The Biology Instrument for the Viking Mars Mission

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The biology instrument for the Viking Mars mission


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Two Viking spacecraft have successfully soft landed on the surface of Mars. Each carries, along with other scientific instruments, one biology laboratory with three different experiments designed to search for evidence of living microorganisms in material sampled from the Martian surface. This 15.5-kg biology instrument which occupies a volume of almost 28.3 dm$^3$ is the first to carry out an in situ search for extraterrestrial life on a planet. The three experiments are called the pyrolytic release, labeled release, and gas exchange. The pyrolytic release experiment has the capability to measure the assimilation 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.

I. INTRODUCTION

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 $^{12}$ 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 instrument contains three separate biological experiments which analyze the Martian surface material for microorganisms by three different methods. The pyrolytic release experiment is designed to measure either photosynthetic or chemosynthetic fixation of CO$_2$ or CO into organic compounds. $^{13}$ The labeled release experiment tests for the presence of metabolic activity during incubation of a soil sample that has been monitored with a dilute aqueous solution of carbon-14 labeled simple organic compounds. $^{14}$ The gas exchange experiment detects changes in the concentration of metabolic gases above a soil sample which can either be incubated in the presence of only water vapor and Mars atmosphere or wet with a rich, nonradioactive, aqueous nutrient solution. $^{15,16}$

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. $^{15,16}$ Throughout the 1960s several different experiments were suggested for detection of extraterrestrial life based on various physical, chemical, and biological approaches. $^{15,16}$ 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 carried on Viking 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 during the development period after detailed engineering and planning studies indicated there was little chance that a four-experiment instrument could successfully be manufactured and

| TABLE I. NASA selected team for Viking active biology investigation. |
|-------------|-----------------|-----------------|
| H. Klein (Ames), Team Leader | W. Vinogradov$^a$, (U. of Rochester), Ass. Team Leader |
| H. Herzwitz (JPL, Cal Tech) | Light Scattering |
| G. Levin (Biosphereics, Inc.) | Porphyrin Release |
| V. Oyama (Ames) | Labeled Release |
| A. Rich (MIT) | Gas Exchange |
| J. Lederberg (Stanford) | |

$^a$ Prof. Vinogradov died in an accident in 1973 while conducting Viking-related experiments in Antarctica.

tests 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) to rather earthlike conditions (the gas-exchange experiment which simulates the Martian atmosphere and temperature). 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 scientific 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 between -5 °C and +27 °C. All electric power is obtained from two radiotransistors 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 305-cm 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 a 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 (PSA), the communication interface (CI), the processing unit (DAPU) before storage of the Lander tape recorder, and the data acquisition and processing unit (DAPU). The instrument is the lander's prime contractor, and continued for 5 years of design, fabrication, and test until delivery of the flight units in the spring of 1975. Three scientific 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.
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The biology instrument resides along with other science instruments and electronic assemblies in the interior of the lander in a thermally controlled environment (−5° to +27°C). All electric power is provided by two radioisotope thermoelectric generators which have the capability of providing average power of about 60 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 3.0-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 instruments, and the guidance and control computer (GCSC) which provides clock signals and commands to the instrument, and the data acquisition and processor assembly which collects the data from the biology instrument for later transmission either to the orbiter or directly to earth. In addition to these electric interfaces, the instrument is exposed to the Martian environment through the SSPDA. Waste gases and vapors are brought out of the lander through these gas and one vapor vent lines.

The three biology experiments have been integrated into 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 several temperature sensors. The MSS 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 1-μm pore-size filters to prevent particles from plugging critical flow resistances.

The illustration shows the three experiments with their functional detail. The experiments include a pyrolytic release experiment which moistens the soil with a nutrient of simple, dilute organic compounds, an incubation cell which moistens the soil with 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.

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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, they are first digitized, then recorded on magnetic tape. Data from the final digitized experiment in the cycle is verified, then transferred to the MSS and stored in the memory. The sequence control of the MSS is provided by three read-only memory (ROM) sequences. The three sequences are designated as the 14C cycle, the 14C cycle, and the 2C cycle. These sequences are divided into blocks which are then automatically repeated as directed by the commands from the GCSC. The individual sequence functions of the instrument are stored within the ROM sequencer with 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 (GEx), 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.

The GEx is designed to incubate a soil sample in the presence of a rich nutrient. This experiment contains a soil, a gas exchange device, and a carousel permitting the use of anyone to sample in the presence of a radioactively labeled carbon from the radioactive gas and therefore become labeled. After the incubation period, the incubation atmosphere is vented and the cell rotated to the pyrolysis head end. There the soil sample, which contains CO2, is pyrolyzed by raising its temperature to 625°C, and the pyrolyzed organics are trapped in an organic vapor trap. The organics are then converted to CO2 by an "efluent" heating of the trap and counted by the separate detector. The data are stored in the ESS and later transmitted to earth for analysis.

The MSS (Fig. 3) is designed as a modular concept. About 77 000 standard cm3 of helium are available for instrument operation. A 200 standard cm3 of helium is used as the gas for the gas chromatograph in the GEx experiment, hence, it is called the carrier gas supply (CGS). It is, however, used by other experiments to move cells, to prevent recontamination during shipping and installation, to prevent recontamination during shipping and installation, to maintain the LR and GEx aqueous 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 labeled. After the incubation period, the incubation atmosphere is vented and the cell rotated to the pyrolysis head end. There the soil sample, which contains CO2, is pyrolyzed by raising its temperature to 625°C, and the pyrolyzed organics are trapped in an organic vapor trap. The organics are then converted to CO2 by an "efluent" heating of the trap and counted by the separate detector. 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 cm3 of soil from the soil sampler processor and distribution assembly. At the start of the experiment cycle, soil distribution is made to the three experiments. The SDA operation involves the use of three valves which are controlled by the GCSC. The valves distribute 0.5 cm3 to the LR, and 0.25 cm3 to the PR. The remainder of the soil is retained in the SDA to provide a sample of the same soil should a decision be made to rerun the experiment cycle. To perform an experiment the soil is obtained from the SDA and rotated to the incubation head end. As in the individual experiment dump cells by driving the SDA in a soil delivery mode.

III. STERILIZATION REQUIREMENTS

An extraterrestrial life detection instrument has placed upon it several unusual requirements. One of the most unique is that the instrument must be capable of being sterilized by dry heat.

Because it is the goal of the biology instrument to detect indigenous life on Mars, there are two reasons for heat sterilization of the instrument and the lander to significantly lower the biological contamination contained thereon: (1) reduce the probability of the biology instrument detecting Earth organisms carried to Mars to less than one in a million, 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 then on earth.

In the preinstallation sterilization, the instrument was heated to 120°C for 54 h in a dry nitrogen atmosphere. This heating killed any microorganisms which were not 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 120°C for 54 h in a dry nitrogen atmosphere at 1 bar. From the time of the sterilization onward, the biology instrument was protected by the bioshield and never again exposed to the airborn microbes 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. The 14C experiment showed metabolism as much as 200 days of incubation on Viking Lander 1, 163

This experiment provides an environment of 10^-12 C, 2 x 10^-12 C, and nutrient rich in amino acids, carbohydrates and salts, and pressure averaging about 200-600 mbar. Under these conditions Earth microorganisms would be expected to metabolize and reproduce. The lack of 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 heaters which maintain the LR and GEx aqueous nutrients, each contained in a sealed glass ampoule above freezing.

During this phase of the mission all solenoid valves are open, except for two valves on the vents. The stored helium is retained in a hermetically sealed container, as are the 14C/CO2 for the PR experiment. The contamination from headspace CO2 would be overwhelming.

Once Mars orbit is achieved and just prior to separation from the orbiter, operating power was applied to the instrument for the first time since launch. During a 12-h sequence, preparation for landing was made. The purpose of this sequence was to close selected valves to prevent exhaust gases from the rocket engines from contaminating the instrument. In addition, the carrier gas supply downstream of the isolation valves was closed to prevent Martian CO2 from contaminating the helium. Because of an automatic reset feature, the initial application of power automatically closes all valves except the vent valves which are opened, and turns on several heaters designed for ambient temperature post-landing cooler. Since the heaters are not yet required, the next operation returns the instrument to the cruise condition which turns off these heaters. Specific valves are now individually commanded closed to prevent the instrument from engine exhaust gases and to retain a vacuum in the CGS regulators. If the regulator system were to fail, the instrument would be exposed to Martian atmosphere. If the contingency were to keep the bottle from reaching the CGS regulators, the instrument was prepared for receipt of its first soil sample.


Viking biology instrument


Viking biology instrument
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, they are digitized by a measurement in one of the analog to digital converters (ADCs) as directed by the commands from the GCSc. The data are stored and transmitted to the Lander as directed by the 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 (GEs), 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.

The GEs are designed to incubate a soil sample in the presence of a rich nutrient. This experiment contains a soil sample and one soil dump cell mounted on a carousel which can be dropped and rotated so as to position either the test cell or the dump cell at the head end of the load port. The soil is obtained from the SDA and rotated to the incubation head end. At the incubation head end the carousel is sealed and an incubation atmosphere is created for the sample. The incubation gas is carried in a capsule within the cell, which contains CO, to simulate the Martian atmosphere, helium to provide the pressure required for obtaining a gas chromatograph analysis, and a standard gas for the gas chromatograph. In all three experiments, temperature control is provided by means of heaters and thermoelectric coolers to maintain the temperature of the cell at 20 °C, 27 °C, and 37 °C. After injection into the incubation chamber, first in a mode to provide only a humid environment in the cell and later to accommodate the gases admitted to the post-sterilization incubation gas for the gas chromatograph in the GEs experiment; hence, it is called the carrier gas supply (CGS). It is, however, used by other experiments to move cells, which is referred to as "vaporizing" or "organics trapping." At periodic intervals during the incubation period, the incubation gas in the headspace is sampled and analyzed using a gas chromatograph. The data from each of these analyses are stored in the ESS and later transmitted to Earth for analysis.

The SDA receives 6 cm of soil from the soil sampler processor and distribution assembly. At the start of the experiment cycle, soil distribution is made to three experiments. The SDA operation involves a pre-sterilization vacuum, the lander and GEx, 0.5 cm to the LR, and 0.25 cm to the PR. The remainder of the soil is retained in the SDA to provide a sample of the same soil should a decision be made to repeat the experiment cycle. To perform an experiment the soil is obtained from the SDA and rotated to the incubation head end. At this point the chamber is sealed and the incubation atmosphere established. A small quantity of aqueous nutrient is then injected onto the soil. This liquid contains low concentrations of radioactively labeled (C) 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.

In the preinstallation sterilization, the instrument was heated to 120°C for 54 h in a dry nitrogen atmosphere. The heat sterilization was performed in the ESS and later transmitted to Earth for analysis. In order to prevent recontamination during shipping and installation, the instrument was handled in the following manner: All test chambers were filtered through 0.45-μm membrane filters. The instrument was shipped to Kennedy Space Center and then to the Mars site. When the instrument was reassembled, it was released to the atmosphere. During installation of the biology instrument in the Viking lander, handling precautions were taken to minimize any possible recontamination 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 mission sample of soil and biology instrument were heated to 112°C for 24 h. The soil was cooled at 2°C h in a dry nitrogen atmosphere at 1 bar. From the time of this sterilization onward, the biology instrument was protected by the bioshield. The instrument was prepared for receipt of its first soil sample.

Viking biology instrument
The sequence of operations starts with the application of power to the instrument. This operation automatically closes all instrument solenoid valves, opens the valves on the vent lines, and powers the instrument radiation detectors. Since the instrument may have been quite cold, all valve operations which would involve pressure are delayed for 100 min to allow the instrument to stabilize thermally.

The experiment is to be reset by one drive operation of the instrument’s motors to their initial positions in preparation for actual cell rotations or soil distribution cycles.

The following operations involve the accessing of the instrument’s stored gases and the GEK column rejuvenative sequence. A command is given to the instrument ambient control heaters. Since the instrument may have been quite cold, all valve operations which would involve pressure are delayed for 100 min to allow the instrument to stabilize thermally.

Confirmation that the ampoule and its fill-port seal are leak free is made for testing by helium leakage from the ampoule under vacuum. The sealed ampoule and nutrient are sterilized in aluminum foil by heating to 135°C for 15 min. Approximately 7 cm³ of the total 8 cm³ nutrient in the ampoule is available for injection; there is a loss of about 0.10 to 0.15 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.

Adding nutrient to the soil in the test cell is accomplished by filling a closed cavity, under a pressure of 5 bar nitrogen, with nutrient from the reservoir 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, the mass of nutrient is increased over full environment above the soil, it is necessary to admit helium to the test cell to raise the total pressure above the vapor pressure of water. The test cell is then depressurized to the pressure in the cell to 60-70 mbar versus the water vapor pressure of 12.3 mbar at 10°C.

2. Test cell system

The test cell is a stainless steel cylinder of 3.25 cm outer radius, 1.5 cm inner radius, and 14 cm length. The cell is placed in a sterile enclosure that portion of the head-end assembly. There are four identical test cells which are rotated by a Geneva drive mechanism. Each test cell is 9.45 cm in diameter. The cell is held in the closed position by spring tension. To lower the cell the 9.2-bar helium is applied via a solenoid valve. The cell remains depressed until the portion of the head-end to which the cell mates with the cell is released. Each test cell is equipped with a 0.5-mm membrane filter. The filled ampoule is sealed at 134 mbar total pressure by melting the glass fill tube. Confirmation that the ampoule and its fill-port seal are leak free is made for testing by helium leakage from the ampoule under vacuum. The sealed ampoule and nutrient are sterilized in aluminum foil by heating to 135°C for 15 min.

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

1. Nutrient supply and injection system

The nutrient supply function has the capability of transporting the nutrient from Earth to Mars in a sterile 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 materials were left in the ampoule. The ampoules were then filled with the carbon-14 labeled nutrient. 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 and is designed to prevent the introduction of a 0.5-mm membrane filter. The filled ampoule is sealed at 134 mbar total pressure by melting the glass fill tube. Confirmation that the ampoule and its fill-port seal are leak free is made for testing by helium leakage from the ampoule under vacuum. The sealed ampoule and nutrient are sterilized in aluminum foil by heating to 135°C for 15 min.

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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 materials were left in the ampoule. The ampoules were then filled with the carbon-14 labeled nutrient. 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 and is designed to prevent the introduction of a 0.5-mm membrane filter. The filled ampoule is sealed at 134 mbar total pressure by melting the glass fill tube. Confirmation that the ampoule and its fill-port seal are leak free is made for testing by helium leakage from the ampoule under vacuum. The sealed ampoule and nutrient are sterilized in aluminum foil by heating to 135°C for 15 min.
The sequence of operations starts with the application of power to the instrument. This operation automatically closes all instrument solenoid valves, opens the valves on the vent lines, and powers the instrument's internal heaters. Since the instrument may have been quite cold, all valve operations which would involve pressure are delayed for 100 min to allow the instrument to stabilize thermally. The instrument is then reset by one drive operation all of the instrument's motor's to their initial positions in preparation for actual cell rotations or soil distribution.

