THE SPACE ENVIRONMENT IN BIOLOGICAL PERSPECTIVE

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The space environment as it relates to biology is a subject which has endless ramifications, but one subject stands out above all the others: it is exobiology, the pursuit of which is our major scientific objective in space exploration.

Our galaxy quite likely was formed from a hydrogenous gas some billions of years ago, and, in time, synthesis of isotopes in the stars brought about the cosmic abundances of the elements. It was probably during this period that coalescence of cosmic elements in cooler regions, such as the Earth, led to the formation of molecules from which life has evolved in a kind of secular equilibrium with the environment. Whether Mars and Venus and other celestial bodies were conducive to the formation of life as they cooled and, if so, what the nature of that life might be, is one of the most complex riddles with which we are confronted as we enter the space arena.

The other field that concerns us in this presentation is environmental biology. It has two aspects. One is the role that environmental inputs play in the establishment and maintenance of life organization and life processes -- in such fields, for

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example, as biological rhythmicity -- and the other is the delineation of those aspects in the space environmenta which are biologically hostile. This is a field interlocking with biotechnology, which is concerned in the monumental task of putting man into space and providing him with conditions under which he can function normally.

Of the greatest import from the standpoint of space travel and extraterrestrial habitation is the delineation of those environmental conditions under which the normal passes into the pathological. This is a field in which the Armed Forces Institute of Pathology has distinguished itself from its inception a century ago, and for this reason, if for none other, is richly deserving of our accolade on this occasion.

Now, this is a vast subject which Dr. Townsend has most generously invited me to discuss. I shall try to bring out some of the highlights.

The Moon, Venus and Mars are our first targets. Mercury does not come into consideration biologically because it has no atmosphere and because its temperature range is extreme: 340°C on the side facing the Sun and close to absolute zero on its dark side. The planets beyond Mars are too cold, excepting, possibly, Jupiter, which may have retained heat because of its great size.

From the exobiological standpoint, we cannot by-pass the Moon. Because of the lack of an oxydizing atmosphere, any material from space that may have impacted the Moon over the millions of years will probably have been preserved. The Moon may thus be a laboratory of organic evolution. It may also be a museum of fossil extinct life.

Venus is so heavily covered by a dense cloud that its surface has never been clearly seen. According to some astronomers, the surface of Venus is covered by a vast ocean, and according to others it may not even contain any surface water.

As deduced from the radio emission from the planet in the microwave region, Venus has a temperature of at least 300°C, but this may be an incorrect figure because of the possibility that the microwave radiation was not generated thermally, but was due to electrical excitation in Venus's ionosphere. As far as is known, Venus is not hospitable to life.

This brings us to Mars. Life forms there would have to cope with an atmosphere consisting mostly of carbon dioxide; its content is 2 to 13 times greater than that of the Earth's atmosphere. The proportion of water vapor in the Martian atmosphere is 1:200,000, while that in the Earth's atmosphere is around 1:100. If the white polar caps on Mars do consist of water-frost - as Kuiper has contended - this would constitute only one-millionth of the water ~~content in~~ found on the Earth's ~~atmosphere~~ surface. Because of the ~~vertical~~ virtual absence of an atmospheric shield in the form of oxygen or ozone, UV light on the surface of Mars is probably intense. In regard to the seasonal color changes on Mars, the prevailing theory, as based on infrared spectral absorption, is that they represent variations in the growth of vegetation. The odd thing about this color change - which consists in a progressive darkening - is that it begins at the edge of the polar caps and extends toward the equator as the season advances. This is the reverse of what is true on our planet.

I shall not go into the pros and cons of whether life exists on Mars, but try, rather, to describe some experimental approaches to the problem under conditions that may have prevailed on the primitive Earth or on some other planet.

One of the most brilliant discoveries in this connection, by Miller and Urey some years ago, was that ~~some~~ amino acids could readily be produced by sending an electrical discharge into a reducing atmosphere consisting in methane, ammonia, carbon dioxide and nitrogen together with some water. And since then it has been learned that this same reaction can be produced through the use of many other forms of energy, such as UV light, ionizing radiation, microwave, or even heat. Other biologically significant compounds (e.g., purines, pyrimidines, and fatty acids) have also been produced under these conditions, though in smaller amounts.

Such a reaction, then, may have been a starting point of biochemical evolution on the primitive Earth. It is not too great a jump to the concept that biochemical evolution will occur wherever there is a physico-chemical environment resembling that of the primitive Earth.

We can be sure that life originated not simply as an unbroken chain of successively more complicat4d molecules, but, rather, as a balance between construction and degradation. The question of life on Mars goes beyond a mere quest of the primordial raw materials and energy sources. Involved heavily in it is the problem of how nature can evolve a genetic mechanism that is stable in a more damaging environment.

