 bar and two regulators downstream reduce pressure to 9.2 and 1.2 bar, respectively, above ambient. If any pressure rise at all outlet rises above its regulator setting, pressure relief valves will limit the rise to a maximum of 11.2 and 1.9 bar, respectively.

The miniature latch solenoid valve. Control of gaseous, liquid, and vapor flow within the experiment is performed by 39 miniature latching solenoid valves distributed throughout the three experiment modules and the pulse whose anode module.

The valve is operated by applying a 39-msec pulse at 28 V dc (nominal) to the coils of the miniature latching solenoid valve. The valve will latch open or closed, depending on polarity to the valve coil's electrical connections. A summary of performance characteristics is presented in Table 1. Five configurations of this valve are used to match the thermal and operational requirements of the experiments: Basic valve with Viton E60C poppet, modified valve with ethylene propylene terpolymer (EPT) poppet, modified valve with Teflon poppet, diaphragm valve with EPT diaphragm seal, and diaphragm valve with PTFE diaphragm seal (unvented). The Viton valves are used...
TABLE XI. Physical and operating characteristics of the miniature latching solenoid valve.

<table>
<thead>
<tr>
<th>Weight</th>
<th>8.7 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil resistance</td>
<td>190 Ω</td>
</tr>
<tr>
<td>Leakage force</td>
<td>0.176 kV</td>
</tr>
<tr>
<td>Dynamic seal load</td>
<td>0.272 kg</td>
</tr>
<tr>
<td>Total stroke</td>
<td>9.8 mm</td>
</tr>
<tr>
<td>Minimum opening voltage</td>
<td>11.8 V</td>
</tr>
<tr>
<td>Minimum closing voltage</td>
<td>13.4 V</td>
</tr>
<tr>
<td>Open response time</td>
<td>0.9 ms</td>
</tr>
<tr>
<td>Close response time</td>
<td>1.6 ms</td>
</tr>
<tr>
<td>Pressure drop</td>
<td>&gt;0.38 atm</td>
</tr>
<tr>
<td>Reverse cracking pressure</td>
<td>&gt;2.45 kg cm²</td>
</tr>
<tr>
<td>Burst pressure</td>
<td>&gt;110 kg cm²</td>
</tr>
<tr>
<td>Internal leakage (std cm⁻³ He)</td>
<td>0.65 x 10⁻⁶</td>
</tr>
<tr>
<td>External leakage (std cm⁻³ He)</td>
<td>1 x 10⁻³</td>
</tr>
</tbody>
</table>

where low leakage rates are required and the operational temperature ranges between -12° and 30°C. The EPV valves are used where low leakage rates are required and the operational temperature ranges between -50° and 150°C. To avoid poppet stiction, Teflon valves are employed in the V1 and V2 vent systems, the only locations where the valves are closed during instrument sterilization and Earth–Mars transit. In special applications in the LR and GEx nutrient systems, the diaphragm valves are used to separate the internal parts which are nickel plated (in GEx because of toxicity concerns) to prevent corrosion of the LR incubation system vent valve (alternately wet/dry with nutrient).

3. Thermal isolation valves

The isolation device selected for the instrument gas and vapor reservoir systems is a thermally actuated diaphragm piercing valve. This device was chosen because of the requirement for greater than 2 years storage with negligible leakage. Principal features leading to its selection over a pyrotechnic device are simplicity, reliability, low weight, low peak power, and absence of combustion gas/stainless steel systems to experiment functions. Six thermal isolation valves are utilized in each biology instrument. The locations and designations of the thermal isolation valves are given in Table XII. All of the thermal isolation valves are actuated on Mars during the initialization sequence.

The thermal isolation valve (Fig. 27) is comprised of a thermal actuator and a burst disk of 0.076 mm thickness. The 0.076-mm disks are used for reservoir supplies pressurized at or below 10.5 kg cm⁻² and the thicker disks are used in the 315 kg cm⁻² helium supply. When the thermal actuator is activated approximately 9 W of heat is transferred from the heater element to the thermal actuator case, Silicone oil, and the surroundings. Heat transferred to the oil causes it to expand and drive the plunger through the burst disk. The plunger automatically retracts during cooldown, being driven primarily by the compressed bellows. In high-pressure applications, the retraction is assisted by the pressurized medium.

4. Lines and fittings

The nutrient gas supply and vent lines are all 304 or 316 stainless steel, 1.6 mm o.d. by 1.1 mm i.d., except for:

(1) LR detector line—3.2 mm o.d., 0.25 mm wall,
(2) High-pressure (315 kg cm⁻²) lines—1.6 mm o.d., 0.45 mm wall,
(3) Various restrictors in the helium, nutrient, and vent systems,
(4) Flexible Teflon lines in the vent system.

Methods of joining the tubing to valve blocks or other tubes are illustrated in Fig. 28. All joints are proof tested to 40.6 kg cm⁻², capable of sealing at 1 x 10⁻⁵ std cm⁻¹ s⁻¹ helium and compatible with biological requirements (toxicity).

The high-pressure lines within the 315 kg cm⁻² helium supply are welded using the tungsten inert gas technique.

C. Nuclear detection subsystem

Both the LR and PR experiments use radioactively labeled carbon as a detection mechanism for the experiment functions. Detection of the radioactive carbon in gaseous form such as CO₂ or CO is the role of the nuclear detection system.

