THE PERMANENT LUNAR BASE: DETERMINATION OF BIOLOGICAL PROBLEM AREAS

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INTRODUCTION

A discussion of potential biological problems in connection with the permanent lunar base might provoke mild skepticism among our engineering friends were we not to consider first certain implications of this paper. While we shall indeed discuss some of the general problems attending the conception of a workable biological life support system for the base, it is also the purpose of this paper first to show cause why the application of biology to life support systems should in fact be considered seriously at this time, and second, in the epilogue, to suggest how we might proceed to approach that goal in a diligent manner.

We are, like a few of you in this audience, biologists living in a sea of engineers. There is one thing we have learned from this experience, and very simply it is this: engineers are very practical men. Were they not, there would be no space systems to which we would be considering the application of biological principles. Then, in a hopefully practical manner, let us approach the question of why biological systems should be explored, and next, what justification there is for immediacy.

If their secret thoughts were revealed, most of our engineering associates undoubtedly would be found to view with some degree of horror the possibility of incorporating a biological subsystem—be it algae or higher plants—into an otherwise hopefully predictable and reliable space system. As a matter of fact, considering the present, and admittedly young, state-of-the-art in biological life support subsystems, most biologists and bioengineers would have to confess that there is indeed substantial basis for concern by systems engineers. It is at this point, however, that a misunderstanding may arise.

Green plants—both higher and lower forms—stand between man and his extinction. The fact that I am here talking to you, and you are here listening to me, is rather convincing evidence that green plants have been fairly dependable guardians of man's existence since he first arrived on the scene. Here is where the misunderstanding may exist. The problem is not that green plants as a component (to use the engineering vernacular) are in themselves unreliable, unpredictable, or basically unmanageable: but, quite the reverse is true. The problem is really one in which biologists simply have not yet demonstrated that green plants can be, with reasonable assurance, suitably mated to a space system. The reasons are several: We are practically before the fact, that is, we are barely started. We need more so-called bioengineers. We need more support, encouragement, and in the applications area perhaps a little more planning.

When the time comes to make a comparative analysis of different kinds of life support systems, say for the permanent lunar base, how can a proper evaluation be made if the different types of biological subsystems have not been thoroughly explored? The answer to that is quite simple: The best intermix of chemical, physical, biological and supply-by-transport elements which will make up the life support system will not be established. And that is why we believe that biological subsystems should be thoroughly explored.

The sense of urgency for space-related biological research was confirmed in late 1961 when the NASA announced the award of the Apollo contract. The first lunar landing will mark the end of the beginning of the space age, since we shall feel compelled to move on as soon as possible: To conduct geophysical studies, make astronomical observations, search for the remains of life and proto-life; avail ourselves of that interesting environment for all manner of biological and physical experimentation; take advantage of communications potentials and engage in many other activities. Surely then there will be an obvious and fairly immediate need for one or more permanent lunar bases.

Until very recently biologists in space-related activities were hard pressed to actually point out a specific space system for which a biological subsystem might serve to support man. Reference to application usually has been qualified in the past by the phrase "extended, or long-duration mission." Such generalization is no longer necessary.

Let us say then that somewhere between 3 to 10 years after the initial landing a first unit of a substantial permanent lunar base will be required. If a base is to be functioning in say 1975, considering erection, transport, packaging, modification, testing, fabrication and engineering, it is not unreasonable to expect negotiations for contracts to begin in or around 1967. If our estimated development schedule is approximately correct, then very little time—something on the order of 4-1/2 years—remains in which we biologists and the bioengineers must secure a minimal body of knowledge by which systems engineers may judge the usefulness of plants in producing food on site, in waste processing, water recovery and gas exchange. And that is why we believe there is need for accelerating biological life support subsystem studies.

As members of a large aerospace corporation, our interests span two different but closely related areas: one concerns the conduct of primarily physiological studies of plants, both higher and lower; the other, of course, relates to systems applications. It is through the latter interest that perhaps we may most usefully serve this symposium.

