Medical and Biological Aspects of THE ENERGIES of SPACE

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Foreword

OTIS O. BENSON, JR.

It was almost exactly nine years ago that we at the USAF School of Aviation Medicine, then situated at Randolph Air Force Base, Texas, began what has now become a highly productive series of conferences and symposia on the biomedical problems of manned space flight. The exact date of the first symposium, which we believe has become historic, was November 6 through 9, 1951. I am certain that the scientific community, especially those associated with space flight, will join me in saying that that first meeting and the series which have followed have had a significant impact on space biotechnology. If I were asked to suggest the dominant reason for the success of these conferences and symposia, I would attach greatest importance to the fact that they have provided a medium for inter-disciplinary efforts of large numbers of distinguished scientists, biologists, physicians, astronomers, engineers, and their associates, whose collective knowledge has covered a broad spectrum of science and technology. These meetings have borne ample witness to the fact that the problems of man in space belong to no single group. Rather, it is only by pooling our knowledge, understanding one another, and working together that we can achieve the goals which we so earnestly seek.

This symposium, in the same spirit of cross-disciplinary effort, is concerned, primarily, with the biological implications of the energies of space. Under the able guidance of my long-time friend and colleague, Colonel Paul A. Campbell, we have again planned this symposium as a means of crossing the disciplines of medicine and biology with those of astronomy, physics, engineering, and related areas. We have asked all our participants to help us in this enterprise because we feel that their past, present, and future contributions to

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science and technology will solve the many problems that lie before us and will, consequently, put man in control of the space environment more quickly and effectively. I am sure that we all realize that the task of consolidating diversified knowledge is no trivial one. It is much more than an academic exercise. Putting man into space and the explorations that follow will not only represent an unparalleled scientific achievement, but also the culmination of the labors of millions of people, like ourselves, and their hopes for a broader understanding of the world in which we live. It is the greatest challenge ever faced by man, and I am confident that the opportunities for communication and thought made possible by this symposium will contribute much toward its resolution.

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Introduction

PAUL A. CAMPBELL

Beyond the earth's atmosphere lies an environment called—for lack of a better word—space. The environment is, in reality, a composite of situations mostly hostile, for which man is poorly endowed; poorly endowed physically, but highly endowed from the standpoint of ingenuity. With his ingenuity he can possibly create an environment with which he can surround himself for his venture into space. A major problem—possibly the most important—will concern energy; energy for lift, energy for support of life, energy for existence on celestial objects, and energy to perform the tasks which need be done. But the energy problem is double-edged, as some of the energies are catastrophically harmful; thus man must be protected against them.

We often hear an analogy comparing man's effort to get into space to the evolutionary era, eons of time ago, when fish came out of the sea; at first burrowing quickly in the tidal sands, awaiting the ebb; evolving a little in the new environment; spawning their young, some with better adaptation than the original; then through natural selection, slowly evolving, proceeding from water creatures to land creatures—a process which required thousands of millenia.

Today man, with his unique endowments, intends to surpass this achievement, hurdling in our generation the entire shoreline and the eons of time, carrying his environment with him and setting up housekeeping with whatever he can carry, or with whatever he can glean from nature to utilize for his needs or for protection against that with which nature threatens him.

As if in compensation for its hostility, there also lies above our atmosphere a new frontier of knowledge which, in time, with its affluent rewards will, in the opinion of many, pay for all of the

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space exploration effort, capital and interest, many times compounded. Our children and their children may wonder why mankind ever hesitated on the shoreline of the cosmic ocean, but there are reasons for hesitancy other than the magnitude of the required effort, capital, and material expenditure, for a great deal of knowledge is still needed, much of which concerns energy. A little time spent in coastal navigation, soundings, sampling, testing, collecting, computing, and even organizing symposia, may add insurance and assurance for final success.

The knowledge we glean from our spatial coastal navigation, soundings, sampling, probing, etc., cannot be measured by material yardsticks. But bits and pieces of knowledge, basic and applied, have furnished and will furnish the lifeblood of our greatest national resource: knowledge, know-how, food for imagination, figures for extrapolation, new energies to harness, and hazardous energies to convert into benefits for mankind.

But as has been shown so many times recently, there are many, many problems. The solution of each series of problems seems to beget a new series. Their solution, in turn, begets new generations, and so on ad infinitum.