For LR (Fig. 29), two solid state detectors view a fixed volume connected to the LR cell head space volume. Since the detection mechanism of the LR experiment is the measurement of radioactively labeled gases, the detectors respond to the radioactivity-labeled carbon contained in these gases. The signal, in the form of a pulse from these detectors, is amplified by a charge amplifier, shaped, and then passed through a discrimination window (discriminator) for transmission to the electronic subsystem. Each of the two detectors has separate channels of electronics with the outputs summed into an accumulator located in the ESS. The output of the detection system is in the form of pulses whose average rate is a direct measure of the quantity of radioactive gas within the detector.

The detectors and electronics are similar for the PR experiment. The process (Fig. 30) is, however, different in that PR uses the 1.26 kg cm⁻² helium gas to push the ¹⁴C CO₂ into the detector and then closes off the detector and counts a fixed volume.

The detectors measure the betas emitted by radioactive ¹⁴CO₂ which have energies up to 156 keV. This task must be accomplished in the presence of a fairly high level of relatively low-energy flux from the radioisotope thermal generators on the lander, and in the presence of a small continuing flux of high energy cosmic rays. The thickness of the solid state detectors is optimized with respect to these considerations so that the CO₂ beta particles have a high probability of capture within the detector and effective use can be made of a "counting window" to discriminate against the two principal sources of background. At low energies there is the exponential noise which is a function of the system noise level. Figure 31 is a graphical representation of the particle interactions with the silicon crystal and the counting rate considerations which were used to determine the lower and upper energy levels (34–85 keV) of the counting window.

Since the energy from radioactive decay follows a Poisson distribution, the detectable limit of the signal is a function of the background from the RTG's and the time over which the signal is counted. The background...
TABLE XII. Summary of the locations and purposes of the thermal isolation valves.

<table>
<thead>
<tr>
<th>Experiment location</th>
<th>Blunt disk thickness (mils)</th>
<th>Stored gas/vapor</th>
<th>Perfect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrolytic release</td>
<td>76</td>
<td>H_2O</td>
<td></td>
</tr>
<tr>
<td>Pyrolytic release</td>
<td>76</td>
<td>^{14}C, {15}N, CO at 525 milli-bars</td>
<td></td>
</tr>
<tr>
<td>Gas exchange</td>
<td>76</td>
<td>He/CrO_{2} at 8.5 bars</td>
<td></td>
</tr>
<tr>
<td>Common service module two used for redundancy</td>
<td>152/92</td>
<td>77,000 std cm^3 at 106 bars, 99.9999% purity</td>
<td></td>
</tr>
<tr>
<td>He exchange (birec)</td>
<td>76</td>
<td>He/CrO_{2} at 8.5 bars, (GCAA rejuvenation)</td>
<td></td>
</tr>
</tbody>
</table>

where low leakage rates are required and the operational temperature ranges between -20° and 150°C. To avoid poppet stiction, Teflon valves are employed in the V1 and V2 vent systems, the only locations where the valves are closed during instrument sterilization and Earth--Mars transit. In special applications in the LR and GEx nutrient systems, the diaphragm valves are used to separate the nutrient from the miniature latching solenoid valve internal parts which are nickel plated (in GEx because of toxicity concern) and to prevent corrosion of the LR incubation vent valve (alternatively wet/dry with nutrient).

3. Thermal isolation valves

The isolation device selected for the instrument gas and vapor reservoir systems is a thermally actuated diaphragm piercing valve. This device was chosen because of the requirement for greater than 2 years storage with negligible leakage. Principal features leading to its selection over a pyrotechnic device are simplicity, reliability, low weight, low peak power, and absence of combustion gas detrimental to experiment functions. Six thermal isolation valves are utilized in each biology instrument. The locations and designations of the thermal isolation valves are given in Table XII. All of the thermal isolation valves are actuated on Mars during the initialization sequence.

The thermal isolation valve (Fig. 27) is comprised of a thermal actuator and a blunt disk of 0.076, 0.1, or 0.15 mm thickness. The 0.076-mm disks are used for reservoir supplies pressurized at or below 10.5 kg cm^{-2} and the thicker disks are used in the 315 kg cm^{-2} helium systems. When the thermal actuator is activated approximately 9 W of heat is transferred from the heater element to the thermal actuator case. silicone oil, and the surrounding medium. In high-pressure applications, the retraction is assisted by the pressurized medium.

4. Lines and fittings

The nutrient gas supply and vent lines are all 304 or 316 stainless steel, 1.6 mm o.d. by 1.1 mm i.d., except for:

(1) 1.R detector line—3.2 mm o.d., 0.25 mm wall,
(2) high pressure (315 kg cm^{-2}) lines—1.6 mm o.d., 0.45 mm wall,
(3) various restrictors in the helium, nutrient, and vent systems,
(4) flexible Teflon lines in the vent system.

Methods of joining the tubing to valve blocks or other tubes are illustrated in Fig. 28. All joints are proof tested to 40.6 kg cm^{-2}, capable of sealing at 1 x 10^{-6} std cm^3 s^{-1} helium and compatible with biological requirements (toward). The high-pressure lines within the 315 kg cm^{-2} CSM are welded using the tungsten inert gas technique.

