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ABSTRACT

This report, the second of a three-part study of Soviet space programs, examines their manned space programs and reviews their quest for a permanently manned presence in space. Also included is information concerning the physiological and psychological findings related to the extended duration of Soviet manned flights and an executive summary. Chapter 1 is an overview of the manned programs of both the Soviet Union and the United States (1957-83). Chapter 2 highlights significant activities in Soviet manned spaceflight from 1981 to 1983. Chapter 3 provides detailed information on manned space flight programs, considering the early years of Soviet manned spaceflight, first generation space flights (Salyut 1-5), Salyut 6, manned missions to Salyut 6 (1977-80), and other areas. Chapter 4 provides additional information on the Soviet space life sciences, examining cosmonaut selection and training, space medicine, life support, negative and positive gravitational forces, biological research in space, and other areas. (JN)

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Part 2

SOVIET SPACE PROGRAMS: 1976-80

(WITH SUPPLEMENTARY DATA THROUGH 1983)

MANNED SPACE PROGRAMS AND SPACE LIFE SCIENCES

PREPARED AT THE REQUEST OF

HON. BOB PACKWOOD, *Chairman*

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

UNITED STATES SENATE

Part 2

OCTOBER 1984

Printed for the use of the
Committee on Commerce, Science, and Transportation

98th Congress
2d Session

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LETTER OF TRANSMITTAL

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC, October 9, 1984.

DEAR COLLEAGUE: I am pleased to transmit herewith for your information and use, part 2 of the Congressional Research Service study, entitled "Soviet Space Programs: 1976-80."

This part of the study focuses on the Soviet manned flight programs, including their space station activities, and the life sciences related to these programs.

Part 2 of this study should prove to be of continuing value to the Members of Congress as issues related to Soviet space programs become increasingly relevant.

Sincerely,

BOB PACKWOOD, *Chairman.*

LETTER OF SUBMITTAL

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC, October 3, 1984.

Hon. BOB PACKWOOD,
Chairman, Senate Committee on Commerce, Science, and Transportation, U.S. Senate, Washington, DC.

DEAR MR. CHAIRMAN: Transmitted herewith is the second of a three-part study, entitled "Soviet Space Programs: 1976–80." This report was prepared by the Congressional Research Service at the request of the Subcommittee on Science, Technology, and Space.

Part 2 focuses on Soviet manned space programs, and reviews the Soviet quest for a permanently manned presence in space. Also included in this part of the study is information concerning the physiological and psychological findings related to the extended duration of Soviet manned flights.

Part 1 of the study, released in 1982, contained a detailed description of supporting vehicles and launch facilities, political goals and purposes, international cooperation, and the future outlook for Soviet space programs. Part 3 will examine Soviet unmanned space programs, including space sciences, applications, and military activities. I believe that this second part, which details Soviet space station activities through 1983, will be of particular value to the Committee as we consider the administration's proposal to develop a permanently manned space station.

The Congressional Research Service is to be commended for its scholarly effort in preparing part 2 of the study. This comprehensive and thorough research will be an important resource to the Committee and to the other Members of Congress as manned space activities in the Soviet Union and the United States become more frequent and consequential.

Sincerely,

SLADE GORTON,
Chairman, Subcommittee on Science, Technology, and Space.

CONGRESSIONAL RESEARCH SERVICE,
THE LIBRARY OF CONGRESS,
Washington, D.C., February 3, 1984.

Hon. SLADE GORTON,
Chairman, Subcommittee on Science, Technology, and Space, Committee on Commerce, Science, and Transportation, U.S. Senate, Washington, D.C.

DEAR MR. CHAIRMAN: We are happy to transmit to you herewith part 2 of our review of Soviet space activities for the period 1976-1980. As you know, Dr. Charles S. Sheldon II, who spearheaded the preparation of earlier editions of this report and was to have been primarily responsible for this edition as well, passed away in 1981. As a result, this report has taken longer to prepare than we had planned, and we have therefore included a supplementary chapter which highlights significant Soviet space activities from 1981 through 1983. Information in this report is current as of December 31, 1983.

This volume has been written by Marcia S. Smith, Specialist in Aerospace and Telecommunications Systems; Alfred Hellman, while he was an exchange fellow with CRS from the National Cancer Institute; and Christopher H. Dodge, Specialist in Life Sciences. Ms. Smith was responsible for all sections of the report dealing with the manned space program, while Dr. Hellman and Mr. Dodge were responsible for the section on space life sciences. Before his illness, Dr. Sheldon had prepared many of the tables which appear in this volume. Mr. Terrence Lisbeth, Ms. Christine Anderson, and Ms. Kaseem Hall, under the direction of Ms. Shirley Williams, Production Support Unit of the Science Policy Research Division, CRS, provided editorial assistance in the preparation of the final manuscript.

It should be emphasized that the report is based exclusively upon unclassified sources, including Soviet announcements and independent analyses made by Western observers of the Soviet space program and reported in the United States and abroad. The work of the Kettering Group, based in Kettering, England, has been particularly valuable in preparing this edition, as it has been in the past. Special thanks are extended to Mr. Geoffrey E. Perry, head of the Kettering Group, for his peer review of chapter three.

Special thanks are also extended to Mr. David R. Woods, an engineer with IBM Federal Systems Division in Owego, NY, who prepared most of the illustrations in the report, and to Ralph F. Gibbons for allowing CRS to use several drawings he had previously prepared for other publications. These illustrations are copyrighted and may not be used elsewhere without their permission. All the illustrations are based on unclassified material appearing in scientific journals or actual models shown at the Paris Air Show and other technical displays.

Part 1 of this review, dealing with launch vehicles and sites, political goals and purposes of the Soviet program, the Soviet attitude towards international cooperation in space, Soviet organization for conducting its space activities, and the resource burden of the space program on the Soviet economy, was published in December 1982 by your committee. Part 3, covering unmanned space activities (space science, space applications, and military activities), will be delivered to you in the near future. We hope that these comprehensive reviews of Soviet space activities, which CRS has prepared since 1961, continue to be useful in your deliberations on priorities for the U.S. space program.

Sincerely,

GILBERT GUDE, *Director.*

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STEADY PROGRESS TOWARD A PERMANENT FOOTHOLD IN SPACE

In the 8 years since the last edition of this report was published, the Soviets have made great strides in their quest for a permanent manned presence in orbit. The introduction of the second generation space stations, Salyut 6 and 7, have provided such an opportunity since 1977, but the Soviets have not yet exercised that option. Barring unforeseen catastrophes, 1984 surely will be the year that one Soviet space crew replaces another already in orbit for the first time, and the final step to permanency achieved (there is substantial evidence that crews were to have been rotated in the fall of 1983, but a launch failure scuttled those plans).

The Soviets have developed a space transportation system of sorts to support orbiting crews, although they use expendable vehicles (that can be used only once), rather than a reusable vehicle like the U.S. space shuttle. The Soyuz spacecraft ferries crews back and forth to the Salyut space station. Progress, a modified version of Soyuz specially designed to haul cargo up to Salyut, was introduced in 1978, and has permitted maintaining crews for as long as 7 months. Its capability is limited, though, since it is not designed to survive reentry and therefore cannot return equipment or the results of scientific experiments to investigators waiting on the ground. Scientific analysis of the crew's work has thus been slowed, but the Soviets have now solved that problem with the introduction of the multipurpose Kosmos 1443-class spacecraft which cannot only deliver 2.5 times the amount of material to orbit than Progress, but can return 500 kilograms to Earth. It also serves as a space tug, and space station module.

While these spacecraft do provide a working link between orbit and Earth, the Soviets obviously could benefit from a reusable system for performing these tasks. There is increasing evidence that they are developing at least one, and possibly two, reusable manned systems. This development program seems to be progressing rather slowly, however, since Kosmos flights as early as 1977 are thought to have been related to reentry tests of a reusable vehicle. The Soviets themselves conceded as long ago as 1978 that a small reusable vehicle was in development. Additional Kosmos flights in 1978, 1979, 1982, and 1983 lent further credence to the existence of a development effort, especially with the release of pictures of one of the orbital test vehicles by the Australians. After all this time, however, there apparently still have been no orbital flights of a full-scale prototype.

The Soviet Union has a slow, methodical, almost plodding, approach to the introduction of new space hardware, however, and test programs traditionally take a long time. It is one of the major differences between the Soviet and U.S. programs. For example, the development of the Kosmos 1443-class space vehicle started in the 1970's. The first test flight, Kosmos 929, was in 1977. The next orbital test, Kosmos 1267, did not occur for 4 more years. Kosmos 1443, the "operational" version according to the Soviets, appeared finally in 1983, 6 years after the first orbital test, and it is unclear that the vehicle is really operational (it probably would have been given a designation other than the generic "Kosmos" name if it were). By contrast, it took only 4 years for the United States to progress from drop tests of the space shuttle from an aircraft to manned orbital flight. For the Soviets, the Soyuz ferry craft is essentially the same vehicle used since 1967 and the booster used to place it in orbit has been in use since the 1950's. U.S. spacecraft from the 1960's, conversely, have long since become museum curiosities.

The U.S. approach would be more aptly described as "fits-and-starts." The design of U.S. manned spacecraft advanced rapidly in the beginning, from Mercury to Gemini to Apollo in a short 9 years. Each of these spacecraft was a substantial technological improvement over the previous model. A quantum leap technologically was then made from the expendable Apollo to the reusable space shuttle, but at the price of having no U.S. manned spaceflights for 6 of the years that shuttle was in development, because there was no support for continuing flights using the Apollo hardware. During those 6 years (1975–81), the Soviets made 21 manned spaceflights, greatly expanding their experience in Earth orbit.

Among other things, the difference in approach to the space programs reflects the difference in political systems in the two countries. The Soviet Union has had only three leaders since Sputnik (Khrushchev, Brezhnev, and Andropov) and all have been strong supporters of the space program. In the United States, there have been seven Presidents since 1957 (Eisenhower, Kennedy, Johnson, Nixon, Ford, Carter, and Reagan) and the architect of the first decade of the U.S. space program, President Kennedy, was assassinated only 2 years after his historic decision to send Americans to the Moon. These seven Presidents, and the Members of Congress who have served in the 14 sessions of Congress that have convened during those years, have had differing levels of interest in and support of U.S. space activities. In the late 1960's and early 1970's, when America's treasury had to support the Vietnam war and the "Great Society" social programs, the amount of money left over for activities such as space exploration was limited, and support for the space program by the public and elected officials was low. Apollo lunar missions were cancelled, and the Skylab space station program was descoped. Production of the giant Saturn V launch vehicle ceased, and America lost its heavy lift capability.

