

Nutrition and Related Studies in the Office of Space Science and Applications, NASA

DALE W. JENKINS
Chief, Environmental Biology Program
Office of Space Science
and Applications, NASA

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The Bioscience Programs Division of the Office of Space Science and Applications, NASA, sponsors basic research in areas having a potential for application or development of systems for use in the space program.

BIOREGENERATIVE LIFE SUPPORT SYSTEMS

Bioregenerative life support systems will be required in future extended manned scientific missions in space. Storage-type systems would impose penalties in weight and space that would not be feasible for voyages lasting months or years.

Looking to the future, the Office of Space Science and Applications has supported limited biological research on gas exchangers involving both photosynthetic and nonphotosynthetic

systems and on bioregenerative management of wastes, including water.

A scientific breakthrough has occurred in the development of a biological regenerative system by the Martin Marietta Company. In this system the electrolysis of water (splitting water into hydrogen and oxygen by electricity) is used with *Hydrogenomonas* (soil bacteria) shown in figure 1, which combines the hydrogen with the carbon of carbon dioxide from the astronaut. (See fig. 2.) This method requires, on a batch basis, only 10 percent of the electric power and from 10 to 20 percent of the volume and weight of the best thermophilic algal (*Chlorella*) gas exchanger system. Optimal concentrations of oxygen and nitrogen, tem-

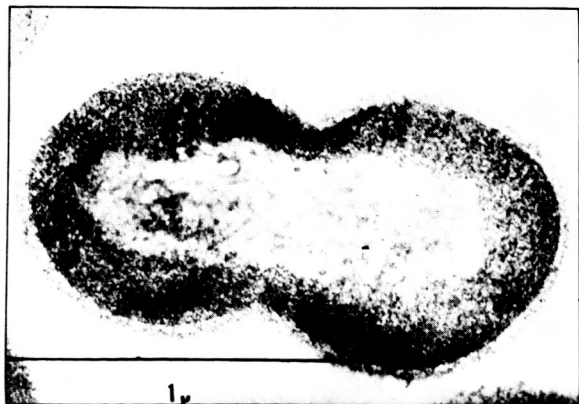


FIGURE 1.—Electron microscope picture of *hydrogenomonas* bacteria.

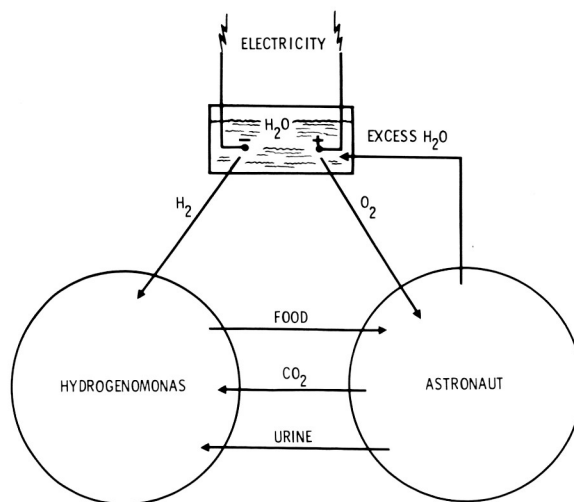


FIGURE 2.—Electrolysis *hydrogenomonas* bacterial bioregenerative system.

perature, and other growth conditions have been established. Special studies were carried out on formation of fat inclusions in the bacteria due to gas limitations.

A continuous culture turbidostat apparatus has been designed and built by the Battelle Memorial Institute. The electrolysis unit feeds hydrogen alternately with oxygen into the bacterial substrate. The system is nearly all automatic but is flexible to allow experimentation.

Mississippi State University is studying the long-term culture methods and possible accumulation of toxic materials. The Magna Corporation is carrying out research on utilization of urine in culture medium.

The rate of progress has been rapid, and the culture methods used for other bacteria in mass culture have been utilized. The electrolysis system developed for other programs has been used effectively. The main problems include change from autotrophic to heterotrophic growth and the presence of a phage which attacks the *Hydrogenomonas* bacteria. These problems are being studied intensively. Quantities of the bacteria are being fed to animals and human volunteers.