C. Nuclear detection subsystem

Both the LR and PR experiments use radioactively labeled carbon as a detection mechanism for the experiment functions. Detection of the radioactively carbon in gaseous form such as C_4O_2 or CO is the role of the nuclear detection system.

For LR (Fig. 29), two solid state detectors view a fixed volume connected to the LR cell head space volume. Since the detection mechanism of the LR experiment is the measurement of radioactively labeled gases, the detectors respond to the radioactivity-labeled carbon contained in these gases. The signal, in the form of pulses from these detectors, is amplified by a charge amplifier, shaped, and then passed through a discrimination window (discriminator) for transmission to the electronic subsystem. Each of the two detectors has separate channels of electronics with the outputs summed into an accumulator located in the ESS. The output of the detection system is in the form of pulses whose average rate is a direct measure of the quantity of radioactive gas within the detector.

The detectors and electronics are similar for the PR experiment. The process (Fig. 30) is, however, different in that PR uses the 1.26 kg cm^{-2} helium gas to push the C_4O_2 into the detector and then closes off the detector and counts a fixed volume.

The detectors measure the betas emitted by radioactive C_4O_2 which have energies up to 156 keV. This task must be accomplished in the presence of a fairly high level of relatively low-energy flux from the radiotrace gas thermal generators on the lander, and in the presence of a small continuing flux of high energy cosmic rays. The thickness of the solid state detectors is optimized with respect to these considerations so that the C_4O_2 beta particles have a high probability of capture within the detector and effective use can be made of a "counting window" to discriminate against the two principal sources of background. At low energies there is the exponential noise which is a function of the system noise level. Figure 31 is a graphical representation of the particle interactions with the silicon crystal, and the counting rate considerations which were used to determine the lower and upper energy levels (34--85 keV) of the counting window.

Since the energy from radioactive decay follows a Poisson distribution, the detectable limit of the signal is a function of the background from the RTG's and the time over which the signal is counted. The background
The full-width half-maximum (FWHM) noise, as measured with a 60 keV pulse, averaged 3.58 ± 0.92 keV FWHM with a maximum of 6.47 keV FWHM for the silicon detectors in the three flight instruments.

D. Soil distribution assembly

The Lander's soil acquisition processing and distribution system provides the required soil samples to the biology instrument. The SDA within the instrument accepts, delivers, and meters the soil samples for each of its test chambers and stores sufficient quantities of each soil sample delivered such that a second distribution may be made to each of the three experiments. If not required for further experiments, the excess soil is transferred to soil dump cavities which are part of each experiment module. An exploded view of the SDA is presented in Fig. 35.

The SDA is capable of accepting, delivering, and metering soil with particle sizes up to 3870 μm and a volume of 6 cm³. The instrument soil hopper is in position to receive soil from the Lander at all times except during the actual distribution of soil to the experiment test cells. The instrument meters and delivers the active soil samples to the individual experiments following a distribution interval obtained from the guidance database and sequencing computer. Prior to receiving a new soil sample, the unused soil is dumped into dump cells by cycling the SDA with dump cells under each instrument's soil load port. The order of soil delivery is gas exchange (1.00 cm³), pyrolytic release (0.25 cm³), and labeled release (0.50 cm³).

E. Thermal design subsystems

The science objectives of the three experiments on the Lander together with equipment operational characteristics impose a wide range of requirements to be satisfied by the thermal subsystem. These requirements range, in the extremes, from 725°C (PR experimental test cell during termination) to 5°C (minimum allowable cell temperature during incubation), and are complicated by the small volume available for the experiment and the requirement that high and low temperature operations be carried out simultaneously (in different experiments). To satisfy these requirements in a Mars atmosphere (nominally 7 millibars CO₂), the thermal subsystem utilizes both active and passive elements. The active elements are thermal electric coolers plus a large number of individually controlled heaters. The passive elements include heat pipes, thermal standoffs, convection/radiation shields, surface coatings or tapes, and component placement.

The MSS consists of the three individual experiments, a common service module for helium supply and regulation, and nuclear detection systems for LR and PR experiment detection electronics as well as the MSS thermal control. The active component of the MSS thermal control is a set of control elements which provide the primary control of the experiment. These include electronic or mechanical thermostat control, where the heater control is a feedback system in which the sensor temperature is compared to a setpoint and the heater power is adjusted to maintain the sensor temperature at the setpoint. Other MSS thermal subsystem elements include passive approaches to reducing heat losses with radiation/convection shields placed on the LR heat exchanger block, on the PR detector assembly, and on the GEx heated nutrient line between the valve block and the head end. The radiation/convection shield on the LR heat end is shown in Fig. 36.

The MSS thermal control is a set of control elements which provide the primary control of the experiment. These include electronic or mechanical thermostat control, where the heater control is a feedback system in which the sensor temperature is compared to a setpoint and the heater power is adjusted to maintain the sensor temperature at the setpoint. Other MSS thermal subsystem elements include passive approaches to reducing heat losses with radiation/convection shields placed on the LR heat exchanger block, on the PR detector assembly, and on the GEx heated nutrient line between the valve block and the head end. The radiation/convection shield on the LR heat end is shown in Fig. 36.
from the RTGs was found to be between 400 and 500 counts per minute as seen by the detectors. These counting periods vary from 19 min in the case of the PR first peak (10-12 cpm expected) to several hours for the second peaks (10 cpm is the minimum requirement). These counting periods must therefore be of sufficient duration to detect the above levels from the background. The background periods before and after the actual data counts should be of similar duration.