In the final analysis, when dealing with space systems, whether biological subsystems play a role in life support or not, will depend entirely on the evaluation of experimental and/or prototype biological subsystems. In turn, whether usefulness of biological subsystems can be demonstrated depends largely upon the nature and success of biological research in universities, institutes, and to a lesser degree in federal agencies and the aerospace companies. The nature of the biological research is the key phrase here. Of course, under no circumstances should full inquiry into the workings of biological processes be constrained, or otherwise denied, whether space-related or not. But, in reference to a possible application of biological elements to a particular system, if certain problems are not recognized and solved prior to the onset of design of the system, then the application concerned cannot be realized. In other words, we—by we, it is meant those concerned with applications—may do well to inform our scientist associates of the probable or possible nature of systems to which biology may apply, in order that they might recognize problems of interest to themselves and in turn solve some of our problems.

Therefore, we intend to examine, in the next few minutes, problem areas which occur to us in connection with four possible subsystems, any one of which might be integrated into the permanent lunar base life support system. We do not propose that our list is by any means complete, nor do we suggest that there exist no other biological solutions.

Before considering the four subsystems we should first review those aspects of the lunar environment which affect the nature of these subsystems.

Sunlight is more or less available continuously in the lunar polar regions depending, of course, upon topography. Since sunlight is available in non-polar regions only for approximately 13 earth days, followed by darkness for 13 days, the poles would seem an ideal location from the viewpoint of the biologist for locating the base were it not for two other factors: solar events and meteoroid infall.

Because the sun essentially travels around the horizon in the polar regions, protection from solar events could be afforded by a ring of rock debris about a surface installation; in non-polar regions a sub-surface location would seem required. However, surface installations may very well be subject to damaging meteoroid bombardment at any point. For the time being, then, until the engineers determine otherwise, or until preliminary lunar surface investigations definitely establish the meteoroid flux, it must be assumed that a biological subsystem will be located underground regardless of its site.

Nevertheless, it might seem reasonable to assume that in a polar location sunlight could be brought underground by a series of reflectors. In the non-polar regions sunlight could be made available in the same manner but supplementary light would be required one-half of the time.

The status of lunar water resources, of course, is no more than conjectural at this point. However, if volcanic rock exists at all—and this seems likely—water can be extracted from it as demonstrated by Dr. Jack Green of North American Aviation (Ref. 1). With a reasonable probability of water resources at this time, and until proven otherwise, the biologist should not limit his studies to water-sparing techniques.

I. "Pure" Algae Subsystem

In terms of application, the so-called "pure" algae subsystem is closer to reality than the other general classes of biological subsystems. Of the four main requirements of a complete life support system - gas exchange, waste processing, water recovery, and provision for/or production of food - the "pure" algae subsystem definitely satisfies only one, namely; gas exchange. Limited consumption as a grain-flour substitute is not to be denied, and indeed, this should be explored further. It would seem, however, that potentially a "pure" algae subsystem does not, by itself, hold much promise for incorporation in a permanent lunar base, since there is at least one other method—the algae-bacteria subsystem—which confers all the advantages of a "pure" algae subsystem and significantly more.

II. Algae-Bacteria Subsystem*

Algae and bacteria populations either in series or in combination could theoretically satisfy three of the four main requirements, namely: gas exchange, waste processing, and water recovery. The combination subsystem, where both algae and bacteria are carried in the same suspension, seems to be the most direct and simple of the two techniques, and, hence, the one we shall discuss.

In the combination subsystem, about 95% - 98% of the biomass is algae; thus, as in the case of the "pure" algae subsystem, some of the harvested material could be diverted to the production of algae flour if desired. Such a proposal may suffer a great deal of criticism because of the existence of partially degraded human wastes and the potential pathogens present in the harvested algae along with the algae. We should like to point

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*We appreciate that this title does not fully describe the nature of the biomass in the technical sense. However, for reason of simplicity we suggest that it continue to be used.

out, however, that the problem of sterilization is a general one and not peculiar to algae-bacteria subsystems. As a laboratory exercise, the maintenance of so-called "pure" algae suspensions may be quite feasible. In a lunar base, reliability must be of the highest order at all times. The very fact that ingress and egress must be afforded for addition of nutrients, gases, and harvesting, as well as equipment maintenance, suggests that even in the case of "pure" cultures the existence of pathogenic organisms is not precluded. It would seem obligate, therefore, that the harvested material be sterilized whatever the method of production.

Possible accumulation of toxic agents in the suspension poses a potential threat to both maintenance of the culture and to human or animal consumption of the product. In experiments extending for as long as six weeks, Drs. Oswald and Golueke of the University of California, Berkeley, (Ref. 2) noted no change in performance of the culture. In this case, the effluent associated with the daily harvest was returned to the suspension. Obviously, this matter must be explored in much longer duration experiments.