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 turn on the power supply for 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 warmed, 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 GEx device is used so much that it is prepared from compounds containing radioactive carbon (14C). The organisms in the soil can then assimilate the compounds and give off carbon gases. The gas chromatograph is set to detect radioactive carbon (14C). The gases are measured in a detector sensitive to 14C beta radiation from the metabolized carbon-dioxide.

For the Viking biology instrument the LR experiment uses a small volume of nutrient compared to the total volume (1:5 ratio). The rationale for not completely wetting the soil is to provide a moist environment (versus the dry environment, which is used in the gas exchange experiment, which is primarily very wet) and create a moisture gradient in the soil to minimize the recombination of 14C with oxygen forms in the soil atmosphere. The experiment is performed after having been exposed to vacuum. The LR experiment is designed to find any differences in the soil's response to the nutrient delivery.

The instrument is now ready for performance of the biology experiments, and the main operating power is turned off to allow the Viking lander batteries to charge for 5 days prior to proceeding on a full experiment cycle.

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 microorganisms. The terrestrial organisms metabolize carbon-based nutrients to gaseous products such as CO2 and CH4. In the LR experiment a nutrient 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 gas chromatograph is set to detect radioactive carbon (14C). The gases are measured in a detector sensitive to 14C beta radiation from the metabolized carbon dioxide.

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B. LR experiment implementation

Figure 4 is an 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. The 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 flow diagram, Fig. 5, shows the various parts of the experiment in diagrammatic form and gives the numbering system used to denote the valves. The experiment operations are listed in Table III. The experiment operation in terms of the functions of the components is discussed below.

1. Nutrient supply and injection system

The nutrient supply function has the capability of transporting the nutrient from Earth to Mars in a sterile container. 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. The nutrient solution is labeled with 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 prevent bacterial contamination of the 0.65-mm 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 135°C.

Adding nutrient to the soil in the test cell is accomplished by filling a closed cavity, under a pressure of 4.0 bar, with nutrient from the generator, 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, the nutrient is contained in a 25-cm3 cavity (7.5 bar) environment above the soil, it is necessary to admit helium to the test cell to raise the total pressure above the vapor pressure of nutrient. This will prevent the nutrient from boiling as it is delivered to the test cell.

Data output from each cell is recorded on a punched card at the completion of each cycle and then transferred to the main computer at the end of each cycle. The soil and nutrient distribution can be monitored by the main computer at any desired time during the experiment. The nutrient solution is labeled with 14C beta radiation from the metabolized carbon-dioxide.

The test cell is a stainless steel cylinder of 3.25-cm3 volume. The nutrient solution is contained in a nitrogen atmosphere which is maintained by the nitrogen gas supply to the cell and by the provision of evacuation equipment. The cell is made of a Viton O-ring seal against a flange and is held in position by spring pressure. The cell is held in the closed position by spring tension. To lower the cell the 9.2-bar helium is applied via a solenoid valve. The cell remains depressed until the high pressure gas is vented. All rotations of the cell take place with the cell in a depressed position. See Sec. VIII A 2 for control design.

The portion of the head end to which the cell mates was filtered isopropanol followed by distilled water to insure no toxic material is turned to the system. They were then wrapped in aluminum foil and sterilized by autoclaving for 15 min. The ampoules were then filled with the carbon-14 labeled nutrient. The ampoule sealing was 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 prevent bacterial contamination of the 0.65-mm 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 135°C.

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.

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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.

The test cell has 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 35°C.

The beta detector is equipped with a heater that goes 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 test 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 heated 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-45 (Fig. 3) 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 leakages. 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 detector at a level above that of the test 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.

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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 test cells.

3. Carbon-14 beta detector assembly

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 diffused-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 35°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 heated 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 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.

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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 pressurized 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 when nutrient is present in the soil. The instrument underwent two sterilizations—a 54-h sterilization at 120°C at TRW and a 112°C sterilization at Kennedy Space Center of 26 h, prior to launch. These
sterilizations heat the nutrient and the radioactive gas generated must be removed before the first experiment.

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 bar is then flowed through the nutrient through S-46 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 mbar 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·s⁻¹ of helium. After injection, the detector carbon-14 background is reduced prior to organisms residing in the vent system. The activity of volatile material in the vent during the 5.3-mbar CO₂ atmosphere of the test chamber for sterilization heat the nutrient and the radioactive gas generated must be removed before the first experiment.

The Martian soil is exposed to these conditions for approximately 2 days. 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 bar is then flowed through the nutrient through S-46 and S-59.

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The Martian soil is exposed to these conditions for approximately 2 days. 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 bar is then flowed through the nutrient through S-46 and S-59.

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The Martian soil is exposed to these conditions for approximately 2 days. 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 bar is then flowed through the nutrient through S-46 and S-59.

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The Martian soil is exposed to these conditions for approximately 2 days. 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 bar is then flowed through the nutrient through S-46 and S-59.

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The Martian soil is exposed to these conditions for approximately 2 days. 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 bar is then flowed through the nutrient through S-46 and S-59.

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The Martian soil is exposed to these conditions for approximately 2 days. 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 bar is then flowed through the nutrient through S-46 and S-59.

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The Martian soil is exposed to these conditions for approximately 2 days. 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 bar is then flowed through the nutrient through S-46 and S-59.

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To remove the radioactive gas 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-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 an adequate 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. This flush is followed by a 30-min flow of nitrogen into the detector to reduce the carbon-14 background and the detector cell heating has been selected so that the adsorbed radioactivity at the end head will be removed and the detector cell background reduced prior to the next experiment. The temperature of 110°C at the detector-cell head and 170°C at the head end is sufficient to remove most of the adsorbed radioactivity.

The vent lines through which the purged gases flow (V-2, V-3, and V-4) are heated to 110°C. The vent line through which the carbon-14 gas flow (V-1) is vented directly to the vent line. The vent line through which the nitrogen gas flow (V-0) is vented to the vent. To accomplish this, a stream of helium at the detector (valve S-42) at 2 std cm·min and above at the detector cell head and cell heating has been selected so that the adsorbed radioactivity at the head end will be removed and the detector cell background reduced prior to the next experiment. The temperature of 110°C at the detector-cell head and 170°C at the head end is sufficient to remove most of the adsorbed radioactivity.

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 option sterilization of the soil for a control analysis. A block diagram of the sequence steps is presented in Fig. 2.

- The soil 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 Martian environment, the instrument was operated in an environmental control chamber at a pressure of 5.3-mbar CO₂ and in a thermally controlled shroud which mimicked the expected diurnal temperature variation within the lnder (0°C-28°C). The data from the carbon-14 detector in the LR experiment are given in Fig. 8 for that test. The test sequence consists of two cycles: an active and a control on sterilized soil.

- The soil used in this test is a red podzolic Aiken series, collected in a wooded area near Placer, CA. The soil had been air dried and stored for 3-6 months in airtight containers. The soil was made up so that all biological activity was stopped and the soil was a solids mixture of nitrogen and 6 × 10⁶ anaerobic organisms, and 3 × 10⁶ viable gram of dry soil. The soil was exposed to the 5.3-mbar CO₂ atmosphere of the test chamber for 1 h before beginning the sequence of Fig. 7. Prior to the test, the entire biology instrument had been sterilized at 112°C for 40 h so that all biologically related soil activity has been reduced to the level of the organic samples.

- Each point on the plot is a recorded carbon-14 detector measurement. The sharp rise in volatile carbon-14 immediately upon nutrient injection is obvious in both the active and control plots. 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 15.3 counts reduces the background level in each case is accounted for by the activity of the same soil in the control chamber.

- The data are presented in cpm and can be converted to dpm using an overall detector efficiency of 3%. The data are converted from the experiment's capability to use only one of the two sensing elements in the carbon-14 detector—a drop to one half of 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. Several nutrient injections have been performed and conducted releases were reported for a total of 3500 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.

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 their incorporation of CO and CO₂ 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 CO₂, the natural Martian atmosphere above the soil which contains both these gases is supplemented with trace amounts of ^13C and ^13CO₂. On Earth, this assimilation process is enhanced by the addition of water vapor and/or simulated sunlight, and as both of these are present on Mars, this capability is part of the experimental hardware. However, the ultraviolet component of the sunlight is removed to eliminate the possibility of nonbiological formation of organic compounds.

- The Martian soil is exposed to these conditions.
tions for about 120 h and then the radioactive atmosphere above the soil is removed and the soil is pyrolyzed in a stream of helium gas. The organic matter including the newly synthesized radioactive material in the soil is volatilized by the pyrolysis and is transported into an organic vapor trap (OVT) by helium carrier gas where it condenses. Any residual $^{14}C$ and $^{14}CO$ from the incubation atmosphere or any generated during pyrolysis of the soil passes through the trap and is collected in a solid-state counter where it 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 vapor trap is obtained by first heating the vapor trap to 625°C in a stream of helium. This heating breaks down the organic material into gaseous radioactive oxides of carbon, and these are again carried into the solid-state detector and counted. This second radioactive active count provides a measurement of the amount of radioactive carbon that was assimilated by the organisms in the original soil incubation. The first radioactive count provides an estimate of the size of the error in the second "organic" count that could be attributed to $^{14}CO$ and $^{14}CO$ that had been adsorbed on the OVT based upon a prior calibration.

A second duplicate experiment can be performed as a control except that a sample of the same soil is sterilized prior to exposure to the incubation gases. This control experiment provides information as to the size of the radioactive "organic" synthesis by the Martian soil and the background of the experiment hardware after heat inactivation of any Martian microorganisms.

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.

### Table V. Labeled release experiment summary of Mars surface operations

<table>
<thead>
<tr>
<th>Experiment description</th>
<th>Soil received, sterilization regime</th>
<th>Nutrient injections</th>
<th>Number</th>
<th>End experiment, soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lander 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>8 None</td>
<td>2</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>Control</td>
<td>24 3 h, 160°C</td>
<td>2</td>
<td></td>
<td>37</td>
</tr>
<tr>
<td>Extended active</td>
<td>38 None</td>
<td>3</td>
<td></td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>End of primary mission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lander 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>8 None</td>
<td>2</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>Low temperature control</td>
<td>28 3 h, 50°C</td>
<td>2</td>
<td></td>
<td>48</td>
</tr>
<tr>
<td>Active, sub rock soil</td>
<td>51 None</td>
<td>2</td>
<td></td>
<td>141</td>
</tr>
<tr>
<td></td>
<td>End of primary mission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low temperature control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>repeat</td>
<td>145 3 h, 50°C</td>
<td>2</td>
<td></td>
<td>171</td>
</tr>
<tr>
<td>High soil, active</td>
<td>None*</td>
<td>1</td>
<td></td>
<td>260</td>
</tr>
</tbody>
</table>

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

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° (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 pressurized 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 normal Martian soil incubation. Each of these systems is physically con-
The amount of radioactive organic material contained in the vapor trap is obtained by first heating the vapor trap to 625 °C in a stream of helium. This heating breaks down the organic material into gaseous radioactive oxides of carbon, and these are again carried into the solid-state detector and counted. This second radioactive count provides a measurement of the amount of radioactive carbon that was assimilated by the organisms in the original soil incubation. The first radioactive count provides an estimate of the size of the error in the second "organic" count that could be attributed to 14CO2 and 14CO that had been adsorbed on the OVT based upon a prior calibration.

A second duplicate experiment can be performed as a control except that a sample of the same soil is sterilized prior to exposure to the incubation gases. This control experiment provides information as to the size of the radioactive "organic" synthesis by the Martian soil and the background of the experiment hardware after heat inactivation of any Martian microorganisms.

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.

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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 normal Martian soil incubation. Each of these systems is physically con-
nected to the incubation cell via the incubation head assembly. The incubation volume formed when the cell is sealed in a small end is made leaktight by compressing the test cell containing soil against an elastomeric seal in the incubation head end. A controlled amount of CO2 and O2 tracer gases are 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 which contains the soil and normal Martian atmosphere. If humidification of the incubation cell is required, the valve between the water vapor reservoir and the incubation cell is opened for a short time period that allows a capillary-controlled flow of water vapor to enter the cell. If simulated sunlight is required, the xenon arc lamp is used to illuminate the soil through an optical window in the incubation cell head. During the incubation, the cell temperature is kept within a predetermined range by automatic operation of heaters and thermoelectric 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-cm³/min helium gas flow. This helium carrier gas flow removes the products of pyrolysis and carries them to an organic vacuum trap. The trap is a temperature-programmable 25-cm-long, 0.3-cm-diam stainless steel tube containing a mixture of Chromosorb and copper oxide. The Chromosorb provides a large surface area for trapping organics, and the copper oxide, when heated above 500 °C, oxidizes the organics to gases of carbon dioxide and water vapor. The helium gas exiting from the incubation cell is directed into a test cell which contains an integrator or heater and a temperature sensor which provide five temperature set points. The first set point is 85 °C ± 5 °C, above which the soil is heated for pyrolysis. The second set point is 115 °C ± 10 °C which is used to heat the soil to a predetermined temperature. The third set point is 250 °C which is used to pyrolyze the soil. The fourth set point is 325 °C, which is used to pyrolyze the soil at a rate that is faster than the natural pyrolysis rate. The fifth set point is 425 °C, which is used to pyrolyze the soil at a rate that is faster than the natural pyrolysis rate. The fifth set point is 425 °C, which is used to pyrolyze the soil at a rate that is faster than the natural pyrolysis rate. The fifth set point is 425 °C, which is used to pyrolyze the soil at a rate that is faster than the natural pyrolysis rate.

During incubation, the cell is sealed under the head and its temperature is controlled to vary between ± 1 °C. This temperature variation is monitored once every 32 min. If the lamp is found to be extinguished, a series of eight start pulses is sent. However, if the lamp does not start at this time, another set of start pulses is sent again 32 min later when lamp current is checked.

2. Analysis system

Organic vapor trap. The OVT is essentially a high-surface-area condensation trap which is used to condense volatile organics in the soil. The organic vapor trap is composed of a mixture whose composition is calculated to be 90% CO2 and 10% CO. It is injected into the head space above the soil from a 2-cm³ reservoir containing 2 ml of gas at a pressure of 335 mbars. During the incubation, this gas is heated to a temperature that is sufficient to provide a clean, constant flow of gas to the test cell. The gas is heated by a spiral heater which is wound around the 2-cm³ reservoir and is controlled by a temperature sensor mounted at a point above the test cell.