Silicon detectors in the three flight instruments.

The full-width half-maximum (FWHM) noise, as measured with a 60 keV pulse, averaged 3.58 ± 0.92 keV FWHM with a maximum of 6.47 keV FWHM for the silicon detectors in the three flight instruments.

D. Soil distribution assembly

The Landcr's soil acquisition processing and distribution system provides the required soil samples to the biology instrument. The SDA within the instrument accepts, delivers, and meters the soil samples for each of its test chambers and stores sufficient quantities of each soil sample delivered such that a second distribution may be made to each of the three experiments. If not required for further experiments, the excess soil is transferred to soil dump cassettes which are part of each experiment module. An exploded view of the SDA is presented in Fig. 33.

The SDA is capable of accepting, delivering, and metering soil with particle sizes up to 870 µm and a volume of 6 cm³. The instrument soil hopper is in position to receive soil from the Lander at all times except during the actual distribution of soil to the experiment test cells. The instrument meters and delivers the active soil samples to the individual experiments following a distribution ramp from the guidance control and sequencing computer. Prior to receiving a new soil sample, the unused soil is dumped into dump cells by cycling the SDA with dump cassettes under each instrument's soil load port. The order of soil delivery is gas exchange (1.00 cm³), pyrolytic release (0.25 cm³), and labeled release (0.50 cm³).

E. Thermal design subsystems

The science objectives of the three experiments on the Lander together with equipment operational characteristics impose a wide range of requirements to be satisfied by the thermal subsystem. These requirements range, in the extremes, from 725°C (PR experiment test cell during termination) to 5°C (minimum allowable cell temperature during incubation), and are complicated by the small volume available for the experiment and the requirement that high and low temperature operations be carried on simultaneously (in different experiments). To satisfy these requirements in a Martian atmosphere (nominally 7 millibars CO₂), the thermal subsystem utilizes both active and passive elements. The active elements are thermoelectric coolers plus a large number of individually controlled heaters. The passive elements include heat pipes, thermal standoffs, and insulation for the insertion equipment.

Table XIII summarizes the various elements making up the MSS thermal subsystem. The majority of thermal requirements are satisfied by the 43 individual heaters coupled with proper control of the conduction and radiation paths, slim involved with the transport to surrounding hardware. Three different heater control schemes are employed: proportional control, electronic thermostat, and mechanical thermostat. The critical heaters are proportional control where, near the operating point, the heater power input is inversely proportional to the sensor temperature. The remainder utilize electronic or mechanical thermostat control, where the heater calls for full power when heating and none when off.

Some heaters are simply sequenced on and off during the mission and are sized to meet requirements for the total range of supplied voltage and environmental conditions. The heat pipes and passive elements (one each for GEx and LR and two for PR) are used to maintain cell head temperatures at or below 27°C when the Lander IMP reaches a higher value. Each thermoelectric cooler, which is actively controlled, is thermally coupled to one of the experiment head ends by a small aluminum heat pipe. When the control thermostat is set at a temperature below 27°C, the thermoelectric cooler is activated. The unit then cools one end of the heat pipe and provides a sink for heat rejection.

The MSS thermal subsystem elements involve passive approaches to reducing heat losses with radiation/convection shields placed on the LR head end block, on the LR and PR detector assemblies, and on the GEx heated nutrient line between the valve block and the head end. The radiation/convection shield on the LR head end is shown in Fig. 34.

Maintenance of particular line at required temperatures is accomplished in two ways. Many of the lines are provided with separate heaters (as shown on the far left in Fig. 34) to maintain a temperature above the minimum environment as well as the large number of complex shaped heaters. A second approach, primarily for maintaining internal ly of the instrument.

The ESS is tested to the extremes of the IMP temperature variation. Individual components in the ESS are mounted to appropriate heat sinks which have necessary thermal paths to the ESS housing. Installed in the Lander, the ESS housing is in intimate contact with the IMP which provides the primary heat sink.
The gold-tape-covered LR nutrient delivery line shown in Fig. 34. The can heaters can be seen at the extreme left behind the heated line. The can heaters provide additional benefit in that they can be controlled to maintain the experiment cell and Szeld above minimum allowable incubation temperatures during the minimum part of the diurnal cycle. The critical specific requirements satisfied by the thermal subsystem were:

1. Incubation—maintain test cells at 15 ± 12°C
dependent on experiment to be performed.
2. Freezing protection—maintain water and nutrient reservoirs and lines above 0°C.
3. Sterilization—maintain specified test cell valve blocks and lines above sterilization temperatures typically 120°C to 140°C for up to 3 h.
4. Pyrolysis, elution, and termination—perform PR experiment detection modes which require test cell and organic vacuum trap (OPT) temperatures as high as 723°C.
5. GCAA detector—maintain the GCAA detector at 32 ± 0.1°C during gas analyses.
6. Detector cleanup—elevate PR and LR detector temperatures above 90°C to desorb trapped radioactive activity.

Another important set of instrument requirements was to allow opening the experiment test cell seals only within specific temperature limits after they experience a high temperature operation, in order to prevent degradation of these critical seals.