When looking at the achievements of the two space programs in the past 26 years, it could be argued that the missing link in the Soviet program is their inability to send cosmonauts to the Moon. Instead, they have focussed on Earth orbital activities. Politics aside, though, the more reasonable approach would seem to be gaining knowledge in orbit and then moving out to other planetary bodies such as the Moon; perhaps the Soviet program is more logically oriented than its U.S. counterpart. They built a space station first, and now are developing reusable vehicles to service it. The United States has a reusable vehicle, but no space station (although this will probably change since President Reagan has made a commitment to build a U.S. space station by the early 1990's). It should be emphasized, however, that this approach was more the luck of the draw than good planning. Clearly the Soviets intended to send men to the Moon during the 1960's—the Moon race was for real. They did not have the technology to accomplish that goal, just as they have not had the technology to build a reusable vehicle, so have been forced to rely on their expendable vehicles.

But technology is, after all, only one factor in making a space program. Commitment is at least as important. With their old technology but steady commitment, the Soviets have made substantial progress in their manned space program. They are the only country to have refueled a space station in orbit, and have done it so often that it is now routine. They have performed major repair work on their space stations, even using hacksaws to replace part of the cooling system on Salyut 6. Perhaps most significantly, they have gained knowledge about what tasks are best performed by man rather than machine, and how crews react to long durations in the weightless void of space, away from family and friends.

One area of the Soviet manned space program that remains grey is the extent to which they use it for military purposes. The distinction that was drawn in the West in the early 1970's between military and civilian Salyut space stations ended with the advent of the second generation design. It would appear that today Salyuts are used for both military and civilian purposes, but where the emphasis lies is unclear. Often there are assertions by U.S officials that Salyut is used heavily or primarily for military purposes, but during recent deliberations over U.S. military interest in a space station, Pentagon planners concluded that there were no military tasks in the foreseeable future that could be done better on a space station than with unmanned spacecraft. Either the Soviet military is quite clever about determining uses for military man in space, or allegations about Soviet military uses of space stations are overstated.

The distinction between which space activities are military and which are civilian has always been difficult to draw. Since the space shuttle is categorized in the United States as a civilian vehicle, even though 37 percent of the launches between now and 1994 are for the military, it is reasonable to classify the current Salyut program as civilian, even though some of the experiments conducted on board may be for military purposes.

For the long-term future, the Soviets have grand plans, including large orbital complexes composed of manned and unmanned modules in different orbits, and manned flights to other planets. The time scale they contemplate for these activities remains unknown. New hardware is needed to accomplish the task, and more knowledge about how the humans involved will react to long periods in space (a year or more) is required.

The physiological and psychological research performed by the Soviets on their long duration flights has shown that psychological problems may be the biggest factor in extending the duration of manned flight. Although there are physiological problems (calcium loss, for example), the feelings of isolation experienced by the crews, and detailed in the diary of one of the crewmembers of the longest flight to date (211 days), may be as difficult if not more so to overcome. Soviet physicians nevertheless remain optimistic about longer duration missions.

In terms of the hardware, test flights of the Soviet Saturn V-class vehicle, which have been anticipated since the late 1960's, may come as early as 1984, and if they are successful, it could be operational a year or two later. It is interesting to note the concern with which Soviet introduction of this vehicle is being greeted in the West. It seems forgotten that the United States had that capability more than a decade ago (hence the term "Saturn V class vehicle") and chose, primarily for budgetary reasons, to throw it away. A shuttle and/or spaceplane should also appear in the next several years, with orbital tests of a full-scale vehicle perhaps as early as 1985. Estimating when new Soviet space hardware might be introduced is always risky, so these dates should be considered with caution.

The theme that has been echoed time and time again in Soviet discussions of their future plans for manned space activities is the desire for a permanent manned presence in orbit, using modular space stations. From 1976 to 1983, the period covered in this report, they have made substantial progress in this regard. But as they themselves admit, in the "Economics Gazette" no less, that is only the beginning:

> In the more distant future scientists foresee the creation of far larger stations which will be of great importance for all the inhabitants of our planet and will make possible the appearance of constructions for the transmission of electric power to the earth from space. From these stations manned ships will be launched into the depths of space, where, in turn, the construction of extraterrestrial settlements will begin.[1]

[1] Federov, B. Ekonomicheskaya Gazeta, January 1981, p. 24.

Chapter 1

Overview of Manned Space Activities: 1957–83

Since their first manned space launch in 1961, the Soviets have doggedly pursued their goals in manned flight. Despite setbacks in their Earth orbital program—from docking failures to space tragedies which have taken the lives of four cosmonauts—their enthusiasm has not waned, and even though they have not succeeded in putting cosmonauts on the Moon, they talk about sending people to Mars in the not too distant future. They have extended the duration of manned space flight to 211 days, enabling Soviet physicians to conclude that although there are medical problems with long duration spaceflight, none will prohibit flights of even greater length.

This report is volume II of the most recent of a series of 5-year reports prepared for the Senate Commerce, Science, and Transportation Committee [1] by the Congressional Research Service, and provides information on manned space activities, including the space life sciences. Volume I, published earlier, discusses launch vehicles, launch and tracking sites, international cooperation, organization for Soviet space activities, and how much the Soviets spend on their space activities. Volume III will address unmanned programs (space science, space applications, and military).

Chapters 3 and 4 provide comprehensive details on manned space flight programs and the space life sciences through December 31, 1980. Chapter 2 has been provided to highlight activities in 1981 through 1983, the time during which the report was written.

This chapter serves as an overview of the manned programs of both the Soviet Union and the United States. Readers interested in more detail on the Soviet flights will find information in the remaining chapters of this volume. Detailed information on U.S. manned space activities is contained in *U.S. Civilian Space Programs 1958–1978*, prepared by the Congressional Research Service for, and published by, the House Committee on Science and Technology in 1981.

THE MOON RACE BEGINS

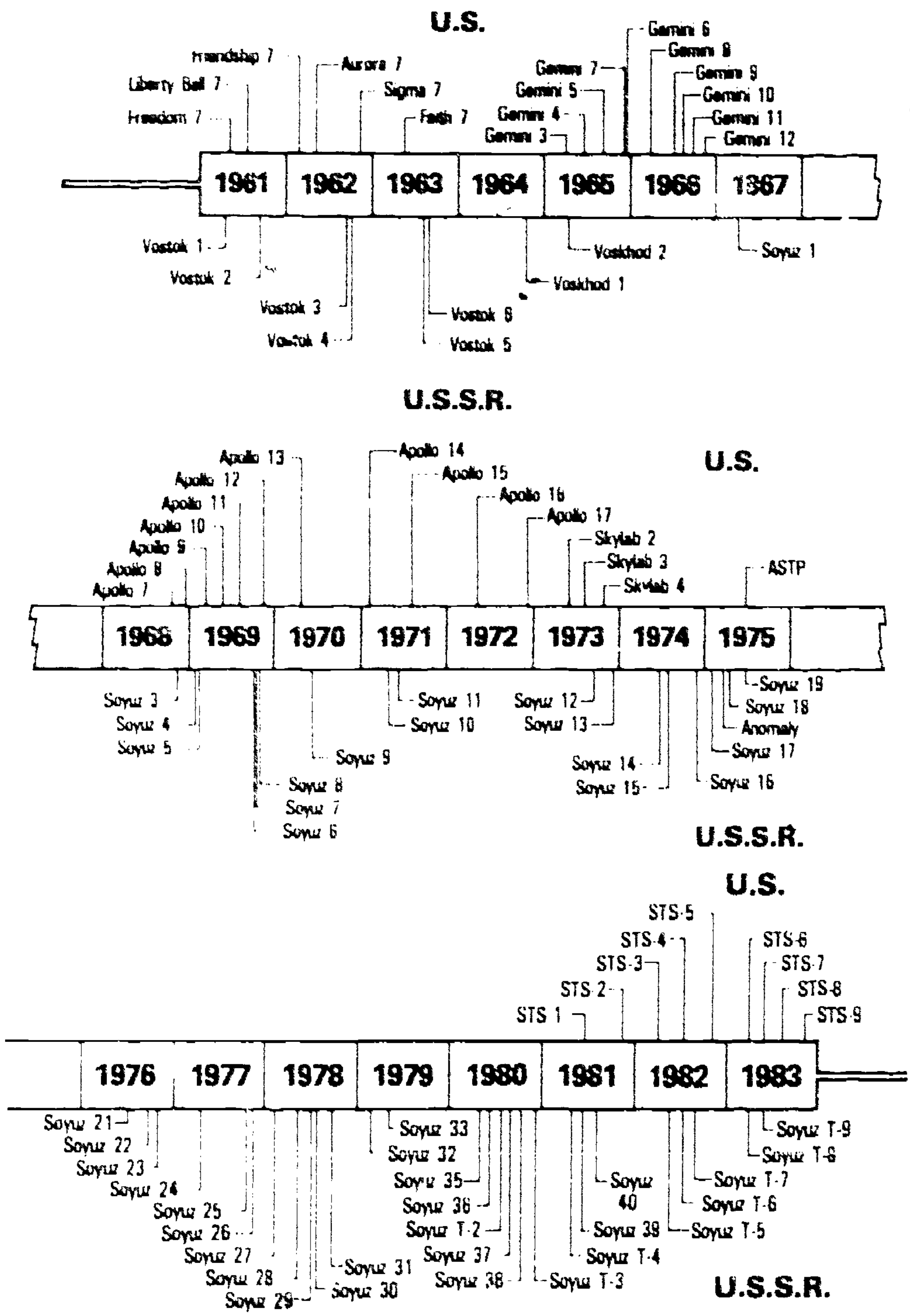
On April 12, 1961, the Soviet Union scored a space spectacular that was to shape the first decade of manned spaceflight. On that day, Yuriy Gagarin became the first man to orbit the Earth in his Vostok 1 spacecraft. Three weeks later, on May 5, the United

[1] Until 1976, the Aeronautical and Space Sciences Committee.

States succeeded in placing Alan Shepard in space. Although his was only a suborbital flight, it was enough to give a new President, John F. Kennedy, the confidence he needed to call upon the Nation to "commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth." This challenge was made on May 25, only 3 weeks after Shepard's flight, but Congress and the American people agreed. The Moon race was on.

The time-line in table 1 shows the course of events since then. The Soviets made six flights in the Vostok series which were similar in purpose to the six U.S. Mercury flights: Establishing the basic parameters of human reaction to spaceflight. On the last Vostok flight, the Soviets achieved another first—Valentina Tereshkova became the first woman in space.

Time Line of U.S. and U.S.S.R. Manned Space Missions



After the six Vostok flights, the Soviets made two more launches of the same spacecraft, but renamed Voskhod. These two flights are often considered to have been more oriented toward public relations than scientific goals, but they did score two more space firsts: The first multiple crew (three men on Voskhod 1), and the first extravehicular activity (Aleksey Leonov on Voskhod 2).

