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DIRECTORATE OF
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Scientific and Technical Intelligence Report

Biomedical Aspects of Establishing a Soviet Manned Lunar Base

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Scientific and Technical Intelligence Report

BIOMEDICAL ASPECTS OF ESTABLISHING A SOVIET MANNED LUNAR BASE

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CENTRAL INTELLIGENCE AGENCY

DIRECTORATE OF SCIENCE AND TECHNOLOGY

OFFICE OF SCIENTIFIC INTELLIGENCE

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PREFACE

It is anticipated that the Soviets ultimately will conduct a manned lunar landing. A payload on the moon of about 40,000 to 50,000 pounds is believed to be within Soviet capabilities. Thus, the USSR is expected to have the necessary payload capability for delivery of lunar base hardware and equipment. This paper examines Soviet biomedical capabilities and limitations for preparing man to exist, remain, and perform useful tasks on the moon.

This report has been prepared by the Office of Scientific Intelligence and coordinated with the Directorate of Intelligence. Information as of July 1969 has been used.

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PROBLEM

To evaluate Soviet biomedical research and development applicable to maintenance of man in a lunar environment.

CONCLUSIONS

1. Given the capability to deliver 40,000 to 50,000 pounds to the surface of the moon, the Soviets possess the biomedical capability for planning and establishing a lunar base for durations up to approximately three months initially and, depending upon the results at that duration, thereafter they could establish a base for approximately six months. The necessary life support equipment and assurance of cosmonaut protective measures gradually will be evolved from the operational experience gained during shorter lunar flights.

2. Before a lunar base can be established, the Soviets will need a more advanced spacesuit technology than they now possess and a better solid waste management system. They will also need to incorporate a water regeneration link into the life support system. The environmental and life support factors which should not prove to be unusual problem areas for the stated mission durations are meteoroids, medical monitoring, circadian rhythm,* and food supply. Those factors which will require further elucidation under actual lunar conditions are some of the effects on man of isolation and confinement, determination of actual radiation dose levels and protective measures required, and the effect of reduced gravity on cosmonaut energy expenditures during task performance.

3. The Soviets probably would make certain changes from their present system in the lunar spacecraft/habitat environmental control system to facilitate cosmonaut excursions on the lunar surface. These changes would include lowering the atmospheric pressure and increasing the percentage of oxygen in the two-gas environment. A change in diluent gases from nitrogen to helium may occur, although it is unlikely. The pressure suit for lunar excursions also would operate at a lower pressure than that used previously.

4. The Soviets probably will test a partially closed physiochemical life support system (water regeneration, stored food, oxygen from superoxide chemicals) under lunar conditions for use in such missions as those of three and six months duration shortly after their initial lunar landing. Accomplishment of the necessary medical and life support development and testing could permit a Soviet base for prolonged manned use (about one year or more) to be established on the moon by the mid-1980's.

*The normal circadian rhythm is a cyclic variation of basic physiological and psychological processes that are coordinated with the daily alternation of daylight and darkness.

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SUMMARY

Since 1964, Soviet statements in the press, at certain international meetings, and by reliable cosmonauts evidence interest in and work toward a goal of establishing a manned base on the moon. Physiological and psychological research and development under conditions said to be similar to those on the lunar surface are carried out at the Vostok Station in the Antarctic by personnel from the key bioastronautic institute in the USSR, the Institute of Medical and Biological Problems.

The Soviets are assessing certain features of the lunar environment of concern to crew survival and performance of tasks on lunar base missions such as the meteoroid and thermal environment and reduced gravity and radiation conditions. Data from Luna 10 indicated that the meteoroid flux on the moon was a hazard to cosmonauts. Later meteoroid data, collected by a new sensing device, give much lower values and indicate that there now is good agreement between US and Soviet data and minimal danger to man from meteoroids on the lunar surface.

The wide temperature extremes (from 260° F to minus 240° F) between lunar day and lunar night are being considered in Soviet studies on temperature extremes and their effect on man for prolonged periods in the Antarctic (average temperature of about minus 67° F with extremes to minus 126° F) and in chamber test experiments (to plus 158° F).

Soviet scientists have conducted a great many investigations into the hazards of radiation related to lunar missions in the research laboratory and during several unmanned spaceflights. The greatest radiation hazard during lunar missions is from solar flare proton events. The next solar maximum after the current one will be from 1980 to 1982. The other major source of radiation on lunar missions is galactic cosmic rays. These are not considered hazardous to cosmonauts because even under the worst conditions, the dose levels are not expected to exceed 50 mrad/day. On the way to the moon, radiation acquired during a one-way passage through the Van Allen Belts with minimal shielding would not exceed 10 rad.* The Soviets have been conservative in allowable radiation dosage levels on manned flights. During the last several years, however, they have raised these limits and now permit a dose of 50 rem** for missions of days or weeks and about 125 rem over a period of a year.

Soviet protective measures against radiation involve avoidance, shielding, and use of chemicals or drugs. They are interested in achieving a world-wide solar flare forecasting network with improved methods of forecasting solar flares during manned missions beyond the present maximum five-day capability. Since occurrence of a solar flare proton event on a lunar mission would necessitate cosmonaut return to shelter, the Soviets have discussed use of lunar material (soil) as an acceptable method of cosmonaut protection during prolonged missions. More information is needed on the depth of the lunar soil before such material could be used for cosmonaut protection, however. A Soviet spacecraft with at least 5 gm/cm² shielding should protect the cosmonaut against solar particles during shorter missions or before any cumulative effect of a series of events is detected. The Soviets have no effective antiradiation drug; any statements concerning such preparations serve to propagandize the safety provided to cosmonauts and function as a psychological crutch for the crew.

Lunar base life support equipment will emerge from lunar excursion technology and will become more regenerative with time. The first regenerative life support link will involve water and could extend the duration of manned missions such as a lunar base for 200 days or longer.

Recently released Soviet data are used to assess several hypothetical lunar base models varying from 90 to 365 days and with a crew range of between four and 12. An evaluation is made on

*Data on the acute effects of whole body radiation give levels of up to 25 rads—no observable effects; 100-200 rads—fatigue, nausea, and vomiting within 3 hours for 50 percent of personnel; and 300-400 rads and up—death for 90-100 percent of personnel.

**rem—Used to measure dose of radiation in terms of a biological effect as for example on the eyes, i.e., 200 rem of protons (100 rad) or 200 rem of X-rays (200 rad) produces the same effect on the eye.

the specific life support developments needed and the capability of the Soviets for attempting such lunar base missions based upon this technology.

Although the Soviets are involved in evaluating various methods of treating solid wastes, they have not developed a workable system and do not appear to have decided upon an optimum design choice. Their eventual choice probably will be based upon some method of incineration. There is no evidence of any Soviet innovative techniques for collecting and handling solid waste material.

The Soviets have done considerable research and development related to closed life support systems which is applicable to a lunar base for prolonged use. They obtained operational data on physio-chemical systems for flight equipment design in the recent one-year chamber experiment. Research on biological regeneration systems may be ready for an initial operational test under unique conditions at the Vostok Station in the Antarctic. Such life support equipment is probably not ready for packaging into a limited volume and will not be considered by the Soviets to be ready for spaceflight for 10 years or more.

A key element in Soviet capability for establishing a lunar base is spacesuit development. The extravehicular suits demonstrated on the Voskhod/Soyuz flights appear inadequate for extended extravehicular activity on the lunar surface. The Soviets need a pressure suit with improved joint flexibility and a better method for removal of high heat loads. They recently demonstrated a new and significant duration portable life support system during the Soyuz 4-5 extravehicular activity based upon superoxide technology. This system has a capability of excursions in excess of four hours with a possible maximum of 12 hours. The Soviets probably have a water-cooled suit which is undergoing testing in the laboratory, but development of a hard suit or capsule with mechanical appendages represents a very advanced state of development beyond that demonstrated thus far in Soviet spacesuit design.

An additional problem in Soviet spacesuit design has been the high metabolic cost to the cosmonaut due in significant part to the high suit pressure used. Soviet utilization of a two-gas cabin environment under one atmosphere of pressure necessitates this high suit pressure, since a lower suit pressure would require more denitrogenation time before extravehicular excursions. Leading Soviet scientists involved in spacecraft environment control system research and development have stated that work is progressing in two ways—on retention of the same cabin environment and in changing this environment in regard to the diluent gas (helium or nitrogen), the percentage of oxygen, and the atmospheric pressure used.

