Astrobiology Education Poster
Activity 3
Life: How do we find it?

Learning Objectives:
Students will be able to:
- Formulate a hypothesis about the presence of life on Mars
- Design a test for the existence of life in soil samples
- Design a test for the life on Mars hypothesis

Standards Addressed
As a result of this activity, students should understand the following abilities necessary to do scientific inquiry:
- Design and Conduct Scientific Investigations. Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations.

Student Prerequisites
- Students should be familiar with the characteristics of life and the conditions needed for life. Both topics are covered in Activities 1 and 2.

Student Misconceptions
Students may have misconceptions about scientific inquiry and the scientific method.
- According to Benchmarks for Science Literacy (p. 333): Students' ideas about the nature of knowledge and how knowledge is justified develop through stages in which knowledge is initially perceived in terms of "right/wrong," then as a matter of "mere opinion," and finally as "informed" and supported with reasons. … Several studies show that a large proportion of today's high-school students are still at the first stage of this development.
- According to Benchmarks for Science Literacy (p. 332): Students of all ages find it difficult to distinguish between a theory and the evidence for it, or between description of evidence and interpretation of evidence.

These misconceptions are addressed in this activity.

<u>Materials Needed</u>
- 1 liter dechlorinated water at about 60°C (140°F)
- 1/3 cups sugar
- 2 seltzer tablets (Alka Seltzer® works well)
- 1/4-ounce packages of yeast
- 6 cups of clean or sterile fine-grained sand
- 3 large glass beakers

<u>Optional materials</u>
- 3 Erlenmeyer flasks
- 3 rubber stoppers with glass tube in each stopper
- 3 rubber hoses, with each hose attached at one end to one of the glass tubes
- 1 glass quart jar of limewater. To make:

1. Fill a one-quart jar with room temperature water.
2. Add 1 tablespoon of lime (CaO), and stir. Lime can be found at gardening stores.
3. Secure the lid.
4. Allow the solution to sit overnight.
5. Pour the clear liquid in the first jar into a second quart jar. Be sure not to pour any of the lime that has settled on the bottom of the first jar into the second jar.

6. Put the lid on the second jar (to keep carbon dioxide in the air from dissolving in it). This second jar contains the limewater for use in the demonstration.

Preparation Needed

- Make three soil sample mixtures as follows:
- **#1** – Pour 2 cups of sand only in the first glass beaker and label as “Soil Sample #1.”
- **#2** – Crush the seltzer tablets into fine pieces using the back of a spoon to press on the packets before they are opened. Open the packets and mix the seltzer with 2 cups of sand. Put the mixture into the second glass beaker and label as “Soil Sample #2.”
- **#3** – Mix the yeast with 2 cups of sand. Put the mixture into the third glass beaker and label as “Soil Sample #3.”
- Make a nutrient solution just before class. Use a thermometer and obtain one liter of hot water, approximately 60°C (140°F). Mix 1/3 cups of table sugar with the hot water. The ideal temperature for yeast gas production is 50°C (122°F). By the time students have discussed how to do an experiment, the nutrient solution will have cooled to about 50°C. It can be reheated on a hot plate to the appropriate temperature right before the experiment if needed. Yeast gas production is not as dramatic when the nutrient temperature is less than 40°C (104°F), and yeast are killed when the nutrient temperature is above 55°C (131°F).

Activity

1. Recall Activity 2. Students researched solar system objects, evaluating them for the possibility of life while keeping in mind Earthly extremophiles and the conditions where they can exist. Students then reported to the class on the results of their research. The class compiled a list of promising places to look for evidence of life and compared the list to where scientists are currently considering looking for life: Mars, Europa, and Titan. Since this activity focuses on “Life: How do you find it?”, tell students that today they will role-play as astrobiologists and focus on finding evidence of life on Mars. Mars is our nearest neighbor and is thought to have been a lot more like Earth in it’s past. While Titan and Europa are enticing with a thick, nitrogen rich atmosphere and potential liquid water ocean, respectively, Mars remains relatively easier to get to and, therefore, it has been explored extensively since the 1970’s.