IX. COMMAND CONTROL

The experiment activities of the biology instrument are controlled by directed commands sent from the guidance control and sequencing computer (GCSC) in the Lander. These commands operate the instrument either by direct access of the three read only memories (ROM) or by directly initiating an instrument function (e.g., operating the SDA). When the ROM for an experiment is accessed it begins to step through a programed sequence of events on a specific timeline. It will continue to execute events per its timeline until such time as it is either disabled, accessed at another address, or the power to the instrument is turned off. The bulk of the activities of an analysis sequence are caused by the automatic execution of these programmed ROM events. During the course of an analysis sequence for the three experiments, several types of data such as temperatures and radioactivity counts are generated. As they accumulate, these data values are stored as digital words in the 128-word (16 bits per word) instrument memory. The contents of this memory are either read by the GCSC or when the memory signals the Lander that it is almost full and requests the data to be dumped. Additionally, the biology instrument generates four analog data points (three temperatures and one pressure) which the Lander samples directly from the data acquisition and processing unit (DAPU).

A. GCSC control of the instrument

The commands with which the GCSC controls the biology instrument are stored in two tables, A and B, within the Lander GCSC. These tables contain the individual biology commands and for each the time to the next command. When a biology sequence is to be run, the GCSC merely accesses one of the tables and reads the first command and the time to the next command. After sending the first command to the instrument it waits the correct time, gets the second command and sends it in this way it follows through the steps of a command table for the particular sequence. When Viking landed on Mars, the biology tables in the GCSC were loaded with a set of commands known as the initial computer load (ICL). ICL table A was set up to initialize the instrument on sol 3 by firing the thermal isolation valves, operating the motors, and regenerating the gas chromatograph columns. ICL table B contained a command set to accomplish the first set of biological analyses on soil from the surface. Of 312 commands in table B only about 200 were necessary to perform within the table so as to allow later reuse of large blocks of commands with only a minimum of uplink modification. This strategy allowed flexible operation of the biology instruments without making the uplink command requirements prohibitively large.

B. Instrument sequencing

To produce the command tables which operate the biology instrument, a detailed knowledge is required of how the instrument will respond to a given command sequence and the constraints which pertain to operation of the instrument. To aid in creation of these sequences, a computer program was used which accurately models the response of the biology instrument to any series of commands that are sent to it. It prints out a complete listing of all experiment events and the time at which they occur for any command sequence. Additionally, the program recognizes almost all of the constraints on the operation of the instrument and will either reschedule experiment activities to avoid constraint violations or will at least alert the user to the existence of a violation.

There are several categories of sequencing constraints on the instrument. One major category is the thermal constraints. Because of the large diurnal temperature variations expected on the Martian surface and the desire to maintain soil samples at fairly constant temperatures, it is necessary to schedule certain events such as high wattage heating or nutrient injections to occur at specific times in the diurnal temperature cycle. A second category of constraints consists of those which forbid some activities in one experiment during critical activities in another experiment. This category of interexperiment constraints includes constraints on simultaneous use of the vent systems and the helium supplies. In addition to the thermal and interexperiment constraints on the operation of the instrument, there is a large assortment of operational constraints including making possible conflicts with certain Lander activities.

During mission operations the creation of an operational sequence for the biology instrument proceeded as follows. First, the biology science team decided which major experiment activities were to occur in this sequence. A logical sequence was then selected from a previously established dictionary of experiment sequences. This was modified to include all of the activities desired by the science team and was processed through the sequence generation program to check for constraint violations. This process was iterated with modifications to the sequence until all constraints were simultaneously resolved. The sequence was then sent to the Lander sequencing computer program where it was checked against the Lander constraints. Once an iterative process with sequence modifications was necessary. When all conflicts had been resolved the command file for the sequence was merged into the Lander uplink file and sent to the Deep Space Network (DSN) for transmission to the Lander.

C. Computer reduction of down-linked data

When the Lander receives the data generated by the biology instrument, it stores it so that a transmission window is available for downlinking. This may be either by direct transmission to earth or via a relay through the orbiter. The biology data is mixed in with all other Lander data during transmission. After data are received by the DSN they are sent to JPL where a computer program separates them according to experiment and makes them available to data reduction programs of the individual experiments.

There are two computer programs for processing data from the biology experiments. The first of these receives the data in the raw and memory frames and, using inputs from the sequence generation program, time-tags the data and separates them according to type (PR, LR) and time frame. The time tagging process is complicated by the absence of any time identification of the data words as they are stored by the instrument. It is accomplished using a precise prediction of the uplink-down link program to match the received data to that which was predicted. It also decalibrates the data into scientific units and checks for out of range values. It gives the instrument team its first quick look at the data as they are returned from Mars.

The first biology data reduction program also creates a working data file for the second program. This is a file of time-tagged and decalibrated data values which is added to daily as the mission proceeds. The second of the biology data reduction programs is interactive and is designed to be used by members of the science team to perform higher order processing of their data. It accesses the data in the working file and produces statistical analyses, curve fitting, and plotting functions as requested from the computer terminal. The science team is able to use this program to analyze in detail the results of their experiments.