The effects of isolation and confinement have been described by a prominent Soviet scientist as major problem areas in the manned space program. Soviet scientists have studied the effects of isolation on man including chamber tests of 120 days and, recently, in a one-year experiment. Soviet crew size requirements for a lunar base are unknown, but several scientists favor an even numbered crew of at least four for prolonged missions. Although circadian rhythm of man was once considered to be a major spaceflight problem, the Soviets now appear cautious but optimistic in their assessment that it is one stress factor which can be overcome at least for short to moderate duration missions. Cosmonauts have made increased use of mission simulators in training for manned flights and reportedly are preparing for lunar missions in several types of training devices including a lunar gravity simulator, a model of the lunar landscape, and landing training in helicopters.

Lunar base missions will necessitate more self-monitoring and medical analysis by the cosmonaut crew. A significant advance in medical monitoring demonstrated during recent flights is the use of a cardiotachometer. This device provides data compression which reduces the need for the crew to monitor the electrocardiogram constantly, permits monitoring of more than one cosmonaut, and allows for periodic transmission to ground stations of biomedical data at a much reduced telemetry bit rate from the moon. The Soviets already have tested their biotelemetry system at lunar distances during recent Zond flights.

The Soviets have been engaged actively in man-machine studies of some other potential problem areas affecting man's performance, including cosmonaut working capacity, task analysis, cabin interior and control panel design, and reliability of man in spacecraft control systems. There is only theoretical evidence of work in lunar base habitat design. This human factors work is generally on a par with that of the United States.

DISCUSSION

INTRODUCTION

Soviet statements

Statements have appeared in the USSR press and have been made by scientists which indicate that the Soviets are interested in and are conducting research and development related to establishing a manned base on the moon (table 1). In a 1965 interview with cosmonaut Feoktistov, *Tass* reported the cosmonaut as saying that one of the major areas where work was proceeding included study of the moon's surface and of the possibilities for establishing manned scientific stations there.[1]

In 1967, the Soviet space program and budget reportedly were directed to exploit the scientific and military advantages of i) enormous earth orbiting laboratories, ii) lunar orbiting laboratories, and iii) *lunar bases*.[2] The current level of Soviet technology was said to be able to accomplish those objectives and the necessary instrumentation and equipment were then being developed.

Table 1

Soviet statements and work related to establishing a manned lunar base

Date	Event
1964	Soviets present paper on possible approaches to lunar base construction
	Soviet interest in key US concept study on manned lunar base
1965	Initial Soviet bioastronautic-related research underway in Antarctic
	Cosmonaut interview that Soviets are studying possibilities of manned station on moon
1966	Antarctic studies continued
1967	Soviet space program reported to include emphasis on lunar base
	Further bioastronautics research in Antarctic
1968	Soviet paper scheduled: life support system on moon
	Statement in USSR press that one objective of Antarctic research was for stay of man on the moon

In 1964 the Soviets presented a paper at the International Astronautical Federation (IAF) meeting in Poland outlining approaches to construction of a manned base on the moon.[3] At that time, the paper was considered important not because it revealed any new concepts but because it was the first discussion on lunar bases presented by the Soviets in open conference. At this same meeting, the Soviets were extremely interested in the information and presentation of the initial US concept study for establishing a manned base on the moon—the Lunar Exploration System for Apollo program (LESA). The United States had published a summary report of this concept some months prior to the meeting.[4] The Soviets also have participated in the Lunar International Laboratory (LIL) symposiums held during the IAF meetings. The first international symposium was held in 1965; the second dealt with the life sciences and lunar medicine aspects of a base on the moon.[5] The last symposium (the fourth) was held in October 1968. During this meeting, V. V. Parin, the leading Soviet scientist in their bioastronautic research and development program, was scheduled to present a paper on life support for lunar conditions, but it was cancelled.[6] This is the first bioastronautics paper, however, that the Soviets were scheduled to give at an LIL that was related directly to the topic of life support on the moon.

An article in *Pravda* in late 1968 stated that Soviet research conducted at the Vostok Station in the Antarctic was under way in order to "study the conditions of a stay by man in space or on the moon."[7]

Antarctic research

The Soviets have conducted bioastronautic-related research at Vostok Station in the Antarctic since 1965.[8–14] This research has been conducted by personnel of the Institute of Medical-Biological Problems, the principal USSR bioastronautics facility.[9 11 15] The Soviets state that the idea of using the central part of the Antarctic as an experimental laboratory simulating conditions on the moon originated at the first symposium on Arctic medicine held in Moscow in 1963.[9]

Work carried out and underway at Vostok Station includes training men for work under extreme conditions, isolation and confinement studies, influence of monotony of the surrounding environment, and group psychological investigations. Other research involved biological rhythms, influence of physical loads on the human organism, water balance studies, food rations for cosmonauts, and accumulation of physical information for medical control of man over prolonged periods in limited quarters. Metabolic studies that were involved also related to the development of protective clothing and possibly even spacesuits. It was estimated by one US visitor to the station that space-related psychological and physiological research was a major reason for keeping Vostok Station in operation.[16]

The studies at Vostok could provide valuable data concerning future biomedical requirements for a manned base on the moon. The enforced isolation, low atmospheric (barometric) pressure, low temperature, and required muscular movements are regarded by the Soviets as being close (except for reduced gravity) to that anticipated for life on the moon.

PHYSICAL ENVIRONMENT ON THE MOON

Meteoroid environment

Soviet data from Luna 10 indicated that the meteoroid flux in the vicinity of the moon was a potential hazard to the cosmonaut walking on the surface of the moon unless protected by a spacesuit possessing considerable penetration resistance.[17] By contrast, US data indicated that there was no major danger to personnel wearing spacesuits. The Soviet data on meteoroid flux on the moon were three orders of magnitude higher than the data revealed by the US lunar orbiter program. Luna 10 in 11 hours and 50 minutes of data sampling registered 198 hits; the US orbiter registered its ninth hit after nearly nine months of continuous data sampling. The Soviets used a piezoelectric microphone-type impact sensing device and the US sensors were pressure cans which registered a hit when penetrated and relieved of their internal pressure.

In 1968, however, the Soviets announced the results of meteoroid sampling from Cosmos 135 and Cosmos 163.[18] They stated that an improved acoustical sensing device, largely protected from the influence of noise, had been used on these flights. The data recorded by this new sensing device were said to be three orders of magnitude lower than those recorded by earlier devices. Thus the Soviets have admitted that their problem with the previous sensing device was its sensitivity to noise. Consequently if this new sampling device were used to record lunar data, there probably would be good agreement between US and Soviet meteoroid data in the vicinity of the moon.

Thermal environment

The moon, lacking an insulating atmospheric layer, receives unattenuated energy from the sun during the lunar day but cannot retain it through the night. This leads to extremes in temperature as the moon passes through the day-night cycle. Surface temperatures on the moon range from 260° F to −240° F.[19]

The Soviets recognize the problems involved in thermal control in the lunar environment and have been studying, for example, the effects on man while living and working in extremes of low temperature at Vostok Station. The lowest temperature on earth was recorded at this base in August 1960, a minus 126.9° F.[20] The mean annual temperature during 1958-61 was −67.7° F.[21] The warmest year was in 1961 with a mean temperature of −65.6° F.

The Soviets have been investigating the adaption of man to these extremes in environment and studying the effect of this stressful environment on the respiratory, circulatory, and autonomic nervous system.[22] They have determined that the design temperatures of building in winter at Vostok must be 64.4° F or 69.8° to 71.6° F at a height 1.2 to 15 m above the floor.[23] Average temperatures during the entire period of observation in the medical or warmest building ranged from 66.2° F to 69° F. However, the Soviets commented that analysis of the data obtained showed insufficient insulation in some of the buildings at Vostok Station and better material and testing were needed.

Soviet scientists also have investigated the adaptation of cosmonauts to possible high-temperature conditions. One series of tests reported recently was carried out with 17 human subjects at chamber temperatures of 122° F to 158° F lasting for one hour with varying exposure periods up to two to

[redacted]

four months.[24] Results of these experiments could be used in the selection of cosmonauts. Adaptation was found, however, to be of relatively short duration (10 to 30 days).

Reduced gravity environment

The cosmonaut must learn to function under the gravitation field on the moon's surface, since lunar gravity is one-sixth that experienced on earth. Little information and only sparse indications exist of Soviet research and development related to determining energy expenditures for work during simulated lunar gravity. The Soviets have released, however, a great deal of information on acceleration research using a centrifuge.[25] This could be applied to the understanding of a hypogravic situation. The centrifuge is used to accustom subjects to a hypergravic force so that on return to the normal gravity form they may experience something similar to the reduction from 1G to reduced gravity. The Soviets also have published numerous papers on hypodynamia (weightlessness) and hypokinesia (diminished movement) which indirectly relates to understanding functioning under an altered gravity situation.[26]

The Soviets were reported in 1966 to have a lunar gravity simulator under construction. It appeared to resemble the lunar surface simulator at Langley Research Center, Virginia (built some two years earlier).[27] The subject is suspended by wires while he attempts to walk on a plane inclined 9° to the vertical. This technique is useful to train subjects in a variety of body maneuvers under simulated conditions of the moon.