As table 1 shows, the Voskhod flights were followed by a period of inactivity by the Soviets while the United States raced ahead with its Gemini program to acquire experience with rendezvous and docking in space, extend the duration of manned spaceflight, and perform extravehicular activity (EVA). Although the Soviets had achieved recognition for the first spacewalk, the United States quickly followed with its own on Gemini 4, and perfected the techniques required for EVA on subsequent Gemini flights in 1965 and 1966. (The Soviets, conversely, did not use EVA again until the 1969 Soyuz 4/5 flight.) Having declared itself in a "Moon race" with the Soviets, the United States discovered that visibly, at least, the competition had temporarily disappeared. Questions began to surface about whether or not there really was a Moon race, but statements by prominent Soviet politicians, scientists, and cosmonauts left no doubt in the minds of U.S. space planners and the Apollo program proceeded.

The first Apollo flight was to have taken place early in 1967, but on January 27, its three-man crew was killed during a prelaunch test when fire erupted in the command module. Three months later, when the Soviets resumed their manned flights, the result also was tragedy. On April 24, 1967, Vladimir Komarov was killed upon impact with the Earth when the parachute lines of his Soyuz 1 spacecraft tangled during descent. Both manned programs were set back for a year and a half, but the development of the large launch vehicles needed for a Moon landing continued. In the United States, the Saturn V was tested several times in 1967 and 1968. As noted in volume I, there is some evidence that the Soviets were in the process of developing the "G" booster during this period, although there were no known flight tests.

When the manned flights began again in October 1968, it was clear who was ahead in the Moon race. The first U.S. flight was Apollo 7, which tested the Apollo command module in Earth orbit. The first Soviet flight, on the other hand, was a simple rendezvous of a manned and an unmanned spacecraft in orbit. The next U.S. flight, Apollo 8 in December, placed astronauts in lunar orbit and 7 months later, on July 20, 1969, two Americans made the first Moonwalk.

The Soviet Union meanwhile was continuing its manned Earth orbital flights, but there were several unmanned flights associated with development of a lunar landing spacecraft from 1968 to 1971. These were made in the Zond and Kosmos series (Zond was a modified Soyuz space craft). Thus, even after the United States had won the Moon race, the Soviets were obviously interested in landing crews there. The "G" vehicle never appeared, however, and cosmonauts have yet to make it to the Moon.

THE SPACE STATION ERA

The Soviets turned their attention to Earth orbit, and in 1971 launched the first space station, Salyut 1. The first crew to this space station, Soyuz 10, docked but could not enter. The second attempt, with the three-man Soyuz 11 crew, was successful, and the crew occupied the space station for 3 weeks. Tragically, though, the crew died during reentry when an improperly sealed hatch allowed the spacecraft atmosphere to vent into space. The crew was not wearing spacesuits and the men were asphyxiated. As a result, the Soviets returned to two-man crews in the Soyuz so there would be sufficient room for the cosmonauts to wear spacesuits. Nearly 10 years elapsed before they were able to redesign the interior of the Soyuz and the spacesuits so that three people could be accommodated again.

During this time, the United States was continuing its lunar landing program. Although the 1971 Apollo 13 flight almost resulted in tragedy when an oxygen tank explosion severely damaged the Apollo spacecraft enroute to the Moon, the mission came to a happy end when the astronauts were able to use the Lunar Module as a liferaft and they returned home unharmed. The United States placed a total of six crews on the Moon, with the last landing in December 1972 (Apollo 17).

Public support for the Moon program had waned after the first landing, however, and three Apollo missions (18, 19, and 20) were cancelled. The once ambitious Apollo Applications Programs for Earth orbital operations was scaled back to a single space station to which three crews were sent. This station, Skylab, was launched in 1973 and although badly damage during launch, was able to function for almost a year following repair work by the crews which occupied it in 1973 and early 1974. The last of the three Skylab crews set a new duration record of 84 days in space. Skylab had approximately three times the interior volume of the Soviet space stations.

While Skylab was in orbit, the Soviets began encountering difficulties in their space station program. Not only were they recovering from the Soyuz 11 tragedy, but the two space stations they launched in 1973 failed as soon as they reached orbit. The first of these was Salyut 2, while the second failed so early in its mission that it was not even given a Salyut designation, but rather was named Kosmos 557. (The Soviets do not readily admit to failures, so often use the catch-all category Kosmos to designate failures, as well as other missions they do not wish to disclose.)

In 1974, the Soviets finally succeeded in placing another space station in orbit—Salyut 3, which is considered in the West to have been the first military space station. This categorization is based on the fact that the crews sent to the station were all military, rather than mixed military/civil as they had been on Salyut 1; the orbit was lower, presumably to expedite reconnaissance photography; and the crew switched to military telemetry once they entered the station. The Soyuz 14 crew stayed on board Salyut 3 for 2 weeks, but the Soyuz 15 crew was not able to dock.

At the end of 1974, the Soviets also launched another civilian space station, Salyut 4, to which two crews were successfully launched (Soyuz 17 and 18) in 1975. One crew which intended to fly up to the Salyut had to abort the mission because of the failure of the third stage of the launch vehicle, and landed 320 kilometers north of the Chinese border. Since this was a failure, the Soviets did not give it a Soyuz designation, and it is referred to as the April 5 Anomaly, having occurred on April 5, 1975.

At this time, it appeared that the Soviets were alternating military and civilian space stations. With hindsight, it is possible to conclude that had they been successful, Salyut 2 and Kosmos 557 would have been a military and a civilian space station, respectively.

DETENTE SPACE—THE APOLLO-SOYUZ TEST PROJECT

From 1972 to 1975, both countries were involved in preparations for the first joint manned mission—the Apollo-Soyuz test project (ASTP). Launched in July 1975, ASPT involved the docking of a three-man Apollo with a two-man Soyuz. The preparations included visits by crews and support personnel to each other's launch, mission control, and training facilities. Although there had been great concern expressed in the United States that it would be giving away advanced technology to the Soviets, there is no evidence that this was the case, although it is interesting to note the Soviets have reconfigured the physical appearance of their mission control center to almost duplicate the National Aeronautics and Space Administration's (NASA) mission control in Houston. Details of the Soyuz 11 accident and the April 5 Anomaly were provided at the insistence of American mission planners who wanted to ensure that the safety of U.S. astronauts would not be endangered. A special docking adapter was designed in the United States and was heralded as insurance that either country could launch a rescue flight to help the other if the need arose, but since this was the last flight of the U.S. Apollo spacecraft, it would never be used again.

As the time-line shows, ASTP was the last flight for the United States for 6 years while the space shuttle was being developed. The Soviet Union, conversely, moved out strongly in its space station program.

Another military space station, Salyut 5, was launched in 1976 to which three crews were launched (one of which was unable to dock). A free-flying Soyuz mission was also launched that year to test an East German multispectral camera, MKF-6, which has subsequently been installed on two space stations.

SALYUT 6 AND 7—SECOND GENERATION SPACE STATIONS

The first of the Soviets' second-generation space stations, Salyut 6, was launched on September 29, 1977. The space station functioned in orbit for 4½ years, until it was finally deorbited in July 1982. The most significant change in the space station was the addition of a second docking port. This enabled the Soviets to send up additional crews to "visit" the main crew on the station, and to send unmanned resupply flights using the Progress vehicle to deliver experiments, personal items, and most importantly, fuel. The Soviets accomplished the first in-space refueling using Progress 1 and

Salyut 6. In other cases, the Progress engines themselves have been fired to raise the space station's orbit.

A total of 16 crews occupied Salyut 6. Two others tried to do so, but the very first mission (Soyuz 25) was unable to dock, and another (Soyuz 33) suffered an engine malfunction and could not rendezvous.

Of the 16 crews that did dock, 5 were long duration crews, the longest of which increased flight duration to 185 days. Most of the others were "visiting" crews that stayed for approximately 8 days and brought new experiments and took back the results of those which had been performed. Nine of these visiting missions involved cosmonauts from non-Soviet countries. All were members of Interkosmos, the organization through which the Soviets cooperate in space research activities with their allies (Bulgaria, Cuba, Czechoslovakia, East Germany, Hungary, Mongolia, Poland, Romania, and Vietnam). Although seen primarily as a public relations part of the space program, each country provided at least one of its own scientific experiments. (The Bulgarian cosmonaut was aboard Soyuz 33 which could not rendezvous with the space station.)

In 1979, the Soviets introduced an upgraded version of the Soyuz spacecraft, designated Soyuz-T. The first flight was unmanned, and was followed by three manned flights to the space station. Although the spacecraft is essentially the same, it has modernized avionics, a better fuel system, solar panels so that it can fly independently for longer periods of time than with batteries alone,[2] and the interior has been redesigned so that it can accommodate three space-suited cosmonauts. Soyuz T-3 in November 1980 marked the first use of a three-man crew by the Soviets since the 1971 Soyuz 11 tragedy. (The original Soyuz is no longer used for the manned program.)

Experiments conducted on Salyut 6 ranged from astrophysical observations to Earth resources imaging to materials processing to biological studies. As can be imagined, a great many experiments could be conducted on such long duration flights, and there has been considerable speculation in the West that military experiments were also conducted, but since information to confirm or deny this speculation is classified, it remains in question. In any case, the distinction which was drawn during the 1970's between military and civilian space stations apparently can no longer be made since if both types of activities are conducted, they are done on the same space station.

In 1981, the Soviets docked an unmanned module, Kosmos 1267, with Salyut 6. The Soviets announced that this was a test of a modular space station, although a Western magazine claimed that it was a battle station in orbit, equipped with meter-long interceptors. The Soviets occasionally reported on tests conducted with Kosmos 1267, which they probably would not have done if it were a military vehicle, and the entire assembly was deorbited in July 1982 with no apparent firing of the alleged interceptors. On the basis of

[2] Early in the space station program, the Soviets removed the Soyuz solar panels since batteries could provide sufficient power to get the spacecraft up to a space station and back again. However, with the several docking failures, the ships had insufficient power to try docking a second time. Hence the return to solar panels on Soyuz-T. In addition, the power from Soyuz can be tied into the space station.

available evidence, it seems clear that Kosmos 1267 was exactly what the Soviets said it was—a test of a modular space station.

Also in 1981, the United States finally resumed manned spaceflights with the reusable space shuttle. The first shuttle flight, STS-1, was made on April 12, which coincidentally was the 20th anniversary of Yuriy Gagarin's flight.[3] A second flight was also made in 1981. Both were successful even though each was delayed from its initial launch date, and the second flight had to return early because of the failure of one of its fuel cells.

In 1982, the Soviets launched a new space station, Salyut 7. Three crews docked with Salyut 7 in 1982. The main crew set a new duration record of 211 days, and was visited twice. The first visit included a Frenchman, who dubbed himself a "spationaut" rather than an astronaut or cosmonaut. The second carried the second woman into space. The United States made three more flights of its space shuttle, including the first military flight (STS-4) and the first operational flight (STS-5).