There is the difficult job of optimizing the environmental variables temperature, light intensity and possibly periodicity, nutrients, and atmospheres, particularly reduced partial pressures; in addition, operational variables such as hydraulic detention period and aeration techniques must be included.

It may be possible to improve the efficiency of the bacteria fraction by the introduction of selected strains, but since the mix of bacteria may be in effect controlled by the character of the organic wastes—other factors favorable—there is some doubt surrounding substantial improvement. Obviously, identification of the major genera of the bacterial biomass should be undertaken prior to any attempt at improvement of efficiency.

Standing alone, the algae-bacteria subsystem would seem, at least theoretically, well adapted for small lunar facilities where food would be available through supply-by-transport.

There is an untidy aspect in the biological systems sense to the algae-bacteria subsystem, and for that matter, the "pure" algae subsystem. As you know, each day a certain portion of the biomass must be removed from the suspension in order that the concentration remain within a specific range. The non-biologist may note here that this is necessary since the growth rate of the population is, among other things, a function of the optical density of the suspension: there being an optimal density range. Where essentially all food is supplied by transport, the accumulation of algae is not a major problem. However, in any system pointed toward a fair degree of self-sufficiency, the carbon and oxygen tied up in this biomass must be returned to the system. There are two basic means by which this may be accomplished: one obviously is incineration, the other is conversion of algae to food animal products. It is the latter which we shall consider next.

III. Algae-Bacteria/Food Animal Subsystem

Broadening of the diet is the one and only purpose for raising food animals. Fortunately, the possibility of utilizing the algae surplus makes the raising of food animals not unreasonable. The relatively high protein content of algae seems to place an upper limit on the amount which can be fed to most land food animals. Partial modification of algae might possibly increase the quantity which could be consumed. The more supplementary (non-algal) feed that is required, of course, the less desirable food animals become as an element of the life support system. Hopefully, this particular area of study will probably require relatively less support from space funding sources largely because of the growing interest in conversion of municipal wastes to algae and subsequently in part to food animals. However, the algae-bacteria/food animal subsystem is yet far from providing the capability for a nearly self-sufficient life-support system—which, brings us to the ultimate or most sophisticated subsystem.

IV. "Complete" Subsystem

The complete subsystem, which comprises algae-bacteria suspensions, food animals, and higher or broadleaf plants, would come closest to providing self-sufficiency in a permanent lunar. The ultimate form of this system hopefully would rely on earth only for resupply of certain minor supplements and makeup for attrition.

Inclusion of the higher plants in the lunar base provides the fullest opportunity for expanding the human diet. Without higher plants, a significant degree of acceptable self-sufficiency cannot be realized.

Even though higher plants have received relatively scant attention in terms of application to space systems, particularly extraterrestrial bases, their usefulness apparently has been subjected to extensive prejudgment. There is the tendency to assume that, based on good agricultural yields, something on the order of one acre of higher plants may be required to sustain one man. Naturally, the thought of providing about 100 acres, or 4-1/3 million square feet, of plant growing area for support of a 100-man crew in a permanent base essentially precludes the use of higher plants. This figure, of course, is absurd. Our calculations show that on the basis of known high yields, if no growing area lies idle, if nearly optimal environmental conditions are provided for each variety of crop by zonation of the growing area, if the protein portion of the human diet is supplied by food animals and by algae and if a very limited supply-by-transport is accepted, then approximately 5 acres of higher plants are required to supply 100 men.

Since the internal environment of the lunar base is completely controlled, then we should be free to make it whatever we desire.

Determining those combinations of environmental factors required for optimal growth and development rates should be one of the main study objectives. This necessary task is hardly simple not only because of the multiplicity of environmental factors, but also because the best combinations of factors will change throughout the life cycle of a particular species, and certainly these combinations will differ between species. The problem is further complicated by interactions between the several environmental factors. It will be necessary to examine selected species in different combinations of ambient temperature in terms of degree and periodicity, light in terms of quality, intensity and periodicity, growth media, and partial pressures of constituent gases. Since much is known of the effects of, and interactions between environmental factors, the task is not quite as difficult as it appears. At some point, however, all factors must be studied simultaneously in a multivariate pattern—to our knowledge no facilities currently exist for handling this kind of exercise.