Several other statements are made in the Soviet literature concerning the need for research and training for man under the reduced gravity conditions on the moon. Cosmonaut Gagarin stated that with special training the cosmonaut will develop new motor coordination and adapt to conditions of lowered gravity on the moon.[28] In a paper presented at the IAF meeting in Warsaw in 1964, Isakov stated that it was "extremely important (to study the effects of gravity on body functions) in preparation for prolonged spaceflights in view of the peculiarities of the gravitation field on the moon's surface." [29] In 1968 Parin stated that studies were underway on the energy loss during movement under conditions of low gravity.[30] A Soviet paper directly related to and titled "Training Humans to Walk on the Moon" appeared in *Aviatsiya i kosmonavtika* in 1966.[31] It is uncertain whether it discusses US or Soviet research, but the article does relate various training devices used for lunar training such as simulation using fluids, spring devices, or suspension from wires. Visual training methods using lunar surface features are discussed also.

Radiation environment

CONSTRAINTS DURING MANNED LUNAR MISSIONS— The particulate radiation flux upon the lunar surface comes from two major sources: galactic cosmic particles and solar flare protons. Galactic cosmic rays, however, are not considered a hazard to cosmonauts, i.e., dose rates from the galactic field even under worst conditions should not greatly exceed 50 mrads/24 hours.[32]

Solar cosmic rays (high-energy protons and alpha particles) ejected during a solar flare proton event are, however, the greatest radiation hazard to man in establishing a lunar base. Periods of solar flare maximum occur in 11-year cycles—the next solar maximum after the current cycle (1969-71) will be from 1980-82. The total dose from an individual proton event varies from insignificant doses of a fraction of a rad to doses approaching 1,000 rad. The acute effects of radiation on man are shown in table 2. Actual Soviet models for calculation of solar cosmic ray events are unknown since most of their literature references US source material. Earlier (1964 and 1967) calculations appeared to use solar flare ratios composed of 85-90 percent protons and 10-15 percent alpha particles.[36] In the last few years, it has been realized (by the United States) that alpha particles as well as protons are given off in quantity by large solar flares.[34, 37] For the larger of these so-called "proton events," the ratio of alpha particles to protons is about 1:1.

In a comprehensive book on radiation safety during spaceflight, several Soviet scientists concluded (in 1964) that "existing data on the frequency and duration of different types of solar flares as well as the intensity and spectral-angular proton distributions are completely inadequate for an accurate determination of radiation danger and, of the necessary shielding thicknesses for inhabited compartments of spacecraft, which will be undertaking

Table 2

Acute effects of radiation on human body [33–35]

Acute whole-body dose (rads)	Biological effect of absorbed doses
0–25	No observable effects.
25–50	Minor blood changes, no discomfort.
50–100	Nausea and vomiting for about 1 day in 10% [a] of personnel. No deaths.
100–200	Fatigue, nausea and vomiting. Will probably occur within 3 hours in 50% of personnel.
200–300	Nausea, vomiting in 90% of personnel along with other signs of radiation sickness. Deaths of 10–50% of personnel within 2–8 weeks.
350–400 and up	Probability is high that deaths will occur in 90–100% [b] of personnel.

[a] An example of variations which should be considered is that a given sign, e.g., nausea, may have a 10 percent probability of occurrence following an exposure of 50 rads delivered over 2 to 4 hrs. (dose rate 12–25 rads/hr), while an exposure of 125 rads (2.5x50) would produce the same probability of response if the dose were protracted over 2 to 4 days (dose rate 30 to 60 rads/day).

[b] Dose estimates at the 10 and 90 percent response levels may be in error by ±50 percent or more. The response levels given are compatible with clinical practice; space radiation response predictions may be additionally uncertain due to the uncertain physiological impact of other physical stresses associated with spaceflight.

long flights." [38] Future studies in this area were said to be necessary as well as development of reliable methods for long-range forecasts of solar flares, radiation warning, and dosimetry.

A spacesuit (shielding of 0.15 gm/cm²) offers little if any protection for the cosmonaut on the lunar surface during solar flare activity.[39] He could receive a dose from a solar flare proton event up to 1,000 rad (a lethal dose) if not warned to take cover. A thin walled vehicle such as the US lunar module (0.1 gm/cm²) also would provide little protection against radiation.[39] Shielding levels of Soviet spacecraft are unknown, but probably are at least as heavy as the US Apollo command module.* The heavier shielded spacecraft would offer the crew protection from a proton event under most circumstances.

An additional source of radiation on the way to the moon are the trapped radiation belts around the earth. Calculations show that on a one-way passage through the radiation belts on a lunar trajectory behind a shielding of 1.0 gm/cm² of aluminum, the dosage would be about 10 rad.[34] This yield is due mainly to trapped electrons.

The Soviets have been intensely concerned about radiation hazards during spaceflights.[40–44] They have conducted numerous experiments in the laboratory and in space on understanding the radiation environment in the earth's magnetic field including the Van Allen Belts (e.g., Proton flights, Cosmos 110), on the way to the moon (e.g., Zond 5 and 6), and on the lunar surface (e.g., Luna–10).[45–47]

RADIATION LEVELS ACCEPTABLE TO SOVIETS—The Soviets traditionally have been conservative on allowable radiation dosages for cosmonauts (tables 3 and 4).[48] During the Vostok flights, the level of risk assumed officially by the Soviets was 25 rems per year. Since 1965 the Soviets (Grigor'yev et al.) raised the allowed dosage to 50 rem for orbital and moon flights.[49] Recent Soviet reports emphasize that these values are not applicable

*It is estimated that 91 percent of the combined Apollo command module and service module has a shielding density of 5 gm/cm² or more.[34]

Table 3

Soviet mission radiation dose limits [48 49]

Classification	Definition	Dose
"tolerable dose"	No perceptible somatic damage during entire life of individual.	15 rem
"justifiable risk"	Slight clinical evidence of temporary radiation injury; no fatalities.	50 rem
"critical dose"	Definite clinical evidence of radiation injury; no fatalities.	125 rem

[redacted]

Table 4

Apollo mission emergency dose limits[34] (surface exposures)

Critical Organ	Maximum Permissible Single, Acute Emergency Exposure				
	rads	x	RBE	=	rems
Skin of whole body	500		1.4		700
Blood-forming organs	200		1.0		200
Feet, ankles, hands	700		1.4		980
Eyes	100		2.0		200

to the total dose received during prolonged spaceflights of months or years as long as the exposures were chronic or intermittent. A dose level under these circumstances of 100-150 rem per year was declared permissible.

A series of experiments were carried out in 1967 on more than 200 dogs which modeled the radiation effects of prolonged spaceflight.[50] Parin stated that this series of experiments indicated that radiation in doses of 25 to 225 rems per year caused "no essential disruptions in the vital activity of the organism or the functioning of the main systems and most important processes." This animal data supports the current Soviet thinking about raising dose limits for prolonged missions.

PROTECTIVE MEASURES—The risk of one or more major solar flare events in any given time interval during 1969-70 (solar maximum) will be about five times the risk in a comparable interval during 1975-76 (solar minimum).* [48] The risk of high solar flare activity could be avoided completely if an accurate forecast for the duration of the mission could be made just prior to launch or if adequate warning time were available to return the cosmonaut to safety before the arrival of a significant solar flare proton event. The Soviets are quite interested in achieving a world-wide solar warning network and in improving methods for forecasting solar flare activity.[51] However, at the present time the Soviets can only claim an accuracy of about 75 percent for predictions two to three days in advance or at most the longest useful estimate is three to five days. This would provide time for the cosmonaut working some distance from the lunar base to return to shelter, but would necessitate protection being provided on the lunar surface.

The Soviets recently published a study "On the Possibility of Building Radiation Shelters with the Use of Lunar Material." [52] Data are given that a roof made up of lunar material is similar in protective properties to aluminum—a shield 0.656 feet thick would insure a 99.9 percent probability of a safe stay for man on the moon for two months; 2.46 to 3.28 feet thick was said by the Soviets to guarantee safe working and living for several years.

The use of lunar material is an acceptable method of protection from the hazards of radiation. One of the earliest tasks of establishing a manned lunar base would be to provide such shelter for the crew. More knowledge about the lunar surface, however, is needed, e.g., the depth of lunar surface material that is available for possible protection.