2. If desired, review scientific inquiry and the scientific method with the class. Websites with helpful information include:
   A light-hearted example of the scientific method with a list of good links:
   http://www.howe.k12.ok.us/~jimaskew/hsimeth.htm
   The Scientific Method from Janice Van Cleave’s Science Fair Notebook:
   http://school.discovery.com/sciencefaircentral/scifairstudio/handbook/scientificmethod.html
   Introduction to the Scientific Method:
   http://teacher.nsrl.rochester.edu/phy_labs/AppendixE/AppendixE.html

   Students should understand the scientific method: state a problem; research the problem; form a hypothesis; test the hypothesis; draw conclusions form the data; modify hypothesis if necessary and re-test if necessary.

3. Ask students to state the problem they are addressing. *(Is there life on Mars?)* Discuss ways to answer this question. Can astrobiologists go to Mars themselves and take samples? *(Not at this time, although NASA is talking about sending humans to Mars in the future.)* If astrobiologists can’t go to Mars themselves, how can they answer the question? *(They can send machines to Mars to test for evidence of life on Mars.)* Discuss how machines might test for evidence of life on Mars. *(Answers will vary, but may include taking photographs and testing the surface soil.)*

   Remind students that two rovers, named “Spirit” and “Opportunity,” landed on Mars in January 2004 (the latest information on both rovers can be found at http://marsrovers.jpl.nasa.gov/home) and that additional orbiter and lander missions are planned. Note that Spirit and Opportunity are not looking for evidence of life itself, but are looking for evidence to answer the question of whether liquid water ever existed on the Martian surface. Remind students that liquid water is a prerequisite for life on Earth.

4. Ask students to describe the characteristics of life and write them on the board *(Living things: consist of one or more cells; grow and develop; respond to changes in the environment; consume raw materials (eat) for energy; produce waste products; and reproduce.*). This material was covered in Activity 1. This research is important to the process.

   Ask students to review what they know about the conditions and characteristics of Mars itself and write them on the board *(Mars has a relatively thin atmosphere which offers very little protection from the Sun's UV radiation, is very dry and has a broad temperature range at the surface, may have had liquid water flowing on the surface in its past, has water as ice at its poles, may have water in the soil as permafrost or as liquid in the deep subsurface).*

   Now ask students to come up with hypotheses about life on Mars that could be tested. *(Answers will vary, but should resemble and include: There is life on Mars and it is in the soil.)* Write student hypotheses on the board. Focus the discussion on testing the hypothesis "*There is life on Mars and it is in the soil*."

5. Display the three soil samples and ask students how they could test for evidence of life in them if they were samples of Martian soil. Guide the discussion toward experiments that could be done to detect the characteristics of life in the soil samples. Accept any reasonable answers, which may include: give it food and see if it eats it; look for things moving in it; look for waste products; look at it under a microscope and look for microbes; and see if anything grows or reproduces if you feed or water it. Encourage students to use their imaginations in designing an experiment, and not limit themselves by what they can do in their classroom. Write students' ideas on the board.

6. Discuss students' ideas in more detail, focusing on specifics of how each idea could show evidence for life in the soil samples. Ask, for example, what food would you give an organism, or what waste products would you look for, or how would you know if anything was reproducing. This will help weed out any fanciful ideas.

7. Focus on the experiment of adding a nutrient to (or "feeding") the soil samples. Assist students in understanding what the evidence for life would be in this test that would support or negate the hypothesis. Discuss the logic behind "feeding" any organisms, pointing out the observation that many Earthly organisms give off carbon dioxide after "eating" nutrients. Prompt the class to then refine the hypothesis – *If there is life in Martian soil samples, organisms in the soil will ingest nutrients and give off a measurable gas waste product.* Write this on the board. Tell the students that reagents have been prepared to test this hypothesis and conduct a "feeding" experiment.

8. Show students the nutrient solution you prepared before class. Explain to students what is in the solution – water and sugar. Remind students that many Earthly organisms (including humans) use carbohydrates (sugar) as an energy source, that is, they will "eat" sugar to produce energy to live. Point out that these Earthly organisms give off carbon dioxide in the course of the energy production.