X. OPERATIONS

On July 20, 1976, Viking Lander I settled gently on the plains of Chryse and commenced operations. For the next 390 Martian sols, the biology instrument successfully conducted 13 experiments on 4 different soil samples. The primary mission was successfully completed before superior solar conjunction when commanding of the Lander science investigations was interrupted for several weeks. After conjunction secondary experiments were conducted until May 1977 when the helium consumption gas used to engage the test cell curvatures and move liquids and gases into and out of the experiments was depleted, as expected. The only degradation in instrument operation occurred in the secondary experiments during the gas exchange experiment when the third soil analysis cycle when the gas chromatograms (Table X) detected no gases due to a presumed leak in the test cell. During the Lander I biology instrument operation 35 gas chromatograms were taken for the GEX experiment, 5 pyrolytic release experiments were completed, and 9 radioactive nutrient injections were made in four different tests for the Lander I biology instrument.

On September 3, 1976 Viking Lander II arrived at
The gold tape-covered LR nutrient delivery line shown in Fig. 34. The can heater can be seen at the extreme left behind the heated line. The can heaters provide another benefit in that they can be controlled to maintain the experiment cell and hold above minimum allowable incubation temperatures during the minimum part of the diurnal cycle.

The critical specific requirements satisfied by the thermal subsystem were:

1. Incubation—maintain test cells at $15 \pm 12$ °C depending on experiment to be performed.
2. Freezing protection—maintain water and nutrient reservoirs and lines above 0°C.
3. Sterilization—maintain specified test cells valve blocks and lines above sterilization temperature typically 120 to 160°C for up to 3 h.
4. Pyrolysis, elution, and termination—perform PR experiment detection modes which require test cell and organic vapor trap (OVT) temperatures as high as 725 0 e.
5. GCSC heater—maintain the GCSC heater at $32 \pm 0.1$ °C during gas analyses.
6. Detector cleanup—elevate PR and LR detector temperatures above 90°C to desorb trapped radioactive.

Another important set of instrument requirements was to allow opening the experiment test cell seals only within specific temperature limits after they experience a high temperature operation, in order to prevent degradation of these critical seals.

IX. COMMAND CONTROL

The experiment activities of the biology instrument are controlled by digital commands sent from the guidance control and sequencing computer (GCSC) in the Lander. These commands operate the instrument either by accessing one of the three read only memories (ROM) or by directly initiating an instrument function (e.g., operating the SDA). When the ROM for an experiment is accessed it begins to step through a programmed series of events on a specific timeline. It will continue to execute events per its timeline until such time as it is either disabled, accessed at another address, or the power to the instrument is turned off. The bulk of the activities of an analysis sequence are caused by the automatic execution of these programmed ROM events.

During the course of an analysis sequence for the three experiments, several types of data such as temperatures and radioactivity counts are generated. As they accumulate, these data values are stored as digital words in the 138-word (16 bits per word) instrument memory. The contents of this memory may be accessed by either direct command from GCSC or when the memory signals the Lander that it is almost full and needs to be dumped. Additionally, the biology instrument generates four analog data points (three temperature and one pressure) which the Lander samples directly from the data acquisition and processing unit (DAPU).

A. GCSC control of the instrument

The commands with which the GCSC controls the biology instrument are stored in two tables, A and B, within the Lander GCSC. These tables contain the individual biology commands and for each time to the next command. When a biology sequence is to be run, the GCSC merely accesses one of the tables and reads the first command and the time to the next command. After sending the first command to the instrument it waits the correct time, gets the second command and sends it. In this way it follows through the steps of a command table for the particular sequence.

When Viking landed on Mars, the biology tables in the GCSC were loaded with a set of commands known as the initial computer load (ICL). ICL table A was set up to initialize the instrument on soil 3 by firing the thermal isolation valves, operating the motors, and regenerating the gas chromatogram columns. ICL table B contained a command set to accomplish the first set of biological analyses on soil from the surface. Of 312 commands in table B only about 200 were necessary to perform within the table so as to allow later reuse of large blocks of commands with only a minimum of uplink modification. This strategy allowed flexible operation of the biology instruments without making the uplink command requirements prohibitively large.

B. Instrument sequencing

To produce the command tables which operate the biology instrument, a detailed knowledge is required of how the instrument will respond to a given command sequence and the constraints which pertain to operation of the instrument. To aid in creation of these sequences, a computer program is used which accurately models the response of the biology instrument to any series of commands that are sent to it. It prints out a complete listing of all experiment events and the time at which they occur for any command sequence. Additionally, the program recognizes almost all of the constraints on the operation of the instrument and will either reschedule experiment activities to avoid constraint violations or will alert the user to the existence of a violation.

There are several categories of sequencing constraints on the instrument. One major category is the thermal constraints. Because of the large diurnal temperature variations expected on the Martian surface and the desire to maintain soil samples at fairly constant temperatures, it is necessary to schedule certain events such as high wattage heating or nutrient injections to occur at specific times in the diurnal temperature cycle.

A second category of constraints consists of those which forbid some activities in one experiment during critical activities in another experiment. This category of experiment conflicts also includes constraints on simultaneous use of the vent systems and the helium supplies. In addition to the thermal and interexperiment constraints on the operation of the instrument, there is a large assortment of operational constraints including possible conflicts with certain Lander activities.

