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SCIENTIFIC INTELLIGENCE REPORT

THE SOVIET SPACE RESEARCH PROGRAM

MONOGRAPH X
SPACE BIOLOGY AND ASTROBIOLOGY

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Scientific Intelligence Report

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NOTICE

The conclusions, judgments, and opinions contained in this finished intelligence report are based on extensive scientific intelligence research and represent the final and considered views of the Office of Scientific Intelligence.

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PREFACE

This monograph, one of a special series on the Soviet space research program, presents intelligence on Soviet efforts in space biology and astrobiology. Space biology concerns the effects of environmental conditions in space and within artificial satellites in space on the activities of terrestrial organisms. Astrobiology is concerned with the existence and nature of living organisms on planets other than earth. Soviet space biology research with mammals is covered in Monograph IX, "Space Medicine."

Before their first extensive manned space flight, the Soviets must solve the problems associated with the effects of space environmental factors on man and other organisms. Space biology research provides means to discover and perfect biological methods of supporting human life in space vehicles. For long-term space flights, a closed biological system of oxygen regeneration, waste-product disposal, and food production would have definite advantages over other conceivable systems because of space and weight considerations. Consequently, the solution of the space biology problems associated with a closed biological system would increase the feasibility of space flights of long duration. Any such system would be tested in comparatively short-duration flights, but short-duration manned space flights are not dependent on the prior perfection of such systems.

Research in astrobiology, as is evident from the definition, bears little direct relationship to space flight research. Astrobiologists seek definite determinations concerning the nature of organisms on planets other than earth as aids in preparing programs for exploration of the planets.

No detailed scientific data on Soviet space biology research were discovered in the literature, probably because such work is classified. Hence, Soviet radio and press releases concerning space biology have been considered as indicative of Soviet intent and status, and Soviet fundamental biological research has been examined for evidence of capability in the space biology field.

This monograph, one of 12 (listed below) on the Soviet space research program, considers data obtained through 1 April 1959. Monographs II through XII are designed to support the conclusions found in Monograph I, which will be an overall evaluation of significant Soviet space research capabilities. Monograph I will be published last.

The Soviet Space Research Program:

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THE SOVIET SPACE RESEARCH PROGRAM

MONOGRAPH X
SPACE BIOLOGY AND ASTROBIOLOGY

SUMMARY AND CONCLUSIONS

In the biological fields pertaining to the space research program of the USSR, Soviet research in space biology closely parallels U.S. work and probably will have become sufficiently advanced to support extended manned space flight by the time such support is needed; on the other hand, Soviet research in astrobiology, although unique, will have little or no influence on the initial space flight research program of the USSR and thus far has added nothing of value to it.

In space biology research, the USSR probably will develop a partially balanced closed biological system of environment for astronauts * in a relatively short period of time, with primary emphasis of the research being placed on the carbon dioxide-oxygen exchange capacity of organisms. The Soviets have sufficient knowledge of the activities of organisms potentially useful under given environmental conditions (variations in temperature, light, radiation, and so forth) to enable them to specify the optimum conditions for maximum activity of the organisms. This recorded knowledge does not cover the effects of weightlessness on the organisms. Soviet research has centered on the search for a single organism that would be effective in balancing man in a biological system; but it is believed that such a closed system will require a multiple number of organisms to effect a balance with man.

No algae known to have been tested by the Soviets can serve as a sole source of food, yet the type tested could serve as the primary source with the deficient food elements being supplied by supplemental materials. The Soviets probably have made sufficient progress in research on an oxygen regeneration system to ensure the future successful use of algae for such purposes on long flights.

Human waste-disposal problems, although important to the closed biological system, have received little emphasis. No Soviet reports have been found that deal with the use of organisms for converting human waste products — other than carbon dioxide — into materials useful in a metabolic closed system. The complete reutilization of waste products probably will not be accomplished by the Soviets in their first system to be used under space flight conditions.