The Soviets have consistently published reports and indicated that the cosmonauts are provided with antiradiation chemicals.[53] There is no evidence, however, that the Soviets have or will have developed in the foreseeable future any effective useful chemical compound for protection against radiation.

Some of the antiradiation chemicals most frequently mentioned by the Soviets include cystamine, serotonin, and mexamine with 5-methoxytryptamine. These compounds are not new and have been investigated for radioprotective action in the United States and other countries. There is no evidence that a cosmonaut has taken any of these drugs during flight, although they have carried them on board probably since the earliest manned Vostok flight. Soviet statements concerning these preparations serve to propagandize the safety considerations given Soviet cosmonauts and provide a psychological crutch for the cosmonauts during flight. However no effective chemical for radioprotection during spaceflight exists.

*Solar flare hazards cannot be ignored even during solar minimum; large events do not necessarily congregate about the peak of the active solar period (e.g., a very large event of 23 February 1956 occurred unexpectedly early—two years after the sunspot minimum of 1954).[35]

LIFE SUPPORT REQUIREMENTS

Introduction

An essential element in establishing a manned lunar base is development of a more advanced life support system than that already demonstrated during spaceflight. An advanced concept of life support is a completely closed system with regeneration of oxygen, water, and food. The techniques for regeneration can be bioregenerative and/or physicochemical. It is likely that the Soviets will gradually close the loop (partially closed life support system). The Soviets have stated that in order to achieve minimal life support weight, optimal energy expenditures, and high spacecraft reliability for long flights, regeneration of water will be provided first, then oxygen, and finally food.[54]

Soviet scientists have conducted much research on development on a bioregenerative life support system. At a recent IAF meeting (1968), Gitelzon presented some practical results in a chlorella-based system which was in a relatively advanced stage of experimentation. The Soviets admitted that the system was rather bulky but replied that it would soon be compact enough to be placed inside a sealed chamber.[55] O. G. Gazenko, a leading biomedical scientist, stated however that it would not be ready for spaceflight for 10 years or more. In late 1969, Gitelzon is scheduled to go on a six-month expedition to what is probably the Vostok Station in the Antarctic. He may well be going to participate in the early developmental phases of a workable closed biological life support system for use in an eventual Soviet lunar base.[56]

Although there has not been as much published by the Soviets on physicochemical regenerative systems, it appears likely that this approach will be used relatively soon to extend the duration of Soviet space missions. The recent Soviet test carried out with three men in a sealed chamber for one year provided experimental data on the operation of a physicochemical system for water and oxygen regeneration.[57] The most advanced Soviet versions of regenerative life support systems for the future probably will incorporate both biological and physicochemical techniques for regeneration of water, oxygen, and food.[58]

In analyzing life support requirements for a variety of manned missions, the Soviets appear to be utilizing an evolutionary concept of development, i.e., various life support modules representing subsystems are added for increased duration missions.[7] This addition permits mission growth.

Atmospheric selection

Selection of an acceptable atmospheric composition and pressure has an important effect on the operation of a manned lunar base. Critical aspects in determining this environment involve consideration of the need for frequent extra vehicular excursions, i.e., gas supplies needed for depressurization and repressurization procedures. (One of the advantages of a reduced pressure environment is that it permits lower spacesuit pressures and consequently increases cosmonaut mobility without the risk of decompression and extended airlock denitrogenization time.) Other considerations are the hazards of fire, aeroembolism, hypoxia, and oxygen toxicity. In addition to physiological considerations, atmosphere selection affects the engineering design of the lunar base, i.e., weight savings, trade-offs for operation of the system, shelter structure weight, and pumping power required for atmospheric selection and processing.[59]

The Soviets originally selected a two-gas atmosphere at one atmosphere of pressure for use in their manned spacecraft. They have not deviated from this composition except when the cabin pressure was lowered during Leonov's extravehicular activity (EVA) on Voskhod 2. Beginning in 1964,[60] however, there is evidence that the Soviets were rethinking their choice of gas atmosphere and cabin pressure for future more prolonged manned spaceflights.[55 61] Gazenko stated that just because they had followed a "conservative position" by using a mixture of 79 percent nitrogen and 21 percent oxygen to duplicate earth atmosphere on all of their past flights, it did not mean they would continue to do so. He added that for future flights, their other more progressive school of thought was to search for a new gas environment and that their tests on helium-oxygen mixture had been significant.[62] Research was said to be proceeding along both lines of thought. Some scientists in the USSR were very much interested in the use of reduced pressures and a helium atmosphere.[63] Gazenko said that if he had to hazard a guess, he felt that some new gas mixture very possibly involving helium would probably find use on long-range spaceflights.[64–66]

This same opinion was expressed the next year by Genin, the leading scientist involved in Soviet life support development. He stated when queried about what kind of atmosphere he would recommend for a three-month space mission that he favored a 40 percent 0_2 atmosphere at a pressure of 0.5 atmosphere using either helium or nitrogen as the second gas.[67] He rejected use of 100 percent oxygen atmosphere for a mission of that length because of the fire hazard. The atmosphere for use on future spacecraft apparently had not been selected by 1966 since a Soviet scientist stated then that the biologists preferred a lower atmospheric pressure than the full pressure currently in use, but they had met a determined resistance from the hardware designers because of the necessity for a complete redesign.[68] It was felt that ultimately the Soviets would go to a lowered atmospheric pressure system, but it would be several years before this system became operational.

The Soviets appear to be doing extensive research on various artificial atmospheres for maintaining life in space. Some of the principal work has been conducted by A. G. Dianov and A. G. Kuznetsov.[63–69] Table 5 summarizes the atmospheres investigated by Kuznetsov. He indicates selections 2, 4, and 5 give promise of further study. Certain of these atmospheres have been studied in 10, 25, 30, and 60 day chamber tests with human subjects.[70 71] The percentage of He_1 was increased to 40 percent in another series of experiments, and the oxygen concentration in a nitrogen-oxygen two-gas atmosphere experiment increased to 90-94 percent at 7,000-10,000 pounds pressure in a 30-day experiment.[72–75]

Table 5

Characteristics of possible Soviet variants of spacecraft cabin atmosphere

	No. 1	No. 2	No. 3	No. 4	No. 5 [a]
Total pressure, mmHg	760	380	308	198	760
pO_2mmHg	160	160	160	150	160
% O_2	21	42	52	80	21

[a] Normal atmosphere in which nitrogen is replaced with helium.

There is no firm information on whether an actual change in atmospheres has been incorporated in Soviet design studies for a lunar base.* It is believed that the Soviets may choose a lower pressure environment and probably a two-gas atmosphere perhaps with helium as the diluent gas. The Soviets are aware of the uncertainties and trade-offs involved in the selection of a new atmosphere and probably will increase their research and development related to understanding the effects of various atmospheric composition on man.

Water

Water management is a key problem area in lunar base environmental control design because of large material requirements for life support in food preparation, drinking water, sanitation, cooling of suit and roving vehicles, and atmospheric supply.[76]

The Soviets recognize the necessity of providing for an increased water supply during longer flights and state that in considering the reserves of water needed with dehydrated food (generally more than half total weight of reserves), the problem of physical and chemical regeneration of water must be solved first of all.[77] Data are given indicating that a water regeneration system is essential even in connection with 15 to 20 day or longer flights.[78 79] Since this conclusion appears to be based on US data, it is uncertain if the Soviets have an identical criteria for the break-even point of a regenerative system as compared with an open-supply system. These same data are quoted by Yu. Yu. Senyak, S. V. Chizhov, and V. I. Yazdovskiy, who have been leaders in various phases of Soviet life support system development. Other Soviet data imply a 30-day crossover point between a regenerative H_2O system as compared with a stored water supply.[77]

The Soviets have investigated various physicochemical methods of water regeneration which they consider the best developed and most reliable. They are vacuum distillation in conjunction with sorbents, lyophilization, and catalytic oxidation.[80]

*The US Initial Study Concept (1964) base selected a 6.0 Psi (310 mmHg) oxygen-nitrogen atmosphere for baseline studies. A 3.5 Psi (176 mmHg) oxygen atmosphere was proposed for the lunar shelter with the stipulation that if future physiological considerations show an atmospheric diluent to be essential or highly desirable, use of helium-oxygen was recommended.[59]

Such research was probably well underway by 1964 when Yazdovskiy indicated some of the pros and cons of research on various water regenerative systems.[78] The method of choice for drinking water appears to be catalytic oxidation. The catalytic method is based on the oxidation of moisture containing human products such as urine.* The recondensed water is said to exceed Soviet public health standards for purity. Water regenerated by this method was fed to humans for periods of one year in a chamber test experiment.[81] In addition during this experiment, water for personal hygiene and sanitation purposes including water for washing and showering was regenerated. Moisture from the atmosphere was regenerated by an oxidation-absorption method involving filtering, exposure to ultraviolet light, and finally filtering through ion-exchange resins.