Rumors grew during 1982 that the Soviets were developing their own space shuttle. In February, the Soviet science attaché at the Embassy in Washington publicly admitted that such a vehicle was in development, and a flight in June (Kosmos 1374) is generally considered in the West to have been a test of a prototype reusable space vehicle. The mission lasted only one and a quarter orbits and landed in the Indian Ocean, where the craft was recovered.

The Soviets continued work on Salyut 7 during 1983, but it was a mixed year of successes and failures. In March, they docked the module Kosmos 1443 with the space station, terming it an "operational" version of Kosmos 1267. The module was described as a combination cargo craft with 2.5 times the capacity of Progress, a space tug, and an extension to the space station which would increase the habitable volume by 50 cubic meters, or 50 percent. It also had a descent module for returning the results of experiments to Earth. Western observers heralded this as the first modular space station, expected for so long, but the Soviets never used it in that manner, but only as a cargo craft and space tug. Whether something went wrong, or if this was the intended mission profile, remains unknown.

Only one crew occupied the station during 1983, although three were meant to visit Salyut 7. The first (Soyuz T-8) could not dock; the second (Soyuz T-9) successfully docked and conducted a 149 day mission; while the third (Soyuz T-10A) never got off the launch pad. A fire erupted in the launch vehicle seconds before lift off, and the crew was rescued using the emergency abort system.

Meanwhile, the United States successfully completed four more shuttle flights, STS-6, STS-7, STS-8, and STS-9. Among the special features was the launch of the first American woman (Sally Ride) on STS-7; the first American black (Guion Bluford) on STS-8; and the first non-American to fly on an American manned mission (Ulf Merbold of West Germany on STS-9). The last flight of the year, STS-9, was the first flight of the European-built Spacelab,

[3] This was not intentional. STS-1 was supposed to take off on April 10, but computer problems forced a last minute 2-day postponement.

and over 70 experiments were conducted by the six-person crew, the largest crew to work in space together.

As for the Soviet shuttle/spaceplane, two more tests similar to Kosmos 1374 were conducted in 1983 (Kosmos 1445 and Kosmos 1517), the latter of which made a "controlled descent" into the Black Sea rather than the Indian Ocean, demonstrating increased confidence in the system.

Whatever the Soviets plan for the immediate future in manned space flight, a critical determinant for long-term goals such as sending people to other planets is the ability of the human body to adjust to weightlessness. The following section provides an overview of what has been discovered about human reaction to long duration stays in orbit.

SPACE LIFE SCIENCES

In the early stages of the Soviet and American manned space programs of the late 1940's and 1950's, there was a striking lack of unanimity in the aeromedical communities of that era about whether humans could withstand the unique rigors of spaceflights. Indeed, there were respected experts in medicine and biology who were firm in the belief that manned spaceflight was impossible. It was reasoned by this small, elite group of doubters that the human cardiovascular, musculoskeletal, and immune systems would fail in a weightless environment. Some even postulated that humans would not be able to swallow food in space, the ultimate barrier to manned spaceflight.

Nonetheless, there were also biomedical experts of that early era who were just as firm in their belief that manned spaceflight was definitely feasible. In the Soviet Union, such notable experts as V.V. Parin and N.M. Sisakyan were prominent in the emergence of space medicine and biology as a discipline. Similarly, in the United States, Maj. Gen. H.G. Armstrong foresaw the development of space medicine. In 1948, the U.S. Air Force School of Aviation Medicine organized a meeting on the topic of "Aeromedical Problems of Space Travel." Presentations were made by the then Colonel Armstrong, Prof. Hubertus Strughold, later to be named the "father of space medicine," and astrophysicist Dr. Heinz Haber.

It was not an easy task for Soviet and American proponents to introduce the concept of manned spaceflight. Opponents in high positions of political power were difficult to convince and many felt that the concept was frivolous, risky, and above all, too expensive. Early vertical flights of animals on Soviet and American rockets did little to dispel what had become entrenched skepticism. Not until 1960 did both countries begin to consider seriously the prospect of manned spaceflight and the legitimacy of space medicine and biology.

On April 12, 1961, Yuri Gagarin became the first human being to experience weightlessness in space during a single orbit of flight in Vostok-1 lasting 108 minutes. That flight broke the ice for additional Soviet flights in the Vostok series and served as a stimulus for the first American suborbital flight.

From a biomedical point of view, there developed a cautious optimism that humans could withstand the rigors of spaceflight, at least for a short time. Nonetheless, skeptics and conservatives persisted in their belief that the human organism was not equipped for spaceflights of days, let alone weeks duration. These fears were reinforced considerably in the Soviet space medicine community after the flight of Vostok-2 carrying cosmonaut Gherman Titov. During his 1-day, 17-orbit flight, Titov experienced spatial disorientation and motion sickness. Inexplicably in that era, no American astronaut in the Mercury or Gemini Programs was to experience those symptoms. Accordingly, the American space medicine community was skeptical about Soviet concerns over motion sickness in space. Many dialogs between American and Soviet space medicine experts took place during the late 1960's about this issue. The Americans remained convinced that space motion sickness was uniquely a Soviet problem and that it really did not merit much attention.

That entrenched attitude was to change radically during the Apollo program. Only during the Apollo era did it become plain that space motion sickness was a serious and potentially dangerous condition. Symptoms of nausea, dizziness, and fullness of the head seemed to occur during the first hours and days of spaceflight. Evidently, the more commodious Apollo module which allowed more freedom of body movement was the reason for the new expression of these symptoms in American astronauts. The extremely cramped Mercury and Gemini modules allowed virtually no freedom of body movement. In contrast, the larger Vostok/Voskhod, and Soyuz modules did allow relative freedom of body movement, perhaps explaining why Soviet cosmonauts had experienced symptoms of motion sickness and fullness of the head on a fairly regular basis throughout those programs.

The Soviet Vostok and Voskhod missions and the American Mercury and Gemini missions of the 1960's were relatively uneventful from a medical point of view, mainly because most missions were only a few days in duration. The longest Gemini mission was 14 days. Accordingly, the medical conclusion following completion of the Gemini program was that humans could survive the space environment for periods as long as would be required for a lunar mission. Significant biomedical findings at that time included:

Loss of red blood cell mass (5 to 20 percent);
Postflight orthostatic intolerance (100 percent of crews);
Loss of postflight exercise capacity;
Decreased bone density (7 percent);
Persistent loss of bone calcium and muscle nitrogen; and
High metabolic cost of extravehicular activity.

These basic physiological responses to the space environment, in addition to space motion sickness, remain major problem areas of concern today.

During the Soviet Vostok and Voskhod era of the 1960's, the presence of humans in space modules was of principal concern to Soviet scientists in four fundamental areas:

Assuring cosmonaut safety in the event of space module malfunction;
Protection of the cosmonaut against space factors and maintenance of normal vital functions;
Reliable operation of module systems in space; and

Safe and accurate reentry and descent.

These were primarily engineering issues, but there was also considerable concern in the Soviet space medicine community about human physiological response to prolonged weightlessness. This concern found its greatest expression after the 18-day flight of Soyuz 9 in 1970. Whereas optimism had reigned in the American and Soviet manned spaceflight communities in the 1960's, new doubts emerged in the Soviet space medicine community after the longest manned flight to date. The two Soyuz 9 cosmonauts exhibited pronounced orthostatic intolerance upon reentry and landing and had to be carried from the space module on stretchers. This anomalous response gave rise to gloomy speculation in both the Soviet and American space medicine communities that the limits of human endurance in the space environment had been reached.. Representatives of both communities began to doubt whether humans could withstand up to 30 days of spaceflight, because the Soyuz 9 cosmonauts required 11 days of postflight readaptation to gravity. It was then that both communities began to focus on the issue of physical conditioning and other countermeasures against physiological deconditioning during relatively long spaceflights of a week or longer.

Subsequent Soyuz. Apollo, Apollo-Soyuz, Soyuz/Salyut, and Skylab missions served to alleviate the anxiety created by the anomalous Soyuz 9 flight. During the 1970's, a number of countermeasures were developed which made it possible for humans to live in the space environment for weeks and even months with relatively little degradation of physiological function. Major biomedical findings from the Apollo program were:

Vestibular disturbances (space sickness);

Suboptimum food consumption (1260–2903 Kcal/day);

Postflight weight loss and dehydration (1 week recovery);

Decreased postflight orthostatic tolerance;

Cardiac arrhythmias (Apollo 15); and

Decreased red cell mass (2 to 100 percent) and plasma volume (4 to 9 percent).

The Soviet Soyuz program resulted in no unusual or unexpected physiological changes other than increased pulse rate during launch and orbit insertion and pulse rate variability throughout the flights. Cosmonauts in the Soyuz program were carefully monitored to assess the physiological effects of weightlessness and became more involved in the conduct of biomedical probes. There was strong emphasis on countermeasures against physiological deadaptation such as chest expanders, isometric exercises, elastic tension straps, and the "Penguin" constant loading suit which simulates the actual body weight of the cosmonaut by requiring him to maintain an upright posture against forces created by the suit.

The early 1970's saw the beginning of the Soviet Salyut space station series and the end of the Apollo era. Only the American Skylab would be active in the remainder of the 1970's. By then, confidence had increased that humans could tolerate missions of long duration. Accordingly, both Soviet and American missions became progressively longer during the 1970's and 1980's. The longest manned flight ever was accomplished on the Soviet Salyut 7 space station (211 days). Missions on the American Skylab were 28, 59, and 84 days. It was then possible to establish the time course of physiological adaptation to the weightless environment of space. Based on the subjective reports of three Skylab crews and vestibular experiments performed on both Skylab and Salyut stations, it was concluded that space motion sickness remains a problem, cannot be predicted on Earth, but can be somewhat alleviated by medications. Perhaps the most significant finding of the Soviet Salyut program is that physiological deconditioning can be substantially reduced through a regimen of vigorous exercises that requires upward of 2.5 hours per day. Soviet cosmonauts on the longer Salyut missions have returned to Earth in generally good physical condition. There has been no recurrence of the problems experienced on the earlier Soyuz 9 flight. Thus, prolonged human presence in the space environment has become an operational reality, although most of the problems enumerated earlier persist. At present, the following biomedical problems are of principal concern to both the American and Soviet space medicine communities:

Space motion sickness;
Cardiovascular deconditioning;
Blood changes (blood cell mass loss); and
Bone mineral loss.

In addition to the above, as a more persistent human presence in space becomes a reality in this and coming decades, the following issues will become more important:

Selection of space personnel;
Flight crew training and conditioning;
Medical care during space flight;
Extravehicular support of space stations;
Protection from radiation and toxic substances;
Use of artificial gravity in space;
Man/machine interactions and engineering; and
Life support systems containing plants and animals.