Scientific personnel are sufficient in number and competence and their facilities are well equipped enough to enable the Soviets to conduct space biology research of high quality. There are indications that both scientists and facilities in this field have been marshaled for such research. Furthermore, space biology research probably is being conducted by the

* Closed biological system — the conversion of waste products to food and oxygen via biological organisms.

laboratories of the Astrobiological Sector of the Kazakh Academy of Science at Alma-Ata, by the Laboratory of Physiology of Circulation of the Blood and of Respiration of the Bogomolets Physiology Institute at Kiev, by the Biophysics Institute of the Academy of Sciences, USSR, and by the Lesgafts Institute of Medical Science of the Academy of Pedagogical Sciences at Leningrad.

Soviet astrobiological research has not provided any conclusive evidence on the existence or nature of life on planets other than earth. Soviet astrobiological researchers have used terrestrial research with plants under extreme climatic conditions as a base and have attempted to translate the research results to dissimilar climatic conditions found on other planets of the solar system. In these translations of results, the existing differences between the terrestrial and the planetary environmental conditions are usually not taken fully into account. Also, this Soviet method of analysis assumes that life on other planets is basically identical to that on earth and discounts almost all possibilities of independent origin and evolution of life on other planets. Although the quality of terrestrial biological research by the Soviet astrobiologists is good and has considerably strengthened man's understanding of the presence and nature of terrestrial organisms under extreme terrestrial climatic conditions, their translation of results to the conditions known to exist on other planets is so fully based on conjecture, supposition, and unproven (and at the present time unprovable) hypotheses that their reports concerning life on other planets must be considered as purely conjectural. It is believed that research in this area has been deemphasized and curtailed in the USSR.

DISCUSSION

INTRODUCTION

The current status of Soviet space biology research cannot be definitely ascertained, but such research apparently began quite recently. A. G. Karpenko of the Interagency Commission on Interplanetary Communications (ICIC) stated in 1956 that "biologists should have begun their research on the problem . . . 5 years ago." [16] Not until 1958 were G. A. Tikhov (Director of the astrobiological laboratories of the Kazakh Academy of Sciences) and his coworkers transferred from astrobiological research to space biology research.[15] Nevertheless, the Soviets have made rapid progress in raising their algal research from its comparatively low position of 6 to 8 years ago and may now be closer to a solution of the closed system problem for space flight than is the West.[1] This evaluation of the rate of acceleration and the possible present Soviet position is based on the quality of the recently published Soviet reports, and the ease with which their good biological research facilities and manpower can be adapted to space biology research.

SPACE BIOLOGY

Organisms as Oxygen Regeneration Agents

Many Soviet and Western authors have suggested that living unicellular algae be utilized as a food source for space vehicle inhabitants and as the biological agent in an oxygen regeneration system.[3,4,5] Yet published Soviet work on the culture of algae under rigidly controlled environmental conditions has been limited. The mass of Soviet work with these organisms has been designed to give information on their use in unmodified environments (ponds, reservoirs, etc.) as a direct or indirect food source for fish, but some of the published Soviet research with algae does have a direct application to space biology research.

A. D. Seryapin, chairman of the Scientific-Technological Committee on Biology of Space Flight, has stated that 1 square meter of surface of leaf of a gourd illuminated by the sun produces the amount of oxygen required by two men doing moderate work, and that 1 square meter of surface of algae manufactures an amount of oxygen sufficient for one man.[6] Also, a broadcast from Moscow on 4 October 1958 describing the work of the Bogomolets Physiology Institute, Kiev, stated, "It has been established that about 200 liters of algae can be grown in a rocket — enough to cover the nutritional requirements for one man for 6 months. These plants will not only supply food for the space travelers but also reoxygenate the atmosphere within the space vehicle. *Chlorella* (a unicellular alga), for instance, in 1 hour emanates a volume of oxygen 50 times its own volume." [7]

Radio and news releases indicate that the Soviets possess considerable knowledge on oxygen regeneration agents. For example, the 200 liters of algae stipulated by the work at the Bogomolets Physiology Institute as being necessary to cover the requirements of one man compares quite favorably with the volume of algal suspension calculated as essential for a one man closed ecological system by a leading United States scientist.[5]

Organisms as Food Sources on Space Vehicles

Soviet reports have suggested the use of algae as a food source for space flight, but, contrary to Western literature, none of their papers indicate that the algae might not be satisfactory as a complete food.[3,4,6,7] The Soviets have made detailed analyses of the composition of algae, so they probably realize that algae cannot be used as a sole food source. In addition, very complete studies have been reported in the open Western literature concerning the use of algae as food sources, so these data are available to the Soviets. (See appendix.)