In addition to the volatile organics, the incubation gas is also used to provide a clean, constant flow of gas to the test cell. The gas is heated by a spiral heater which is wound around the 2-cm³ reservoir and is controlled by a temperature sensor mounted at a point above the test cell.

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 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 volume, which is composed of the test cell and the incubation head end volume, is 4.13 cm³. Each test cell has an integral heater and a temperature sensor which provide five temperature set points. The first set point is 85 °C ± 5 °C, above which the soil is heated for pyrolysis. The second set point is 115 °C ± 10 °C which is used to heat the soil to a predetermined temperature. The third set point is 250 °C which is used to pyrolyze the soil. The fourth set point is 325 °C, which is used to pyrolyze the soil at a rate that is faster than the natural pyrolysis rate. The fifth set point is 425 °C, which is used to pyrolyze the soil at a rate that is faster than the natural pyrolysis rate.

A xenon arc lamp is used to provide the required light intensity. This lamp is a 150-W xenon arc lamp which is mounted on a stainless-steel cylinder that is surrounded by a 0.8-cm-diam outer gold-plated tube. The xenon arc lamp is protected by a quartz window which is placed on top of the pyrolyzed soil. Earlier experiments have shown that this "over pyrolysis" procedure is able to extract more organics from the soil during pyrolysis. The xenon arc lamp is used to provide the required light intensity. This lamp is a 150-W xenon arc lamp which is mounted on a stainless-steel cylinder that is surrounded by a 0.8-cm-diam outer gold-plated tube. The xenon arc lamp is protected by a quartz window which is placed on top of the pyrolyzed soil. Earlier experiments have shown that this "over pyrolysis" procedure is able to extract more organics from the soil during pyrolysis.

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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 flow of water vapor to enter the cell is required. The valve between the water vapor reservoir and the incubation cell which contains the soil and the normal incubation gases are allowed to diffuse out of the incubation cell. The amount of water vapor is controlled by a flow restrictor and the time 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 tubes and valves are maintained at 30°C. This ensures that the reservoir is always better 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 can be varied in multiples of 1 min. A 1 min injection was used which provides excellent water vapor saturation to the test cell atmosphere when the cell is at about 24°C. The lamp is started by a 7.5-kV pulse and sustained by the flight configured illuminator including the filters. The xenon-arc lamp spectrum is that which is generated by the flight configured illuminator including the filters. The xenon spectral deviation from the solar spectrum in the infrared region is eliminated with the use of filters. The total lamp intensity is about 20% of the maximum Martian solar irradiation from 335 to 1000 nm. The lamp is started by a 7.5-kV pulse and sustained by a 12-V, 0.5-A power supply. The lamp output power is controlled by a high-voltage power supply and it operates at an average power consumption of 6 W. During irradiation, the lamp supply current is monitored every 32 min. If the lamp is found to be extinguishing in a short period of time pulses is sent. However, if the lamp does not start at this time, another set of restart pulses is sent again 32 min later when lamp current is checked.

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 2.54 mm-thick 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 sealed with stainless steel ferrules which permit the flow of gas but which retain the packing material. The packed stainless steel tube is surrounded by a 0.6-cm-diam outer gold-plated tube to reduce radiative losses. The inner quartz tube has a platinum resistance sensor mounted at a point midway from either end. This sensor provides housekeeping and also is used for heater control. The OVT has two temperature set points of 120°C ± 10°C and 652°C ± 25°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.
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 adventitious background 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 625°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 10^14. 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 10^7 dpm, the resultant organic peak will produce ~10^6 dpm from OVT adsorption of oxides 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 capacitive oxide to act as a strong trapping 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 make the provision of the heater and condenser necessary. For 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 reaches 625°C. The selected heater for H-22 (Fig. 10) is a metallic sheath designed to work with the H-22 AA regenerative heater. The line junction between the head end and H-22 AA is maintained at the required temperature by a coating of aluminized Kapton sealed with gold tape. This heater is an integral part of the PR module. The thermal environment provided by thelander and the instrument is supplemented by a variety of heaters and coolers. The normal heater (H-22 AA) is maintained by a heater at 11 PM which is positioned on the stainless steel can surrounding the module.

To provide control of the incubation temperature during warm periods within the lander, two thermoelectric coolers are connected through heat pipes to the 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 similar "warm" (versus cold or hot) Martian conditions, the incubation head end temperature range is 0°C--11°C while the instrument undergoes a -5°C to 28°C temperature variation. This ensures that any water present in the cell does not freeze and

**Data collection requirements.** The PR detector is designed to be used in an experiment to measure the radioactive background in a soil sample. The system is based on the comparative size of the organic (second) count from an "active" and from a sterilized soil blank. Somewhat arbitrarily, the size 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.

The background count rate is dependent on several factors. The total noise level is based on the comparative size of the organic (second) count from an "active" and from a sterilized soil blank. The size 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. The background count rate is dependent on several factors. The total noise level is based on the comparative size of the organic (second) count from an "active" and from a sterilized soil blank. The size 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.
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 background 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 625 °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 (1:10^4). 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 10^6 dpm, the result will contain 10^4 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 copper 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 reduction of adsorption of these gases with the associated heating of the OVT makes it desirable to distinguish this gas from the organics that are condensed out on the OVT. The OVT elution count is not as important as the pyrolysis count, it does not need to be counted as accurately and in order to obtain an adequate estimate of the radioactivity produced in the pyrolysis cycle, the OVT directly above the detector chamber is considered as an integral part 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% (averaged for six flight detector assemblies). In order to reduce 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 length of each individual gas activity to the material is exposed and the exposure time, 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 vented.

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.

Data counting requirements. The PR criterion for detecting small changes in the activity in a soil sample is based on the comparative size of the organic (second) 14C peak from an "active" and from a sterilized "inactive" soil sample. The activity 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, so it will need to be counted for a time period equal to

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

The background count rate is dependent on several processes, but the largest contributor to this background is produced by secondary electrons resulting from neutron emission from the plutonium in the radioisotope thermoelectric generator (RTG) that provides power for the lander. The best estimate based on testing with non-Viking RTGs of the magnitude of this radioactive background is 1360 cpm and based on Eq. (1) the second peak would need to be counted for 100 min at 10^4 dpm. In addition to the RTG background, other background sources include cosmic and galactic radiation and radioactive decay processes associated with the magnesium-thorium (Mg-Th) alloys used in the construction of several lander science instruments including biology. These additional radiation sources were expected to provide an increase in the background level above the existing background level. The uncertainty in the background due to increased radiation with RTG fuel age and impurity level, a count period of 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 3σ test could be performed. The total amount of radioactivity that was used for the analysis was 5700 dpm which included a 3σ test count interval was 16 min. Therefore, the 8-h count period provides 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 14C count rate is associated with the effect of temperature on the silicon detectors. The detector noise (N_s) due to these thermal effects is equal to (N_s)(F - N_s)^2, where N_s is the detector noise in keV full width at half-maximum (FWHM), N_s is the total noise in keV FWHM, and N_s is the electron system noise in keV FWHM. This detector noise varies in a manner described by N_s = A × 10^(-F), where A and T are constants [4 = 0.461 and T = 27.22]. Based upon the lower discrimination level applied to the silicon detectors (30 keV), the total noise should not exceed 10.7 keV FWHM at 109 °C. This figure agrees with a measurement of 7.1 keV for the detector and 8.0 keV for the charge amplifier (FWHM). Testing of the detectors eventually used on Mars indicated that the noise requirement could be met at temperatures up to 50 °C.

Based upon statistical arguments, a background count with no "active" present was carried out for a time period equivalent to the length of the peak count and was carried out both before and after the critical organic peak count.

The other important count period is associated with the measurement of the radioactive products from a soil pyrolysis. The OVT adsorbs small quantities of the oxides of C as well as acting as a condensation trap for organics. It is not possible to differentiate between the adsorbed oxides of C and those produced from organics during the OVT heating to 625 °C. It is important to obtain a measure of the amount of oxides of C that have passed through the OVT to provide a direct indication of the amount adsorbed by the OVT (normally 1:10^4 parts are adsorbed). From earth tests the size of the pyrolysis peak was judged to be between 10^4 and 10^5 dpm. With this magnitude of signal, the count period can be substantially shorter. As a result of the large amount of oxides of C, the background from the holding chamber is used, the additional volume of this chamber reduces the overall efficiency of the detection system to (2.64 ± 0.53)% from the (109 ± 5) °C detector chamber. With this detector efficiency, a first peak of 10^4 dpm is equivalent to...
toward 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.

\[
\sigma^2 = \text{Background} + (\text{Background} + \text{Signal})
\]

where \( \sigma \) is in minutes, \( \sigma \) is 3, and Background and 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 clearly distinguish 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, yet quick interpretation of the count and to provide a contingency against spurious system noise, the data period was increased to 1-h 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 SDA drops 0.25 cm^3 of soil into a test cell at the load port position. The PR test cell is then lowered, rotated, and sealed to the incubation head end. At this point, water vapor may be added if desired. This injection of water vapor is effected by opening valve S-7. Then the 14CO2/12CO tracer gas is injected into the test cell head space from the reservoir by alternately opening and closing valves S-5 and S-6. If artificial Martian sunlight is required for the experiment, the lamp is activated at this time and the incubation of the soil is begun.

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 had been set in the atmosphere to equilibrate the hardware surfaces, especially the OVT, with CO2 and 12CO. At the start of the soil incubation, during the period from the soil cell dropped to index A new position, the pyrolysis system is retitled with Martian atmosphere. On the third day of the soil incubation, the OVT is heated to measure its background level of 14C activity. The 12CO purge is removed, and the heating of the OVT to 625°C (H-3 on for 3 min) in a 0.5-cm^3/min helium purge which carries any detected 14C activity is performed for counting.

After this background heating, the OVT is vented (S-11 open) for reequilibration with Martian atmosphere. At this point the helium purge is discontinued and not restored in this or the other two experiments until just prior to pyrolysis. This ensures that the system is completely equilibrated with 14C and 12CO prior to the exposure for 8 h and then the gases in the detector are allowed to diffuse out of the module via the vent line. However, the detector counting continues until pyrolysis, in order to obtain an accurate value for the general background level of radiation. Only one other operation at the pyrolysis station occurs prior to pyrolysis and that is a further 14C and 12CO system equilibration process. Approximately 2 h before pyrolysis, the OVT is heated to 625°C for the normal 3-min period and then it is allowed to cool to 120°C, its pyrolysis set point, in the Martian atmosphere. The incubation is terminated after 5 days, and the test cell is vented by opening S-12 and allowing the 14CO2/12CO mixture to diffuse from the cell. After 20 min, the test cell is heated to 120°C for 30 min to oxidize and desorb any 14C gas from the soil. The soil is isolated (close S-9), and the detector is heated to 120°C only removes 99% of any 14C gases. This sequence involves the OVT to equilibrate with CO2 prior to the next experiment.

Once the second peak has been determined, another (12-h, 14C background count) is performed. This essentially ends the experimental analysis. However, the effluent of the OVT to 625°C only removes 99% of any organic material condensed out during the pyrolysis. The OVT now needs to be cleaned of this residual material. The OVT is, therefore, eluted twice more for 3 min at 625°C, and after each elution, the gaseous effluent is counted in the usual manner to determine the effectiveness of the cleaning. Finally, the analysis system is vented to the Martian atmosphere to allow the OVT to equilibrate with CO2 prior to the next experiment.

The PR experiment was tested on Earth in the same full-instrument test as described for the LR experiment. The sequence used was for one active cycle followed by one control cycle in a manner nearly identical to the operations just described. The results (Table VI) are indicative of typical responses of a moderately active earth soil where the pyrolysis carbon-14 (first peak) is of the order of 10^3 dpm for both active and dry heat sterilized control and the OVT elution (second peak) is a minimum of several fold greater for the active over the control. The PR experiment presents an interesting problem for a test under simulated Martian conditions. Be-
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 determined by

\[
i = \frac{a \times \text{[Background]} + (\text{Background} + \text{Signal})}{\text{Signal}}
\]

where \( i \) is in minutes, \( a \) 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 10^4 dpm plus background counts. In order to obtain a reasonable, reproducible interpretation of the count and to provide a contingency against spurious system noise, the data period was increased to 1-h minimum 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 SDA drops 0.25 cm^3 of soil into a test cell at the load port position. The pyrolysis system is refilled with the hardware surfaces, especially the OVT, with CO and \(^{12}\text{CO} \). At the start of the soil incubation, during the period when the cells are dropped to index position, the pyrolysis system is refilled with \(^{14}\text{CO} \) and 12CO. The OVT is heated to 625°C. The soil from the 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 injection gas is added. The remainder of the experiment is performed in exactly the same manner as an active experiment.

During the incubation period, the pyrolysis station is preparing for the soil pyrolysis, and both station heads are rotating and sealed to the pyrolysis station. The helium from the pyrolysis station is vented to the holding chamber. This sequence involves injection of water vapor is effected by opening valve S-7. The cell is raised to 180°C for 3 h to sterilize the soil, and thermoelectric coolers are activated, and the incubation cell is allowed to temperature stabilize. At this point the incubation is started and not restarted in this or the other two experiments until just prior to pyrolysis. This ensures that the system is completely equilibrated with \(^{14}\text{CO} \) and 12CO prior to the exposure for 8 h and then the gases in the detector are allowed to diffuse out of the module via the vent line. However, the detector counting continues until pyrolysis, in order to obtain an accurate value for the general background level of radiation. Only one other operation at the pyrolysis station occurs prior to pyrolysis and that is a further \(^{14}\text{CO} \) and \(^{12}\text{CO} \) system equilibration process. Approximately 2 h before pyrolysis, the OVT is heated to 625°C for the normal 3-min period and then it is allowed to cool to 120°C, its pyrolysis set point, in the Martian atmosphere. The incubation is terminated after 3 days, and the test cell is opened to allow the \(^{14}\text{CO} \) and \(^{12}\text{CO} \) mixture to diffuse from the cell. After 20 min, the test cell is heated to 120°C for 30 min to yield diffusion and desorption of \(^{12}\text{CO} \) gas from the soil. One minute before the cell heater is turned off, the incubation cell is lowered. It is then rotated and sealed to the pyrolysis station. The helium flow is initiated and for 8 min, while the pyrolysis head and exit line are heating to approximately 200°C, the helium flows through the cell and OVT and out of the vent line via S-11.