At Colorado State University the responses of plants to high-energy radiation (ultraviolet to infrared) are being studied. Plants from high mountain tops normally exposed to higher intensities of ultraviolet light and the effect of temperature on photosynthesis are being studied. Corn, beans, and tomato plants are being grown under germ-free conditions.

Screening of various higher plants for use in bioregenerative systems at Connecticut Agriculture Experiment Station resulted in selection of corn, sugar cane, and sunflower for possible use in bioregenerative systems. Optimal conditions have been established and the amount of leaf surface required to support an astronaut has been shown to be from 100 to 130 square feet of leaf surface.

A recyclostat has been developed, under a NASA grant, by the University of Maryland for continuous culture of *Chlorella* algae. This apparatus is completely automatic and conserves

and recycles all water, adds nutrient, and removes excess algal cells. This grant is primarily responsible for basic physiological studies on algae and for determination of optimum algal growth conditions.

The photosynthetic process in plants is being studied intensively by the Research Institute for Advanced Studies of the Martin Company. The respiration process has been studied during photosynthesis and several metabolic pathways have been elucidated. Mechanisms are being studied to explain the inhibitory effects of strong visible light on this process. This program may lead to the use of chloroplasts or chlorophyll without cells in future photosynthetic bioregenerative systems for long-term space travel.

REDUCTION OF METABOLISM

A research program in the Office of Space Science and Applications is being undertaken as a long-range objective for reduction of metabolism in astronauts for long-term manned space flight, such as a Mars mission in the 1980's. The reduction of human metabolic rate may be accomplished by reduction of temperature or artificial hibernation, response to hot dry conditions or artificial aestivation, and depression of metabolism by various pharmaceutical drugs. Reduction of metabolism would result in lowered requirements for food, water, and oxygen, and would produce less carbon dioxide, urine, and waste. It is assumed that the astronaut could be aroused following a long flight and would be active during planetary landing and exploration.

The present state of the art with regard to lowered temperature to produce lowered metabolism is not well advanced. While some human beings have been exposed or subjected to decreased temperature for relatively short periods without serious problems, no long-term sleep or hibernation has been induced. A major problem encountered with humans and primates when subjected to severe cold is ventricular fibrillation, which may result in death. Much research is required to understand this well enough to develop potential use of induced hibernation.

Even less is known of the mechanisms involved in aestivation.

NASA presently supports a modest research program of hypothermia, hibernation, and aestivation with the objective of inducing decreased metabolism in humans.

LOSS OF SKELETAL CALCIUM

When man lives under weightlessness conditions, loss of muscle tone and mass, as well as loss of calcium from the skeleton, is expected. During periods of bed rest, patients lose rather large quantities of bone mineral.

A bone X-ray densitometry method (fig. 3) has been developed by Texas Woman's University for accurately determining the loss of bone mineral (± 2 percent accuracy) in humans and animals. The heel bone and spine are X-rayed using a calibrated aluminum wedge for a base-line comparison. It has been recommended that the bone X-ray densitometry method be used on astronauts before and after flights in the Gemini and Apollo programs.

Bed rest and immobilization studies at Texas Woman's University have shown loss of skeletal mineral and increased loss of calcium in the urine and excreta. Four bed-rest studies, each