   Ask students what they think will happen if you add the nutrient solution to a soil sample that has living organisms in it. (*Organisms will "eat" the sugar in the nutrient solution, then give off carbon dioxide gas that can be detected and measured.*) Point out that this is based on the assumption that Martian organisms use the same energy production [metabolic] processes as some Earthly organisms.

9. Write "Soil Sample #1" on the board. Add nutrient solution to soil sample #1. This is the sample with sand only. Ask students to describe what happens and write their observations in their notes and on the board *(No changes occurred.)* Ask students to explain why no changes were observed. *(Answers will vary, but should include that there were no living organisms in Soil Sample #1.*) Write explanations on the board.

   NOTE: Astute students may note that the experiment only shows that there were no organisms that “eat” sugar in the soil sample. If this is mentioned, discuss the limits of designing experiments to test for something with which there has been no prior experience (for example, organisms that don’t use carbohydrates and sugar for energy). How do you test for “anything” that might happen, including things you don’t expect? Scientists try to design experiments that answer specific questions. Sometimes the experimental results force scientists to reconsider their basic assumptions.

10. Write “Soil Sample #2” on the board. Add nutrient solution to soil sample #2. This is the sample with the seltzer tablets added to the soil. Ask students to describe what happens and write their observations in their notes and on the board. *(Bubbles should form in the soil and water sample, some of which move to the top of the water and burst.)* Ask students to explain what happened. *(The nutrient solution caused a reaction. It could be due to living organisms.)* Write the explanations on the board.

11. Write “Soil Sample #3” on the board. Add nutrient solution to soil sample #3. This is the sample with yeast added to the soil. Ask students to describe what happens and write their observations in their notes and on the board*. (Bubbles should form in the soil and water sample, but less than in soil sample #2.)* Ask students to explain what happened. *(The nutrient solution caused a reaction. It could be due to living organisms.)* Write the explanations on the board.

    OPTIONAL EXTENSION: Have students investigate the gas given off in the reactions in soil samples #2 and #3. If you do this, put all three soil samples in Erlenmeyer flasks instead of beakers. Plug the flask with the rubber stopper immediately upon addition of the nutrient solution. Put the other end of the rubber hose in the solution of limewater. If carbon dioxide is present in the flask, a milky white precipitate will form in the limewater solution.

    If desired, write the chemical reaction of what is happening in the limewater on the board:
    $CaO + CO_2 = CaCO_3$
    NOTE: CaO is lime (in solution in the limewater). $CaCO_3$ is calcium carbonate.

12. After a few minutes have passed since the nutrient solution was added to soil samples #2 and #3, have students describe what is happening now in each soil sample and write their observations in their notes and on the board. *(There should be no more bubbles forming in soil sample #2, while they continue to form and may even be forming more vigorously than when nutrient was first added in soil sample #3.)*

13. Ask students to explain what happened and to explain the different reactions observed in each of the soil samples. Write their observations on the board. Steer the discussion to include the idea that living organisms will continue to eat sugar and produce carbon dioxide. Well-fed organisms will reproduce as time goes on, meaning more sugar will be eaten and, therefore, more carbon dioxide produced until the organisms die or run out of food. A purely chemical reaction, on the other hand, will generate a lot of carbon dioxide initially, and then the reaction will stop completely, with no more gas generated, once one of the chemical reactants (e.g., the seltzer in soil sample #2) is used up.

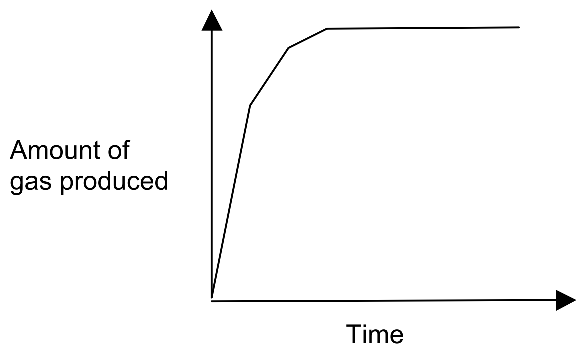
14. Have students summarize what happened in soil sample #1 in their notes and, if desired, on the board. *(Soil sample #1 had no living organisms and no chemical reaction.)* Tell students that soil sample #1 was only sand.