The Soviet Union is planning the construction of multimodular space complexes, but in addition, is also planning for manned missions to planets in the solar system (particularly Mars). Clearly, the Soviet space program is larger and more ambitious than the U.S. program based on the large effort underway in the Soviet space life sciences. The research is plainly directed toward the development of hardware and life support systems that will permit man to exist safely in the space environment for months and even years.

STATUS OF U.S. AND SOVIET MANNED PROGRAMS AT THE END OF 1983

Thus, as 1983 drew to a close, the Soviet Union and United States were both heavily involved in manned space activities. The Soviets with their space station program and the Americans with their reusable ferry craft, seem to have adopted opposite philosophies in the development of manned vehicles.

In the early 1970's, the United States had had to choose, for budgetary reasons, between developing a space station or a reusable vehicle. It chose the reusable space shuttle, and now is considering whether or not to build a space station. The Soviets took the opposite path, building first the space station, and now the reusable vehicle.

By selecting the path it did, the Soviets have outdistanced the United States in gaining experience with human beings in outer space. They have more than doubled the duration of manned space missions from the 84-day Skylab flight in 1974 to 211 days for the Soyuz T-5/7 crew in 1982. With that much time to perform experiments, the Soviets have greatly expanded knowledge in fields such as plant growth in space; the processing of pharmaceuticals, metal alloys, and crystals; Earth resources photography; astrophysical observations; studies of the upper atmosphere; and most importantly how the human body withstands extended exposure to the conditions of space. But for all of this, they still have problems in returning the results of their scientific work to Earth. The Progress vehicle which takes supplies up to the space station is not designed for reentry, so it cannot bring results back. They have partially compensated for this by developing the Kosmos 1443-class spacecraft with a descent module, but it has flown only once. They could obviously benefit from having a reusable ferry craft.

The United States, on the other hand, has made a great technological leap by developing the reusable space shuttle. It is designed to allow routine and comparatively inexpensive access to space—but it has no space station from which to ferry crews and experiments. The debate over whether or not to build a space station is a current issue in both Congress and the executive branch that had not been resolved by the end of 1983. By contrast, Soviet space technology has advanced little in the past decade and a half. Their primary manned spacecraft is simply an uprated Soyuz, which was first used in 1967, and it is launched by the same launch vehicle that placed Sputnik 1 in orbit in 1957.

The roles of the military and civil communities in manned activities is also becoming more controversial. Since the entire Soviet space program is the responsibility of the military—there is no Soviet equivalent of NASA which conducts civilian space activities in the United States—it is sometimes represented in the West as being an entirely military program. If the same criteria are applied to Soviet manned activities as are applied to those of the United States, however, one would have to conclude that to date both have been heavily oriented toward civilian goals.

The United States would certainly count Mercury, Gemini, Apollo, Skylab, and ASTP as entirely civilian, and the shuttle as primarily civilian since it was developed by NASA, even though 37 percent of anticipated shuttle flights through 1994 will be for the Department of Defense. Similarly, then, Vostok, Voskhod, Soyuz, and Salyut 1 and 4 can be counted as civilian, while Salyut 3 and 5 could be counted as military. As noted earlier, the military/civil interface on Salyut 6 and 7 is unclear, but a study of what the Soviets have openly discussed about Salyut experiments leads to the conclusion that the cosmonauts could not be spending a majority of their time on unannounced military experiments in order to have time to spend on those that have been announced as civilian. Assuming that the Soviets are honestly reporting the nonmilitary experiments, the conclusion can be reached that Salyut is no more militarily oriented than the space shuttle (that is, no more than 37 percent of Salyut experiments are for military purposes.)

Manned spaceflight is also becoming increasingly international in the 1980's. The Soviets took the lead in sending non-Soviet cosmonauts into space. By the end of 1982, representatives of the nine Interkosmos countries plus France had flown on Soviet missions, and two Indian cosmonauts are now in training. The United States followed suit in the fall of 1983 with the launch of a European on the first Spacelab flight. Spacelab, which fits inside the cargo bay of the space shuttle, was developed by the European Space Agency. In December 1982, President Reagan invited Brazil to send an astronaut on a future space shuttle flight, and Australia, Canada, and Japan have ind ted interest in doing the same (Canada has already chosen six ca ates).

The future for manned spaceflight then would seem to include a wide variety of uses of space—both military and civilian—by people from many countries, not just the United States and Soviet Union. Although the United States has no plans to go back to the Moon or to other planets in the foreseeable future, the Soviets have openly talked about the possibility of manned flights to Mars (although they have not specified whether they would circumnavigate the planet or land). The United States is debating whether to build a space station, and some have suggested that it be an international effort, while the Soviets apparently are already developing their version of the space shuttle. Whether the two space powers will return to the manned space cooperation of the ASTP-era, perhaps with U.S. shuttle flights to Soviet space stations as envisioned in the 1977 agreement for cooperation between the two countries (which was allowed to lapse in May 1982 because of Soviet activities in Afghanistan and Poland) is very much uncertain, but with the growing number of countries involved in space activities, and the efforts by the United States and Soviet Union to send people from other countries into space, it would appear that space will be international regardless of U.S. and Soviet attitudes toward cooperation with each other.

Chapter 2

Significant Activities in Soviet Manned Spaceflight: 1981–83

As noted earlier, the main text of this report adds data for the period 1976–80 to existing versions of *Soviet Space Programs*. Since this edition has taken additional time to prepare following the 1981 death of Dr. Charles S. Sheldon II, Senior Specialist in Space and Transportation, who spearheaded the 1966–70 and 1971–75 editions and was in the process of preparing this edition, the current authors have decided to include a chapter that briefly highlights what has happened since 1980. Information in this chapter is not as extensively detailed as that in the remainder of the volume, since its purpose is only to bring the reader up to date.

MANNED SPACE PROGRAMS

Salyut 6

The final manned flights to Salyut 6 were launched in 1981. First, a resupply mission, Progress 12, was sent to the space station on January 24. Then Soyuz T–4, carrying cosmonauts Vladimir Kovalenok and Viktor Savinyk, was launched on March 12, 1981, and the crew stayed on board for 75 days. They were visited by two crews, each of which brought Interkosmonauts to the station. The first, Soyuz 39, was launched on March 22 and was composed of Vladimir Dzhanibekov and Jugderdemidiyan Gurragcha (the first Mongolian cosmonaut). The second, Soyuz 40, was commanded by Vladimir Popov and included the first Romanian cosmonaut, Dumitru Prunariu, and was launched on May 14, 1981. The Soviets reported that this would be the last flight of the original Soyuz, with future flights to be made with Soyuz–T.

The Soyuz T–4 crew was the final crew on Salyut 6, and left the space station on May 26. During the time they were on board, the crew continued experiments similar to those conducted by earlier crews on Salyut 6 and detailed in chapter 3. As discussed below, the space station was deorbited in July 1982.

Kosmos 1267

On June 19, 1981, the Soviets docked an unmanned module, Kosmos 1267, with Salyut 6. The spacecraft, which weighed 15 metric tons, almost as much as the Salyut itself, had been launched on April 25, 1981, and had performed numerous orbital maneuvers prior to the time it docked with the space station, including separa-

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tion of a large modular section weighing 600 kilograms on May 24 which reentered and was recovered. Kosmos 1267's orbital activities closely paralleled those of a previous flight, Kosmos 929, in 1977, whose purpose was then unknown.

When Kosmos 1267 docked with Salyut 6, the Soviets announced that it was "designed to test systems and elements of the design of future spacecraft and for training in the methods of assembly of orbital complexes of a big size and weight." [1] In other words, a modular space station. They also stated that the earlier orbital maneuvers were to test the satellite in an independent mode, including midcourse corrections and other dynamic operations.[2] This was not unexpected, as the Soviets had been discussing plans for large orbital stations for several years.

In July, September, and December 1981, the Soviets released details of the experiments being conducted with the combined spacecraft, emphasizing that the purpose was to generate knowledge in the creation of even larger stations in the future. Numerous maneuvers of the complex were made using the Kosmos 1267 engines.

In October and November, however, the U.S. trade magazine *Aviation Week and Space Technology* reported that the spacecraft was, in fact, an "antisatellite battle station equipped with clusters of infrared-homing guided interceptors," with "firing ports to eject 1-meter-long miniature vehicles guided by infrared sensors." [3]

The Kosmos 1267/Salyut 6 combination was deorbited by the Soviets on July 29, 1982. Because the Soviets do not usually report on military satellites at all and there was considerable coverage of Kosmos 1267, and since there were no known test firings of any projectiles which were allegedly aboard Kosmos 1267, it is difficult to conclude that *Aviation Week* was correct in its allegations that this was an antisatellite-related device.

SALYUT 7

During the final months of flight for the Salyut 6/Kosmos 1267 complex, the Soviets launched Salyut 7, another second-generation space station. The station is very similar to Salyut 6, with an improved navigation system, a strengthened forward docking port, and modifications to the solar panels to permit attachment of additional arrays.

Salyut 7 was launched on April 19, 1982, and received its first crew in May. Soyuz T–5 was launched on May 13 carrying two cosmonauts: Anatoliy Berezovoy and Valentin Lebedev. This crew set a new duration record of 211 days, returning on December 10. They were visited by two missions. The first, Soyuz T–6, was launched on June 24 and carried the first Frenchman into space, Jean-Loup Chretien. The crew also included two Soviets: Vladimir Dzhanibekov and Aleksandr Ivanchenkov. The second set of visitors arrived in Soyuz T–7 and included the second woman in space, Svetlana Savitskaya. Launched on August 19, she was joined by Leonid

[1] Tass in English, 1100 GMT, June 19, 1981.
[2] Ibid.
[3] Killer Satellites. Aviation Week and Space Technology, Oct. 26, 1981, p. 15. Cosmos Threat. Aviation Week and Space Technology, Nov. 30, 1981, p. 17.

Popov and Aleksandr Serebrov. There were four Progress resupply flights during 1982.

Among the important results of experiments on Salyut 7 during 1982 was the first successful growing of a seed through the entire life cycle of the plant and back to seed again. The Soviets had been attempting to do this since Salyut 1, but only succeeded in 1982 using an Arabidopsis seed (wallcress). Other work included electrophoresis experiments using the Tavria unit in which molecules are separated from each other by passing an electrical current through a fluid. Researchers are optimistic that more pure vaccines and other pharmaceutical products can be produced in space, without the influence of gravity. The cosmonauts experimented with interferon and urokinase, and found that it is possible to purify substances between 10 and 15 times better than on Earth, and the productivity in space is hundreds of times higher.

The main crew took more than 20,000 photographs of the Earth using the MKF-6M and KATE-140 cameras. They also used a television apparatus called Niva to videorecord and relay back to Earth information on observed areas, thus avoiding the delay waiting for another crew or the end of the mission to return the film from MKF-6M and KATE-140 systems for processing (the Progress spacecraft is not recovered so cannot return the results of experiments).