Physicochemical techniques will probably be employed relatively soon during Soviet manned flight for reclamation of water from urine and the atmosphere. The Soviets also are working on biological means of water regeneration. In 1968, Gitelzon et al. reported an experiment with a human involving continuous cultivation of microalgae with water regenerated for a 30-day period.[55] The water regenerated by this system (during a 30-day period) was said to be suitable for human consumption.

Food

In the foreseeable future, the diet of Soviet cosmonauts on the moon will be based on stored food in dehydrated form. During the past several Soviet manned flights, the cosmonauts have eaten reconstituted dehydrated food, but as yet no hot food has been prepared, i.e., only cold water has been available for adding to the food packs.[82] The dehydrated foods have been described as quite similar to US preparations in packaging and size.[83] During the Vostok flights, the Soviets used mainly pureed food in tubes and food prepared in bite-sized portions.[71] The Soviets reportedly have been experimenting also with irradiated meat products evidently to increase the food palatability to the cosmonaut.[82]

*This method is regarded by the Soviets as a simple, highly productive method which eliminates the need for low temperature and on-board vacuum. It also requires a minimum of electrical energy when solar energy is available for the vaporizer and superheater stages.[8]

Calculations based on gravity conditions have been made by the Soviets on energy requirements for man and animal on the moon. Parin states that 2,310 calories* will be needed; such figures appear to be low estimates.[84] With increased energy requirements especially during extravehicular activity on the lunar surface, minimum figures would probably be more in the 3,200 K-calorie range. (The calorie content of the food for the one year experiment was 3,000 K-calories.) The daily ration of the Vostok cosmonauts varies from 2,526-2,772 K-calories; this ration was increased to 2,800 for Voskhod 1 and 3,250 for Voskhod 2.[71] Stored food requirements are estimated by the Soviets to weigh approximately one and one-half pounds per man day (660-700 gms).[85]

The diet of men in stressful environments has been studied as part of the biomedical research program at the Vostok Station in the Antarctic. This program should provide some insight into nutrition and rations of cosmonauts for other unusual environments such as the moon.[10]

The Soviets have done considerable work on bioregenerative life support systems based an algae, primarily chlorella, and higher plants. An integral part of this system would be the ability to produce an edible biomass for use as a dietary supplement or as the sole source of food.[80] However at the present time, the food aspect of the process does not appear to be of paramount importance to the Soviets.[56] One Soviet scientist remarked recently that closure of the food link would only result in about a 10 percent weight saving.

Soviet scientists are continuing research related to utilizing chlorella as a food supplement for man on prolonged space missions. In 1966, they first reported results of feeding humans 50, 100, and 150 grams daily of dry biomass algae which was combined with other palatable food such as sugar, raisins, and gelatin for periods up to 22 days. Recently, a 30-day experiment on the suitability and effects of chlorella consumption by humans was reported. Experimentally, the chlorella diet has been tolerable but unacceptable to most subjects for prolonged periods.[80]

*Usage of the term means large or great calorie expressing energy-producing value of food and is the same as the term kilocalorie.

[redacted]

Animal protein also has been studied as an additional source of food for prolonged missions. These included studies of the use of chickens (highest feed conversion efficiency of animals) and fish.[86] But oxygen and other requirements make this scheme less attractive when considering the trade-off points between stored food and the animal husbandry approach.

According to Soviet estimates, the crossover point between stored food and a simple algae bioregenerative system would be missions on the order of 200 to 300 days.[77] It appears unlikely, however, that the Soviets will find processed algae suitable as the sole food source for longer missions.[87] More acceptable food could be added to the cosmonaut's diet such as higher plants (or possibly animals) or stored food to the life support system. Therefore, stored food (with water recovery) probably could have weights comparable to an augmented algae (with higher plants, animals, stored foods) bioregenerated system for missions of less than two years.

Waste management system

The Soviets have been evaluating various methods of treatment of solid wastes.[88] They apparently have not decided upon an optimum choice for inclusion into a possible lunar base design. Such a design choice would probably be based upon new methods related to larger crew size and longer periods of occupancy with a minimum of maintenance and low power requirements. Yazdovskiy et al. discuss several methods which the Soviets have been studying.[89] They conclude that the thermal method (temperatures range from 1,292° F to 1,472° F) is technically simple, but they imply there is a high power requirement. One of the most promising is said to be the thermal catalytic method (initial temperatures on the order of 392° F). This method would be included for use in partially closed life support systems. There is some difficulty in understanding Soviet terminology for the various methods of waste treatment described, but it appears they have attempted the known approaches to the problem. The eventual system selected probably will be based upon incineration. Eventually the processing of human waste products would be an important advantage in developing a completely closed life support system.

Two major experiments were carried out involving regeneration of potable water from human excreta in closed or partially closed systems using chlorella in the presence of bacteria. The regenerated water obtained in the five-month experiment, however, was not considered suitable for drinking without further purification by the use of physico-chemical methods.[80]

There is almost no information about Soviet innovative techniques for collecting and handling solid wastes, although this is considered an important problem requiring solution for extended missions. The Soviet one-year experiment, which tested regenerative techniques for use in a partially closed life support system, appears to have ignored the solid waste management problem. Solid wastes were not regenerated or utilized but were removed from the chamber.[90]

The Soviets probably intend to recover water from liquid wastes or urine during a lunar base mission. In the one-year experiment, the Soviets regenerated drinking water from urine by the catalytic oxidation method; they regenerated drinking water from urine during the entire duration of the experiment.

Other factors

Soviet scientists also have considered other potential problem areas involved in establishing a manned base on the moon. Such investigations include studying the effects on man of: i) possible transfer of microorganisms between crew members; ii) long-term toxicity of trace contaminants; iii) decompression sickness; and iv) optimum CO_2 content at various pressures. Evaluation of the information concerning these effects indicates interest and concern by the Soviets in studying and resolving these factors, but few innovative steps or detailed results are revealed.[91–95]

Spacesuit development

Soviet spacesuit development is one of the key elements involved in their establishing a lunar base, e.g., the performance capability of the cosmonaut is a major consideration in conducting extensive lunar operations. This capability is greatly affected by the restrictions imposed by the spacesuit worn by the cosmonaut for EVA.[4]

The Soviets have demonstrated during spaceflight essentially two pressurized spacesuits—one for use as an emergency and ejection/descent suit in the Vostok program, the other as an extravehicular suit such as that worn by Leonov during his EVA on Voskhod II. The air-cooled suit worn by the cosmonauts during the Soyuz 4-5 extravehicular transfer operation appears to be similar to the Voskhod II suit.[96] The quality of these suits was adequate for the missions for which they were designed. However, more advanced suits are needed for a lunar mission. The lunar spacesuit will require good joint flexibility for the increased mobility needed for walking and working on the lunar surface. Another critical requirement is an increased capability for removal of the high heat loads expected during the cosmonaut's work activity on the moon. This will necessitate use of a liquid-cooled garment for removal of the high metabolic heat loads.[59]

The earlier Soviet extravehicular suit was deficient in joint flexibility and inadequate for extended EVA.[97] Any movement required considerable effort which consequently increased the metabolic cost to the cosmonaut. The Soviet suit was pressurized to 0.4 atmosphere while the US suit was pressurized to 0.25 atmosphere—the lower pressure allows the man better mobility. The last demonstrated Soviet extravehicular suit (Soyuz 4-5) appeared to have similar limitations, i.e., considerable effort was required which necessitated deliberate and measured movements outside the spacecraft. [98] The design pressure of the spacesuit can be directly related to the choice of cabin atmosphere and pressure.

In general, the time required for denitrogenation before going EVA safely is dependent upon the pressure differential between the cabin and the suit.[99] The Soviets in their two-gas environment and one atmosphere of cabin pressure require more denitrogenation time to use a suit pressure of 0.25 and thus have used an extravehicular suit pressure of 0.4. This pressure requires only a minimum period of denitrogenation but necessitates an increased metabolic work load on the cosmonaut. The Soviets could develop a constant volume joint (one that does not change its volume with motion) which would be relatively independent of suit pressure. There is no evidence of such an advanced joint development, however.