The analysis is started by closing vent valve S-11, and pyrolyzing the soil at 625°C in the stream of helium. The helium is used to carry the volatile products of the organic material condensed in the OVT which is maintained at 120°C during pyrolysis. With the OVT at 120°C, approximately 99.99% of the \(^{14}\text{CO} \) and \(^{12}\text{CO} \) gas released from soil during pyrolysis is carried through the OVT with the soil gaseous effluent and is then into the detector and holding chamber. The majority of heavy molecular weight compounds condense in the OVT which is maintained at 120°C during pyrolysis. With the OVT at 120°C, approximately 99.99% of the \(^{14}\text{CO} \) gas released from soil during pyrolysis is carried through the OVT with the soil gaseous effluent and is then into the detector and holding chamber, which are pressurized to 1031 mbars by the carrier gas during the pyrolysis process. The PR experiment activity is confined to the analysis procedures at the pyrolysis station (Fig. 14).

The amount of \(^{12}\text{CO} \) that passes through the OVT needs to be measured since the amount retained by the OVT is a function of the amount to which it was exposed. Since the majority of this nonbiogenic \(^{12}\text{CO} \) is released from the soil early in the pyrolysis heating, the holding chamber, which fills with gas before the detector, contains a high proportion of the gas. The holding chamber is isolated (close S-9), and the detector is vented to Martian pressure (open S-11, open and close S-8). Opening S-9 then fills the detector with a portion of the holding chamber contents. This gas is then counted as the first peak (nonbiogenic). After the count on the detector, the system is reequilibrated with Martian atmosphere, and the OVT holding chamber is vented. The detector is cleaned by heating for 2 h at 109°C. During this heating, the OVT and detector are purged with helium to remove residual \(^{14}\text{CO} \) and \(^{12}\text{CO} \).

Following detector cleanup, there are two helium purges of the OVT and detector to remove adsorbed radioactive gases. The first purge is conducted with the OVT at ambient temperature. The helium from the last 2 min of this purge is trapped in the detector and counted for 6 h. The OVT is heated to 120°C during the second purge, and again a portion of the purge is counted in the detector for 2 h to measure the level of radioactive gases in the OVT.

After measuring the \(^{14}\text{CO} \) background of the OVT, an evaluation of the trapped organics is made. This is performed by heating the OVT to 625°C for 3 min. Any organic compounds volatilized from the OVT during this heating are oxidized to \(^{14}\text{CO} \) by the CuO in the OVT packing. The resulting effluent is carried into the detector by the helium gas stream and counted for at least 12 h. This second (organic) peak is thus composed of assimilated carbon-14 formed during the 5-day incubation period and any residual \(^{12}\text{CO} \) gases still retained by the OVT.

Once the second peak has been determined, another (12-h) \(^{14}\text{CO} \) background count is performed. This essentially ends the experimental analysis. However, the elution of the OVT to 625°C only removes 99% of any organic material condensed out during the pyrolysis. The OVT now needs to be cleaned of this residual material. The OVT is, therefore, eluted twice more for 3 min at 625°C, and after each elution, the gaseous effluent is counted in the usual manner to determine the effectiveness of the cleaning. Finally, the analysis system is vented to the Martian atmosphere to allow the OVT to equilibrate with CO prior to the next experiment.

The PR experiment was tested on Earth in the same full-instrument test as described for the LR experiment. The sequence used was for one active cycle followed by one control cycle in a manner nearly identical to the operations just described. The results (Table VI) are indicative of typical responses of a moderately active earth soil where the pyrolysis carbon-14 (first peak) is of the order of 10^4 dpm for both active and dry heat sterilized control and the OVT elution (second peak) is a minimum of several fold greater for the active over the control.

The PR experiment presents an interesting problem for a test under simulated Martian conditions. Be-
The test conditions are the same as those described for the LR experiment in Sec. V D.

The preincubated fraction was exposed to $^{14}C\text{O}_2 / ^{14}C\text{O}$, built into the soil before it was tested in the instrument. Soils are markedly different from changes caused by nonbiological phenomena. 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.\textsuperscript{16,17}

### 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.\textsuperscript{18} 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 $\text{H}_2$, $\text{N}_2$, $\text{O}_2$, $\text{CO}_2$, $\text{CH}_4$, and $\text{CO}_2$. 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.\textsuperscript{16,17}

### TABLE VI. Pyrolytic release experiment active and sterilized soil

<table>
<thead>
<tr>
<th>Test</th>
<th>Soil</th>
<th>Incubation condition</th>
<th>Pyrolysis condition</th>
<th>$^{14}C\text{O}_2$ Elution</th>
<th>Active (%)</th>
<th>Control (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>100% preincubated, 90% Aiken</td>
<td>Lamp ON Dry 5 days 14\textdegreeC</td>
<td>Lamp ON Humidified 5 days 180\textdegreeC</td>
<td>$5.6 \times 10^7$</td>
<td>855</td>
<td>179</td>
</tr>
<tr>
<td>Control</td>
<td>100% Aiken</td>
<td>Lamp ON Dry 5 days 14\textdegreeC</td>
<td>Lamp ON Humidified 5 days 14\textdegreeC</td>
<td>$6.6 \times 10^7$</td>
<td>145</td>
<td>145</td>
</tr>
</tbody>
</table>

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.
cause 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 tested on the active cycle only was prepared by mixing soils that were packed to give an active response. The soil sample was subjected to sufficient water present to allow earth soil microorganisms to metabolize and assimilate carbon-14 from the atmosphere into their organic material. The test conditions are the same as those described for the LR experiment in Sec. V D.

The PR experiment has successfully operated on the Martian surface according to the sequence summary in 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 cell and the usable helium. On Lander 2 the three sequences in the primary mission provided useful data 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 experimenter V. I. Oyama and co-experimenters B. Berdahl and G. Garle, 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 are stimulated either by humidifying the soil or contacting the soil with an aqueous solution containing a variety of nutrients and growth factors. 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 solutions 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 wheels rotate to the head end and port 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 valves 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 unclamp 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 0.100–120 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/Kr/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...
column temperature (±0.5°C) and constant detector temperature (±0.1°C) during analyses. Cooling of the test cell is provided by thermoelectric coolers attached to a heat pipe to prevent overheating of the soil during incubation.

Other important components necessary to the experiment operation which are shared with the other two biology experiments include the soil distribution assembly, the high- and low-pressure helium supplies and a 77 000-std-cm³ He reservoir, the vent manifolds and a liquid samp and charcoal trap assembly to minimize the effect of substances vented by the biology instrument on other experiments on the lander, and the electronic subsystem for experiment control and for data processing. The relationships among the various components and the functional flow are shown in Fig. 16.

The GEx test cell and head end were designed to include capacity for two 1-cm³ soil samples; ability to humidify the cell without nutrient contacting the soil; capability of wetting the soil from the bottom to the water holding capacity of the soil without the soil sample being completely submerged; maintenance of a liquid path between the nutrient in the soil and the remainder of the nutrient in the cell; ability to drain most of the nutrient from the cell without opening the cell; a head-space volume in the range of 4-10 cm³; and a 77 000-std-cm³ He reservoir, the vent manifolds to prevent water from condensing in the line leading to the gas chromatographic analysis assembly (GCAC).

The GCAC is basically a conversion to flight hardware of the chromatographic system used in the laboratory. The GCAC (Fig. 18) is 9 cm square by 6 cm high and consists of a gas sampling system, a pair of matched porous polymer bead chromatographic columns, and a thermistor thermal conductivity detector. The carrier gas (He) is supplied by the He tank and regulators in the common services module discussed under common support elements. The detector data processing is carried out in the electronic subsystem (ESW).

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) 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 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 130°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.

### Table VIII

<table>
<thead>
<tr>
<th>Gas chromatograph analysis requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gases separated</strong></td>
</tr>
<tr>
<td>H₂, N₂, O₂, CH₄, Kr, CO₂ (CO and Ar are art of the O₂ peak)</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
</tr>
<tr>
<td>99% between peaks of 70 nM of N₂ and 7 nM of O₂</td>
</tr>
<tr>
<td><strong>Sample size</strong></td>
</tr>
<tr>
<td>Minimum detectable quantities in nM</td>
</tr>
<tr>
<td>H₂: 10; CO₂: 1.0; CO: 0.3; O₂: 0.5; Kr: 0.4</td>
</tr>
<tr>
<td><strong>Carrier gas purity</strong></td>
</tr>
<tr>
<td>99.999%</td>
</tr>
<tr>
<td><strong>Data sampling rate</strong></td>
</tr>
<tr>
<td>Constant throughout chromatogram</td>
</tr>
</tbody>
</table>

### Chromatographic analysis system

The lower part of the GEx module contains the gas chromatographic analysis assembly (GCAC) and the nutrient reservoir. The GCAC 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.
column temperature (±0.5°C) and constant detector temperature (±0.1°C) during analyses. Cooling of the test cell is provided by thermoelectric coolers attached to a heat pipe to prevent overheating of the soil during incubation.

Other important components necessary to the experiment operation which are shared with the other two biology experiments include the soil distribution assembly, the high- and low-pressure helium supplies and a 77 000-std cm³ He reservoir, the vent manifolds and a liquid sampl and charcoal trap assembly to minimize the effect of substances vented by the biology instrument on other experiments on the lander, and the electronic subsystem for experiment control and for data processing. The relationships among the various components and the functional flow are shown in Fig. 16.

The GEx test cell and head end were designed to include capacity for two 1-cm³ soil samples; ability to completely submerge, and 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-mm injection at a nominal flow rate 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 inner cup is rotated 180° in one direction to reach the head port and then 180° in the opposite direction to return to the incubation position. 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 chromatography-mass spectrometry) experiments.21

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 bar) 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 a 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.

### Table VIII. Gas chromatographic analysis requirements.

<table>
<thead>
<tr>
<th>Component</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data sampling rate</td>
<td>Constant throughout chromatogram</td>
</tr>
<tr>
<td>Carrier gas purity</td>
<td>&gt; 99.999%</td>
</tr>
<tr>
<td>Gas chromatograph</td>
<td>High and consists of a gas chromatograph, a pair of matched porous polymer bead chromatographic columns, and a thermistor thermal conductivity detector with a 0.25 cm o.d. He tank</td>
</tr>
<tr>
<td>Gas sampling valve</td>
<td>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</td>
</tr>
</tbody>
</table>

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*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 conducting 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.*

*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 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.*
type thermal conductivity detector proportionally heated to 32°C during GCAA operation with a heater mounted on the gold plated copper block. The thermistors are operated in a bridge circuit that maintains the bridge resistance at 800.0 which corresponds to approximately 100°C. The signal output of the bridge is the variation in the power required to maintain the active thermistor at 800.0 versus the reference side. The advantages of the constant temperature circuit are greater stability. Furthermore, the detector can be operated for testing purposes in any environment without the need for an earth reference air intake, used without any possibility of thermal stress on the beeds.

The chromatographic system consists of a matched (pressure drop) pair of 760-cm-long, 0.11-cm-i.d., 0.033 cm wall thickness stainless steel tubes packed with 100-120 mesh Porapak Q, batch 1182. The performance of these columns is similar to that of the columns described in Ref. 22. The use of matched columns was a conservative approach to providing a reference flow to the detector to minimize baseline phenomena which caused partial loss of the sample in the columns. The use of matched columns was a conservative approach to providing a reference flow to the detector to minimize baseline phenomena which caused partial loss of the sample in the columns (and control valves) for flow regulation.

- **Gas supply**: High pressure regulator (9.07 ± 0.15 psi) was used during chromatographic operation. External insulation was used for the He supply to prevent premature cooldown of the detector when exposed to space vacuum.

- **Sample introduction**: The column pressure drop was matched to the output of the He supply high-pressure regulator (9.07 ± 0.15 psi) by use of 0.0076-cm-i.d. capillary tubing upstream of the columns and (control valves) for flow regulation. The column temperature of 24°C was selected as the best tradeoff between resolution and ability to control the column temperature by heating only. The column temperature was maintained in a 8.6-cm-d.o. coil 1 cm thick. The column heater is a film type applied to the inside of the mandrel, and is proportionally controlled during chromatographic operation. External insulation of the line between the detector and the column (and control valves) is not required because the amount of convection heat loss is small under Martian atmospheric conditions.

- **Temperature regulation**: The column pressure drop was matched to the output of the He supply high-pressure regulator (9.07 ± 0.15 psi) by use of 0.0076-cm-i.d. capillary tubing upstream of the columns and (control valves) for flow regulation. The column temperature of 24°C was selected as the best tradeoff between resolution and ability to control the column temperature by heating only. The column temperature was maintained in a 8.6-cm-d.o. coil 1 cm thick. The column heater is a film type applied to the inside of the mandrel, and is proportionally controlled during chromatographic operation. External insulation of the line between the detector and the column (and control valves) is not required because the amount of convection heat loss is small under Martian atmospheric conditions.

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of the column assembly (and detector) is not required. The columns are bifilar wound in a 8.9-cm-o.d. coil 1 cm thick. The column heater is a film type applied to the inner surface of the Pyrex column, so that the column plug and the solder joint during installation are heated to 24°C with good sensitivity. The pressure drop is large for these columns (typically 6.7 bars at 13.5 std cm³/min flow) but this does not interfere with the normal performance. The flow-rate used for S-25 was 13.5 std cm³/min which is near the optimum flow-rate for N₂-O₃ resolution with this system.

The column plug was matched to the output of the He supply high-pressure regulator (9.07 ± 0.34 bars) by the use of 0.0076-cm-i.d. capillary tubing up-stream of the columns (and control valves) for flow regulation. The column temperature of 24°C was selected as the best tradeoff between resolution and ability to control the column temperature by heating only. The column plug, of the length equal to 8.9-cm-o.d. coil 1 cm thick. The column heater is a film type applied to the inside of the mandrel, and is proportionally controlled during chromatographic operation. External insulation of the column (to prevent overheating) is not required because the amount of convection heat loss is small under Martian atmospheric conditions.

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Vacuum results in certain reversible adsorption phenomena which cause partial loss of the sample in the initial chromatographs after vacuum exposure. Testing also indicated that the problem could be corrected by exposing the columns to a CO₂/He gas mixture for pretreatment of the chromatographic columns and vacuum. The gas mixture was added late in the design of the instrument and was expected to be helpful in the design of the instrument. Over the course of the experiment, the CO₂/He gas mixture was found to be effective in preventing partial loss of the sample in the initial chromatographs after vacuum exposure. The gas mixture was found to be effective in preventing partial loss of the sample in the initial chromatographs after vacuum exposure.