Soviet scientists have studied the alteration of carbohydrate, protein, and lipid concentrations in algae by variation of the nitrogen content of the mineral nutrient culture solution. The concentrations of these end products are readily adjusted and maintained at predetermined levels (within specified limits). The ranges obtainable (calculated as percentage of dry weight of the algae) are: carbohydrates, 5.7 to 37.5 percent; lipids, 18 to 85 percent; and proteins, 9 to 50 percent. Basically, a low nitrogen content of the nutrient solution produces a low-protein and high-lipid alga, and a high nitrogen content produces a high-protein and low-lipid alga.[8,9] The ability to adjust and maintain the quantities of basic constituents in the algae (protein, lipid, and carbohydrate content) is extremely important with respect to maintenance of a balanced diet for man.

Under continuous culture with optimum conditions for photosynthesis and growth, rapid cell division and growth of the cells produced by division have been noted by Soviet scientists. The weight of algae in a culture often doubles by growth in 16 to 20 hours or sometimes even quicker (up to twelve times increase in weight in 1 day). However, close monitoring of the mass culture device is essential, as no device can be considered to maintain a maximum growth rate without provisions for adequate nutrition, light, and temperature. A regimen of daily harvesting and replacement of nutrients is essential for optimal growth and cell division of the alga culture.[8,9]

Organisms Used in Waste-Disposal Systems

No evidence is available to indicate that the Soviets have been working toward development of a biological waste-disposal system for space vehicles. On the other hand, the West has not published much on this problem either. (See appendix.)

Weight and Volume Considerations

Dr. P. Isakov, a Soviet biologist, has stated that in flights of several months or more, it would be expedient to utilize plants on the space ship to effect gas exchange.[10] For flights of less than several months, a biological gas regeneration system would take more space and weight than would a chemical regeneration system. This statement by Isakov is in general agreement with U.S. research on the weight and volume taken up by a workable biological gas exchange system.

Effect of Space Flight Environmental Factors

Soviet scientists, as well as those in the West, have conducted much research concerned with the effects of environmental factors on the organisms potentially useful in a closed biological system in space. These studies have determined optimum, maximum, and minimum temperature; light intensity; and gas composition for the various potentially useful organisms. In addition, maximum allowable radiation and gravitation effects have been determined. (See the appendix for a discussion of these environmental factors.) In general, Soviet research on the effects of these environmental factors on unicellular organisms has been less extensive than comparable Western research, but it is still sufficient to satisfy the requirements posed by the development of a closed biological system for space travel.

Research Organization, Manpower, and Facilities

Organized planning and control of space biology research is probably carried on by the ICIC, but no definite information on the organization of research efforts or official plans of the program is known.

Research personnel studying photosynthesis using algae as test organisms and those scientists conducting research on the mass culture and physiology of algae can competently conduct research in specific areas of space biology without undergoing extensive reorientation or training. Microbiologists conducting research in the physiology of microorganisms and in industrial and residential sewage disposal are likewise, for the most part, qualified to carry out specific phases of space biology research. The USSR has some highly trained, competent research workers in these fields, and it is probable that some of these individuals are participating in the Soviet space biology research program.[12-14]

Only minor modifications of many of the normal microbiological or photosynthetic research facilities would have to be made before space biology research could be carried out. The facilities have proven adequate for Soviet microbiological and photosynthetic research and would prove equally adequate for space biology research.[12-14] Included in the Soviet research facilities are controlled-environment chambers which would be invaluable in space biology studies.

Other Bloc and Chinese Support

Several of the European Satellite countries, notably Czechoslovakia and Poland, have in the past done some excellent microbiological and algal mass culture studies, and the Chinese have recently reported on their mass algal culture research. These research studies on mass culture of algae are concerned with the mass production of the organisms for use as food supplements and as sources of desirable organic compounds. They are not designed as space biology research projects, but the information obtained will be valuable in the design of algae carbon dioxide-oxygen exchange and food production systems for space vehicles. The quantity of these studies has not been great, but the quality of some of the research has been high. There is no direct evidence to prove involvement of the research workers in a Soviet organized space biology research program.