The Soviets have not demonstrated, as yet, a liquid cooled suit during flight. In 1965, this type suit appeared to be in an early stage of development. Recently, however, Gazenko commented that the Soviets had developed a water-cooled spacesuit.[100]

There is little information related to Soviet development of a "hard" suit other than several years ago Gazenko stated that they should be developing such a suit, implying that they were not doing so at that time.[101] They have talked openly about enclosing man in a small capsule with mechanical appendages for location and manipulation.[102] Such a development would be a considerable advance of the demonstrated Soviet state-of-the-art in suit development. At an August 1968 UN Conference on Outer Space, cosmonaut Leonov and a group of Soviet scientists displayed specific and strong interest in and thoroughly examined the flexibility of the joints of the US spacesuit.[103] Since the suit examined by the Soviets was an Apollo soft suit, it may indicate that the Soviets, for at least the near term, are interested in soft suit development rather than in a rigid anthropomorphic shell (hard suit) or in a capsule with mechanical appendages.

Preliminary analysis of the Soyuz 4-5 spacesuit indicates that the Soviets have developed a new portable life support system (PLSS) for use during EVA.[104] This PLSS probably contains a superoxide which releases oxygen and removes carbon dioxide for life support of the cosmonaut. The Soviets appear to have developed this technology originally for an operational diving unit. US analysis of the diving unit indicates it is a superior development which is light in weight with a life support capability in excess of four hours. A Soviet cosmonaut recently stated privately that their PLSS duration is 12 hours. A Soviet engineer involved in spacesuit development earlier (1965) had described such a life support system under development. He stated that its regenerative oxygen supply was to last for a period of four hours.[105]

The Soviets apparently have been involved actively in determining the physiological conditions that may be encountered by the cosmonaut when walking on the lunar surface. In a space technology and science meeting, I. T. Akulinichev, an im-

[redacted]

portant Soviet scientist involved in the design of bioinstrumentation, was especially interested in the stability of the body in traversing rough terrain under low G conditions as well as in data about one-sixth gravity as it would be experienced on the moon.[106] The actual metabolic rates anticipated by the Soviets on the moon are unknown. However, tabulation of energy expenditures under various terrestrial conditions (in 60- and 120-day chamber tests) in a Soviet manual on space biology and medicine indicates relatively high energy levels were calculated (2,433-4,536 kcal/day with an average of 3,300 kcal/day).[107 108] Kas'yan et al. recently published results of a series of experiments involving calculations of energy expenditures of human subjects under various conditions (bed rest, short-term weightlessness, and the Voskhod 2 orbital flight). Energy expenditures were said to be very high during orbital flight (especially during Leonov's EVA) in comparison with other simulated conditions. Such studies are related directly to the design of spacesuits and cosmonaut procedures for ability to conduct work outside the spacecraft.[109] There is some evidence that the Soviets have obtained data on energy expenditures in the Antarctic which may be related to subsequent more advanced spacesuit development.[12]

Soviet life support system (LSS) data for manned missions

A recent publication on "Life Support of Spacecraft Crews" by G. I. Voronin and A. I. Polivoda, Soviet authorities on life support development, has provided some detailed information on trade-offs involved in various methods of life support.[77] These data are presented here because they are believed to be the best available bases for predicting future Soviet life support approaches. Previous intelligence estimates on the weight and power penalties associated with Vostok/Voskhod superoxide environmental control system were verified as exact by the data in this publication.[87]

Table 6 illustrates Soviet estimates of module requirements for specific LSS. Table 7 identifies the characteristics of certain LSS. Data on the flight duration and weight characteristics of the various LSS are given in table 8. The weight penalties for electrical power assume solar cells with secondary batteries. Values for the photosynthetic systems assume that sunlight is delivered directly to the plant rather than indirectly via electricity and artificial illumination. In Systems C6 and C12, the weight (500 kg) of power systems and temperature control systems are not taken into consideration; system C10 does not include the weight (200 kg) of power systems for heat control. Data on life support system weights as a function of mission duration are given in figure 1.

Evaluation of status of Soviet LSS development

Soviet data indicate that stored chemicals (superoxides etc.) and food will continue to be the basic system of choice for many future manned missions. The addition of a water reclamation system would greatly extend the usefulness of the system for mission durations up to 200 days or longer with resupply.[87] Physicochemical reduction of carbon dioxide will have limited applicability and may never be a system of choice within the next 10 years. Bioregenerative systems will probably not be chosen as a primary system until the most advanced lunar base is established.

Lunar base life support equipment probably will evolve from lunar excursion technology and the life support systems will become more and more regenerative with time. If an advanced Soviet lunar base develops to the point where it has a large electrical power supply available (presumably from a nuclear reactor), complex LSS should be advantageous. The Soviets could gradually develop highly regenerative equipment with less sophisticated standby systems available in case of failure. The ultimate ecological system probably would be a complete "farm" similar to system C14. Such an elaborate complex with a variety of higher plants and food animals could use reactor power to provide artificial light, at least during the period of lunar night, and could use lunar material as a heat sink for a large cooling system. Advanced Soviet closed LSS probably will include both physicochemical and biological techniques for regeneration of water, oxygen, and eventualy food.

Hypothetical examples of Soviet LSS lunar base requirements

If several lunar base models are hypothesized (see table 9) it is possible to make some rough estimates in general terms of Soviet life support requirements and capabilities for carrying out such a lunar mission.

Table 6

Soviet estimates of module requirements for certain life support systems [77]

Name and Number of Module Units	Systems			
	C2	C6	C10	C14
Oxygen storage unit	1	....	....	.....
Drinking water storage unit	1	....	....	.....
Food storage unit	1	4	....	1
Food preparation unit	1	1	1	.....
Carbon dioxide chemical absorption unit	1	....	....	.....
Liquid waste collection unit	1	1	....	.....
Solid waste collection unit	1	4	....	.....
Condensate collection unit	1	1	1	100
Unit for emergency oxygen storage for man	1	3	4	4
Emergency water storage unit	1	3	4	4
Emergency food storage unit	1	3	4	4
Unit for processing of condensate to drinking water	....	1	1	10
Unit for physicochemical regeneration of water	....	1	....	.....
Ozone water sterilization unit	....	1	1	1
Physicochemical regeneration of oxygen	....	1	....	.....
Carbon dioxide absorption-desorption unit	....	1	....	1
Electrolytic decomposition unit, water	....	1	....	.....
Reserve instrument tool unit	....	1	1	1
Tool unit	....	1	1	1
Unit combining collection of liquid and solid wastes	....	....	1	1
Physicochemical sterilization unit	....	....	1	1
Suspension physicochemical mineralization unit	....	....	1	1
Liquid waste physicochemical mineralization unit	....	....	1	.....
Solid waste physicochemical mineralization unit	....	....	1	.....
Single-celled photoautotroph cultivation unit	....	....	1	1
Biomass preliminary processing unit (centrifuge)	....	....	1	1
Biomass final preparation unit (food automation)	....	....	1	1
Medical-sanitary service unit	....	....	1	1
Unit, storing microelements and salts	....	....	1	10
Vitamin reserve unit	....	....	1	1
Unit for preparing nutrient media for higher and lower plants	....	....	1	1
Suspension separation unit	....	....	1	1
Light energy introduction unit	....	....	1	10
Greenhouse unit for higher plants	....	....	....	10
Vivarium for higher animals	....	....	....	1
Lower animal unit	....	....	....	1
Food microorganism unit	....	....	....	1
Unit processing biomass of higher plants	....	....	....	10
Combine unit for processing feeds	....	....	....	1
Unit for processing liquid and solid wastes of higher animals	....	....	....	1
Aquarium for fish and mollusks	....	....	....	1
Unit processing feed for fish and mollusks	....	....	....	1
Unit for preparing food for higher animals	....	....	....	1
Unit for preparing food for lower animals	....	....	....	1
Unit biological mineralization of liquid & solid; human, animal, & plant wastes	....	....	....	1
Emergency oxygen storage unit for animals	....	....	....	10
Emergency water reserve for animals	....	....	....	10
Emergency feed supply unit	....	....	....	10
Veterinary service unit	....	....	....	1
Solar energy distribution unit	....	....	....	10

Table 7

Characteristics of life support systems as estimated by Voronin and Polivoda [77]

System	CO_2 removal	O_2 supply	Water supply	Food supply
C2......	Stored chemicals.......	Stored chemicals.......	Stored................	Stored.
C3......	Stored chemicals.......	Stored chemicals.......	Stored, recovered from atmosphere.	Stored.
C4......	Stored chemicals.......	Stored chemicals.......	Stored, recovered from atmos., urine.	Stored.
C6......	Zeolites...............	Electro-reduction of CO_2.	Stored, recovered from atmos., urine.	Stored.
C10.....	Algae.................	Algae.................	Recovered from atmos., urine, bioregen.	Processed algae.
C11.....	Algae and higher plants.	Algae and higher plants.	Recovered from atmos., urine, bioregen.	Higher plants and processed algae.
C12.....	Chemosynthetic bacteria.	Chemosynthetic bacteria.	Recovered from atmos., urine, bioregen.	Processed bacteria.
C14.....	Higher plants and algae.	Higher plants and algae.	Recovered from atmos., urine, bioregen.	Higher plants and animals.