The incidence of this rejuvenation process was 5.1575%, 2.84% CO₂ with the balance He. He is present to provide adequate pressure to obtain a representative sample for chromatographic analysis. The CO₂ is introduced into the cell by opening valve S-25 (with S-24 closed) for 1 min, closing S-25, and then opening S-24. The pressure in the reservoir is matched to the volume of the column (35 cm³) to ensure that under nominal conditions with 1 cm³ of soil present (assuming 50% void volume) and 2.5 cm³ of nutrient solution, the partial pressure of CO₂ would be 10,000 mbar, CO₂ 5 millibars and the total cell pressure would be 200 millibars.

The column pretreatment (rejuvenation) gas reservoir was added late in the design of the instrument and is physically located on the LR module. In the initial design of the GCA assay, it had been intended to seal the columns during interplanetary transport. The GCA assay to prevent exposure to space vacuum. Later in the development program it was determined that leaving these valves closed for about 1 year was not suitable because of the possibility of valve sticking. 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 chromatographs after vacuum exposure. Testing also indicated that the problem could be corrected by exposing the columns to a CO₂/He gas mixture in He prior to the use of the columns for analysis. Prelaunch testing with accelerated exposure at elevated temperatures and long-term vacuum exposure tests verified the efficiency of this rejuvenation process.

### Table IX: Composition of the gas exchange experiment nutrient

<table>
<thead>
<tr>
<th>Nucleic acids (A-D)</th>
<th>Forming conc. in M</th>
<th>Vitamins (E)</th>
<th>Forming conc. in M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di-adenine</td>
<td>2.0</td>
<td>Acetic acid</td>
<td>3.0</td>
</tr>
<tr>
<td>Di-arginine</td>
<td>1.0</td>
<td>Biotin</td>
<td>3.0</td>
</tr>
<tr>
<td>Di-cysteine</td>
<td>0.5</td>
<td>Choline Cl</td>
<td>3.0</td>
</tr>
<tr>
<td>Di-cytosine</td>
<td>3.0</td>
<td>Cobalamin</td>
<td>3.0</td>
</tr>
<tr>
<td>Di-glutamic acid</td>
<td>2.0</td>
<td>Niacin</td>
<td>3.0</td>
</tr>
<tr>
<td>Di-histidine</td>
<td>1.0</td>
<td>Phosphine  HCl</td>
<td>2.0</td>
</tr>
<tr>
<td>Di-inosine</td>
<td>0.7</td>
<td>Pyridoxal</td>
<td>2.0</td>
</tr>
<tr>
<td>Di-lactate</td>
<td>1.0</td>
<td>Thiamine</td>
<td>2.0</td>
</tr>
<tr>
<td>Di-lithium</td>
<td>0.5</td>
<td>Xanto B</td>
<td>1.0</td>
</tr>
<tr>
<td>Di-l Threonine</td>
<td>0.8</td>
<td>Polyn (folic acid)</td>
<td>1.0</td>
</tr>
<tr>
<td>Di-tryptophan</td>
<td>0.3</td>
<td>Xanto E</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### Table X: Composition of the gas exchange experiment nutrient

<table>
<thead>
<tr>
<th>Coh (G O₂)</th>
<th>Forming conc. in M</th>
<th>Subs (D)</th>
<th>Forming conc. in M</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>5.0</td>
<td>H₂O</td>
<td>5.0</td>
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<tr>
<td>CaO</td>
<td>5.0</td>
<td>CaO</td>
<td>5.0</td>
</tr>
<tr>
<td>MgO</td>
<td>5.0</td>
<td>MgO</td>
<td>5.0</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>10.0</td>
<td>Fe₂O₃</td>
<td>10.0</td>
</tr>
<tr>
<td>Glucose</td>
<td>10.0</td>
<td>Glucose</td>
<td>10.0</td>
</tr>
<tr>
<td>Acetone</td>
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<td>Acetone</td>
<td>1.7</td>
</tr>
<tr>
<td>DL-alanine</td>
<td>1.0</td>
<td>DL-alanine</td>
<td>1.0</td>
</tr>
<tr>
<td>DL-arginine</td>
<td>0.7</td>
<td>DL-arginine</td>
<td>0.7</td>
</tr>
<tr>
<td>DL-tyrosine</td>
<td>0.3</td>
<td>DL-tyrosine</td>
<td>0.3</td>
</tr>
<tr>
<td>DL-threonine</td>
<td>0.8</td>
<td>DL-threonine</td>
<td>0.8</td>
</tr>
<tr>
<td>DL-trypophan</td>
<td>0.5</td>
<td>DL-trypophan</td>
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</table>

### Table XI: Composition of the gas exchange experiment nutrient

<table>
<thead>
<tr>
<th>E. coli nutrient</th>
<th>Forming conc. in M</th>
<th>Subs (D)</th>
<th>Forming conc. in M</th>
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</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>5.0</td>
<td>H₂O</td>
<td>5.0</td>
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<tr>
<td>CaO</td>
<td>5.0</td>
<td>CaO</td>
<td>5.0</td>
</tr>
<tr>
<td>MgO</td>
<td>5.0</td>
<td>MgO</td>
<td>5.0</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>10.0</td>
<td>Fe₂O₃</td>
<td>10.0</td>
</tr>
<tr>
<td>Glucose</td>
<td>10.0</td>
<td>Glucose</td>
<td>10.0</td>
</tr>
<tr>
<td>Acetone</td>
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<td>Acetone</td>
<td>1.7</td>
</tr>
<tr>
<td>DL-alanine</td>
<td>1.0</td>
<td>DL-alanine</td>
<td>1.0</td>
</tr>
<tr>
<td>DL-arginine</td>
<td>0.7</td>
<td>DL-arginine</td>
<td>0.7</td>
</tr>
<tr>
<td>DL-tyrosine</td>
<td>0.3</td>
<td>DL-tyrosine</td>
<td>0.3</td>
</tr>
<tr>
<td>DL-threonine</td>
<td>0.8</td>
<td>DL-threonine</td>
<td>0.8</td>
</tr>
<tr>
<td>DL-trypophan</td>
<td>0.5</td>
<td>DL-trypophan</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Table XII: Composition of the gas exchange experiment nutrient

<table>
<thead>
<tr>
<th>Nucleic acids (A-D)</th>
<th>Forming conc. in M</th>
<th>Vitamins (E)</th>
<th>Forming conc. in M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di-adenine</td>
<td>2.0</td>
<td>Acetic acid</td>
<td>3.0</td>
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<tr>
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</tr>
<tr>
<td>Di-cysteine</td>
<td>0.5</td>
<td>Choline Cl</td>
<td>3.0</td>
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<tr>
<td>Di-cytosine</td>
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</tr>
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<td>2.0</td>
</tr>
<tr>
<td>Di-l Threonine</td>
<td>0.8</td>
<td>Xanto B</td>
<td>1.0</td>
</tr>
<tr>
<td>Di-tryptophan</td>
<td>0.3</td>
<td>Xanto E</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### Table XIII: Composition of the gas exchange experiment nutrient

<table>
<thead>
<tr>
<th>Coh (G O₂)</th>
<th>Forming conc. in M</th>
<th>Subs (D)</th>
<th>Forming conc. in M</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>5.0</td>
<td>H₂O</td>
<td>5.0</td>
</tr>
<tr>
<td>CaO</td>
<td>5.0</td>
<td>CaO</td>
<td>5.0</td>
</tr>
<tr>
<td>MgO</td>
<td>5.0</td>
<td>MgO</td>
<td>5.0</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>10.0</td>
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<td>10.0</td>
</tr>
<tr>
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<td>10.0</td>
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<td>1.7</td>
</tr>
<tr>
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<td>1.0</td>
</tr>
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</tr>
<tr>
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<td>0.8</td>
</tr>
<tr>
<td>DL-trypophan</td>
<td>0.5</td>
<td>DL-trypophan</td>
<td>0.5</td>
</tr>
</tbody>
</table>
pericent is operated as much as possible according to the programmed sequence steps in order to minimize the number of commands required.

On soil 3 after landing, the rejuvenation procedure is conducted where the 100 std cm\(^3\) of 10\% O\(_2\) and 10\% CO\(_2\) in helium is allowed to flow through both Porapak Q columns and out to vent through valves S-17 and S-18 (Fig. 16) in a one-time operation. A sample of the rejuvenation gas is trapped in the sample loop during the He purge removal procedure which flows forward through the reference column and back through the sample column with S-15 closed. This sample is analyzed by the gas chromatograph as a diagnostic to demonstrate the CO\(_2\)/He rejuvenation of the columns actually occurred.

The details of a chromatographic analysis of the test cell gas are as follows. First the column and detector are heated to their operating temperatures prior to initiating a carrier gas flow. Time of day constraints on the analysis indicate that it is conducted when the instrument 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 volumes with 9.2-bar He from S-21 and venting through S-18. This is done twice and the second time S-18 remains open for 3 min to assure that proper venting of the sample loop to Mars ambient pressure occurs. Flow through the columns is then started by opening valves S-16, S-20, and S-15, which is the normal carrier gas loop operation. The sample is then introduced into the S-18 closed, sampling of the cell head space is carried out by opening S-19. The reason the He/Kr/CO\(_2\) injection and S-19A are removed 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-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 0.11-cm\(^3\) loop volume with a total consumption of approximately 0.5 cm\(^3\) of He 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-19 to sweep the column to the injection valve into the injection interface. Then 8.2 s (using a special timing circuit) later S-17 and S-18 are closed and S-20 reopened. The sample is swept through the column where it is analyzed by the detector. The detector signal from the GEx low-level electronics is sampled once per second during the 16-min 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 32 Hz, 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 biology instrument chromatographic data, the peak shapes 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 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 can be reconstructed with better than 1\% accuracy. The GEx peak widths vary from approximately 3 s (H\(_2\) and N\(_2\)) to 15 s (CO\(_2\)), 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 experimental chromatograms since any sampling rate adequate to Gaussian profile. Baseline noise is not well characterized because the noise bandwidth is large in comparison with the Nyquist frequency. However, the baseline noise is not at all important in the characterization of the chromatographic data. Peak tailing defects 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 error is relatively small and does not occur in the normal range of peak heights obtained with the GEx experiment.

Figure 19 shows a chromatogram from above a Martian soil sample. The data shown here is the first gas analysis taken from above the Martian soil after exposure to water vapor (Landers-1, 6-9, July 27, 1976). The applied detector signal from the GEx low-level, a pressure dependence was found at the instrument level that did not exist during the GCAAs component pressure 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 GCAAs 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 mbar). Since the in-situ volumetric purity of Kr as an internal standard, this pressure dependent effect has little impact on measuring changes in gas concentrations in the cell since such changes are referenced to the Kr peak. The correction is of importance only when absolute quantities are desired, as in determining the amount of O\(_2\) 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 dead space volume in the cell which in turn depends on the amount of soil and nutrient present in the cell. Typical
The incubation gas contains helium is that the helium acts as the sample loop to Mars ambient pressure occurs. Flow through the reference column and backward through the sample loop with S-15 closed. This sample is analyzed by the gas chromatograph as a diagnostic to demonstrate the O₂/O₃/He rejuvenation of the columns actually occurred.

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 instrument 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 volumes 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 2 min to assure that proper venting of the sample loop to ambient pressure occurs. Flow through the columns is then started by opening valves S-16, S-20, and S-15, which is the normal carrier gas flow for the sample injection. When S-18 is closed, sampling of the cell head space is carried out by opening S-19. The reason the He/Kr/CO₂ injection and S-19A is set for a 10-min interval 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-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 0.11-cm³ loop volume with a total concentration of approximately 0.5 cm³ of head space gas (including the gas in the line between S-19 and S-19A) which is injected 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 gas through the columns to the detector. Then 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 columns 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-17 to minimize any high-pressure column side effects. Valve 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-min chromatogram produced 960 data points which are transferred to the Landers 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 3.2 Hz; provided that no frequency components exist at a frequency higher than 0.1 (the Nyquist frequency). While this requirement is not completely satisfied by the biomarker profile, chromatographic data, the peaks do meet it closely enough to allow accurate reconstruction of the sampled data. The peaks are reconstructed 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 can be reconstructed with better than 1% accuracy. The GEx peak widths vary from approximately 3 s (H₂ and N₂) to 15 s (CO₂), 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 experimental chromatograms since any sampling rate adequate to digitize the baselines is adequate for the sample injection. The baseline noise is not well characterized because the noise bandwidth is large in comparison with the Nyquist frequency. However, baseline noise is not at all important in the characterization of 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 error is relatively small and does not occur in the normal range of peak heights obtained with the GEx experiment.

Figure 19 shows a chromatogram from above a Martian soil sample. The sample is well 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-17 to minimize any high-pressure column side effects. Valve 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
values are 6.5% removal per analysis for a humidified case and 8.8% removal 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 attain equilibrium between the loop volume and the atmosphere via diffusion. Valve S-18 is then closed, 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 0.3% 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 another 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 all subsequent nutrient injections, the nutrient valve block and line from the valve to the head 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 one sterilized soil wet mode cycle are given in Fig. 21. Evidence for biological activity is not seen until after exposure 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 observed in the sterilized soil mode 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 is purged, incubation gas and nutrient added, and the cell is incubated as conducted before. A summary of the sequence run on both Landers on Mars is given in Table IX.

The cell must also be dried prior to opening the cell 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).

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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 again, 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 sample was designed for four complete incubation cycles with 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 dehydrated in a vacuum oven. 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 a humidified soil mode cycle, one sterilized soil mode cycle, and one active soil mode cycle 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
values are 6.5% removal per analysis for a humidified cycle and 8.8% per analysis for a nominal case with 2.5 cm² 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 atmospheric air diffusor. Valve S-18 is then closed, the GCAA warmed and column flow established and the sample injected. The system is sufficiently sensitive that N₂ and O₂ can be detected down to approximately 0.25% for N₂ and 0.3% for O₂ 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 and 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 cm² of nutrient added. The test cell pressure is about 150 millibars at this point. Later in the first incubation an additional 2 cm² 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 all subsequent nutrient injections, the nutrient valve block and line from the 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 O₂ can be detected down to approximately 20 micrometers for N₂ and 40 micrometers for O₂. In this manner the nutrient organic matter is retained 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 is purged, incubation gas and nutrient added, and the incubation and gas analyses conducted as before. A summary of the tests run on both Landers on Mars is given in Table IX.

The cell must also be dried prior to opening the test cell to acquire a 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 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 degraded in a simulated Martian atmosphere and one 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. 24 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 a humidified nutrient cycle sequence, 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 CO₂ and N₂ are seen to increase and H₂ 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 CO₂ and H₂ 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
concentration is assumed to be unchanged by biological activity. Therefore all subsequent gas analysis data is normalized to the original krypton value.