As I see it, and have repeated in past symposia, a major problem of extended space and celestial exploration and the denominator which must find its place in all our equations is that of logistics (1)—in our case the science of supply of energies and materials during a space operation. Logistics, used in the sense in which we apply the term, includes movement of supplies so that they may be in the proper place at the proper time; the stockpiling of the proper things—energies, etc., in the proper place for preservation and use at the proper time. Further, the concept embraces the art of conservation of supply and energy through reutilizing those things which can be used over and over again, recycling in a closed ecological loop; using in multiple ways those things which can have more than one use; packaging in the smallest, most accessible packages; and, reducing weight to the minimum. Lastly, and most important of all, is ability to live off the energies and material resources available, using everything which can be used, and stockpiling the excess which might be useful. I believe the logistics problems of space operations are not too unlike those of the old Cavalry operations in which mobility and often the achievement of a mission depended, to a large extent, on ability to utilize energies and materials at hand—"living off the land," so to speak.

It takes very little imagination to visualize the difficulty of lifting vehicles, people, and materials into space and resupplying them in the hostility of space or on hostile celestial objects. The tremendous weight cost in terms of fuel and structure required to lift each pound of payload into orbit is well known to all. For space operations, one has a choice—carry it along at a tremendous cost in lift requirements, stage many times, limit the operation to exactly meet the contingencies of available supply, or *utilize to a maximum the energies and material resources available*, whenever and wherever they may be found.

One of the lists of cosmic abundances is that of D. H. Menzel and colleagues (2). His list is that of abundances in the solar atmosphere, shown in Table 1.

Table 1. Abundances of Elements in the Solar Atmosphere

Element	*Percentage Volume*	*Mass (milligrams per square centimeter)*
Hydrogen	81.760	1,200
Helium	18.170	1,000
Oxygen	0.030000	10.
Magnesium	0.020000	10.
Nitrogen	0.010000	2.
Silicon	0.006000	3.
Sulphur	0.003000	1.
Carbon	0.003000	0.5
Iron	0.000800	0.6
Calcium	0.000300	0.2
Sodium	0.000300	0.1
Nickel	0.000200	0.2
Aluminum	0.000200	0.1
Zinc	0.000030	0.03
Manganese	0.000010	0.01
Potassium	0.000010	0.003
Chromium	0.000006	0.005
Cobalt	0.000004	0.004
Titanium	0.000003	0.003
Copper	0.000002	0.002
Vanadium	0.000001	0.001

Now to consider available resources. The material resources available in space or on celestial bodies embrace the entire periodic table of elements. They are distributed in globular masses, accretions, clumps, wisps, the thinnest of veils, and in the single particles sparsely scattered about the very hard vacuum of space. These resources appear to be distributed poorly for our particular purposes but, nevertheless, they are there.

A sample of an accretion or clump is that of our earth. Table 2 shows an estimate of its composition (3):

Table 2. Abundances of Elements in the Earth

Element	*Percent*
Iron	67
Oxygen	12
Silicon	7
Nickel	4
Others	10

It is interesting to compare the abundances of elements found in man, and therefore needed by him. Table 3 shows these (4):

Table 3. Abundances of Elements in Man

Element	*Percent*	*Approximate Amount in Grams in a 70 kg. Man*
Oxygen	65.0	45,500
Carbon	18.0	12,600
Hydrogen	10.0	7,000
Nitrogen	3.0	2,100
Calcium	1.5	1,050
Phosphorus	1.0	700
Potassium	0.35	245
Sulphur	0.25	175
Sodium	0.15	105
Chlorine	0.15	105
Magnesium	0.05	35
Iron	0.004	3
Manganese	0.0003	0.2
Copper	0.0002	0.1
Iodine	0.00004	0.03

The energies available are those of the entire electromagnetic spectrum (Figure 1), plus the kinetic energy of masses in motion, plus sources possessing energy potential such as those afforded by gradients (5).

It can be generalized that the radiant energies of space run the entire gamut of the electromagnetic spectrum extending from the radio waves through the infrared, the visible, and the ultraviolet portions and thence through the X-ray, gamma-ray, and cosmic-ray regions. In addition, there is particulate matter of a wide range of speed and energy.