Table 8

Soviet data on certain life support systems [77]

System	Flight duration, (days)	Heat liberation, (kw)	Power consumption, (kw)	Approximate weight (kw)	Expendables kg. man/day
C2............	30	0.3	0.012	325	9.4
C3............	65	0.31	0.014	465	6.4
C4............	90	0.33	0.03	470	4.0
C6............	120	2.25	1.26	325	2.0
C10...........	365	1.2	0.19	670	Negligible.
C11...........	365	7	0.4	1815	Negligible.
C12...........	365	1.4	1.28	590	Negligible.
C14...........	365	80	2.66	20100	Negligible.

Table 9

Hypothetical lunar base models

Base Model	Crew Size	Mission Duration
1...........	4.................	Up to 90 days.
2...........	6.................	Up to 180 days.
3...........	10–12 or more......	Up to 365 days.

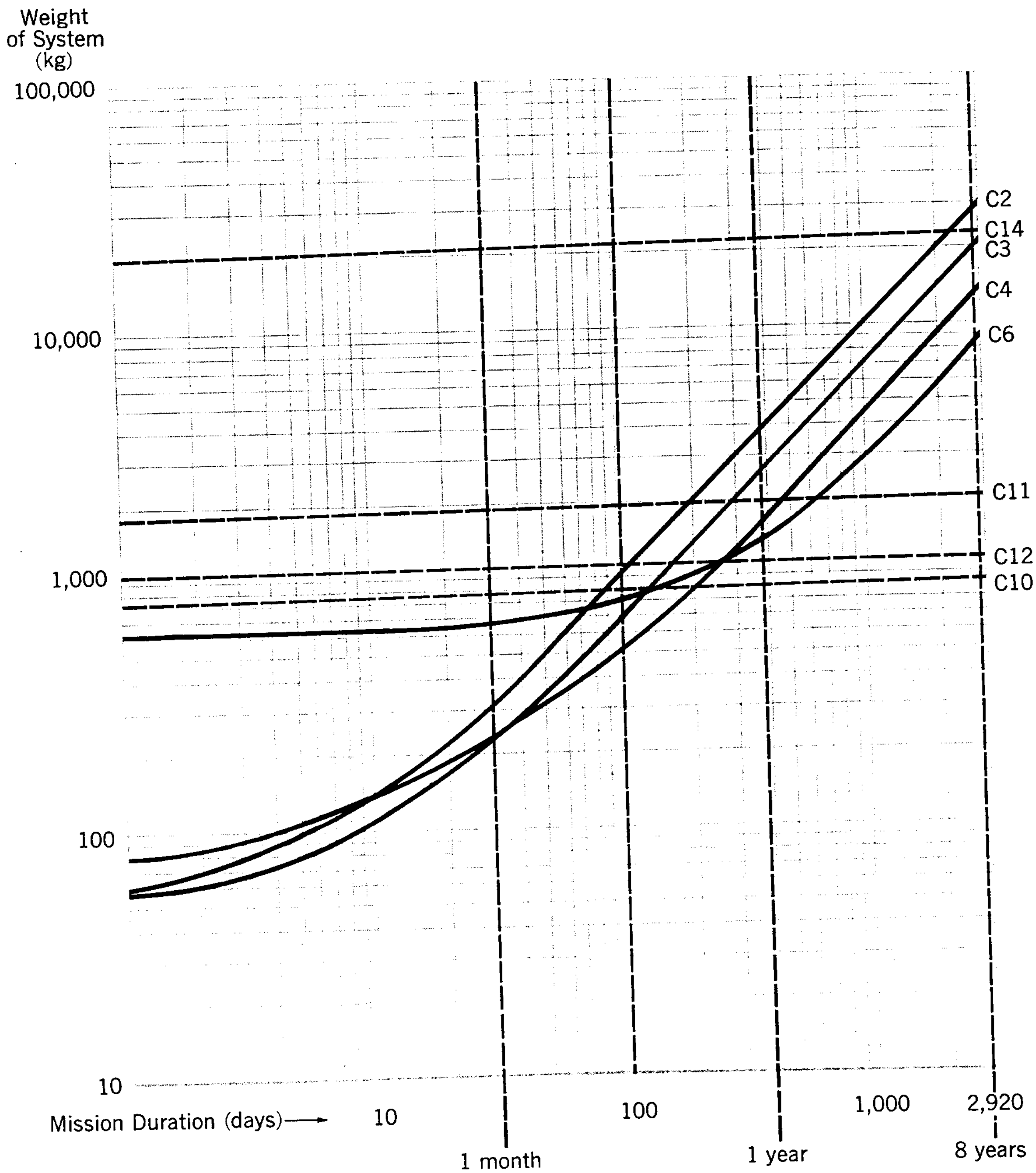

Figure 1. Soviet estimates of life support system weights for one man as a function of mission duration (including power supply and cooling equipment penalties except for systems C11 and C14). 77/

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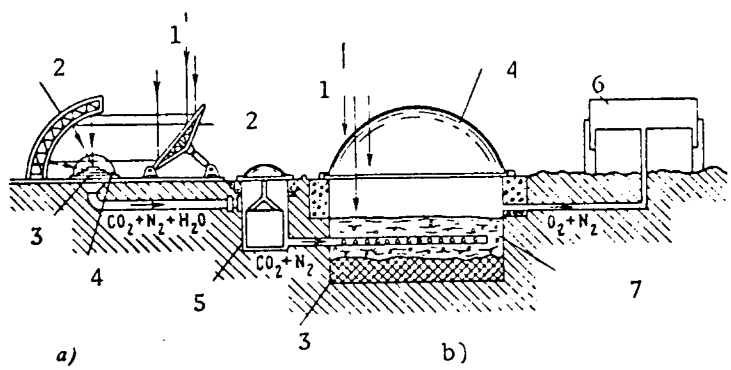
[redacted]

Using Soviet data, it is estimated that the life support/ECS system weight for Base Model 1 would be on the order of 4,136 pounds (1,880 kg). This figure is in close agreement with US estimates for the same duration missions.[4] The life support system for Lunar Base 1 would use stored food and oxygen (superoxide). A water reclamation system is required, however.

Base Model 2 gives a LSS/ECS weight estimate of 10,890-12,804 pounds (4,950-5,820 kg). This figure is similar to US weight calculations involving a resupply mission using the Apollo system (and a small nuclear reactor for power). This life support system would require stored food, a physicochemical system for regeneration of water, and the addition of at least a partial system of regeneration of oxygen.

Lunar Base Model 3 gives a LSS/ECS weight value of 17,600-21,120 pounds (8,000-9,600 kg). This estimate is probably unrealistic as the Soviets provide an actual estimate of the current operation of such a system about 10 orders of magnitude higher than these figures indicate. The LSS/ECS system required involves a single algae bioregenerative system for oxygen and food. It also includes a system for regeneration of water and an advanced system for waste management. Even the low weight estimate figures indicate such a mission could require very advanced technology (with an increased power supply available) and probably a resupply capability.

A Soviet representation of an advanced lunar base is shown in figure 2. This concept includes the use of lunar materials to supply some of the life support substances for the base.[77]



a. Device for production of water, oxygen, nitrogen and other inorganic materials from lunar materials
b. Device for biosynthesis of food materials

1. Solar rays
2. Mirror
3. Lunar materials
4. Transparent cupola
5. Water vapor condensate
6. Oxygen collector
7. Water and chlorella algae

Figure 2. Soviet hypothetical concept of an advanced lunar base life support system. 77/

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OTHER FACTORS RELATING TO CREW PERFORMANCE

Isolation and confinement

In 1967, Yu. Ye. Moskalenko, a prominent Soviet biomedical scientist, stated that one of the major problems in the Soviet manned space programs was in the field of isolation and its psychological aspects.[110] The Soviets have recognized the importance of research on psychological factors such as isolation and confinement in spaceflight since the early Vostok flights. Vostok cosmonauts were studied under conditions of isolation for a period of 7 to 14 days.[111] Subsequently, Soviet scientists have investigated the effects of isolation and confinement on human subjects for periods up to 120 days and recently for a period of one year.[112]

A principal Soviet investigator is F. D. Gorbov who heads a section on group psychology at the Institute of Aviation and Cosmic Medicine in Moscow.[113] Another section at the institute is involved with studies on sensory deprivation environments. Gorbov states that the two main lines of his research are study of the psychological aspects of cooperation between operators during interdependent activity and study of the psychological aspects of living together under the complex conditions of prolonged group isolation.[114] In addition, more realistic operational data and experience on isolation and confinement under simulated lunar base conditions have been underway at Vostok Station in the Antarctic.[8] The Soviets have stated this as a primary purpose of their investigation at Vostok.

