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Zapping Mars Rocks with Gamma Rays

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Because we do not know what deadly microorganisms might be lurking inside samples returned from Mars, the samples will either have to be sterilized before release or kept in isolation until biological studies declare them safe. One way to execute microorganisms is with radiation, such as gamma rays. Although quite effective in snuffing out bacteria and viruses, gamma rays might also affect the mineralogical, chemical, and isotopic compositions of the zapped rocks and soils. Carl Allen (Lockheed Martin Space Operations, Houston) and a team of 18 other analysts tested the effect of gamma rays on rock and mineral samples like those we expect on Mars. Except for some darkening of some minerals, high doses of gamma rays had no significant effect on the rocks, making gamma radiation a feasible option for sterilizing samples returned from Mars.

Reference:

Allen, Carlton C. and 18 others, 1999, Effects of sterilizing doses of gamma radiation on Mars analog rocks and minerals. *Journal of Geophysical Research,* v. 104, p. 27,043-27,066.

The Possibility of Tiny, Hostile Extraterrestrials

The *Andromeda Strain* by Michael Crichton is a scary and, some people fear, realistic story about a dangerous disease that fell to Earth from a satellite in space. If life exists on Mars, the samples we expect to return during the next decade might be teeming with microorganisms, some of which might be out to get us here on Earth. Although we have samples of Mars already (Martian meteorites) with no apparent ill effects, the fear and the possibility are still there, so the samples will be treated as if they were biohazards. The Space Studies Board, an arm of the National Academy of Sciences, studied the issue and stated in a report that,

> "Controlled distribution of unsterilized materials from Mars should occur only if rigorous analyses determine that the materials do not constitute a biological hazard. If any portion of the sample is removed from containment prior to completion of these analyses it should first be sterilized."

The trouble with biohazards is that they have to be studied inside a containment facility that ensures that the organisms cannot escape into the surrounding environment. This means that all studies of the non-biological nature of the samples will have to wait until the samples are deemed safe by a team of biologists, take place inside the containment facility, or use sterilized samples.

Waiting would be torture for scientists who have waited for years to study samples returned from Mars, and would deprive the public of the excitement of their discoveries. Doing all the work inside the special laboratory would limit the number of scientists involved to a small, elite (and possibly elitist) group. The samples should be studied by the best scientists with the best equipment all over the world. Besides, some equipment is too large to be housed inside the containment facility.

Sterilization of part of each sample is an interesting alternative, but it needs to be done without changing the nature of the samples. Dry or steam heating the samples can alter the structures of some minerals and result in loss of Martian gases. Exposure to ultraviolet light or plasmas would sterilize only the surfaces of the samples, leaving the interiors potentially crawling with Andromeda-strain-like organisms. Gamma rays might do the trick with minimal damage, but no studies have been done until now.

Effectiveness of Gamma Rays as Germ Killers

Radiation causes ionization inside tissues, which damages cells, including their DNA. A common measure of the amount of radiation is the rad (radiation absorbed dose). One rad is the amount of radiation delivered by about ten chest x-rays.

Studies have shown that some bacteria are more resistant to radiation than others. The record holder for radiation resistance is *deinococcus radiodurans,* which requires more than one million rads to decrease its concentration in a culture to 0.1% of its starting value. Increasing the dose by a factor of ten increases the effectiveness by about a factor of 8000. Common bacteria, such as *Escherichia coli,* require about 100,000 rads to knock off. Viruses are rendered inactive by about a million rads. Even the feared *Ebola, Lassa,* and *Marburg* viruses are deactivated with 700,000 rads. So, assuming Martian organisms have the same resistance to gamma radiation, doses of a million or more rads should sterilize a sample, though caution might call for much larger doses, perhaps 10 million rads.

The Experiments

Carl Allen

To cover the range in which bacteria and viruses are killed, Carl Allen zapped samples with four different levels of radiation: 300,000 rads, 3,000,000 rads, 30,000,000 rads, and 100,000,000 rads. He used the High Dose Research Irradiator at the Centers for Disease Control and Prevention (located in Atlanta). This is a six-foot tall box lined with lead (see photo on **left**). Allen used the radioactive isotope cobalt-60 to supply gamma rays, which produced 31,500 rads per minute. (Lucky that box is lined with lead!) Samples were exposed inside the chamber for as short as 9 minutes to as long as 53 hours.

The samples used in the experiments represented a variety of geological materials expected to be found on Mars: rock (basalt, carbonaceous chondrite, chert), minerals (quartz, feldspar, olivine, pyroxene, clay minerals, halite, aragonite, gypsum), and a simulated Mars soil. Both before and after irradiation, these materials were analyzed by numerous techniques. These measured chemical compositions, the atomic structures of the minerals, and optical properties. The techniques and results are briefly outlined below. (Allen's team did not study the effect of gamma rays on organic compounds or on bacteria in their samples. However, such studies would be done on non-sterilized Martian samples inside the containment laboratory as part of the biological assessment.)