ASTROBIOLOGY

Scientific observations related to astrobiology have dealt with the possible existence of life, as it is known on earth, under the environmental conditions thought to be present on planets other than earth. Currently available evidence does not indicate that results of such scientific studies have been published by the Soviets, but does indicate that such studies are among the Soviet objectives. Reported Soviet astrobiological research has employed scientific methods for the collection of data but has followed unproven hypotheses and conjectures for the interpretation of these data. Most of this research has been conducted by the staff of Tikhov's astrobiological laboratory at Alma-Ata. Considering the small size of the group, Tikhov and his coworkers have conducted a vigorous, fruitful program on the absorption and reflection of light rays by plants under varied terrestrial environmental conditions.[18]

The research concerning the terrestrial plants has been competently executed and evaluated and has added considerably to an understanding of the life of plants under adverse terrestrial climatic conditions. Nevertheless, these data have done little to prove whether living organisms are or are not present on Mars as some members of the Alma-Ata group claim. The data show that plants growing under extreme terrestrial climatic conditions differ in their light absorption and reflection capacities from those grown under more temperate terrestrial conditions. But, in translating these data so as to prove the existence of life under the extreme climatic conditions of Mars, these Soviet workers either discount or do not take into consideration the greatly reduced atmospheric pressure and deficient oxygen and water content on Mars. Nor do they consider the possibility of a variance in the evolutionary trends of extraterrestrial organisms as compared to terrestrial organisms.

The answer as to whether life is or is not present on Mars must await observations from a vantage point closer to Mars than the surface of the earth. The hypotheses of the Astrobiological Sector of the Kazakh Academy of Sciences (which supposedly prove that living organisms are present on Mars) use scientific evidence in part but rely heavily on suppositions for translation of terrestrial data to Martian conditions. The resulting combination of hypothetical and scientific approaches is of questionable validity.

A more realistic Soviet approach to the question of life on Mars was summed up by V. G. Fesenkov (Director, Institute of Astronomy and Physics, Kazakh Academy of Sciences) as follows:

> The surface of Mars is smooth; "seas" and "continents" do not essentially differ from each other; they are similarly covered with dust. "Seas" [of Mars] get warm to a greater degree, that is they behave like a surface covered with mineral substances. There is no oxygen in the atmosphere of Mars. There is only an insignificant amount of water; if one imagined it to be a layer spread out over the whole surface of Mars, then the thickness of this layer would equal 0.1 millimeter. The hypothesis about plant life on Mars is one-sided, because it explains the appearance of periodic coloring of "seas" only after the analogy of terrestrial vegetation. A volcanic hypothesis can explain a greater number of observed facts, although it too presents many difficulties. . . . From the cosmic point of view, the surface of Mars, both in the past and in the future, in regards to conditions of life, can be likened to a plateau on earth 18–20 kilometers high with an absolute absence of oxygen and water. It would be strange to assume an origination of life under such conditions at the present time, and in the remote past also life on Mars could not have originated because the conditions of environment were the same as now.[16]

As a result of a 1956 Soviet conference concerning the existence of life on other planets, a Scientific Council was elected, charged with coordination of scientific research on the problem of prognostication of conditions of life on other planets, and further charged with the development of a Five-Year Plan for scientific research in this field. In addition, the conference approved a Five-Year Plan for "astrobiological" research by the Institute of Biophysics of the USSR which included four basic subjects: (i) studies of spectral characteristics of terrestrial plants under extreme conditions of existence and their comparison with corresponding data of astrophysicists and astrobiologists; (ii) laboratory experiments with plants under conditions imitating planetary environmental conditions; (iii) selection of terrestrial forms of plants that grow satisfactorily under extreme conditions; (iv) study of the peculiarities of photosynthesis under conditions found on Venus and Mars and analysis of conditions for the origin of life on those planets in connection with data about the history of life on earth.[16]

Results of portions of this Five-Year Plan of the Biophysics Institute can be of value in determining whether terrestrial organisms can exist under extraterrestrial planetary conditions and can allow development of hypotheses concerning the possibility of the existence of earth-type life on those planets at the present time. The planned research will not lead to proof of the validity of the developed hypotheses.