15. Have students summarize what happened in soil sample #2 in their notes and, if desired, on the board. *(Something in the nutrient solution caused a chemical reaction with chemicals in the soil. The reaction began fast, went fast, and ended abruptly when the reactant chemical was used up. There was no living organism in soil sample #2.)* Tell students that soil sample #2 contained seltzer tablets mixed in with the sand. The soil was exhibiting a chemical reaction.

    If desired, write the following equation on the board to show what happened:
    $3NaHCO_{3(aq)} + H_3C_6H_5O_{7(aq)} \rightarrow 3CO_{2(g)} + 3H_2O_{(l)} + Na_3C_6H_5O_{7(aq)}$
    or, if you prefer, the net equation of what’s taking place:
    $HCO_3^-{}_{(aq)} + H^+{}_{(aq)} \text{---->} H_2O_{(l)} + CO_{2\,(g)}$

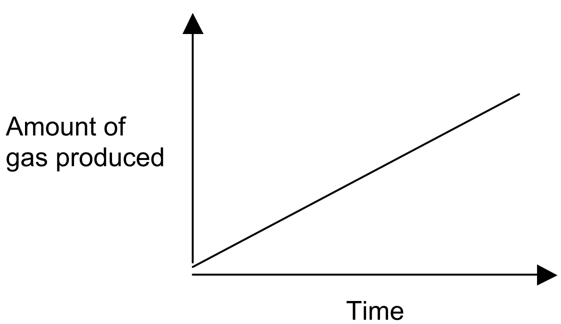
NOTE: Alka Seltzer tablets “fizz” in water because of a reaction between sodium bicarbonate (baking soda) and dehydrated citric acid in the tablet. Once water is added, the citric acid is no longer dehydrated and the reaction takes place. The reaction results in the production of carbon dioxide, water, and sodium citrate.

Have students draw on the board a graph of what they think the production of carbon dioxide gas in soil sample #2 as a function of time would look like. The result should be something along the lines of:



16. Have students summarize what happened in soil sample #3 in their notes and, if desired, on the board. *(The warm nutrient activated dormant life. Gas production began slowly, built up, and continued, as the activated yeast “ate” the nutrient, grew, and reproduced. There were living organisms in soil sample #3.)* Tell students that soil sample #3 contained dormant yeast, a living organism, mixed in with the soil, that was activated when the warm nutrient solution was applied.

    Have students draw on the board a graph of what they think the production of carbon dioxide gas in soil sample #3 as a function of time would look like. The result should be something along the lines of:



17. Point out to students that a conclusion of this experiment is that it’s not enough to detect that the same gas was given off after adding the nutrient solution to soil samples #2 and #3. What’s important is the rate at which the gas is given off. Point out that this is what scientists do – perform an experiment then try to understand why the results happened and draw conclusions based on the observed data.

18. Point out that the experiment they just did as a class mimics what the Viking landers did on Mars in 1976. Each lander contained equipment to scoop up some Martian soil, then perform tests for life on the soil. Among the tests was one that added a warm nutrient solution to the soil and then studied the amount and rate at which any gases were produced, very similar to the type of experiment students just discussed.

    In that experiment, rapid and extensive reactions were observed. At first, scientists thought they had detected signs of life on Mars. But later analysis showed that simple chemical reactions between the water, nutrients and the Martial soil could have produced the same results.

If desired, pass out the graphs of the Viking experiments and a control (or use overhead projection - Viking graphs are given below for reference and in an appendix to this activity for overhead projection or handout reproduction). Explain that when Viking scientists plotted the rate of gas produced in the experiment versus time, the resulting plot looked very much like the graph students just drew for a soil sample with a chemical reaction (soil sample #2), not a living organism. The control experiment done on Earth prior to launch produced a graph that looks very much like the graph students just drew for a soil sample with a biological reaction (soil sample #3).