Until initial lunar explorations have established the nature of the surface, both water culture or hydroponic, and soil studies should be pursued. In the case of soil culture, it may be desirable to work with a minimal organic fraction in order to keep the amount of carbon committed to the soil as low as possible, otherwise we would be faced with an excessive carbon requirement in the life support system.

Without information as to the existence of clay-like materials on the lunar surface, studies probably should revolve about manufactured soils based on suitable proportions of basalt and rhyolite. Admittedly, the manufacture of the high base-exchange capacity fraction is not simple, but this may be the method required if we were to adopt soil culture in the base. For the water culture method, gravel culture would seem most suitable. Again, the problem probably is best handled by terrestrial analogy, that is, crushed basalt or rhyolite.

As pointed out in the beginning, with the possible exception of a polar location, artificial light sources would be required. Here the biologist must join hands with the engineer to develop lamps of the proper quality, intensity, and efficiency for maximum photosynthetic rates per unit of power consumed and minimum undesirable photomorphogenic effects.

The impact of a gravitational field 1/6th that of the earth's poses another disturbing problem. From time to time it has been conjectured that a reduced gravity field would inspire plants to grow higher, or more rapidly. Tentatively, the reverse seems to be the case. If plants are placed in a horizontal position and rotated about their stems by means of a clinostat and, incidentally, exposed to full sunlight, the rate of elongation of their stems is significantly less than controls. (Ref. 3, 4) Other work (Ref. 4) using a centrifuge-clinostat apparatus seems to suggest that it is possible to simulate any acceleration between 0 and 1g with the petioles -

even though, theoretically, continuous exposure to less than 1g on the earth's surface is impossible at this time. Through this technique, particularly in connection with petioles studies, it may be possible to learn more of growth rates in reduced gravity environments.

The ecology of the entire lunar base microbiological community is of critical concern to the general well-being of the biological life support system, particularly a "complete" subsystem. Essentially sterile or asceptic, or even antiseptic, conditions cannot be assumed. Aside from obvious pathogenic considerations, there is another aspect worthy of studious inquiry: methods of control should be carefully evaluated since the accumulation of toxic compounds in the biological subsystem would seem readily possible.

When more information is available for characterization of the complete subsystem, that is, the subsystem which combines algae-bacteria cultures, food animals and higher plants, or whatever the subsystem may be, a thorough biological systems analysis would be required. In effect, this would constitute an ecological analysis of an artificial biosystem. Energy transfer, flow of elements and compounds, action and reaction particularly in reference to transients must be analyzed. Models should consider, for example, the impact of excessive nitrification or denitrification, the best method for recovery of mineral nutrients, the possibility or value of considering the addition of more exotic foodstuffs such as fungi, and an attempt to identify the causes of potential imbalances or other undesirable factors inherent in the total biosystem. Lastly, a prototype of the entire system should be operated for a sufficient test period—perhaps 1 to 3 years.

EPILOGUE

It should be apprent from what we have said, or perhaps from what we have not said, that some form of guidance—a plan—is required. We submit that a plan of four phases be considered. Certainly these phases might overlap and hence may occur simultaneously in some aspects.

The first phase would revolve about a permanent lunar base life support study which would consider the entire intermix of chemical, physical, biological, and supply-by-transport elements, and control. The purpose of this study would be to consider the entire range of possibilities of combinations of subsystems and variations within subsystems. In effect, it should represent the studied effort of engineers and scientists from universities, institutes, the federal organizations and industry. All factors, however peripheral, should be considered, for example: The need for psychologists to gain an adequate understanding of diet under long term exposure to high stress environment, with all its implications, is a must.

The usefulness of this overall study would lie in serving as a guideline to funding agencies to insure that solution of problems peculiar to lunar base life support would, in fact, be undertaken.

The second phase from the biological standpoint would involve the construction of experimental units and/or development of prototypes of the more plausible biological subsystems. The third phase, here again from the biological view point, would concern evaluation of subsystems. The fourth phase would involve long-term testing of the final biological subsystem.

Finally, we should like to thank you for your patience, and leave you with these thoughts: Let us recognize that it is fairly obvious there is a space system—the lunar base—to which biological elements may very well be applicable. We should spur our research efforts, and also join hands with the engineers to build and evaluate the different experimental life support biological subsystems. And to efficiently utilize our resources, some sort of flexible national plan should be developed as soon as possible. Perhaps this may appear to be too grand a scheme, but then the permanent lunar base will be no less than this, itself.

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