In January 1958, Tikhov received instructions from the Soviet Academy of Sciences to turn the full resources of his institute to studies of the "biology of Sputniks and space flight" and the establishment of laboratories that will "support human beings in Sputniks." The total professional staff of Tikhov's laboratory was five people; with the reorientation of research duties, the staff was increased to 20 people.[15] During August and September 1958, Tikhov indicated a deemphasis of astrobiological research in the USSR.

Even at the 1956 conference concerning life on other planets, some individuals requested that space biology research rather than that described and defined above as astrobiological research should be undertaken without delay in the Soviet Union. A. G. Karpenko of the ICIC stated, "This [lack of space biological information] obliges us to conduct a careful preparation on a wide scale for the forthcoming flights to other planets. Biologists should have begun their research on the problems under consideration five years ago, yet they appear to be unprepared even for the future launching of artificial satellites."

APPENDIX

SCIENTIFIC BACKGROUND

INTRODUCTION

Research in space biology consists basically of studies in four areas, namely, (i) replacement of respiratory carbon dioxide in a space vehicle atmosphere with photosynthetically produced oxygen, (ii) continuous production of food for the vehicle occupants, (iii) disposal of solid, liquid, and gaseous human waste products and utilization of these altered products in the closed biological cycle, and (iv) studies of the effects of space flight environmental factors on organisms potentially useful in a closed cycle system.

Myers, in 1954, summarized the closed cycle system for space vehicle as follows:

> It is an idea which suggests that we reconstruct in a small space the same balance for oxygen-carbon dioxide accomplished by the entire biological world. If this could be done completely, it would duplicate the balance in the total biological world in which foods, exchange of gases, and excreta become balanced by the action of many organisms into a materially closed system driven by high energy input alone.[5]

ORGANISMS AS OXYGEN REGENERATION AGENTS

Data pertaining to this problem has been developed in photosynthesis and algal mass culture studies over a period of many years. The data have been published in the world's biological journals and are readily available to research workers. Research in this area has shown that unicellular algae have a greater photosynthetic efficiency than other plants tested. Recent studies have produced strains of algae with exceedingly high carbon dioxide-oxygen exchange capacities.[5 8 19-21]

In 1954, Myers published the following information concerning the closed one-man ecological system using the algae *Chlorella pyrenoidosa*:

1. A conservative estimate is made that 2.3 kilograms of *Chlorella* will supply sufficient gas exchange capacity for one man.
2. A concentration of 10 grams of algae per liter of solution will absorb 97 percent of the incident light at a solution thickness of 0.4 centimeter; if illuminated from both sides, the thickness of the culture could be 1 centimeter.
3. Therefore, the 2.3 kilograms of algae diluted to a 10 percent concentration in a layer 1 centimeter thick for efficient use of light, would require a lighted surface area of 230,000 square centimeters or 240 square feet.

ORGANISMS AS FOOD SOURCES ON SPACE VEHICLES

Unicellular organisms grown in mass culture systems have been suggested as high-yield, high-quality food sources. In a limited number of cases, actual use of such organisms has been made, but primarily as a supplement to an otherwise protein- or vitamin-deficient diet. Algae have been suggested as a potentially valuable sole food source for use in space flight. Experimentation, however, has shown that algae are deficient in specific amino acids and vitamins, primarily the amino acids cystine and methionine* and several vitamins, especially vitamin D. A surprising consistency in the amino-acid and vitamin content has been found in all algae analyzed. Animal experiments indicate that supplemental feeding of the deficient amino acids and vitamins allows normal growth and metabolism on an algal diet.[5 8 11 19 22-26]

*Methionine is one of the eight amino acids which cannot be synthesized in the human body and, therefore, must be supplied in food. Cystine can be synthesized in the human body but methionine is needed to supply sulphur for the synthesis.