On the Martian surface, the GEs experiment has conducted 9 months of operation on Lander 1 and 8 months of operation on Lander 2 (Table X). During that time three 1-cm³ samples of soil were placed in the single test cell on each Lander, and 32 gas analyses performed on Lander 1 and 57 on Lander 2. In addition, Lander 1 performed two Mars atmosphere gas analyses and Lander 2 performed none. The GEs experiment operations ceased on both Landers in April 1977 with the consumption of all the 77.000 usable std cm³ of helium from the carrier gas supply.

VIII. COMMON SUPPORT ELEMENTS

The Biology Instrument is packaged in two assemblies: the electrical subsystem (ESS) and the mechanical subsystem (MSS). The MSS contains the three experiments previously described and common support elements for the experiments. All elements of the MSS occupy 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, 39 latching solenoid valves, 5 supplies of nutrients or special gases, 1 temperature control heater, and provision for all power, except for the cruise/down mode heaters and the thermo-electric coolers and has a minimum interdependence among the three experiments. The ESS is functionally and mechanically divided into two main slices, A1 and A2. The first slice (A1) contains all of the power conditioning and distribution circuitry. The conditioning is done with three separate power supplies operating from the two power buses. The second slice contains the three experiment sequencers along with the instrument's command processor, buffer memory, and A/D converter. This slice also contains the GE operating electronics, housekeeping circuits, and the IC digital data processing logic. The third slice (A3) contains the MSS control and interface circuits. These consist of proportional and limit switching heater controllers, thermal isolation valve drivers, solenoid valve driver matrix, a four-phase stepper motor controller, and a heater prerequisite.

Some electronics are located in the MSS in order to reduce susceptibility to generation of electromagnetic interference. This includes both the local temperature circuitry for the detectors, two electronic thermostat heaters, 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:

(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/down 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 an emergency, when bio operating power is not available.

The illumination control power supply. The illumination control power supply takes power from the bio operate bus and provides power to the xenon lamp power supply. This slice also contains the mass spectrometer circuit, a special Xenon lamp parasitic detector, and two electronic thermostats (bang-bang limit switching heater controllers). The heater controllers, which are located in the A1 slice only for packaging convenience, are discussed in the MSS 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 +15 V from the bio operate bus. Its frequency of operation is determined by the load demand of the system and can rise to 100 kHz when the Lander 2 power controller is off. The switching regulator takes its feedback from a separate winding on the converter. This feedback is then used to maintain constant flux in the output transformer of the converter.

The 20-kHz converter uses a two-transducer oscillator based on a nonsaturating transformer. The transducer output is a square-wave voltage amplifier. This voltage is added to the oscillator circuit to provide a single square-wave output which provides drive for a square-wave power amplifier. This 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 one set of +5-V output which is the control voltage for the oscillator. Master reset. The master reset logic signal (MROI) is used throughout the ESS to initialize the system. This logic signal is generated by a bistable multivibrator which senses the +5-V output of the primary power supply and thus the MROI reset signal is produced whenever bio operate power is applied to the instrument. This signal resets all of the logic and causes all of the system voltages to go to a known state.

In the case where the lander bus, a 24 resistor is in series with the bio operate bus to reduce filter in rush current during the initial power turn-off. The circuit uses the MROI reset signal to shut 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 24 resistor will be in the circuit when 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 pulse 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 power supply.
concentration is assumed to be unchanged by biological activity. Therefore all subsequent gas analysis data is normalized to the original krypton value.

On the Martian surface, the GEs experiment has conducted 9 months of operation on Lander 1 and 8 months of operation on Lander 2 (Table X). During that time three 1-cm$^3$ samples of soil were placed in the single test cell on each Lander, and 52 gas analyses performed on Lander 1 and 57 on Lander 2. In addition, Lander 1 performed two Mars atmosphere gas analyses and Lander 2 performed none. The GE experiment operations ceased on both Landers in April 1977 with the consummation of all the 77,000 usable std cm$^3$ of helium from the carrier gas supply.

VIII. COMMON SUPPORT ELEMENTS

The Biology Instrument is packaged in two assemblies: the electrical subsystem (ESS) and the mechanical subsystem (MSS). The MSS contains the three experiments previously described and common support elements for the experiments. All elements of the MSS occupy a space of less than 16 500 cm$^3$ (19.8 x 27.7 x 30.0 cm). The contents of this small package include: 8 experiment test cells, 4 geared stepper motors, 6 thermally actuated isolation valves, 39 latching solenoid valves, 5 supplies of nutrients or special gases, 1 regulator supply, 2 xenon-arc lamp, 43 heater elements, 1 dual column gas chromatograph, 1 xenon-arc lamp, 4 thermoelectric coolers and heat pipes, 1 high-pressure pure helium gas supply, and 3 Geneva driven mechanisms for the test cell carousels. Additionally, there are traps, sumps, plumbing, wiring, and all other elements needed to implement the three biological experiments. The MSS is physically arranged as a group of separable and interchangeable 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 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 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 structural support.

The interface module includes the illuminator assembly 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 electromechanical control. A functional block diagram of the ESS is shown in Fig. 22. As can be seen from the figure, the ESS contains the GEs electronic circuitry. The conditioning is done with three separate power supplies operating from the two lunar power buses. The first slice (A1) contains all of the power conditioning and distribution circuitry. The conditioning is done with three separate power supplies operating from the two lunar power buses. The second slice (A2) contains the three experiment sequencers along with the instrument's command processor, buffer memory, and A/D converter. This slice also contains the GE electronic circuitry. The third slice (A3) contains the MSS control and interface circuits. These consist of proportional and limit switching heater controllers, thermal isolation valve drivers, xenon valve driver matrix, a four-phase stepper motor controller, and a heater prerequisite controller. Some electronics are located in the MSS in order to reduce susceptibility to generation of EMI. This includes the low level circuitry for the 14C 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 two 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/drain-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 landing 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 off on duty 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 limiters, the power supply, and the xenon lamp power supply. This slice also contains the main relay circuit, switches, power supply, and the two electronic thermostat controllers, which are located in the A1 slice for packaging convenience, as discussed in the section on the 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 +15 V from the bio operate bus. Its frequency of operation is determined by the load demand of the system and can rise as high as 150 kHz. The power converter has feedback from a separate winding on the switching regulator. The output transformer of the switching regulator supplies the high voltage (250 V) for the xenon lamp power supply 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 preamplifiers.

Master reset. The master reset logic (MROI) is used throughout the ESS to initialize the system. This logic signal is generated by a random logic circuit which senses the +5-V output of the primary power supply and thus the MROI reset signal is produced whenever bio operate power to the instrument. This signal resets all of the logic and causes all the system switches and latching relays to go to a known state. In addition, the master reset logic provides the lander bus, a 24-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 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 24-resistor will be in the circuit when power is reapplied. A special relay driven by the bio thermal bus is triggered by a phototransistor in an optical coupler which responds to a light pulse 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 experiment and provides simulated sunlight for photothermal 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 sets the lamp voltage through the feedback network such that lamp power is nominally constant (within 5%) over the entire operating range. Lamp ignition is accomplished by supplying a voltage of instantaneous peak value of 7.5-8.0 kV to the lamp while the lamp supply is also attempting to draw high current through the lamp. This sustains lamp ignition and the
ables or disables the circuit on command from the power supply to maintain the desired temperature operated in series by one control circuit. Temperature sensors are placed in contact test cells, located on the GCSC end. The temperature sensors are thermocouples which are designed to provide the required precision temperature measurements such as Lander bus current. The command holding register, which are the last 6 bits (bits 19 through 24) of the command word shifted into the register, as two subfields of 3 bits each. For each combination of bits within these subfields, a discrete command signal is generated. As mentioned above, bits 1–8 of the command word contain no information. Bit 9 is a parity bit for the 8-bit command word, and is employed or as required to achieve odd parity. For the commands which provide access to one or another of the modular sequencers, it is sent to the referenced module sequencer when the appropriate command signals are decoded from the command subfields.

The control logic for the thermoelectric controller enables or disables the circuit on command from the Lander bus. The pulse width of the output pulse determines the thermoelectric relays to the off state if the coolers are on when it appears.

2. Command, control, and data handling

All of the command, control, and data signals are produced by the A2 slice. The heart of the slice is the three experiment sequencers. These sequencers provide almost all of the control signals required by the instrument to control individual experiments. The sequencers are controlled by commands from the Lander received and controlled by the command processor. After commands are operated on by the command processor, the information is stored in the buffer memory along with the other data requested by the sequencers. The memory receives its data from two sources. The first is the buffer memory in the A/D converter. The buffer memory is used to sample the analog GEX data and the temperature data. The other source of data is from the clock pulses produced by the clock processor. The clock processor is a crystal controlled clock generator which provides the clock signals required by the instrument to control the sequencers. The clock processor provides the clock signals required by the instrument to control the sequencers.

A 2048-bit static sequential-access memory 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 clock is required by the instrument, all timing clocks are produced by this clock. The clock processor is a crystal controlled clock generator which provides the clock signals required by the instrument to control the sequencers. The clock processor provides the clock signals required by the instrument to control the sequencers. The clock processor provides the clock signals required by the instrument to control the sequencers.

The GEx subroutine when activated causes the output of the GEx LLE to be sampled at a rate of 1/s for the three temperature ranges of interest. The two temperature ranges of interest are 760°C and 200°C. The three temperature ranges of interest are 760°C and 200°C. The two temperature ranges of interest are 760°C and 200°C. The three temperature ranges of interest are 760°C and 200°C. The two temperature ranges of interest are 760°C and 200°C.
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Command processor. The command processor provides a bridge between one command and another in the Lander guidance command and sequencing computer (GCSC). Commands are 24 bits long and are sent from the GCSC in a serial N/RZ code. The processor serves two functions in the Lander. One is to receive, decode, and execute distinct command functions, and the other is to provide access through the telemetry system to the experiment sequencers. The commands are received and held in a 16-bit shift register which utilizes serial loading (and readout to the memory) with parallel output for decoding of the stored word. It provides the multiple functions of receiving the command word, holding it for verification and decoding, and providing temporary storage for the command until it is sent directly to the referenced module sequencer. It is also possible to have one command received by the instrument to store the memory whether executed or not. Although commands are 24 bits in length, the 16-bit register is long enough to store any command. The first 8 bits are not used internally to the biological instrument but are used by the Lander to trigger support measurements such as Lander bus current. The command decoding gates decode the leftmost 6 bits of the command holding register, which are the last 6 bits (bit 19 through 24) of the command word shifted into the register, as two subfields of 3 bits each. For each combination of bits within these subfields, a discrete command signal is generated. As mentioned above, bits 1-8 of the command word contain no information. Bit 9 is a pulse for the 14-bit command word, and is for the sequencer to order, or one, as required to achieve odd parity. For the commands which provide access to one or more of the module sequencers, it is also possible to have a "flag" bit 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 10-18 is sent to the referenced module sequencer when the appropriate command signals are decoded from the command subfields.

Master clock generator. 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 the clock is much higher than the 288-kHz required by the instrument itself, all timing clocks are produced by synchronous division of the 288-kHz clock. The master clock generator produces 14-segment clock lines for the instrument, each clock is further divided into 2 pulses/h with the dominating clocks being 97 kHz and 1 pulse/min. The 96-kHz clock is used as the main control frequency and all data are moved internally at this rate. The 1-pulse/min clock provides the main timing base for the sequencers.

A 2048-bit static sequential-access memory is designed to store the program words. It is a 128-kilobyte memory which is a 256 × 1024 ROM random-access memory integrated circuit. The memory operates in three modes: (1) standby, where a minimum level of power is applied to the memory stack to retain stored information; (2) write, where the memory is organized to accept 12-bit data words from any of four data sources, and is used for programming data words, and is used for programming the memory stack; and (3) read, where the memory will go into a read mode upon Lander 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 (identification and frame data (frame number and number of words in memory)) and then transmits the memory contents (first in, first out) to the Lander (DATU). When empty, the memory reverts to the standby mode.

In standby mode, a counter within the data select and control function continually scans the write-cycle request lines and read-cycle lines looking for results.

Sequencer. The sequencer is the unit which controls the complete operation of the biology instrument. It is composed of three independent sequencers—one each of LR, PR, and GEX.

The operation and composition of the three sequencers are similar, each using microprogramming for operational control. The microprogramming is performed with the use of 256 × 1024 MOS read-only memories (ROMs). The GEX 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 command 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 information for the sequencer. This instruction determines whether some time interval is made 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 sequencers is shown in Figure 3. The sequencer operation is initiated with the receipt of an access command from the command processor. The command is 9 bits long and contains the ROM address, the ninth being 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 micro-instruction) 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 mHz) 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 contents. At this point, an access request is sent 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 or is commanded by the Lander to stop or change subroutines. Each sequencer also has a data subroutine which it calls on for its own data sampling. The PR and LR subroutines cause the respective °C data counts to be sampled along with the associated detector temperatures once every 16 min. The data is then transmitted, the output of the GEX LLE to be sampled at a rate of 1/8s for the duration of a chromatogram.
There are no temperatures to be monitored between 200° and 300°C; therefore, this range is bypassed. Specific experiments used 311 V, and no temperature affects. By including the three test cells, Gd, and detectors temperatures, and the PR organic vapor trap temperature. Two thermistors mounted on the “C” detector monitors as well as monitoring and ac. These voltages are fed through the output analog switches to the A/D processing and are selected in the same way as the plate gain.

Test cell position monitor. The test cell position for each of the three experiments is detected by the use of low-sensitivity. In each experiment’s module interface, the test cell can be rotated to do so as many as six positions by the use of a geared stepper motor coupled to a Geneva wheel. This Geneva wheel is motorized at a 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 1.52-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 of 1000 is not used for any positions because a 1000 would not be distinguishable from a solid part of the Geneva (i.e., no holes or slots to read through) and an 1111 is distinguishable from a Geneva wheel slot. Each TCPM has three LEDs and three phototransistors, so that 9 bits of TCPM data are available.

Gd low-level electronics. The function of the Gd 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 Gd LLE, Fig. 24, gives a representation of significant features. Inasmuch as the gas chromatograph (GC) is a “differential” device, the 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 is fed to an integrator from the beginning of the apparatus, then summing input at the next stage with a gain of 50. The gain-of-two summation is the main output amplifier for bead power. The 2.5-V output of 10 is applied to the output converter and servohydraulic 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 45 heaters. The valves are controlled by mechanical thermostats, electronic thermostats, or proportional heater control. All heaters and solenoid valves run from raw bus power in order to reduce conversion efficiency losses. The maximum power level in the voltage bus was 24-37 V, and the proportional heater controllers require a heater preregulator. The preregulator along with the other MSS components is described below.

Vandal 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 do 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 voltage 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 pairs of matrix-selection logic signals is also used to enable the 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” clock’s. The result is that the latching relay is closed for 50 ms in the middle of the logic pulse cycle on the valve voltage pulse direction. This assures that the valve selects relay contacts are closed and settled before after the current pulse is transmitted.