During mission operations the creation of an operational sequence for the biology instrument proceeded as follows. First, the biology science team decided which major experiment activities were to occur in this sequence. Above each sequence was then selected from a previously established dictionary of experiment sequences. This was modified to include all of the activities desired by the science team and was processed through the computer program to check for constraining violations. This process was iterated with modifications to the sequence until all constraints violated by the sequence were resolved. The sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once an acceptable sequential arrangement of events was accomplished, the sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once an acceptable sequential arrangement of events was accomplished, the sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once an acceptable sequential arrangement of events was accomplished, the sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once an acceptable sequential arrangement of events was accomplished, the sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once an acceptable sequential arrangement of events was accomplished, the sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once an acceptable sequential arrangement of events was accomplished, the sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once an acceptable sequential arrangement of events was accomplished, the sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once an acceptable sequential arrangement of events was accomplished, the sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints.

C. Computer reduction of down-linked data

When the Lander receives the data generated by the biology instrument, it stores them in a memory window available for downlinking. This may be either by direct transmission to earth or via a relay through the orbiter. The biology data is mixed in with all other Lander data during transmission. After data are received by the DSN they are sent to JPL, where a computer program separates them according to experiment and makes them available to the biology data reduction programs of the individual experiments.

There are two computer programs for processing data from the biology experiments. The first of these receives the data in the raw sampled memory frames and, using inputs from the sequence generation program, time-tags the data and separates them according to type of event. The time-tag process is complicated by the absence of any time identification of the data words as they are stored by the instrument. It is accomplished using a precise prediction of the down-link data generated by the command up-link program to match the received data to that which was predicted. It also decalcifies the data into scientific units and checks for out of range values. It gives the science team its first quick look at the data as they are returned from Mars.

The first biology data reduction program also creates a working data file for the second program. This is a file of time-tagged and decalcified data values which is added to daily as the mission proceeds. The second of the biology data reduction programs is interactive and is designed to be used by members of the science team to perform higher order processing of their data. It accesses the data in the working data file, performs statistical analyses, curve fitting, and plotting functions as requested from the computer terminal. The science team is able to use this program to analyze in detail the results of their experiments.

X. Operations

On July 20, 1976, Viking Lander I settled gently on the plains of Chryse and commenced operations. For the next 300 Martian sols, the biology instrument successfully conducted ID experiments on 4 different soil samples. The primary mission was successfully completed before superior solar conjunction when commanding of the Lander sequencing investigations was interrupted for several weeks. After conjunction secondary experiments were conducted until May 1977 when the helium consumable gas used to engage the test cell curvatures and move liquids and gases into and out of the experiments was depleted, as expected. The only degradation in instrument operation occurred in the secondary experiments during the gas exchange experiment, which used the third soil analysis cycle when the gas chromatograms (Table X) detected no gases due to a presumed leak in the test cell. During the Lander I biology instrument operation 52 gas chromatograms were taken for the GEx experiment, 6 pyrolytic release experiments were completed, and 9 radioactive nutrient injections were made in four different tests for the GCSC.

On September 3, 1976 Viking Lander II arrived at Viking biology instrument...
The biology instrument’s primary mission was also completed by conjunction and the secondary experiments prevented collection and measurement of the carbon-14 during the 4th and 5th soil sequences. The only malfunction occurred during the Lander II biology instrument operation, 13 separate experiments on 4 different soil samples were successfully completed, and 9 radioactive nutrient investigations were performed. A pyrolytic release experiment was made in five different tests for the labeled release experiment. A total and about 2900 commands were processed by the biology instrument on each Lander during the complete mission.

The scientific results of these experiments are being published separately by members of the biology science team.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of the nearly 1000 people at TRW whose participation in the development of the biology instrument made its successful operations on the Martian surface possible. We thank the Martin Marietta Corporation residents team and its chief engineer, Dale Buckendahl, for many long years spent at TRW assisting in the instrument’s development. The special expertise of NASA/Langley Research Center, NASA/Ames Research Center, and the Jet Propulsion Laboratory was brought to bear on some of the more obstinate problems encountered during the program. We especially thank Richard D. Johnson of NASA/GRC, G. Calvin Broome, Roy Duckett, and J. B. Lovell of NASA/LaRC and the members listed in Table I of the Biology science team lead by H. P. Klein. Support for this work was provided under NASA contracts NASI-9000 and NASI-12431.}

Precision absolute measurements of strong and highly inhomogeneous magnetic fields

A. Honig and M. Moroz

Physics Department, Syracuse University, Syracuse, New York 13210

(Received 28 February 1977; in final form, 8 June 1977)

The low-temperature (~2 K) dependence of the photoconductance in n-type silicon on the conduction electron and bound donor electron spin state serves as the basis of a high-precision, wide-range magnetic field measuring probe, which by virtue of its very small dimensions and low output, is suitable for spatial mapping of highly inhomogeneous, highly magnetized superconducting magnets. The probe may also be adapted to power and frequency measurement of microwave sources operating at ~mW power levels and frequencies up to ~500 GHz.