- **Gamma ray spectroscopy:**
  This technique searched for radioactivity induced by the gamma rays. Radioactivity levels were the same before and after the samples were irradiated.

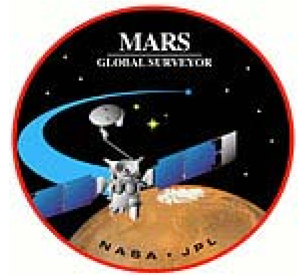
- **Isotopic analysis and age dating:**
  Age dating is a crucial geological measurement, but it requires that processes other than radioactive decay do not affect the abundances of the isotopes. Rubidium and strontium are crucial elements for dating old rocks, so the team tested the effect of gamma rays on rubidium and strontium isotopes. Analysis of the basalt sample indicated that these isotopes were not affected by the irradiation.

- **Instrumental neutron activiation analysis:**
  This is a well established technique for measuring the abundances of both major (abundant) and trace elements in rocks and minerals. In this method, samples are exposed to radiation in the form of neutrons. The neutrons cause numerous isotopic changes and the formation of short-lived radioactive isotopes. These decay and emit gamma rays, which are counted. Comparison to a rock of known composition establishes the composition of the sample. The gamma rays used for sterilization might interfere by making some elements radioactive before the neutron irradiation. Fortunately, neutron activation analysis of the basalt and simulated Martian soil showed that there was no effect from the gamma irradiation. The concentrations of twenty-seven elements were the same within analytical uncertainty before and after irradiation.

- **Inductively Coupled Plasma Emission Spectrometry:**
  In this analytical method samples are dissolved in solutions and aspirated into a plasma (a cloud of hot, ionized gases) to determine their concentrations. This excites the atoms in the samples, and the atoms emit light when they return to their initial state. The light is characteristic of each element and the amount of light is measured with a special detector. The analyses were not affected by the gamma irradiation: all elements fell within experimental uncertainty of their pre-irradiation values.

- **X-ray diffraction:**
  This is a classic technique to characterize the crystal structure of a mineral. It uses the fact that x-rays bounce off planes of atoms inside a crystal. By varying the angle between the sample and a x-ray detector, peaks in x-ray intensity occur. The peaks correspond to the spacing between planes of atoms in the crystal. The minerals were not affected by the gamma irradiation. No new x-ray peaks were observed and the observed peaks were in their correct positions.

- **Thermal emission spectroscopy:**
  Minerals emit radiation in the infrared, with characteristic peaks and valleys on plots of emission intensity versus wavelength. This is a useful technique that can identify minerals and estimate some physical properties such as grain size, although it is not routinely used in the laboratory to characterize rocks. Its main use is in remote sensing. In fact, a thermal emission spectrometer is onboard the Mars Global Surveyor spacecraft, trying to determine the mineralogy of the Martian surface. The minerals tested showed no difference in the positions of the peaks and valleys between the irradiated and unirradiated samples, except for halite (sodium chloride). The halite sample used contains tiny inclusions of other minerals, and variations in the abundance of these might cause the small differences observed. The authors conclude that the differences are so small that they would not prevent identification of halite in irradiated samples.



Right: The Mars Global Surveyor spacecraft is mapping the surface of Mars. The instrument payload includes a thermal emission spectrometer, built by a team headed by Phil Christensen at Arizona State University.

- **Raman spectroscopy:**
  This is an analytical technique for identifying molecules in gases, liquids, and solids. It involves the scattering of laser light. When a laser is shined on a mineral, molecules making up the mineral scatter the light. Most is scattered at the same wavelength (hence the same energy), but some is scattered at a different wavelength. This is called Raman scatter. The energy difference between the incident light and the Raman scattered light is called the Raman shift. Different minerals have characteristic sets of Raman shifts and intensities of the effect, thus allowing identification of a mineral. Allen and coworkers found no differences in the Raman shifts or their intensities between unirradiated and irradiated samples.

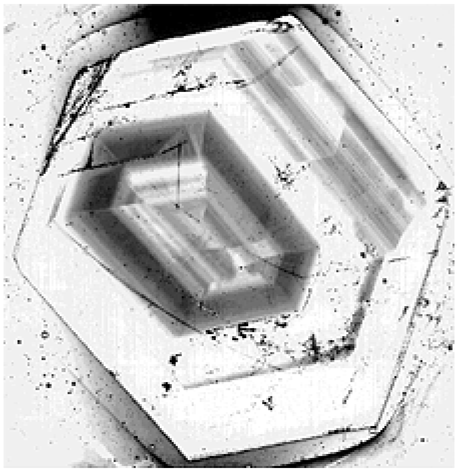
- **Specific surface area:**
  An interesting property of soils is the total surface area of the individual minerals in them, expressed as square meters per gram of soil. This property affects the way fluids and a soil or other particulate materials adsorb gases. Specific surface areas were not affected by the irradiation. For example, the specific surface area of the Mars soil simulant remained about 140 m^2/g, even after irradiation with 30,000,000 rads. (The amazing thing is how large the surface area is of all the small grains in a soil. It is not easy to visualize that a thimble full of soil has a total internal surface area of over 100 square meters.)