If asked, explain that the warm nutrient solution used in Viking contained radiolabeled carbohydrates and if there were any "hungry" bacteria on Mars, scientists hoped they would "eat" the radiolabeled carbohydrates and then emit radiolabeled $C0_2$ gas. Radiation detectors monitored the gas in the chamber for signs of this radioactive exchange. As more gas was produced, the radioactive "count" increased (it is this data which Viking scientists plotted on their graphs).

Figure 1: Pre-launch control experiment with Viking "sister" instrumentation with microbe-rich soil from California:

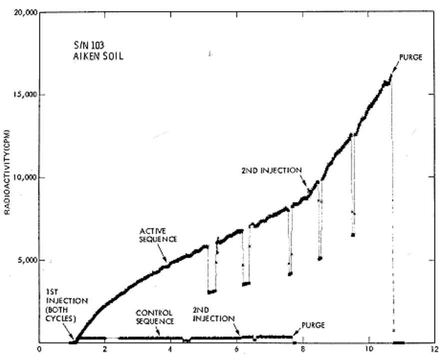


Fig. 1. Test of viable terrestrial soil in LR flight-type instrument under simulated Mars conditions.

Figure 2: First injection results from Viking Lander 1:

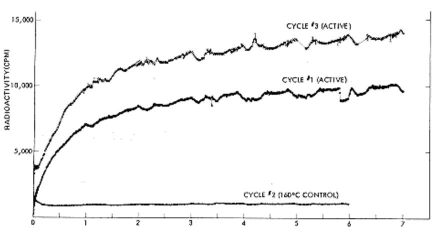


Fig. 3. Viking 1 LR data.

Figure 3: First injection results from Viking Lander 2:

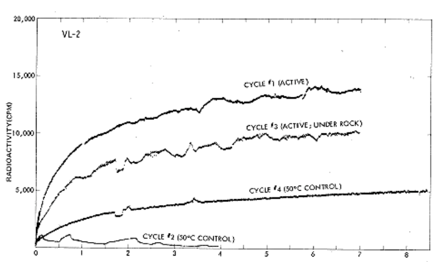


Fig. 4. Viking 2 LR data.

19. Point out that other tests performed by the Viking landers indicated that life was not present.

- Other tests of the Martian soil showed they contained no organic (carbon-containing/biological) compounds.
- Tests of the Martian atmosphere showed no compounds, such as oxygen or methane (both produced by life on Earth) that would indicate the presence of life.
- The cameras showed no movement of living things or other signs of life (no Martians moved in front of the lenses of the cameras on the Viking landers, nor did they see any signs of plant life).

20. Ask students if they think the Viking experiments indicated that life exists on Mars. (*Answers will vary. Accept any answer that is logical and based on the evidence.*) Point out that scientists can find nonbiological explanations for all the biology experiment results. It is also possible, although not considered likely, that some kind of contamination brought from Earth on the landers influenced the results. Proof of life requires unequivocal evidence of life, and Viking's results were not unequivocal.

21. Ask students if they can think of reasons why Viking might have failed to detect life if life does actually exist there. Steer discussion to the following points:

- Perhaps Viking's landers landed in lifeless areas. Only a tiny part of the Martian surface was tested. Point out, however, that it is difficult to find places on Earth completely devoid of life.

- Perhaps life does not exist in the surface soils of Mars, but does exist deeper underground where conditions are more favorable for it, or in the ices of the polar ice caps. Viking could only sample the surface soils, not dig deeper underground. The Viking landers did not land near Mars' polar ice caps.

- Viking's experiments were conducted before scientists knew about extremophiles here on Earth, for example those that live deep underground or in ice. The scientists who designed Viking's experiments assumed any life would be similar to that found in moderate conditions on Earth and designed their experiments to look for such life. They did the best they could with what they knew at the time. We now know, however, that the Viking mission relied on information and assumptions about the conditions and characteristics of life that were limited.