A third feedback signal commands the motor to step in the appropriate direction. As the motor is stepping, the controller is constantly ascertaining voltage pulse direction. This assures that the appropriate 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 pairs of matrix-selection logic signals is also used to enable the 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” clock’s. The result is that the latching relay is closed for 50 ms in the middle of the logic pulse cycle on the valve voltage pulse direction. This assures that the valve selects relay contacts are closed and settled before after the current pulse is transmitted.

A second feedback signal causes the motor to step in the appropriate direction. As the motor is stepping, the controller is constantly ascertaining voltage pulse direction. This assures that the appropriate 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 pairs of matrix-selection logic signals is also used to enable the 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” clock’s. The result is that the latching relay is closed for 50 ms in the middle of the logic pulse cycle on the valve voltage pulse direction. This assures that the valve selects relay contacts are closed and settled before after the current pulse is transmitted.

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Motor control. The valve control circuit operates 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 reverse and thus the motor direction to change. The TCPM and, for the SDA, causes the step sequence to reverse and thus the motor direction to change. These requirements on heaters can be easily met by sizing of the heaters, based on constant power input.

The preregulator 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 draw the same power at 24 V as at 37 V. Available power to the same load at intermediate voltages is slightly less with a minimum of over 92% of end-point values at 30.5 V.

Heat controllers. The methods of heater control are used for thermal control. The simplest is with mechanical thermostats. These thermostats are located in the MSS close to the thermal power source (for the TCPM) and, 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 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 sequence 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 sequentially. The preregulator for the MSS was an electronic thermostat. Isolation valve driver. The isolation valve driver operates only once during the mission—during the landing—where accurate and gas supplies are available. It is activated by a Lander command and uses a counter and driver to sequentially apply +15 V to the system transistors for 3 or 5 min, depending on the specification TIV’s for either 3 or 5 min. During the landing, all pressure is released, and the system inadvertently reroutes to the back-up Lander control scenario.
There are no temperatures to be monitored between 200° and 300°C; therefore, this range is bypassed. Specific temperature ranges below 200° or above 300°C 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 plateaus described above.

**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, 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 photodiodes to detect the six positions of a Geneva wheel for each of the three experiments. Light from an LED which passes through a 1.52-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 numbers 000 and 111 are not used for positions between 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.

A block diagram of the GEs LL-E, Fig. 24, represents a significant feature. Like the gas chromatograph (GC) which 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 function of the GEs low-level electronics (LLE) circuit is to measure the difference in thermal conductivity between gases passing through detector cell ends at the active and reference gas chromatograph columns and to make the information available to the analog-digital converter through the multiplexer.

The MSS contains 6 thermal isolation valves, 39 latching solenoid valves, a 48-hour timer, 28 three-position switches, 6 x 7 diode matrix, a 32-bit computer, 6 x 7 diode matrix, an auxiliary relay, whose state is controlled by a 6 x 7 driver matrix. Since the valves run off raw power, the control voltages for the drivers require a substantial reduction in both parts count and power requirements.

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 the 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 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” clocks. The result is that the bio bus relay is closed for 50 ms in the middle of the logic pulse to ensure that the proper relay is energized and the voltage pulse direction. This assures that the valve-select relay contacts are closed and settled before and after the current pulse is transmitted.

**Isolation valve driver.** The isolation valve driver operates only once during the mission—during the lander’s descent through the Martian atmosphere. It is activated by a Lender command and uses a counter and driver to sequentially apply +15 V to the system power line for either 3 or 5 min. Depending on the specific TIV thermometer or pressure sensor.

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

The preselector is accomplished by generating a ramp and an accurate binary ramp signal of constant amplitude and with a duty cycle. The circuit is such that a resistive load switched to the bus at the resulting duty cycle would draw the same current as a constant current source from the bus at 37 V. Available power to the same load at intermediate voltages is slightly less with a minimum of over 92% of end-point values at 30.5 V. The second method of operation in which the motor is sequentially stepped twice in one direction and twice in the other is used for other control.

Heater preselector. The heater preselector is similar to the TCPM monitor described earlier. A full description of the common circuitry to be shared by all of the motors resulting in a substantial reduction in both parts count and power requirements.

Upon receipt of a command from the sequencers (for the TCPM) or from the command processor (for the SDA), the controller turns on the appropriate power line. It also generates a four-phase 24-V power line from raw power line (between 24 and 37 V). The actual power to the same load at intermediate voltages is slightly less with a minimum of over 92% of end-point values at 30.5 V. The second method of control is with electronic thermostats. These "bang-bang" (limit switching) controllers use thermistors 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 microcomputer and its accessories are proportionally controlled heaters. These controllers use pulse width modulation at 2 kHz from the heater preselector. Each controller is required to provide 15 W of heating power. The proportional controllers power the heaters directly from the...
the shaping amplifier is between two preselected voltage levels equivalent to an energy range of 34 - 85 keV. The input of a double-ended voltage level discriminator is applied to the input of a double-ended voltage level discriminator and then has the ignition current sustained. 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 tickle 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 in the ESS. This power supply provides the sustaining lamp power. The trigger pulse is used to turn on 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 then 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 comonality of designs and hardware. Requirements for low leakages (10^-5 to 10^-8 std cm^-2 s^-1) coupled with ranges of pressures, low weight, tight pressure regulation, and accurate flow metering resulted in hydraulic and pneumatic systems constructed primarily of (1.6 mm o.d.) stainless steel tubing. The design and operation of these systems are described below. The system flow schematics are shown in Figs. 5, 10, and 16.

1. Common services module

The common services module (CSM) contains the helium reservoir which provides energy storage for pneumatic actuators, a carrier gas for the gas chromatograph, and a purge gas for use in the LR and PR experiments, and the waste management system for the instrument. Major components within the CSM include the carrier gas supply, the high-pressure helium manifold, low-pressure helium manifold, and the liquid vent system consisting of the liquid sump and the charcoal trap. An exploded view of the CSM is shown in Fig. 25.

Carrier gas supply. The carrier gas supply consists of a high-pressure spherical bottle welded to a manifold to which is attached an isolation device, filter, pressure regulators, pressure relief valves, and gas outlet tubes. The mounting lugs are integral with the manifold. A pressure sensor and a filler and drain valve are remotely located upstream of the bottle.

Prior to the flight phase of the Viking Mission, the helium reservoir was filled with a usable 77 000 std cm^2 of helium (99.999% pure) at a pressure of 315 kg cm^-2 through a fill and drain valve. After the correct charge was achieved, the tubular extension was welded closed.

Gas bottle pressure is contained by the thermal isolation valves. These isolation valves use a thermal actuator to pierce a diaphragm, opening a path for gas from the bottle to the roughing regulator by way of a 10-μm (absolute) filter. The high-pressure regulator reduces bottle pressure to 10.2 bar and two regulators downstream reduce the pressure to 9.2 and 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 (CCS), 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 V1 vent is used for venting of the PR detector, the V2 vent acts as a vent for the gas chromatograph system and the high-pressure manifold. The V3 system was designed for minimum resistance within the biology instrument to minimize pressure differentials for 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 control module. Requirements 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-mA 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 control module. 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...
the shaping amplifier is between two preselected voltage levels to reduce the output pulse whose amplitude and width are produced by the shaping amplifier and then applied to a discriminator. The discriminator produces a 10 MHz discriminator pulse, which is then used to turn on the lamp and integrate the pulse shaping amplifier. The resulting output pulse is used to turn on the lamp and set the capacitor charge. This energy level discriminator is used in the LR experiments to reduce the output pulse and set the secondary output voltage to 7.5 kV at the secondary winding and then across the lamp electrodes.

In actual operation the voltage seldom rises above 5 kV since the xenon lamps operate 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.

**Hydraulic and pneumatic systems**

The multiplicity of flow and pressure requirements for the various liquids, gases, and for the electrical and electronic requirements is the fundamental component of numerous components and assemblies, utilizing commodity, and hardware requirements. For low leakage, low weight, high pressure, and accurate flow metering resulted in hydraulic and pneumatic systems constructed primarily of (1.6 mm o.d.) stainless steel tubing. The design and operation of these systems are described below. The system flow schematics are shown in Figs. 5, 10, and 16.

### 1. Common services module

The common services module (CSM) contains the helium reservoir which provides energy storage for pneumatic actuators, a carrier gas for the gas chromatograph, and a liquid vent system consisting of pressure regulators, pressure relief valves, and gas outlet tubes. The three gas vent systems are used to vent helium gas from the instrument. The V3 system was designed for minimum resistance within the biology instrument to facilitate the vent diffusion times for 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 a liquid vent system consisting of the liquid sump and high-pressure manifold. The V3 system was designed for minimum resistance within the biology instrument to facilitate the vent diffusion times for the PR cell system and the gas exchange gas sample loop.

### 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 providing module. Require-iments for low-power, low-weight, low-leakage, and high reliability led to the development of a miniature latching solenoid valve for low-leakage requirement. The valve will latch open or closed, depending on polarity to the voltage applied to the coils. A summary of performance characteristics is presented in Table X. 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 PTFE diaphragm seal (unvented). The Viton valves are used for handling helium (99.999% purity) at a pressure of 31.5 kg cm⁻² through a fill and drain valve. After the correct charge was achieved, the tubing extension was welded closed.

Gas bottle pressure is contained by the thermal isolation valves. The isolation valves use a thermal actuator to pierce a diaphragm, opening a path for gas from the bottle to the roughing regulator by way of a 10-µm (absolute) filter. The roughing regulator reduces bottle pressure to 10.2 bar and two regulators downstream reduce the pressure to 9.2 and 1.2 bar, respectively, above ambient. If 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), 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 V1 vent is used for venting of the PR detector, the vertical actuator gases, the gas chromatograph system, and the high-pressure manifold. The V3 system was designed for minimum resistance within the biology instrument to match the vent diffusion times for the PR cell system and the gas exchange gas sample loop.

Two of the experiments rely on the assumption that carbon-14. Detection of the L'IC (which is a beta emitter) produces a great deal of EMI and operational problems. The lamp starting circuit has the lamp assembly. The diaphragm valve is operated by applying a 50-ms pulse at 24 V (terminal) to the coil of the miniature latching solenoid valve. The valve will latch open or closed, depending on polarity to the voltage applied to the coils.
where low leakage rates are required and the operational temperature ranges between -12° and 50°C. The EPT valves are used where low leakage rates are required and the operational temperature ranges between -20° and 150°C. To avoid poppet stiction, systems, the diaphragm valves are used to separate the gas exchange (located in the stainless steel biological incubation vessel) and vapor reservoir systems is a thermally actuated diaphragm piercing valve. This device was chosen for red undancy (GCAA rejuvenation) and to prevent corrosion of the LR module.

Table XI. Physical and operating characteristics of the miniature latching solenoid valve.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>8.7 g</td>
</tr>
<tr>
<td>Coil resistance</td>
<td>190Ω</td>
</tr>
<tr>
<td>Latching force</td>
<td>0.738 kV</td>
</tr>
<tr>
<td>Dynamic seal load</td>
<td>0.272 kg</td>
</tr>
<tr>
<td>Total stroke</td>
<td>0.45 mm</td>
</tr>
<tr>
<td>Maximum opening voltage</td>
<td>11.8 V dc</td>
</tr>
<tr>
<td>Minimum closing voltage</td>
<td>13.4 V dc</td>
</tr>
<tr>
<td>Open response time</td>
<td>0.89 ms</td>
</tr>
<tr>
<td>Close response time</td>
<td>1.6 ms</td>
</tr>
<tr>
<td>Pressure drop</td>
<td>&lt;0.38 mm office with Cg = 0.85</td>
</tr>
<tr>
<td>Reverse cracking pressure</td>
<td>&gt;24.5 kg cm-2</td>
</tr>
<tr>
<td>Burst pressure</td>
<td>&gt;49 kg cm-2</td>
</tr>
<tr>
<td>Internal leaking (std cm3/He)</td>
<td>1.5 x 10^-7 to 5 x 10^-7 depending on seat material configuration</td>
</tr>
<tr>
<td>External leakage (std cm3/He)</td>
<td>1 x 10^-7</td>
</tr>
<tr>
<td>Burst</td>
<td>&gt;49 kg cm-2</td>
</tr>
</tbody>
</table>

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 gases 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 burst 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 supply lines. 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) L 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^-5 std cm^3/s atm helium and compatible with biological requirements (toxicity). 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 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 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 Earth-Mars transit.

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 CO₂ into the detector and then closes off the detector and counts a fixed volume.

The detectors measure the betas emitted by radioactive CO₂ 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 continuous flux of high energy cosmic rays. The thickness of the solid state detectors is optimized with respect to these considerations so that the 14 C 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 XI. Physical and operating characteristics of the miniature latching solenoid valve.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.726 kg</td>
</tr>
<tr>
<td>Cell resistance</td>
<td>190 Ω</td>
</tr>
<tr>
<td>Latching force</td>
<td>0.778 kg</td>
</tr>
<tr>
<td>Dynamic seal load</td>
<td>0.272 kg</td>
</tr>
<tr>
<td>Total stroke</td>
<td>0.24 mm</td>
</tr>
<tr>
<td>Minimum opening voltage</td>
<td>11.8 V dc</td>
</tr>
<tr>
<td>Minimum closing voltage</td>
<td>13.4 V dc</td>
</tr>
<tr>
<td>Open response time</td>
<td>0.89 ms</td>
</tr>
<tr>
<td>Close response time</td>
<td>1.6 ms</td>
</tr>
<tr>
<td>Reverse cracking pressure</td>
<td>24.5 kg cm⁻²</td>
</tr>
<tr>
<td>Burst pressure</td>
<td>306 bars</td>
</tr>
<tr>
<td>Internal leakage (std cm⁻³/sec He)</td>
<td>0.10⁻⁷</td>
</tr>
<tr>
<td>External leakage (std cm⁻³/sec He)</td>
<td>1.0⁻⁷</td>
</tr>
</tbody>
</table>

TABLE XII. Summary of the locations and purposes of the thermal isolation valves.

<table>
<thead>
<tr>
<th>Location</th>
<th>Blunt disk thickness (μm)</th>
<th>Stored gas/vapor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrolytic release</td>
<td>76</td>
<td>H₂O</td>
</tr>
<tr>
<td>Pyrolytic release</td>
<td>76</td>
<td>¹⁴C CO₂/¹⁴C CO at 525 milli-bars</td>
</tr>
<tr>
<td>Gas exchange</td>
<td>76</td>
<td>He/C₂O₂ at 8.5 bars</td>
</tr>
<tr>
<td>Common service module</td>
<td>152/102</td>
<td>77 000 std cm⁻³ He at 96 bars (99.9999% purity)</td>
</tr>
<tr>
<td>Gas exchange (located in LR modulator)</td>
<td>76</td>
<td>He/C₂O₂ at 8.5 bars (GCCA rejuvenation)</td>
</tr>
</tbody>
</table>

The thermal isolation valve (Fig. 27) is comprised of a thermal actuator and a burst 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 to the element to 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.