The space station carries an X-ray spectrometer called SKR-02M, with which they made observations of interstellar space for a total of 40 hours of observing time. Two French astrophysics experiments are also on board. The first, Piramig, is a highly sensitive camera used to study the upper atmosphere, the interplanetary medium, and galaxies, in the visible and near-infrared bands. The second, PCN, is used for nighttime studies of weak light sources in space (such as the luminosity of interstellar dust) and the upper atmosphere (luminescent clouds and lightning).

Human physiology studies were continued, as well as other biological experiments, including Cytos-2, which concerned the effects of weightlessness on bacteria under the influence of different antibiotics, and Biobloc, which investigated the effects of cosmic rays on biological material.

Although the Soviets have never admitted to conducting military experiments on any space station, including this one, the trade press carried accounts of several military investigations thought to be taking place. *Aerospace Daily* reported on speculation by the Pentagon that antisubmarine warfare experiments were conducted, including observations of bioluminescence produced by plankton, which might reveal the path of a submarine.[4] *Air Force Magazine* reported that there was "strong circumstantial evidence" that the Soviets used Salyut 7 for calibrating and refining the targeting and tracking mechanisms of ground-based military lasers.[5] Finally, *Aviation Week and Space Technology* reported that the Soviets conducted pointing and tracking tests similar to those planned for the U.S. Talon Gold experiment (to be carried on the space shuttle in 1985) in which ballistic missiles and other spacecraft were tracked.

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[4] Aerospace Daily, Nov. 29, 1982, p. 137.
[5] Air Force Magazine, March 1983, p. 24.

These tests could be related to development of a space-based laser system.[6]

Two small (25 kg) satellites, Iskra 2 and Iskra 3, were deployed from Salyut 7 in 1982 through the airlock. Both were reportedly used during their short lifetimes (the orbit was low so they decayed rapidly) by amateur radio operators. The cosmonauts performed a 2½ hour EVA during which they practiced the use of various tools while in their spacesuits, practiced connecting mechanical joints which could be used to join large structures, and evaluated materials (e.g., rubber) which might be used as sealing agents in space construction.

In 1983, a lengthy article was published in *Pravda* consisting of extracts from Lebedev's diary.[7] His frank remarks about the loneliness of living in space, away from family and friends, problems with insomnia despite a tiring workload, and establishing a working relationship with his colleague on the flight that would not be influenced by the presence of the visiting crews, revealed the psychological pressures involved in long-duration spaceflight. The mere fact of its publication was interesting and surprising.

In 1983, three crews were intended to occupy Salyut 7, but only one successfully achieved that goal. In March, the unmanned module Kosmos 1443 docked with the space station (see below). The first crew intended to dock with the Salyut 7/Kosmos 1443 complex was Soyuz T–8, but its rendezvous radar failed to deploy and the crew was unable to dock. The attempts by the three-man crew (Vladimir Titov, Gennadiy Strekalov, and Aleksandr Serebrov) to compensate for the lack of the radar system by "seat-of-the-pants" flying were detailed in an article in *Krasnaya Zvezda* only 4 months after the attempt failed.[8] Again this was uncharacteristic candor, since previously, docking failures had nevertheless been described as mission successes.

A successful docking was achieved by the Soyuz T–9 crew which had been launched on June 27. Vladimir Lyakhov and Alexandr Alexandrov remained on board for 149 days. Supplies were delivered by Kosmos 1443 and two Progress missions, and the Progress was modified so that fresh foods could be placed inside only a few hours before launch, instead of days before launch as had previously been the case. During the mission, a fuel leak developed in one of the Salyut fuel tanks, but the problem was not serious enough to cause the Soviets to bring the crew home.[9]

The T–9 crew continued work on experiments similar to those conducted by previous Salyut 7 occupants. Earth photography was expedited by the presence of Kosmos 1443 in the early part of the mission because it was used for stabilizing the complex (and therefore did not exhaust Salyut 7's fuel supply or require the crew's time), and could return a large amount of exposed film in its descent module. Thus, in 1 week, Lyakhov and Alexandrov took as many photographs as the previous crew had taken during its entire

[6] Aviation Week and Space Technology. Oct. 25, 1982. p. 15.
[7] Gubarev, V. His Heart Remains on Earth. Pravda, Aug. 15, 1983. p. 7.
[8] Titov, V. Trial in Orbit. Krasnaya Zvezda, Aug. 9, 1983. p. 4.
[9] The fuel leak had been reported by Aviation Week and Space Technology, (Oct. 10, 1983. p. 23) and in December the Soviets confirmed that there had been a leak, although it would appear that it was not as serious as Aviation Week had suggested.

211-day mission.[10] By the end of their 149 days, they had held 43 sessions of Earth resources observations, obtaining 3,000 photographs with the MKF-6 camera, and 100 with the KATE-140. The crew also performed a series of experiments called "Kometa" for improving mathematical models for reproducing colors of the sea as they are perceived through the atmosphere, to enable space crews to make more accurate observations.

A wide range of experiments related to materials processing were conducted. Nineteen experiments in the electrophotograph series were conducted to study the effect of space flight conditions on thin film coatings which were exposed to the conditions of outer space in an airlock. Electrophotograms were made of the materials after several hours or days of exposure. Results of the first set of experiments were returned via the Kosmos 1443 descent module, and after processing them on the ground, scientists requested several changes in the manner in which the tests were conducted, including the use of film more sensitive to electric fields, and more frequent observations by the crew (including taking color photographs) of changes during the exposure time. Little mention was made of the Splav and Kristall furnaces, other than a general reference at the end of the mission that semiconductors (including cadmium selenide) had been processed in Kristall.

Electrophoresis experiments continued with the Tavria unit. A pure protein substance was produced toward the end of Soyuz T-9 mission from the membranes of an influenza virus. The Soviets commented that although such a preparation can be made on Earth, the experiment showed that it could be made much more economically in space. The T-9 crew produced 35 milligrams of the substance, "sufficient for our laboratories to be supplied with material for research over the course of many months. . . . This superpure substance is . . . a domestic standard with which we can now compare all the vaccines that are produced."[11]

Fourteen sessions of experiments were performed with the Pion unit for studying heat and mass transfer in, and the physics of, multiphase media in weightlessness. The Pion apparatus recorded changes in the density and temperature of substances as the container in which they were held was heated. The processes were recorded on motion picture film and videotape using a holographic device.

Plant growth experiments continued, and included work with some of the Arabidopsis seeds produced on the 1982 mission.

The crew used the SKR-02M, Piramig, and PCN astrophysical equipment, as well as a reflecting X-ray telescope (called RT-4M).

Repair work continued on different components of the space station, most notably the Delta navigation system. The computer began sending new data to storage locations, and erasing important information. The crew replaced the system's memory unit, and the computer was reprogrammed via telemetry from the ground, a process that took a week.[12]

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[10] Izvestiya, July 18, 1983, p. 2.
[11] Leningradskaya Pravda, Nov. 29, 1983, p. 4.
[12] Sotsialisticheskaya Industriya, July 17, 1983, p. 3.

A micrometeorite struck one of Salyut's windows in July, causing a loud crack and creating a crater with a 4 mm diameter.

The Soyuz T-9 crew became the first cosmonauts to perform two EVA's on a single flight as the result of the failure of the Soyuz T-10 crew to make it into orbit (see below). Lyakhov and Alexandrov performed EVA's on November 1 and November 3 to install additional solar panels to increase the electricity supply for the experiments on the station, with each excursion lasting almost 3 hours. According to the Soviets, the new panels increased the electricity supply by 50 percent, although a picture of the crew installing the additional panels showed them to be only about one-third (or less) the size of the main arrays (see fig. 1).[13] This accomplishment was cited as extremely important for planning for the development of orbiting industrial facilities and solar power stations.

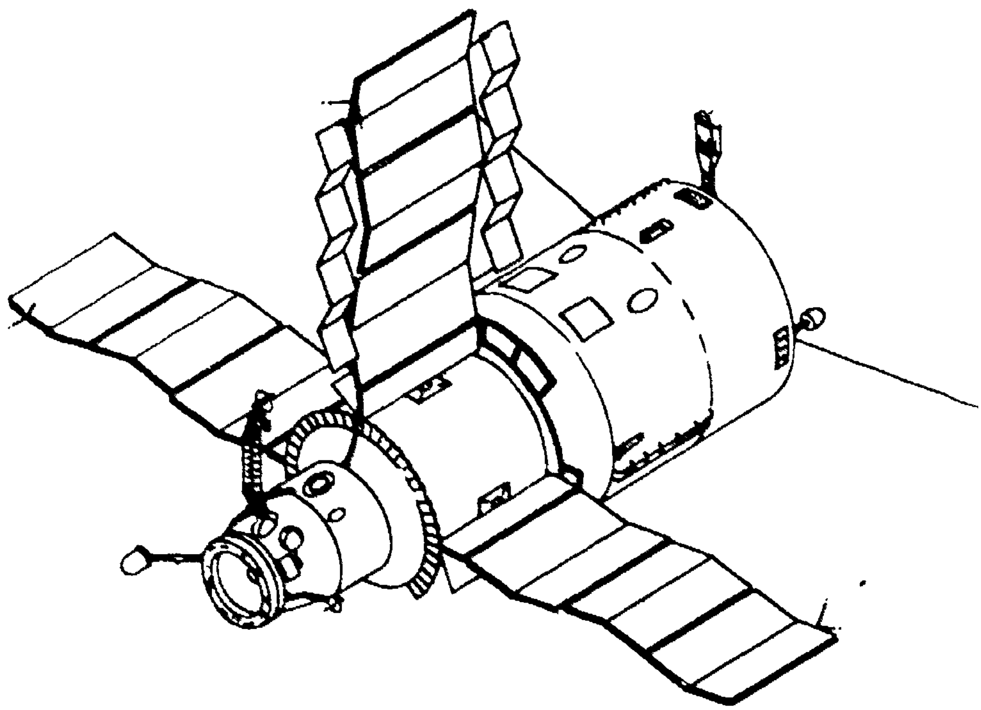

FIGURE 1 - Salyut 7 with additional solar arrays installed by Soyuz T-9 crew. (Drawing by R. F. Gibbons and Teledyne Brown Engineering.)

The duration of the Soyuz T-9 mission was extended following the aborted Soyuz T-10 mission on September 26, 1983. The T-10 crew was to have docked with Salyut 7, and probably would have replaced, rather than visited, the T-9 crew. Seconds before liftoff, however, a fire erupted in the launch vehicle, and the two men on board (V. Titov and Strekalov, both veterans of the Soyuz T-8 failure) were jettisoned by the Soyuz emergency abort system. They were safely recovered 3 kilometers downrange.