22. Point out that Earthly extremophiles have changed scientists' ideas of the conditions in which life can survive. This means there may be a lot more places on other planets and moons where life could exist. Scientists are now conducting a more detailed survey of Mars and other solar system objects, trying to identify all possible places where life might exist. First, they need to identify places likely to have life, then, future missions can land in these places and sample soil or drill into the ground or ice as they search for life. Scientists now know that understanding biology alone is not enough. They have to also understand the physical and environmental conditions on other planets and moons if they are to look for evidence of life elsewhere. The search for life elsewhere depends on increasing both our knowledge of biology (the origin and present diversity of life here on Earth) and our knowledge of the conditions on other planets and moons (in our Solar System and potentially beyond).

    Point out that there is still a lot that scientists are trying to understand – how extremophiles survive and how they came to be where they are; how life started on Earth; how life has changed the Earth's environment and vice versa; whether life has evolved anywhere else than Earth; and how you would detect it. Astrobiology is the science addressing all these questions, and the work is ongoing.

23. Have students write a lab report on the experiment done in class. The report should include the hypothesis that was tested, the experimental design, the data collected, interpretations and conclusions, and what a next step might be.

24. If desired, as homework, have students draw a concept map based on the word "Astrobiology." The concept map will draw on ideas presented in all three activities. Prompt students with the questions: What is astrobiology? What is life? Where do astrobiologists look for life? Why? Concepts that should be mentioned are:
    Life
    Origin

Characteristics of life (include list)
Conditions of life
Extremophiles (include examples)
Places to look for life
Mars
Viking
Europa
(extra point if they include Titan and why it's interesting to astrobiologists)

Additional information on concept maps can be found at:
http://www.graphic.org/concept.html
http://classes.aces.uiuc.edu/ACES100/Mind/CMap.html
http://www.cast.org/ncac/ConceptMaps1669.cfm
http://www.udel.edu/chem/white/teaching/ConceptMap.html

OPTIONAL EXTENSION: If you conducted all three activities, you can have students write an essay explaining how scientists are looking for life on Mars or other solar system objects. Topics included in the essay should include: determine a place likely to have life based in part on our understanding of extremophiles and the conditions in which they can survive and on the geology of that solar system object; design a mission to go there, sample soil or drill into the ground or ice; perform experiments on the soil or drilled sample; make sure any reactions observed are not just chemical reactions, but are indeed due to living organisms (for example, look at the rate at which carbon dioxide gas is produced, not just that it is produced); combine all observations, not just the results of biological experiments, into a conclusion of whether or not life has been detected on that solar system object.

APPENDIX: Viking graphs:

FIGURE 1:

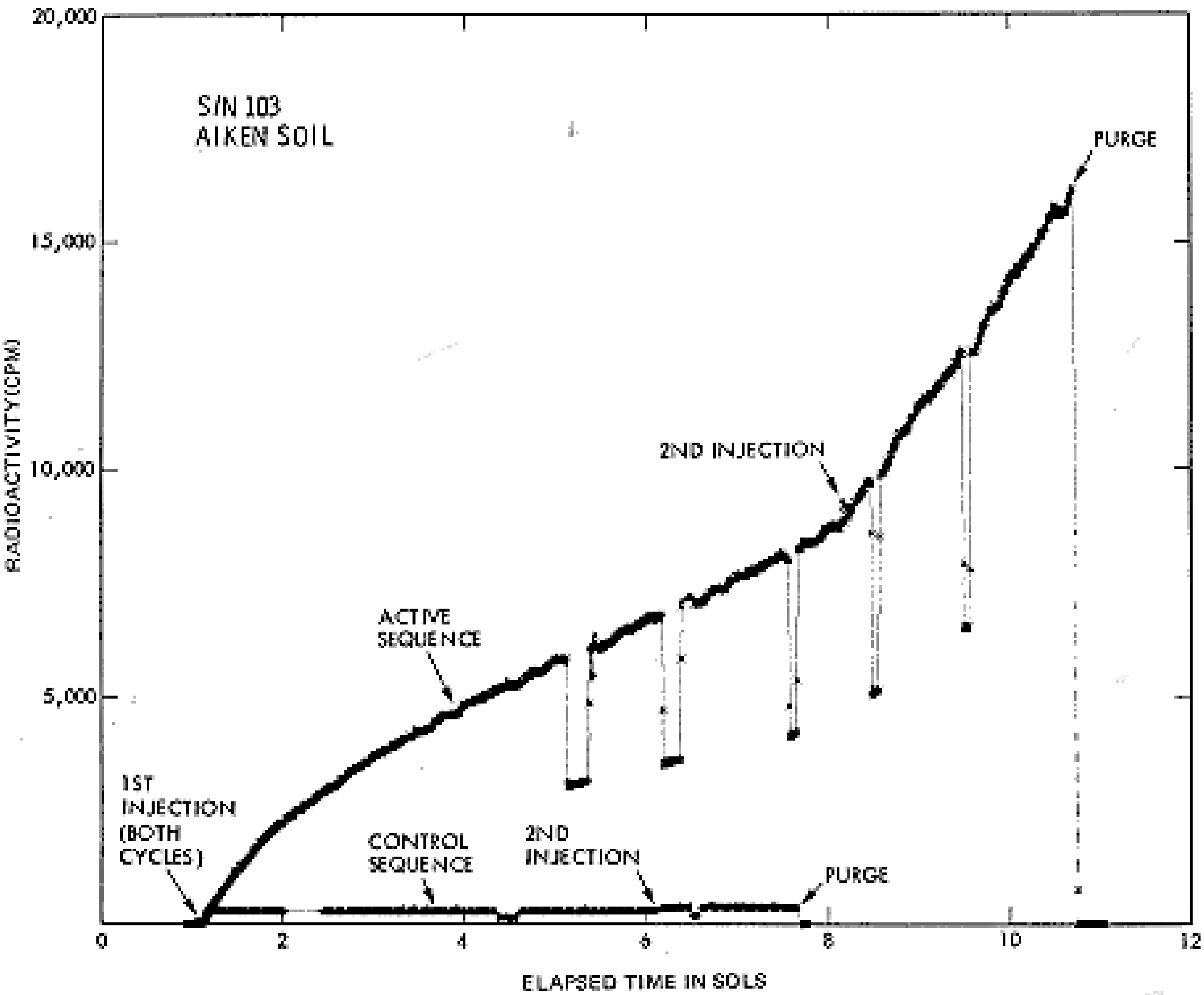


Fig. 1. Test of viable terrestrial soil in LR flight-type instrument under simulated Mars conditions.

FIGURE 2:

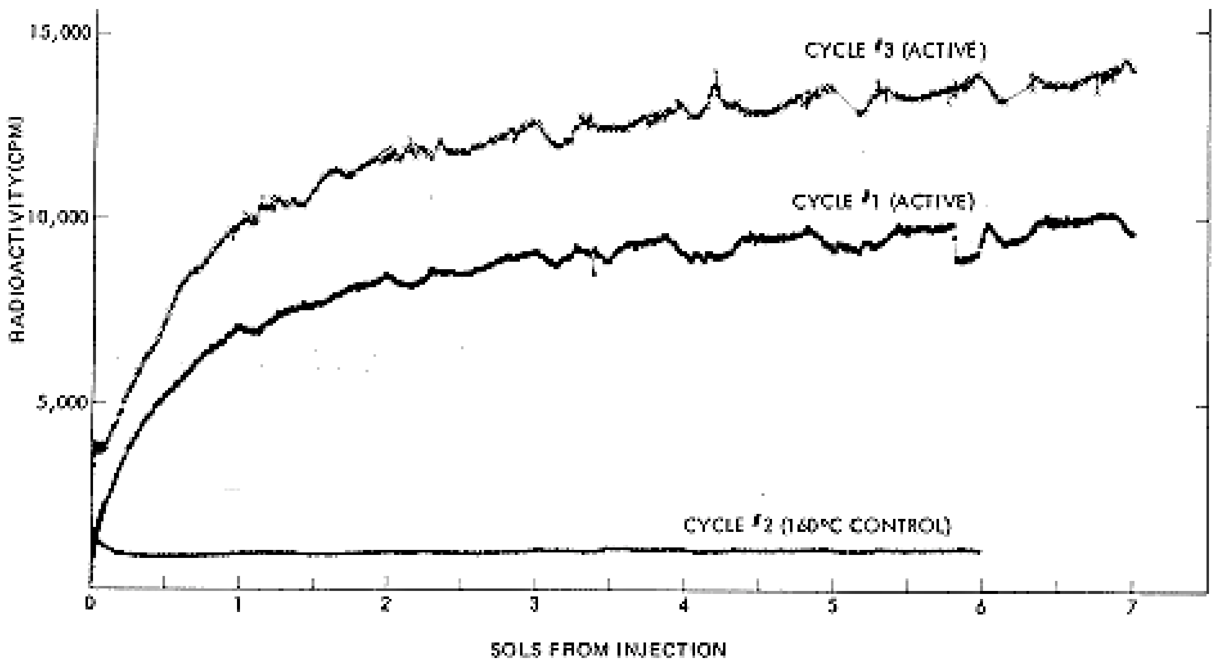


Fig. 3. Viking 1 LR data.

FIGURE 3:

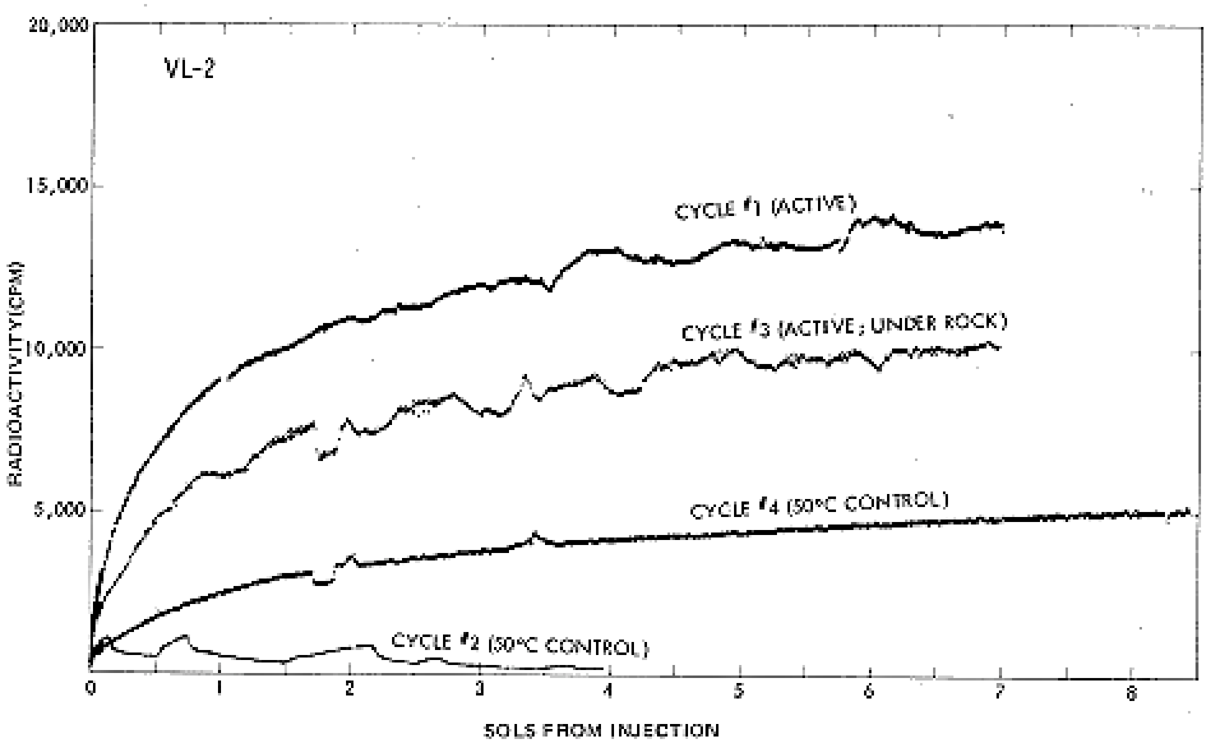


Fig. 4. Viking 2 LR data.