A. D. Agadzhanyan and A. G. Kuznetsov (1962) indicated an impairment of the mental abilities during the prolonged stay of subjects in a soundproof chamber. F. D. Gorbov, V. I. Myasnikov, and others (1962) found, however, that psychopathological phenomena in Soviet cosmonauts during tests in a soundproof chamber were absent.[115] Under conditions of isolation, some investigators stated that fatigue develops. Other Soviet scientists have concluded that the influence of isolation and sensory deprivation on the human organism is very serious. Further study of this problem and the development of a whole system of measures and procedures were considered necessary.

Soviet data on actual crew size requirements are sparse. They have stated, however, that from a psychological point of view, spaceflights with two-man crews were not desirable.[116] Likewise, some Soviet scientists consider a crew of three unstable because of the possibility of two members countering the third. Consequently, the Soviets probably will use an even-numbered cosmonaut crew for prolonged missions such as a lunar base.

Circadian rhythm

The Soviets earlier (1962) considered "disturbances of the accustomed rhythm of life" as a major problem in space medicine.[117] They have since conducted numerous studies of the problem affecting the performance and well-being of the cosmonaut. This work was summarized at a Moscow symposium on "Biological Rhythms and the Formation of Work and Rest." [118] Soviet scientists appear optimistic but cautious in their current appraisal that a change in circadian rhythm is one of the few stressful factors of spaceflight which can be avoided by the cosmonauts.

The Soviets have decided to maintain a roughly 24-hour circadian schedule, which they consider optimum from the standpoint of cosmonaut well-being and long-term performance. Lunar base missions will involve approximately a two-week interval of light and about the same interval of darkness. The communications period for a lunar base will come at intervals of 24 hours 50 minutes, allowing for an easy adaptation of the cosmonauts to about a 24-hour daily cycle.[117 119]

Soviet cosmonaut Bykovskiy and V. Lebedev suggest that an optimum duty watch for space crew members should not exceed four hours.[120] For longer missions, the best schedule is said to be a four-hour period on watch followed by four hours active rest and four hours of sleep. If there were four crew members available, for example, the daily schedule on longer missions would consist of a total of 8 hours of sleep, a total of 8 hours active-rest period, and one or two four-hour watch periods.

The Soviets also have studied biorhythms in the polar regions including the Vostok Station in the Antarctic. The daily periodicity of functions were said not to be affected significantly by the modified light regime in the polar day and in the polar night and different intensity in physical loads.[118] However, during the second to eighth months of wintering over (polar night), there was a prevalence of complaints of general weakness, sleep disturbance, decreased appetite, and shortage of breath at rest and at work.[9] At the height of polar night, there were a number of disorders involving irritability, fatigue, lack of balanced behavior, and an aggravation of chronic illnesses. During the advent of polar day (ninth to the twelfth months), the number of complaints decreased sharply, sleep and appetite became normal, and pains and shortage of breath occurred less often.

As in the polar experience, there is often an initial short period of adaptation required on space missions before sleep becomes normal. The Soviets have recommended and used in the Soyuz spacecraft a separate compartment for sleeping. Use of this separate compartment for sleeping apparently lessens the disturbance from noise and any activity of the other crew members.[121]

Cosmonaut training

Soviet cosmonaut training procedures have been designed around specific mission requirements, vehicle characteristics, and anticipated physiological stresses. They have differed from the United States largely in the emphasis on physical conditioning of the cosmonaut and in vestibular training after Titov's problems on Vostok 2.[122] Use of various types of simulators has increased with mission complexity and acquisition and design of equipment such as pressure chambers, centrifuges, and simulator devices.[123] [124]

There rarely has been prior knowledge of cosmonaut training for specific mission requirements. There have been reports, however, that the Soviets have a simulator designed to train cosmonauts for walking on the lunar surface.[27] A model of the lunar landscape for training cosmonauts also has been reported to be located at Tyuratam.[125] Cosmonaut Belyayev has stated that one group of cosmonauts was using helicopters in the training program; this can relate to practice for landing a vehicle on the moon.[126] The cosmonaut group has included scientist-cosmonauts for several years. This group may well involve physicians, engineers, geologists, and astronomers.[127]

Medical monitoring

Medical control of the cosmonaut during missions such as a lunar base will necessitate more on-board analysis and self-monitoring by the crew due to the longer distances and communications limitations involved.[128] Power requirements will not allow Soviet ground personnel to monitor the physical condition of the cosmonaut crew in real-time continuously by the 20 MHz signal which has been used during previous Soviet manned flights. Consequently there is a need for acquisition of a reduced amount of data in a given period of time, i.e., compression of physiological data. The Soviets also will need improved sensors for greater freedom of movement and better on-site medical monitoring during extensive extravehicular activity on the moon.[129]

The Soviets have demonstrated several medical monitoring improvements and changes in their manned space program recently which will be important in carrying out lunar missions as well as prolonged earth-orbital flights. Inclusion of a cardiotachometer on board the Soyuz flights marks a significant advance in Soviet biomedical monitoring practice.[130] The cardiotachometer offers data compression and thus reduces the requirement for constantly monitoring the electrocardiogram itself. It also allows for periodic transmission of the data at a much reduced telemetry data bit rate and would easily permit monitoring of more than one crewman. The cardiotachometer data have appeared in mode D or playback data, and thus heart rate data could be relayed to ground stations on earth during appropriate communications periods.

In spite of widespread Soviet claims, there is no evidence that sophisticated on-board diagnostic computers will be utilized in the near future.[128] Simple devices based on the status (normal, low, high) of a small number of bioenvironmental parameters may be employed during lunar missions.

There is no evidence thus far that the Soviets have highly innovative hardware for monitoring the cosmonaut during extravehicular activity (EVA). The cosmonauts have been monitored by hardware connections contained in the tether during the EVA on the Voskhod 2 and Soyuz 5-6 missions.

Biotelemetry instrumentation has been tested by the Soviets at lunar distances as part of the Zond flight program.[131] Zond 4, for example, had simulated biotelemetry monitors of the cardiotachometer, electrocardiogram, seismocardiogram, and pneumogram. The Soviets are also expected to monitor the condition of the cosmonaut during specific periods by means of voice communications and video transmissions.

Other human factors problems

Soviet research and development in human factors/man-machine systems appears in concept to be on a par with the United States. They have studied many of the known problem areas such as working capacity of the cosmonaut, task analysis, design of an informational model of cosmonaut body movements during extravehicular activity, and arrangement of the cabin interior and control instrumentation.[132 133] During the past few years, the Soviets also have published articles relating largely to the reliability of man in spacecraft control systems apparently in preparation for the cosmonaut's manned docking of the Soyuz spacecraft.[114]

Information on human factors studies directly related to establishing a lunar base is limited; it probably is classified by the Soviets. The theoretical basis for the need of such work was provided in the Soviet paper on lunar base construction which was presented at an IAF conference in 1964.[3] It was said necessary to find the optimum utilization of space while providing for maximum comfort of the crew. An example of a lunar base design was provided, with provision for life support, airlock, living, and laboratory quarters.

V. A. Popov is one of the leading researchers in man-machine relationships. He stressed in a recent study that there was insufficient data from ground-based investigations on the operational characteristics of a cosmonaut controlling the spacecraft during actual spaceflights.[134] Such Soviet scientists probably recommended that the Soyuz 5 cosmonauts adapt to the space environment a full day before attempting manual docking on the Soyuz 4-5 mission.

Soviet spacecraft interiors have been of relatively simple design. The role of man in the Soviet manned space program has been largely one of a passenger and experimenter rather than a pilot. This philosophy has tended to minimize the control system/instrumentation panels in the cabin. All primary instrumentation on the Vostok and Voskhod appears to be well within the cosmonaut's direct or peripheral field of vision.[135] The panel instruments appear to be plainly marked and logically grouped, i.e., cabin environmental parameters are registered in two adjacent instruments. The most important indices appear at the top of the dial and less critical values are displayed at the sides in accordance with good design practice. However, the pointers sometimes obscure the numbers on the scales. This design defect could account to some extent for inaccurate data reports transmitted to ground stations by cosmonauts during several Vostok/Voskhod flights.