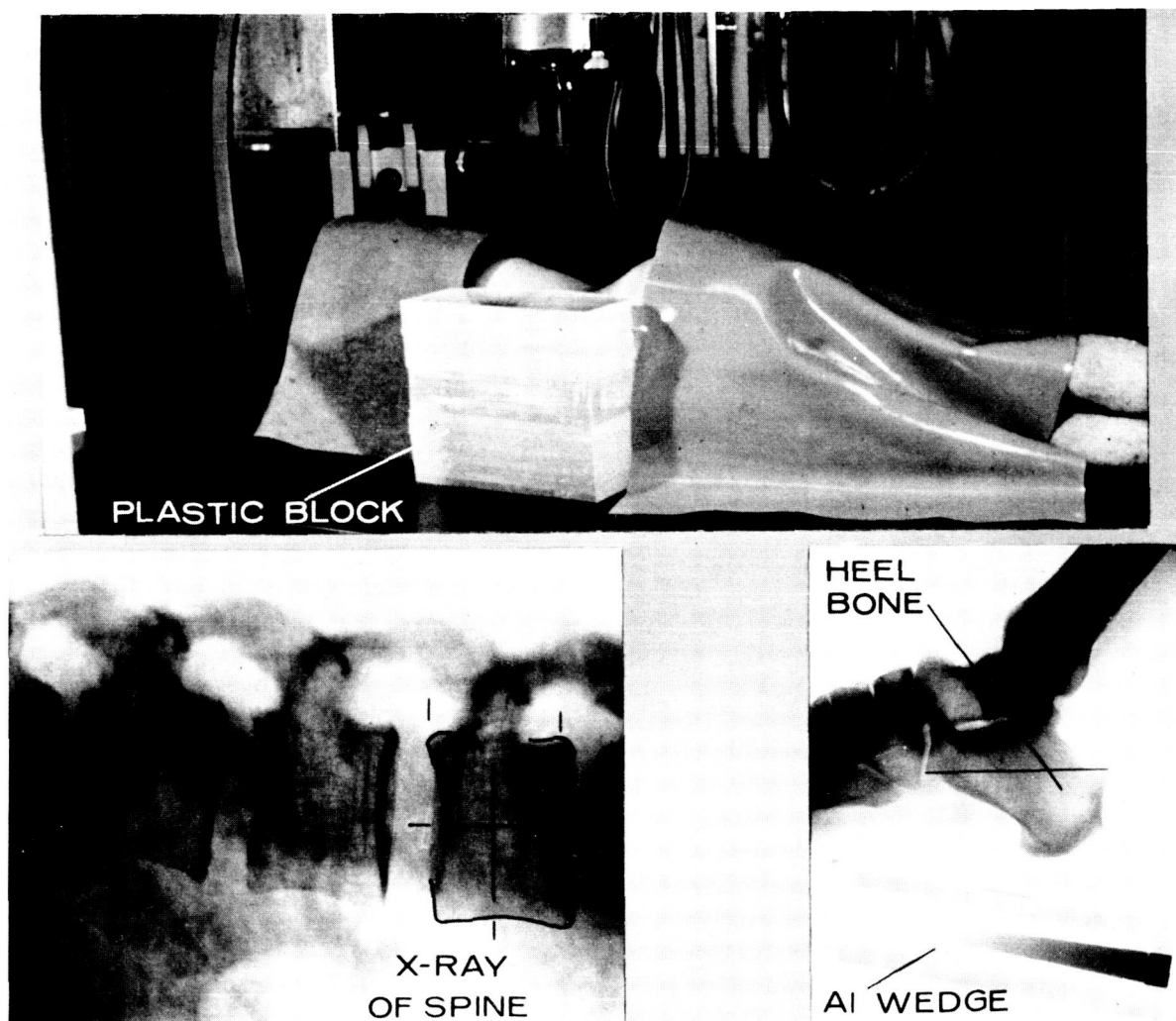


FIGURE 3.—Bone X-ray densitometry studies relating to calcium loss with weightlessness.

extending for 2 weeks, were carried out comparing different levels of calcium intake. Four men were used in each study and the men served as their own controls during extended ambulatory periods. During 2-week periods, up to 10 percent of calcium mineral was lost from the heel bone (fig. 4). The calcium loss was also determined in the urine and feces. In other studies, isometric exercises have helped prevent some loss during bed rest.

Studies are planned at the Harvard School of Public Health to determine the results of feeding fluorine to animals, preliminary to feeding human volunteers during bed rest simulating weightlessness. It is possible that fluorine may prevent the loss of calcium or decrease the rate of loss.

CHEMICALLY DEFINED SYNTHETIC DIET

A chemically defined synthetic diet for humans has been compounded by Dr. Milton Winitz, formerly with the Medical Sciences Research Foundation. The complete liquid diet is composed of required amino acids, fat, carbohydrate, vitamins, and minerals. A cubic foot of the diet (in 50 percent H_2O) supplies 2500 calories per day for 1 month, and has been flavored with a variety of artificial flavors.