Within our own planetary system the sun provides the most obvious source of energy from its radiation spectrum. Solar radiation

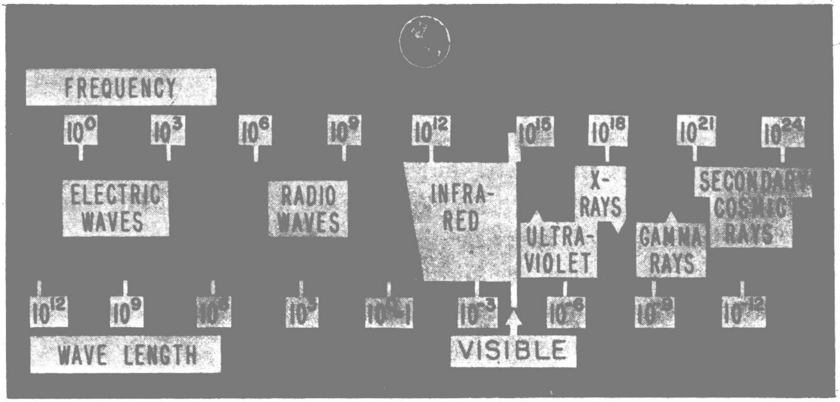

Figure 1. The Electromagnetic Spectrum

Wave lengths are given in centimeters; frequency in waves per second.

can be converted into heat which, in turn, can be converted into electricity. Possibly its photon energy can be converted directly into electricity or into other forms of energy through transduction in plants. This latter, however, has the limitation of relatively low intensity—about 130 watts per square foot in the earth's vicinity (6).

What are man's energy requirements for space travel and for the exploration and possibly colonization of celestial bodies? The list would be very long indeed. From the human factors viewpoint a few are: energy for life support, for environmental control, for nutrition and food preparation, for recycling metabolic products; energy to change CO_2 to O_2, to remove noxious substances and waste products, to prepare water, to extract oxygen; energy for photosynthesis, for construction on celestial bodies, for locomotion, for light, for communications; and energy for protection against other energies.

The engineers have much greater needs than the biologists. They need, among other energies, energy for propulsion, for guidance, for navigation, and energy to make available new energies Thus, the problem of the "utilization" segment of the symposium is to match man's needs with what is available and to incite his ingenuity to take advantage of it, if it is in any way possible.

Now to turn to the segment of the symposium concerned with protection. We, and other forms of life, plant and animal, have evolved in and beneath a benevolent protective atmosphere and magnetic shield. Earth life has evolved as the atmosphere has evolved, and their mutual needs are magnificently entwined in a series of situations and interactions known as ecology. Above the protective layers of this atmospheric blanket and magnetic shield man, through his ingenuity, must replace the blanket and shield or nullify in some manner his dependence on them. He must, in fact, in some manner, carry or devise a substitute for the protection afforded by the atmosphere and terrestrial magnetic field.

Protection within the present state of the art, in most instances, depends upon sheer mass for its protective qualities. Thus, again, we are confronted with the problem of logistics. How can we trade something heavy for something light? How can we use something for more than one purpose? How can we conserve? How can we make use of the energies and materials which are available? How can we replace the protective qualities of the ozone of our atmosphere, the shielding qualities of water vapor, or the repulsion qualities of the earth's magnetic field, and yet have a vehicle which can be lifted into space by available propellent energy?

There are other situations which, in the present state of the art of space travel, must receive consideration in almost all of the elements of space vehicle systems, that is, the phenomena of weightlessness.

As orbit is achieved, the problem of too much weight within a few seconds changes to the problem of lack of weight—zero "g." This phenomenon requires consideration in many life-support systems and possibly even in protective systems. In the weightless state the behavior of fluids, and some other materials, change. This must be borne in mind; for instance, in photosynthetic systems or electrical systems depending on fluid electrolytes.

Similarly, one must bear in mind that the inhabited compartment of a space vehicle during space operations is a closed system from the standpoint of materials, but an open system from the standpoint of radiant energy. As it must remain closed from the standpoint of material exchange, resupply is very difficult as is also the getting rid of used or waste materials. Either operation requires expenditure of energy.

In conclusion, we may say that the human being is an extremely versatile creature, capable of producing tools to perform his work and possibly to think for him. He is rapidly learning how to construct an environment which will allow him to explore situations for which he does not have physical adaptation and the time element is too great for him to wait. It is his desire to create an 8ft. × 8ft. environment to do essentially that which the earth with its 8,000 miles × 8,000 miles diameter does. Possibly he can perfect plant and animal symbiosis, each utilizing to full advantage that which is disposed of by the other. Possibly the energy source coming from outside the system will be of solar origin or from a star.

If we consider the basic limitations of space flight to embrace: 1) the distance one can travel in an acceptable period of time; 2) the amount of radiation one can tolerate as a function of time; and 3) logistics of support, then energy is involved in each item.

This symposium has been organized to delineate those energies which are available for utilization, point out, if possible, how they can be utilized, delineate those energies from which man must be protected, and evolve some of the elements of the required protection. It is hoped a few new ideas, or a few new slants will be forthcoming, but if the symposium only delineates the problem areas, that in itself will be a contribution.

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