There have been many suggestions as to forms of life that should first be sought on Mars by devices landing on the Martian surface. Some of the most logical substances to look for are organic phosphorus compounds, porphyrins, and ~~amino~~ amino-nitrogen. ~~Promising~~ Possible candidates among the life forms are those that provide for their own organic substances through purely chemical means (heterotrophs); also denitrifying and sulfatizing bacteria, and certain photosynthetic bacteria which give off no oxygen. Search for thermophilic bacteria has also been suggested, as has also search for those life forms resistant to various kinds of radiation, for example, certain pigmented bacteria, which, because of the carotenoids they contain, are resistant to UV radiation. Plants living in dry habitats, fungi, and Actinomyces also need to be taken into account.

In the not too distant future, some OPOs (Orbiting Planetary Observat~~ions~~ories) will be orbiting Mars in order to detect gaseous components in the Martian atmosphere, such as ~~methane~~ ammonia and carbon dioxide, and they will try to get readings through gaps in the Martian blue haze in the 2500 to 2900 Å range in order to specify the ultraviolet environment of any organisms that may exist.

LS #1 & #2

I shall like to show you a device which will be landing on Mars. It is the Gulliver, devised by Levin and Horowitz. Basically, it monitors a metabolic process. Two silicon-impregnated strings are shot out by projectiles for some 50 to 100 ft., then are withdrawn by a motor-driven windlass, bringing about 25 to 50 mg of surface material ~~soil particles~~ with them. ~~Surface samples are~~ The material is thus introduced into a nutrient medium that contains radioactive C^{14}. For ~~these~~ this device to work it is necessary that any organisms present on the Martian surface take up the radioactive carbon and give off CO_2. The tagged CO_2 is collected on a film, and above the film is a solid state radiation detector. The C^{14} in the CO_2 gives off weak beta rays, which are seen by the detector and telemetered back to Earth.

Now let me turn to some problems in environmental biology. In the extraterrestrial environment the greatest concern is that man will be able to function satisfactorily. Man must take much of his terrestrial environment with him for survival. Thermal radiation will present a large engineering problem. The other electromagnetic radiations (UV, X-ray) should be easier to cope with than thermal radiation. The energetic particle radiations - trapped, solar and cosmic - present difficult problems. Not only do we not know how to deal with them; we do not even know what they may do to us.

Intergalactic space is thought to be filled with a tenuous gas, predominantly hydrogen, of the order of 100 atoms/cm3. While this gas has a very low energy, cosmic rays of similar composition have the highest energies known. A weak magnetic field of the order of 1 gamma pervades the galaxy and may be an important source of energy for accelerating these particles. The energy stored in even a region of galactic dimensions is inadequate to explain the highest energies observed (10^{20}ev), and thus attention is being given presently to supernovae as a source of some of the particles. Galactic cosmic rays seem to be ~~positions~~ portions of stellar atmospheres, accelerated partially during ejection, but mainly by magnetic inhomogeneities in intergalactic space.

More will be known of this vast region before man voyages into it. Of more immediate interest is interplanetary space.

The Sun's magnetic field modulates the cosmic rays in interplanetary space, deflecting only those of lower energy away from the Earth's atmosphere. Over the 11-year cycle of solar activity, the total cosmic ray flux in interplanetary space and near our Earth varies from 2.5 to 5 particles/cm^2/sec. The highly energetic primaries are not deflected, and thus the radiation hazard due to cosmic rays is essentially constant, despite the subtle effects noticed in ~~various~~ the 11-year cycles on the Earth.

LS #3, #4 and #5

Of course, charged particles trapped in Van Allen belts are of great concern, as are also cosmic ray flares from the Sun, but ~~as to the~~ on the problem of the biological effects of ~~their~~ those phenomena we have ~~no~~ little direct specific data. Let me, therefore, indicate some results of recent experiments carried out at ~~in the narrow region at~~ balloon altitudes and in the Earth's orbit.

~~The~~ Balloon flights ~~carried on~~ were carried out by the NASA a few months ago in collaboration with many scientists, including some from the U.S. Air Force and The ~~members of the~~ AFIP ~~staff~~. They were run in Canada for the purpose of studying the effects of cosmic particles on a wide range of biological systems. The balloons were launched from Goose Bay, Labrador. During the flight they maintained an average altitude of approximately 130,000 ft. for some 50 hours. The particle flux at this altitude is indicated

LS #6

In the gelatine emulsions that were carried inside the capsules, counts were made of tracks having $\geq$200 Mev/cm rate of energy loss (i.e., tracks of relativistic carbon and higher Z particles). Preliminary observations have indicated approximately 1500 of these heavy primaries/cm^2 during the flights.

Among the plant materials carried on the flights were the seeds of corn, beans, African daisies, lobelia, and marigold. Control seeds were kept at ground level, and some were exposed to 2300 r of 100 kv x-rays.

Reference will be made only to the effects of the flights on the corn. I am referring to studies of Drs. Slater and Tobias at the University of California in Berkeley, who were participants on these flights.

Slide #7 and #8

Developmental defects appeared in the leaves of the corn as they grew. These consisted in streaking and spot bleaching. The ratio of such defects in the untreated controls, x-irradiated controls and balloon flown corn was 0:1:9. Similar changes have been noted by Dr. Curtis of Brookhaven A.E.C. Laboratory some months ago, in corn carried on a satellite flight, but the incidence was much lower, and such changes have also been observed in the flowers of petunia and other plants as a mutuable condition induced by gamma radiation (Sparrow, 1960).