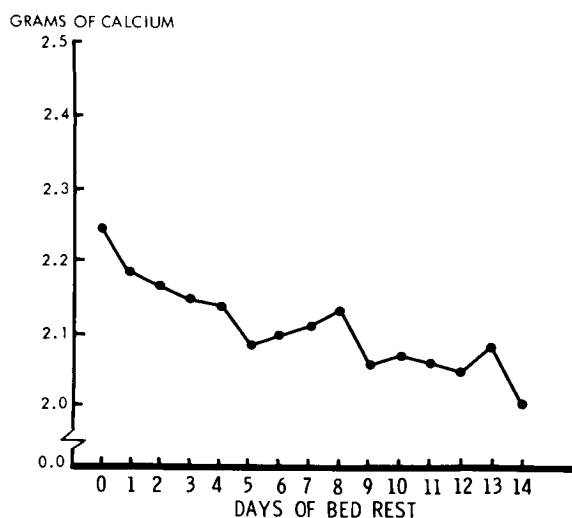


FIGURE 4.—Loss of skeletal calcium from heel bone during bed rest.

The synthetic diet has been fed in a pilot study to human volunteers at the California Medical Facility by the Medical Sciences Research Foundation for a 6-month period, and the results are now being reviewed. The feeding has been completed but analyses of specimens and data interpretation must be completed before determination of what future research is required. It is expected that the Space Science Board, Life Sciences Committee, will be consulted in this connection.

Schwarz Bioresearch, Inc., is carrying out studies on the storage, stability, and packaging of chemically defined synthetic diets for human and animal flights.

STUDIES WITH ARTIFICIAL ATMOSPHERES

Animal growth and development have been studied in atmospheres almost devoid of nitrogen, atmospheres composed of oxygen under a reduced pressure, or of helium and oxygen mixtures at 1 atmosphere. These studies at Ohio State University indicated a deleterious effect of low nitrogen which may mean that nitrogen is necessary for normal adult life.

Continuous exposure of rats at Oklahoma City University to 100 percent oxygen for 25 days at a simulated altitude of 26 000 feet resulted in a 10-percent decrease in total metabolism. Using the radioisotope carbon technique, there was a significant reduction of lipid metabolism in the liver, but no decrease in heart metabolism. Exposure to 80-percent argon and 20-percent nitrogen at sea-level air pressure resulted in slight slowing of metabolism with an increase of two to three times in the amount of fat deposition.

Studies on the ability of test-subject men to exercise at levels beyond which they are able to supply oxygen are being carried out at Indiana University. Men on a treadmill accumulated an oxygen debt in 3 minutes and could continue 8 minutes; however, in this study the debt did not continue for 15 to 40 minutes after stopping exercise as reported in another laboratory. Arterial and venous blood was sampled continuously during exercise by use of catheters.

EFFECTS OF SPACE ENVIRONMENTAL FACTORS

Research in the Bioscience Programs Office includes basic biological studies to determine the effects of space environmental factors on living organisms, and basic research related to manned space flight.

A Biosatellite Program is being carried out to study the effects of unique space environmental factors. The Biosatellite spacecraft will be recoverable, and the first of a series of six flights will be in mid-1966.

Twenty experiments have been selected for flight from 175 submitted by the scientific community to study the effects of weightlessness and decreased gravity at the cellular, organ, and

organism levels from 3- to 30-day orbital periods. The experiments include a wide variety of plants and animals from single-celled organisms to higher plant and animals, including primates.

Experiments have been selected to study the effects of weightlessness combined with a known source of radiation to determine if there are any antagonistic or synergistic genetic or somatic effects on various organisms. Experiments are included to study the effects of the unique environment of the Earth-orbiting satellite and removal from the Earth's rotation in relation to biological rhythms of plants and animals. Various animals will be fed different diets and the effects of space flight factors on digestion and metabolism will be assessed.