- **Fluid inclusions:**
  When a crystal form in the presence of a fluid (gas, liquid, or magma) it may trap some of the fluid as it grows. Study of the trapped fluid sheds light on the environment in which the mineral formed. The analysis involves heating samples to determine the temperature at which gas bubbles appear or dissolve, and at which the inclusion becomes homogeneous. The homogenization temperatures of fluid inclusions in quartz did not change after irradiation, so critical information was not lost.

- **Visible and near infrared reflectance spectroscopy:**
  When light shines on a mineral, light at some wavelengths is absorbed by the mineral while light at other wavelengths is not. This is why minerals have color. The wavelengths at which the light is absorbed is effectively a fingerprint of each mineral, so the technique can be used to identify minerals. This is not commonly used in laboratories to identify minerals, but, like thermal emission spectroscopy, it is used in remote sensing observations of planets. Irradiation with gamma rays greatly affected the color properties of the minerals. The quartz, for example, was initially completely colorless. After exposure to 30,000,000 rads it was so dark that it was almost opaque. The darkening was not uniform throughout the quartz crystals. Instead, it concentrated in bands parallel to crystal faces. There were higher aluminum concentrations in the bands (250 parts per million) compared to the remainder of each crystal (about 100 parts per million), so the amount of darkening depends on the abundances of impurities inside the quartz. The same interaction of radiation with aluminum produces naturally-occurring smoky quartz.

Carl Allen

Left: This quartz crystal was originally clear, but is nearly opapue after being zapped by 30,000,000 rads. Crystal is 2.5 cm across.



Carl Allen

Right: The darkening of the quartz crystals occurs in bands inside the crystal, as shown in this cross section. The dark specs are fluid inclusions. Crystal is 2.5 cm across.

Halite turned blue with irradiation. This is a common effect, and was observed in the purple and blue halite discovered recently in meteorites. [See **PSRD** article, "Purple Salt and Tiny Drops of Water in Meteorites".] On the other hand, carbonate minerals became brighter with irradiation. The positions of the main absorption bands did not change in any of the minerals studied.

- **Thermoluminescence:**
  Light can be emitted from minerals when they are heated. In this case, the investigators heated samples from room temperature to 500 ^{o}C. As the sample is heated at a uniform rate, the amount of light emitted increases to a maximum value, then begins to decline. The temperature of the maximum emission provides information about the structural state of a mineral. After samples are heated, they are given a dose of radiation from strontium-90, and measured again. The amount of light emitted at the peak temperature is compared to the initial amount. This parameter is called thermoluminescence sensitivity. Quartz and feldspar showed significant changes in thermoluminescence sensitivity with increasing dose of radiation, but not in the peak temperature. Other minerals were not significantly affected by the gamma irradiation.

What It Means for Martian Samples

NASA is planning two sample-return missions to Mars during the next ten years. The returned samples will contain cores and soil collected by a rover, as well as core material collected by a drill on the lander. The goals of the missions are to search for evidence that the conditions for life existed on Mars (especially standing water), the raw ingredients for life (organic compounds), and for evidence for life (fossils, diagnostic organic compounds, minerals produced by organisms). Sample return mission will also provide rocks and soil for inorganic analysis. Landing sites will be chosen to maximize the chances for finding life and studying the history of the Martian climate.

NASA

Rocks and soil, like those at the Pathfinder landing site shown **above**, will be collected by future sample-return missions to Mars. Some might harbor microscopic organisms. These will be of intense scientific interest, but there is a small chance that they could threaten life on Earth if released into the terrestrial environment.

The samples will be studied in a special biological laboratory to search for Martian organisms. This will take months. However, some samples could be released soon after return to Earth for non-biological studies if the samples were sterilized. Carl Allen and his colleagues have shown that very high doses of gamma radiation, known to be quite effective at snuffing out terrestrial bacteria and viruses, will not harm most of the studies planned for the returned samples. If biologists conclude that gamma radiation is a safe way to sterilize Martian samples, then work on the chemical and mineralogical compositions and ages of the samples could begin within weeks after the samples were returned to earth. Allen notes that their studies were done with cobalt-60. Radioactive elements that emit gamma rays with much higher energy than those spewed out by cobalt-60 might cause more alteration than they observed in their experiments. Thus, their conclusions apply only to radiation like that emitted from cobalt-60. Fortunately, sterilization using cobalt-60 is a standard practice. Gamma sterilizers are available commercially and are a proven technology.

Additional Resources

Allen, Carlton C. and 18 others, 1999, Effects of sterilizing doses of gamma radiation on Mars analog rocks and minerals. *Journal of Geophysical Research,* v. 104, p. 27,043-27,066.

Athena (Mars Rover) homepage at Cornell University.

Space Studies Board, 1997, *Mars Sample Return Issues and Recommendations,* National Research Council, Washington, DC. on-line from the National Academy of Sciences.

Thermal Emission Spectrometer on Mars Global Surveyor: homepage at Arizona State University.

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