ORGANISMS USED IN WASTE-DISPOSAL SYSTEMS

Much of the space biology work on closed cycle biological systems has concentrated on employment of a single organism to satisfy all requirements. Algae have been the primary subject of research because of their extreme activity in oxygen regeneration and their rapid increase in edible mass. Yet only a portion of the unprocessed human excreta could be used in a closed algal system, and unprocessed excreta would satisfy only part of the mineral nutrient requirements of algae. The remainder of the excreta must be converted by microbiological or chemical methods into substances usable in a closed system cycle.

As indicated, attention has been directed toward development of a closed cycle biological system using only algae to balance man's metabolism. Evidence currently available indicates that a multiorganism system must be developed to balance the metabolism of human space-vehicle occupants, since no single organism which has been tested can completely produce metabolic balance for man in a closed cycle. Considerable data is available in the open literature that will aid in solving the waste-product disposal problems but, as far as can be determined in this survey, a workable waste-disposal system has not been designed which will return all, or even almost all, waste products into the metabolism cycle.[2 5 11 17 26]

EFFECT OF SPACE FLIGHT ENVIRONMENTAL FACTORS

Scientists have conducted many studies concerning the effects of temperature; light intensity; irradiation with X-, alpha-, beta-, and gamma-rays; centrifugation; and changes in gas composition on organisms which might be useful in a closed biological system for space flight.

Temperature Effects

In general, the microorganisms which might be useful in a closed system have a wide range of temperatures at which their effectiveness is optimal. The optimal temperature range varies with the species of organisms but falls within the range normally considered as optimal for human activity. Information pertaining to these temperature ranges is common knowledge in the scientific community.

Light Intensity

The photosynthetically active microorganisms potentially useful in a closed system vary as to their light intensity, quality, and duration requirements for optimal photosynthetic activity. Data on these requirements also have been developed over a period of years and are known fully to the scientific community.

Strains of algae have been tested that have a higher growth rate and a greater photosynthetic rate than the commonly employed research strains of *Chlorella* and *Scenedesmus*, but new problems are introduced through the use of some of these high-yield strains. For example, the Sorokin high-temperature strain has a lower photosynthetic rate at low temperatures and light intensities than does the normal research strains of *Chlorella* and *Scenedesmus*.[21] Consequently, both light intensity and temperature must be maintained within comparatively narrow limits in any device utilizing this strain of alga for gas exchange or food purposes.

Irradiation Effects

The treatment of microorganisms with X-rays, alpha-rays, beta-rays, gamma-rays, and, to an extent, ultraviolet-rays has been shown in Soviet and Western research to be primarily lethal. Presumably a comparable effect, but of different intensity, would be obtained with cosmic rays. The death of some cells in a culture of microorganisms does not, however, result in death of the total culture. Consequently, unless it were sufficiently intense to induce death of all the cells, irradiation would reduce but not stop the activity of a microorganism culture. The reduction in activity would be proportional to the percent of organisms killed or inactivated, but the growth rate of the remaining undamaged cells would soon bring the microorganism population back up to the optimal concentration. Radiation-induced mutations might be produced in the utilized organisms. These mutations would be primarily lethal and would result in death of the irradiated cells or their progeny. The few nonlethal mutations might possibly lead to an ultimate decrease in the efficiency of the biological system, but it is not believed that a significant reduction is likely.

Centrifugation

Microorganisms have been subjected to many hundreds of times the force of gravity in centrifugation, and on reculturing have shown no decrease in vital activity. Hence, the limiting factor for manned space flight, as far as acceleration rates are concerned, will be man or equipment rather than the microorganisms used in any closed system. The effect of weightlessness on the active organisms potentially useful in a closed biological system has not been determined, but it is believed that this factor will not have any harmful influence on the organisms suggested for use.

Gas Composition

No literature has been found pertaining to the activity of organisms in the helium-oxygen atmosphere suggested by some scientists. It is not believed that this modification would alter the activity of any of the organisms potentially useful in a closed system. On the other hand, any great reduction in oxygen concentration would induce anaerobic respiration and result in alcohol production in most of the potentially useful organisms (including the photosynthetically active organism *Chlorella*). Maintenance of the oxygen conditions necessary for the survival of man will preclude the possibilities of such a respiration effect on the microorganisms in a manned space vehicle.

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