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 burst 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 mediums. 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 314 or 316 stainless steel, 1.6 mm o.d. by 1.1 mm i.d., except for:

(1) L.R detector line—3.2 mm o.d., 0.25 mm wall, 176 bars (99.999% pure)
(2) High-pressure (315 kg cm⁻²) lines—0.16 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 10⁻⁸ std cm⁻³ s⁻¹ atm helium and compatible with biological requirements (toxicity). 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 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 interaction 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 accumulator electronics subsystem. 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 ¹³C into the detector and then closes off the detector and counts a fixed volume.

The detectors measure the betas emitted by radioactive ¹³C CO₂ 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 radiosotope 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 ¹³C 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 RTC's and the time over which the signal is counted. The background signal is a function of the background from the RTC's and the time over which the signal is counted.
The detector is 0.4 cm$^3$ in volume. The full-width half-maximum (FWHM) noise, as measured with a 60-keV pulse, averaged 5.38 ± 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 cm$^3$. 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 so minimal 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 cells under each experiment module's soil load port. The order of soil delivery is gas exchange (1.00 cm$^3$), pyroelectric release (0.25 cm$^3$), and labeled release (0.50 cm$^3$).

**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 temperatures be satisfied simultaneously in different experiments. To satisfy these requirements in a Martian atmosphere (nominally 7 millibars CO$_2$), 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, convective/radiation shielding, surface coatings or tapes, and component placement.

The MSS consists of the three individual experiments, a common services module for helium supply and regulation, and nuclear detection systems for LR and PR experiment detection regions. The MSS is designed to thermally isolate each of these units from the other and, except for the nuclear detection system and the PR illumination assembly, from the Lander IMP. Within each experiment, subassemblies which are not at high temperatures (>900 °C) are further isolated from the remainder of the module.

Table XII summarizes the various elements making up the MSS thermal subassembly. The maximum of thermal requirements are satisfied by the 43 individual heaters coupled with proper control of the conduction and radiation heat path from the part to be controlled towards the ESS housing. 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 pipe line between heaters and coolers (one each for GEx and LR and two for PR) is used to maintain cell head temperatures at or below 27 °C when the Lander IMP reaches a higher value. Each thermostatic control includes both active and passive elements. A second approach to reducing heat losses with radiation/convection shielding 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. 35.

Maintenance of particular lines 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) which can be set to improve the temperature variation of the IMP from 35 °C to 26 °C. Another approach is to use insulation to maintain cell head temperatures greater than 5 °C. The 11 individual heaters mounted to the experiment carts. Nutrient lines are then thermally bonded to the cans (heated to approximately 100 °C) and remain comfortably above freezing even in the extreme environments expected. This concept is illustrated by...
The detector is 4 cm³ in volume.

The electrical feedthroughs are molybdenum.

56% are counted.

absorb more than 85 keV for minimum ionizing particles.

particles striking a silicon diode are stopped by 168 cm.

High-energy radiation from the RTGs is thus discriminated against. The maximum energy pulse is produced for each accepted pulse. These pulses time constants to minimize system noise is used to shape the active volume are collected as a charge proportional leakage current is 0.2 A.

The silicon is large enough to thick is used as the active element for the detectors. These silicon sensors charge is amplified by the hybrid charge sensitive preamplifier, the FWHM, 

FWHM with a maximum of 6.47 keV FWHM for the silicon detectors in the three flight instruments.

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. 33.

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 sequence 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 cells under each experiment's soil load port. The order of soil delivery is gas exchange (1.00 cm³), pyrolytic release (0.25 cm³), and component placement.

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 out simultaneously (in different experiments). To satisfy these requirements in a Martian atmosphere (nominal 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, convection/radiation shields, surface coatings or tapes, and component placement.

The MSS consists of the three individual experiments, a common services module for helium supply and regulation, and nuclear detection systems for LR and PR experiment detection. The MSS is thermally isolated from each of these units and, except for the nuclear detection system and the PR illumination assembly, from the Lander IMP. Within each module, subassemblies which maintain extremely high temperatures (>90°C) are further isolated from the remainder of the module.

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 heat paths from the part to be controlled 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 detectors (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, mounted to the IMP with four screws, is electrically controlled to vary between components and on the GEx heated nutrient line between the valve shield on the LR head end is shown in Fig. 34. The MSS thermal subsystem elements involve passive approaches to reducing heat losses with radiation/convection shields placed on the LR heat exchanger block, on the GEx heated heat exchanger block, 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 lines 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) that are turned on when required. The temperature variation of the IMP from 35°C to 26°C. The minimum environment assumes no heat dissipation internal to the instrument; the minimum Lander plate temperature will increase by approximately 0.5°C for each degree below 27°C externally by 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. For the MSS the use of the individual experiments, a common services module for helium supply and regulation, and nuclear detection systems for LR and PR experiment detection is to thermally isolate each of these units from the other.

FIG. 32. Cross section of the pyrolytic release and labeled release each 14 μm 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 (10⁻¹⁰ cm⁻³ expected) to several hours for the second, more (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.

Diffused-junction silicon 250 μm thick is used as the active element for the detectors. These silicon sensors are operated with a reverse bias of 100 V applied to a small guard ring surrounding a 1 cm³ active area. The active area receives its bias through the impedance between the active area and the guard ring. The normal leakage current is 0.2 A. Figure 32 shows a cross section of the two detectors.

Charged particles ionize the silicon and the ions in the active volume are collected as a charge proportional to the energy deposited in the active volume. This charge is amplified by the hybrid charge sensitive preamplifier, whose height is proportional to the energy deposited. A hybrid shaping amplifier with time constants to minimize system noise is used to shape and amplify the signal pulses. Those pulses with heights between the nominal values of 0.8 and 2.0 V, corresponding to 34 and 85 keV energies, respectively, are then accepted by a hybrid window discriminator. A 5-V pulse is produced for each accepted pulse. These counts are counted by accumulators in the ESS. The 250-μm thickness of the silicon is large enough to absorb more than 85 keV for minimum ionizing particles.

High-energy radiation from the RTGs is thus discriminated against. The maximum energy 4°C beta particles striking a silicon diode are stopped by 188 μm of silicon. Of the 4°C beta particles striking the silicon 46% are counted.

The geometry of the detection chambers has been optimized with respect to overall detection efficiency. For the LR experiment a 2.5-mm² closed at both ends by the 1-cm³ active area of the silicon diodes provides the optimum efficiency. The PR detector is 1.4 cm³ in volume.

The detector body is made of Kovar (Fe–Ni–Cu) with feedthroughs and stainless steel tubes brazed to the body. The electrical feedthroughs are molybdenum pins, ceramic insulator, and Kovar tubes. The two silicon sensors are soldered in place to enclose the detection volume. Gold-plated Kovar covers are then soldered to the Kovar body to hermetically enclose the moisture sensitive side of the sensors.
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 another benefit in that they can be controlled to maintain the experiment cell and held 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 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 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.

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 direct commands sent from the guidance control and sequencing computer (GCSC) in the Lander. These commands operate the instrument either by accessing 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 store are controlled Lander either by 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 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 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 chromatographs columns. ICL table B contained a command set to accomplish the first set of biological analyses on soil from the surface. Of 122 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 every 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 radioactivity 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 inter-experiment constraints introduces constraints on simultaneous use of the vent systems and the helium supplies.

In addition to the thermal and interference 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. The 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 Lander sequencer computer program to check for constraining violations. This process was iterated with modifications to the sequence until all constraints were satisfied and resolved. The sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once again, 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 for a transmission window is available for down linking. This may be either by direct transmission to earth or via a relay through the orbiter. The biology data is mixed 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 for 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 format and memory frames and, using inputs from the sequence generation program, time-tags the data and separates them according to their experiment type (P, H, or L). 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 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 and 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 13 soil 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 consumptive gas used to engage the test cell curvelines 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. 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 Lander LNT experiment.

On September 3, 1976 Viking Lander II arrived at Viking biology instrument
Viking biology instrument

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 head end 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 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°C (60°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°C.
5. GCSC detector main the GCSC detector at 32 ± 0.1°C during gas analyses.
6. Detector cleanup—elevate PR and LR detector temperatures above 90°C to desorb trapped radioactivity.

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 direct commands sent from the guidance control and sequencing computer (GCSC) in the Lander. These commands operate the instrument either 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 is 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 may represent activity in the Lander either by 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 of 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 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 chromatograph columns. ICL table B contained a command set to accomplish the first set of biological analyses on soil from the surface. Of 122 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 up-link 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 experimental 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 inter-experiment constraints provides 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. The 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 GCSC computer program to check for constraining violations. This process was iterated with modifications to the sequence until all constraints violated during the validation were resolved. The sequence was then sent to the overall Lander sequencing computer program where it was checked against the Lander constraints. Once again, 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 the data in a working data file. If 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 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 decalibrates 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 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 data files, 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 13 separate 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 gauge used to regulate the test cell currents 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 was in the gas chromatographs (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 test cells for the LR experiment.

On September 3, 1976 Viking Lander II arrived at

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Utopia plains of Mars approximately 180° around Mars from Lander 1, and at a much more northerly latitude. The biology instrument's primary mission was also completed by conjunction and the secondary experiments 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-14 during the 4th and 5th soil sequences. During the Lander II biology instrument operation, 13 separate experiments on 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, in the development of the biology instrument made possible. We thank the Martin Marietta Corporation resident 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/Aimes 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/ARC, 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.

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The low-temperature (22 K) dependence of the photoductive in x- 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, is well suited for spatial mapping of highly inhomogeneous fields produced by superconducting magnets. The probe may also be adapted to power and frequency measurement of microwave sources operating at ~50 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 10⁴ 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 10⁴ is about as high as can be expected. The resonance methods, based on accurate frequency standards and known magneto- optical properties of the substrates, 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 photoconduction in semiconductors, the physics of which has been the subject of several publications. 1, 2 Most of the work has been on x-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 V donors at concentrations below 10¹⁷/cm³ is negligible in relation to the photocurrents which will be em- ployed. The presence of extrinsic radiation (0.05 < hv < 1.18 eV) or intrinsic radiations (hv > 1.18 eV), where hv is the photon energy, the photocurrent is proportional to the product of carrier generation rate (hv) and mobility, carrier mobility, and carrier lifetime. The latter two quantities vary with mode of illumination (extrinsic or intrinsic) because of the different charge states of the impurities resulting from the two types of illumination. Since the technique we are about to describe operates most effectively at impurity concentrations and temperatures where the lifetime of photoexcited carriers is the dominant parameter for determining the photoconductance, we confine the description of operation to that case, losing little generality by neglecting changes in mobility. 3 Thus, under constant radiation intensity (and assumed constant mobility), the photoconductance is proportional to the carrier lifetime. For a silicon sample doped with group V donors to a concentration of, for example, 3 x 10¹⁷/cm³, and held to a group III acceptor concentration of, or below, 10¹⁰/cm³, a readily obtained condition, the dominant conduction-electron lifetime limiting mechanism at low temperatures is capture by neutral donors, denoted by the reaction

\[ D^+ + e^- \rightarrow D^- (1) \]

This reaction, however, occurs only when the neutral donor, D⁺, and a conduction electron interact in a singlet spin state, 4, 5 since the resultant D⁻ 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 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 (D⁺ D⁻), 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 unpolarized (D⁺ D⁻) system, when a singlet state collision between conduction electrons and donors is abundant, the photoconductance is reduced because the carrier lifetime

\[ D^+ + e^- \rightarrow D^- (1) \]
Utopia plains of Mars approximately 180° around Mars from Lander 1, and at a much more northerly latitude. The biology instrument’s primary mission was also completed by conjunction and the secondary experiments 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 processed, 57 gas chromatograms were taken for the GEx experiment. 3 pyrolytic release experiments were successfully completed, and 9 radioactive nutrient injections were made in five different tests for the labeled release experiment. A total of about 2000 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 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/Aries 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/ARC, 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 NAS-11-9000 and NAS-14231.

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Precision absolute measurements of strong and highly inhomogeneous magnetic fields

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The low-temperature (≤4 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 is ideally suited for spatial mapping of highly inhomogeneous ambient superconducting magnets. The probe may also be adapted to power and frequency measurement of microwave sources operating at -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 10^8 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 10^6 is as high as is expected. The resonance methods, based on accurate frequency standards and known magneto-grams of specific samples of electrons, 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 for 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 reviewed in several publications. Most of the work has been on α-type silicon, and for simplicity of presentation we confine ourselves to that material. At liquid helium temperatures (-4.2 K), the dark current for uncompensated silicon containing group V donors at concentrations below 10^12 cm^-3 is negligible in relation to the photocurrents which will be employed to generate the magnetic field. Most of the work reported here has been done in the presence of intrinsic radiation (0.05 ≤ hν ≤ 1.18 eV) or intrinsic radiative (hν > 1.18 eV), where h is the Planck constant, the photocurrents

Dp = εp - Dr = εr

(1)

is proportional to the product of carrier generation rate (ε) with radiation intensity, carrier mobility, and carrier lifetime. The latter two quantities vary with mode of illumination (extrinsic or intrinsic) because of the different charge states of the impurities resulting from the two types of illumination. Since the technique we are about to describe operates most effectively at impurity concentrations and temperatures where the lifetime of photoexcited carriers is the dominant parameter for determining photoconductance, we confine the present description of operation to that case, losing little generality by neglecting changes in mobility. Thus, under constant radiation intensity (and assumed constant mobility), the photoconductance is proportional to the carrier lifetime. For a silicon sample doped with group V donors to a concentration of, for example, 3 x 10^15 cm^-3, and held to a group III acceptor concentration of, or below, 10^18 cm^-3, a readily obtained condition, the dominant conduction-electron lifetime limiting mechanism at low temperatures is capture by neutral donors,

Dn = εn - Dr = εr

(1)

denoted by the reaction

Dn + e^- → D^- + hν

(1)

This reaction, however, occurs only when the neutral donor, Dn, and a conduction electron interact in a singlet spin state,23 since the resultant D^- 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 ratio 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 longer carrier lifetimes and a high photoconductance, whereas in an unpoled (P = 0) state, the neutral donors and conduction electrons and donors are abundant, the photoconductance is reduced because the carrier lifetime

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