Press reports of the accident appeared in the West within a week of the accident (most stating, incorrectly, that three people were

[13] Pravda, Nov. 4, 1983 p. 3.

aboard, one a woman), and 2 weeks later, at the International Astronautical Federation [IAF] conference in Budapest, Hungary, the Soviets themselves admitted that it had occurred (and named the two men who were on board). In December 1983, at a press conference for the T-9 crew, Soviet officials added that the T-9 mission had been extended because of the T-10 failure, and the EVA was to have been conducted by the T-9 crew and the two men who were "to have relieved them." [14] The use of the phrase "to have relieved them" virtually confirmed the speculation that the T-10 crew would have replaced rather than visited Lyakhov and Alexandrov. A turnover of operations from one crew to another has been expected since the launch of Salyut 6 in 1977. When it finally happens, very probably in 1984, the Soviets will have made another major step toward their stated goal of a permanent presence in space.

The Soyuz T-10 launch failure, coupled with the rumors about the fuel leak on Salyut 7, led many Western journalists to declare an emergency on board the space station, despite a lack of evidence to support such an assertion. The longest time a Soyuz T spacecraft had remained in orbit had been 113 days, so after 111 days, a BBC journalist reported that in 2 more days the crew would be stranded in orbit and they were running out of supplies. This hyperbole continued until the very day Lyakhov and Alexandrov returned to Earth. In fact, the crew had plenty of supplies from Kosmos 1443 and the two Progress missions, and there was no evidence that the design lifetime of Soyuz T was only 113 days. At the IAF meeting in Budapest, for example, it was unofficially unacknowledged that the design lifetime was on the order of 180 days.

Even if there had been a problem with reactivating the ferry craft, an unmanned Soyuz T could have been launched to bring the crew home, as had been done with the Soyuz 32 crew (see chapter 3). Thus, there was no evidence that the crew was ever in danger, despite the numerous press reports to the contrary.

KOSMOS 1443

On March 2, 1983, the Soviets launched Kosmos 1443 and described it as an operational version of Kosmos 1267, although the fact that it retained a Kosmos designation instead of having a new name like Progress suggests that it may still have been preoperational. The Soviets reported that Kosmos 929 (see chapter 3) had been a precursor flight for this type of spacecraft, confirming many years of Western speculation.[15] The spacecraft docked with Salyut 7 on March 10, 1983.

The Soviet press gave considerable coverage of the spacecraft and its mission and it was described as serving several purposes: (1) a cargo craft both for bringing supplies and equipment to an orbiting crew (2.5 times the amount that Progress can carry) and returning up to 500 kg of cargo to Earth in a descent module; (2) a space tug; (3) an extension to the space station to increase its habitable

[14] (1) Burns, John F. Soviet Launching Explosion and Salyut 7 Leak Confirmed. New York Times, Dec. 13, 1983. p. C 4. (2) Soviets Acknowledge Salyut Fuel Leak, Note Mission Extension. Aerospace Daily, Dec. 13, 1983. p. 217. (3) Paris AFP, 1626 GMT, Dec. 12, 1983.

[15] Pravda, July 3, 1983. p. 3. Sotsialisticheskaya Industriya, July 3, 1983. p. 4.

volume by 50 cubic meters (or approximately 50 percent); and (4) as an autonomous module for various tasks such as materials processing or astronomical observations.

The spacecraft had two solar panels of its own with a total span of 16 meters and an area of 40 square meters, and weighed as much as Salyut (20 tons). It was 13 meters long and 4 meters in diameter at its widest point. The descent module resembled an American Gemini capsule from the 1960's. Pictures of the vehicle were published in *Pravda*,[16] and renditions based on those pictures are shown in figures 2 and 3.

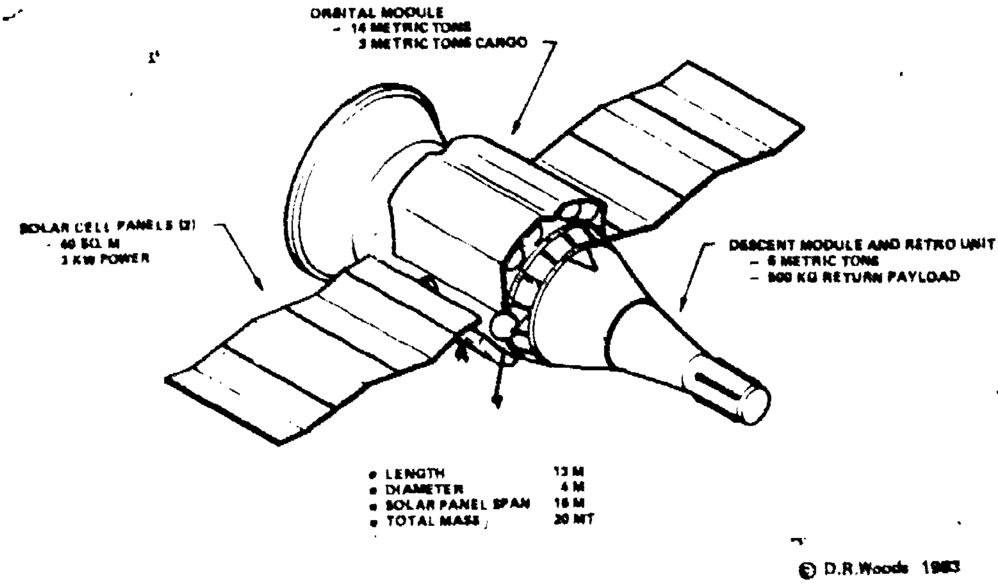

FIGURE 2.—Kosmos 1443 spacecraft. Kosmos 929 in 1977 introduced a whole new class of spacecraft that appears to be related to the manned program. Kosmos 929 conducted extensive maneuvering in Earth orbit and returned a recoverable capsule part way through its mission. Two follow-on missions: Kosmos 1267 and Kosmos 1443 linked up with Salyut space stations (Salyut 6 and Salyut 7 respectively). They may eventually become building blocks for larger, permanent space structures.

[16] July 2, 1983 and Oct. 9, 1983.

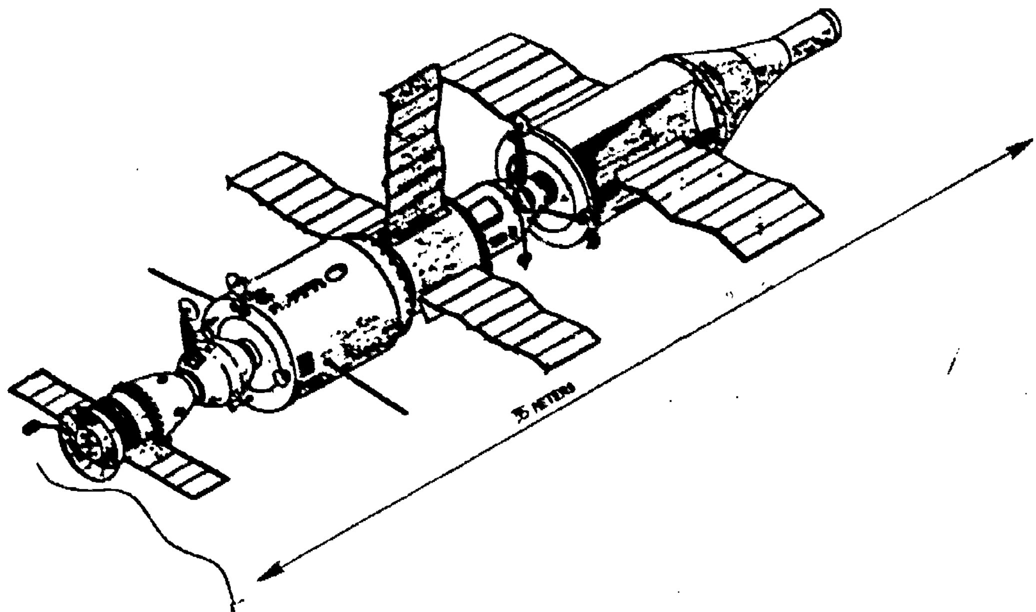

FIGURE 3.—Salyut 7 docked with Soyuz T-9 and Kosmos 1443. (Drawing by R. F. Gibbons and Teledyne Brown Engineering.)

In its cargo craft role, it delivered almost 3 tons of supplies and equipment to the space station, including the solar panels which were later installed by the Soyuz T-9 crew. The descent module returned 350 kilograms of material on August 23, 1983, a week after Kosmos 1443 separated from Salyut 7. Among the cargo were the results of more than 45 experiments, and pieces of equipment that had functioned aboard the space station (e.g., an air regenerator and components of the Delta computer) to enable studies of the deterioration of these systems.

The main body of the spacecraft, which had been filled with trash by the Soyuz T-9 crew, was deorbited on September 19, 1983.

As a space tug, Kosmos 1443 raised and lowered the orbit of the complex several times, and also made numerous maneuvers after it undocked from Salyut on August 14. The Soviets commented that in the not so distant future such tugs would be used to assemble structures weighing many metric tons, the components of which would be launched into orbit stage by stage.[17]

Somewhat surprisingly, it never really functioned as an extension to Salyut 7, which Western observers had assumed was its primary task. Instead, shortly after the supplies were unloaded and the crew had loaded the material to be returned to Earth in the descent module, the entire spacecraft (instead of just the descent module) undocked. It remains unclear as to whether the Soviets simply did not intend to use it as a modular space station extension on this flight, or if something went wrong.

[17] Moscow Domestic Service, 0000 GMT, July 1, 1983.

SPACEPLANE TESTS

Rumors have existed for many years that the Soviets are developing a reusable space vehicle similar (in concept, at least) to the U.S. space shuttle (see chapter 3).

In the 1980–82 time period, however, Soviet space officials began to downplay the possibility of their developing a reusable vehicle on the basis that their present spacecraft were more economic. In April 1981, for example, cosmonaut Vitaliy Sevastyanov responded to a reporter's question about Soviet development of a space shuttle by saying that a shuttle would be more effective than existing systems "only for a short term investigation of a certain phenomena [sic] or subjects, and only when new, stronger and cheaper materials are invented."[18] At the 1981 IAF meeting, another cosmonaut, Aleksey Yeliseyev told reporters that "at the present time, there is no plan for a Russian space shuttle."[19] In February 1982 Anatoliy Skripko, Science Attaché at the Soviet Embassy in Washington, publicly announced in a speech to the American Astronautical Society that the Soviets were, in fact, developing a shuttle, but cautioned that nothing would be seen of it for another 2 to 5 years.[20]

Despite these statements to the contrary, on June 3, 1982, only 4 months after Skripko's talk, the Soviets launched Kosmos 1374. It was an unusual mission, launched from Kapustin Yar and recovered in the Indian Ocean after one and a quarter orbits. U.S. Government sources were quoted as saying that this was a test of a shuttle type vehicle.[21] Subsequent media accounts stated that the vehicle was a 2,000 lb (900 kg) sub-scale vehicle, launched on a C-1 booster.[22]

The use of the term "shuttle" could be confusing, however, since earlier reports had indicated that the Soviet "shuttle" would be only one-third the size of the U.S. shuttle (see chapter 3). The Western media suggested that the ultimate vehicle for which this test was conducted would be a 40,000 lb (18,000 kg) vehicle,[23] compared to the approximately 106,000 kg U.S. shuttle orbiter.