The reaction of many plant forms to conditions existing in the Earth's orbit has been studied intensively in Cosmic Sputniks. One was Cosmic Sputnik II, which orbited for 25 hours at 306 to 398 km from the Earth. Under these conditions the average primary cosmic-ray flux for protons is 2/cm^2/sec, for alpha particles 0.3/cm^2/sec, and for particles Z $\geq$ 3, 0.03/cm^2/sec;

energy loss by the pr fields

and the average linear ~~loss~~ is 3.5 Mev $cm^{-2} gm^{-1}$.

LS #9

In general, a significant acceleration of the processes of cell division was noted in the sprouts of the maize, pea and wheat seeds. But of especial interest were changes in the development of Actimomyces in cultures. Growth of radioinsensitive strains increased 6--fold as compared with the controls, while the growth of radio-sensitive strains decreased 12-fold. On this same flight the seeds of maize, string beans and wheat (some radiosensitive and others not) were sent aloft, and the experiment consisted in determining the effects on the rate of subsequent root growth. Chromosomal alterations in the anaphase and telephase was frequent. Mitotic index was significantly increased in the corn and string beans, but was decreased in gamma-and-fast-neutron sensitive wheat (6.59 vs 8.02 for the control) (Glembozkei, 1961).

In regard to the corn experiment in the balloons, it should be emphasized that virtually no changes were noted in the control corn following exposure to 2300 r x-radiation. If such results can be confirmed in future balloon flights, we will have an indication of the effects that may be expected on plant life when exposed to the space environment, as on a Moon base. Mutants readily appear following response to gamma radiation, and we shall soon know whether they will appear under high-altitude balloon-flight conditions.

The data of the seed experiments carried aboard the Cosmic Sputniks also indicated striking growth disturbance, but whether or not these are attributable to cosmic radiation must await further experimentation on which to judge. The Russian investigators were emphatic in their belief that the changes they observed were not due to cosmic rays. Much the same problem arises in respect to Neurospora sent by DeBusk into the Van Allen belt for a brief period. Under these conditions, mutation rates were found to be orders of magnitude higher than anticipated from simultaneously observed radiation in this belt. In experiments of this kind, perhaps we are dealing with combined effects of various space environmental factors - a subject on which we have as yet no concrete information.

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There are many other important biological problems in the space field, such as photosynthesis and its relation to solar illuminance on the Moon, Venus and Mars, and the degree of dependence of plants and animals on the gravitational fields of these extraterrestrial bodies.

But I have time only to make some remarks on the problem of biological clocks.

Over the course of millions of years living organisms have evolved under complex environmental conditions. One important factor of the environment is its rhythmicity. Contributing to this rhythmicity are movements of the Earth relative to the Sun and Moon. The Earth's rotation relative to the Sun gives us our 24-hour day and, with its axis titled as it revolves about the Sun, we have our years and seasons. Our lunar day is the time from Moon rise to Moon rise. The Moon's arrival every 29-1/2 days at the same relative position between the Earth and the Sun gives us our synodical month. The daily and annual rhythms related to the Sun are associated with changes in light and temperature. The lunar day and synodical month are associated with Moon-dominated tides and in changes in nighttime illumination. These 4 physical, or extrinsic, rhythms include changes in forces, as in gravity, barometric pressure, high-energy radiation, and magnetic and electrical fields. Considering the rhythmic changes in the physical world it is not surprising that living creatures should display daily and monthly rhythmic patterns which serve as biological clocks as dependable as the sun dial.

Evidence has been accumulating that rhythms pervade the entire physiological and biochemical system, which is innately an oscillator whose frequency is an evolved match to that of the physical environment it inhabits. The environmental inputs that regulate this oscillator - the light and temperature cycles - act only as entraining periodicities regulating phase and period of the living oscillator.

The problem now in the stage of heated discussion is the degree to which biological clocks are responsive to such environmental factors as cosmic-ray showers, magnetic lines, barometric pressure, etc. The difficulty in resolving the problem is that these environmental factors cannot be experimentally controlled. One can only attempt correlations which are highly suggestive but not conclusive.

LS #10

A very interesting study along this line is that of Prof. Brown of Northwestern University. He has correlated the daily metabolic cycles of fiddler crabs, potatoes, sea ~~weak~~ weed and oysters during the spring and summer of the years 1954 and 1955. Between these 2 years the daily metabolic cycles of these organisms seemed to have turned upside down. Comparing this with cosmic-ray cyclic data, which he obtained from the Fermi Institute of the University of Chicago, he found that just as the crab, potato, seaweed and oyster metabolic cycles were inverted in one of these two specific periods of study, so were also the cosmic-ray cycles in the same period.

Drastic alteration of phase in biological rhythmicity can lead to irreparable damage to an organism, and thus research on biological rhythmicity carried out in the space environment has its practical aspects as well as allowing one of the most basic problems in biology to be explored.