Among the many methods for measuring magnetic fields, only the resonance ones provide absolute field measurements to a precision of better than 1 part in 1010 with a simple laboratory instrument. Rotating cells, Hall-effect probes, and magnetoresistance probes each have their respective merits and disadvantages, but dimensions of at least a few mm are required, and precision of about 1 part in 1010 is about as high as can be expected. The resonance methods, based on accurate frequency standards and known magneto- optical characteristics of the elements, offer high precision but require relatively large samples when the resonances are detected by standard means such as monitoring the reactive electromagnetic radiation field. In addition these conventional radio-frequency and microwave resonance methods are frequently narrow band, requiring tuned coils or cavities for high sensitivity measurements. We describe here a method of carrying out resonance measurements which retains all the advantages of the standard resonance method, but is also broadband and applicable even for very small sample volumes. This is achieved by detecting the resonance at liquid helium temperatures, where the noise level is very low, and (through a property of the system for which the signal-to-noise ratio decreases more slowly than linearly with decreasing sample volume, in contradistinction to the standard detection technique in which the reactive electromagnetic field is monitored. The method is based on spin-dependent photocarrier conductivity in semiconductors, the physics of which has been studied in several publications.1 Most of the work has been on n-type silicon, and for simplicity of presentation we confine ourselves to that material in this report. At liquid helium temperatures (~1.4 K), the dark current for uncompensated silicon containing group V donors at concentrations below 1015cm-3 is negligible in relation to the photocurrents which will be em-
The biology instrument's primary mission was also compromised by the secondary experiments that were terminated by depletion of the helium reservoir on the expected date. The only malfunction occurred during the secondary mission when a leaking valve in the PR experiment prevented collection and measurement of the carbon dioxide during the 4th and 5th soil sequences. During the Lander II biology instrument operation, 13 separate experiments on 4 different soil samples were successfully completed, and 9 radioactive nutrient injections were made in five different tests for the labeled release experiment. A total of about 2900 commands were processed by the biology instrument on each Lander during the complete mission.

The scientific results of these experiments are being published separately by members of the biology science team and its chief engineer, Dale Buckendahl.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of the nearly 1000 people at TRW whose participation in the development of the biology instrument made its successful operations on the Martian surface possible. We thank the Martin Marietta Corporation resident team and its chief engineer, Dale Buckendahl, for the many long years spent at TRW assisting in the instrument's development. The special expertise of NASA/Langley Research Center, NASA/Aeromet Research Center, and the Jet Propulsion Laboratory was brought to bear on some of the more obstinate problems encountered during the program. We especially thank Richard D. Johnson of NASA/GRC, G. Calvin Broome, Roy Duckett, and J. B. Lovell all of NASA/LaRC and the members listed in Table II of the Biology science team lead by H. P. Klein. Support for this work was provided under NASA contracts NASI-9000 and NASI-14231.

Among the many methods for measuring magnetic fields, only the resonance ones provide absolute field measurements to a precision of better than 1 part in 106 with a simple laboratory instrument. Rotating cells, Hall-effect probes, and magnetoresistance probes each have their respective merits and disadvantages, but dimensions of at least a few mm are required, and precision of about 1 part in 105 is about as high as can be expected. The resonance methods, based on accurate frequency standards and known magneto- optical properties of the elements, offer high precision but require relatively large samples when the resonances are detected by standard means such as monitoring the reactive electromagnetic radiation field. In addition, these conventional radio-frequency and microwave resonance methods are frequently narrow band, requiring tuned coils or cavities for high sensitivity measurements. We describe here a method of carrying out resonance measurements which retains all the advantages of the standard resonance method, but is also broadband and applicable even for very small sample volumes. This is achieved by detecting the resonance at liquid helium temperatures, where the noise level is very low, and (through a property of the system for which the signal-to-noise ratio decreases more slowly than linearly with decreasing sample volume, in contradistinction to the standard detection technique in which the reactive electromagnetic field is monitored)

The method is based on spin-dependent photoconductivity in semiconductors, the physics of which has been described in several publications. Most of the work has been on n-type silicon, and for simplicity of presentation we confine ourselves to that material in this report. At liquid helium temperatures (4.2 K), the dark current for uncompensated silicon containing group IV donors at concentrations below 10^{17} cm^{-3} is negligible in relation to the photocurrents which will be em- ployed to carry out the experiments described here. The ratio of intrinsic radiative (hν > 1.18 eV) to nonradiative (hν < 1.18 eV), where h is the Planck constant, the photoconductance is proportional to the product of carrier generation rate (γ radiation intensity), carrier mobility, and carrier concentration of, or below, 10^{17} cm^{-3}, a readily obtainable condition, the dominant electron-electron lifetime limiting mechanism at low temperatures is capture by neutral donors, denoted by the reaction

\[ D^+ + e^- \rightarrow D_1^0 \]  

This reaction, however, occurs only when the neutral donor, \( D^+ \), and the conduction electron interact in a singlet spin state, since the resultant \( D_1^0 \) state is stable (bound) only in the electronic singlet spin state, and the probability of spin flip during capture is very small.

If the neutral donors are highly spin-polarized, the conduction electrons also are highly spin-polarized, since for the impurity concentrations employed, the relative rate of spin exchange between donors and conduction electrons exceeds the rate of electron capture or generation. Thus, for donors in a highly spin-polarized state (\( P = 1 \)), the neutral donors and conduction electrons are expected to collide mostly in a triplet spin state, leading to long carrier lifetimes and a high photoconductance, whereas in an unipolarized (\( P = 0 \) state), the neutral donors and conduction electrons and donors are abundant, the photoconductance is reduced because the carrier lifetime is...