In 1983, two more tests of the prototype were conducted. Kosmos 1445 was launched on March 15, and landed in the Indian Ocean as had Kosmos 1374. The Australian Navy was at the scene during the Soviet recovery operations, and they released several pictures of the vehicle. A rendition of the vehicle based on those pictures is shown in figure 4. The pictures showed what resembles thermal protection tiles used on the U.S. space shuttle on part of the top of the vehicle, what appears to be a cockpit window, and a smooth bottom, suggesting either a ceramic or carbon-carbon coating.

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[18] Bratislava Pravda, Apr 14, 1981 p 6

[19] Soviets Air Space Station Goals at IAF. Astronautics and Aeronautics, Jan. 1982. p. 18.

[20] Aviation Week and Space Technology. Mar 1, 1982. p. 24

[21] Washington Post, June 10, 1982. p. A 4.

[22] Soviets Test Sub-Scale Shuttle. Aviation Week and Space Technology. June 21, 1982. pp. 16–17.

[23] Ibid

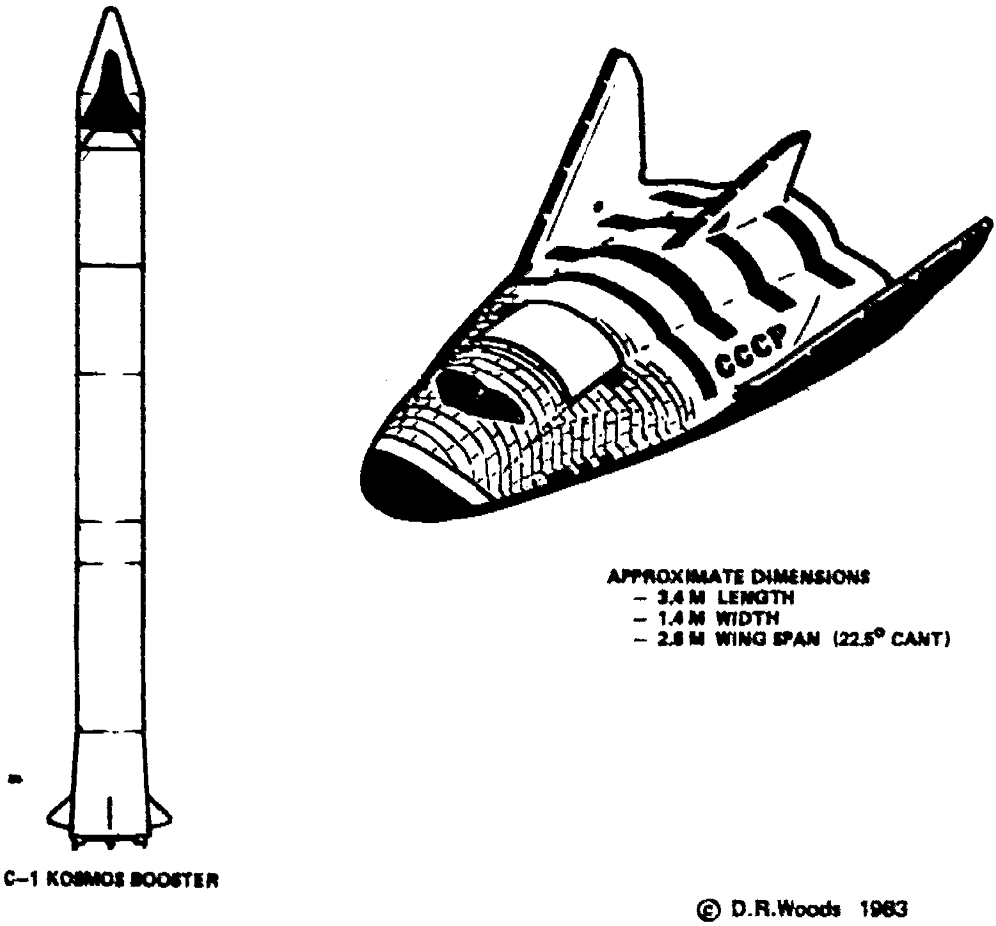

FIGURE 4.—Kosmos Mini-Shuttle Spacecraft. Three Kosmos spacecraft have been launched to test lifting reentry vehicles. Kosmos 1374, 1445, and 1517 were each launched from the Kapustin Yar launch facility on C–1 boosters. After completing one orbit, retro burns brought the first two down in the Indian Ocean off the Cocos Islands, and the third into the Black Sea. Royal Australian Air Force patrol aircraft monitored recovery operations in the Indian Ocean, and obtained excellent photographs of the spacecraft details on which this drawing is based.

The third flight was made on December 27, 1983, establishing a pattern of flights 9 months apart. This flight differed from the earlier two missions because it made a "controlled descent" into the Black Sea, indicating increased confidence in the system.

Information released by the Pentagon in 1983 revealed that the Soviets are developing two reusable vehicles, the first the same size as the U.S. shuttle, the second, a smaller "spaceplane."[24] The Western press reported that the version equivalent to the U.S. shuttle had been seen in intelligence photographs mounted on the back of a Bison aircraft (as the U.S. shuttle is mounted on a Boeing 747 for transport across the country), and is virtually identical to the U.S. shuttle (see fig. 5). According to *Aerospace Daily*, the vehicle is 109

[24] U.S. Department of Defense. Soviet Military Power. Washington, U.S. Government Printing Office, March 1983. p. 66.

feet long with a 76-foot wingspan, compared to the U.S. shuttle's length of 122.2 feet and wingspan of 78.1 feet.[15]

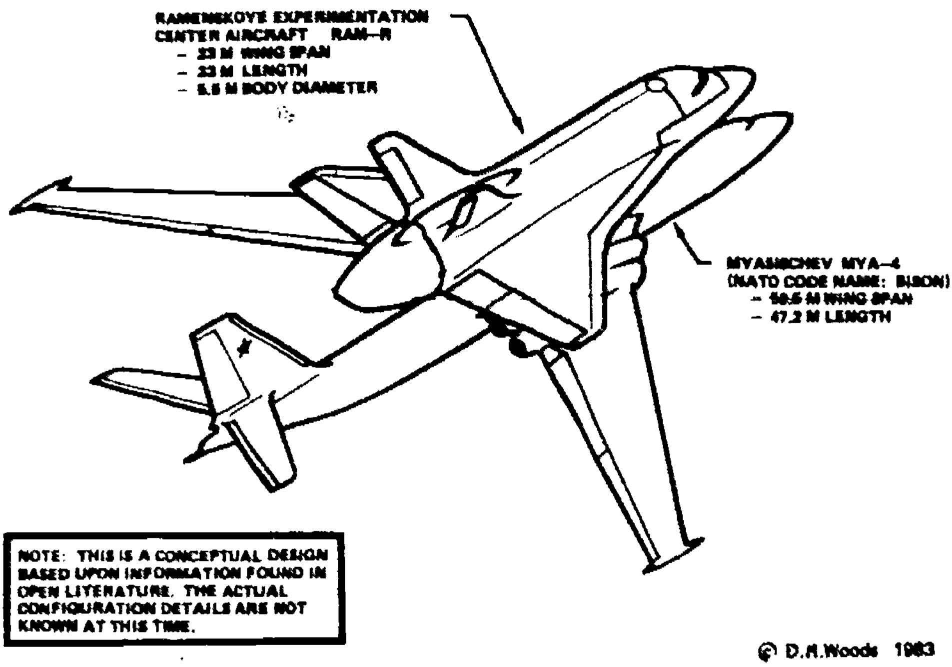

FIGURE 5.—Ram-R Shuttle Prototype Test Vehicle concept. A large shuttle prototype vehicle has been observed being tested at the Ramenskoye Experimental Test Center. It is carried on a Bison bomber much like the U.S. space shuttle is carried on a 747. No design details are available other than the dimensions listed here. However, since it has been stated elsewhere that their shuttle will discard its engines with the propellant tank, it may have an aft cargo door, instead of one on top like the U.S. shuttle. The elimination of engines may have been to include jet engines for a powered landing. This design concept shows a fairing for such an engine between the twin tails.

At the end of 1983, it remained unclear as to whether the three prototype flights were related to the generic development of reusable space vehicles, or if they were sub-scale models of the spaceplane. The potential missions for a Soviet spaceplane are not clear, although the United States is also considering development of a smaller, more versatile version of the space shuttle. Missions planned for this American spaceplane might include orbital reconnaissance, retrieval and repair of satellites, antisatellite activities, and/or weapons delivery. Similar uses of a Soviet spaceplane would not be surprising.

FUTURE PLANS

More information came to light about Soviet future plans in the 1981–83 time period, but nothing that was basically new. Discussion of the possibility of sending a crew to Mars continued at a low level, but some Soviet officials hastened to add that they do not have a specific timetable for mounting such an effort. At the Feb-

[15] Soviet Shuttle Orbiter Seen at Ramenskoye. Aerospace Daily, Mar. 4, 1983. p. 26.

ruary 1982 speech by Skripko, however, he stated that they might attempt a manned Mars mission in 10 to 15 years. He did not say whether they would try to land people on Mars or simply fly them around the planet and bring them home.

Discussion continued to focus on the need for modular, permanently manned space stations, and in November 1983, a lengthy article was published in *Pravda* which described future Earth orbital activities. According to the article,[26] the Soviets plan to build a complex of large facilities in orbits ranging from 200 to 4,000 kilometers, served by freight and passenger transport spacecraft. Included in the list of separate installations were research laboratories, housing modules, powerful energy installations, a refueling station, repair workshops, and construction sites for producing and installing standardized components. Some of these facilities would operate automatically, while others would be permanently manned. Among the benefits of this "orbital complex" cited in the article would be the ability for continuous monitoring of the state of the atmosphere and crops, detecting forest fires, and producing mineral resource surveys; tracking ships and aircraft; providing stable television reception and permanent radio and television communications; batch production of materials unattainable on Earth, and serving as a base for "ambitious space projects like night-time illumination in regions of the Far North using reflected sunlight." Among the technological challenges of such a project would be construction of a parabolic antenna with an effective aperture of 300 to 350 meters that could operate for 15 to 20 years. Such an object would be constructed in low Earth orbit and taken to a higher orbit using a tug. No time frame was given for completion (or initiation) of such a complex.

In the nearer term future, it would not be unexpected to see more frequent launches of the Kosmos 1443-type spacecraft. Some could be outfitted as industrial plants in space that could operate autonomously for a time, and then dock with Salyut for a change of materials by a space station crew.

If the Soviets are finally successful in developing a Saturn V-class launch vehicle, they might use it to launch a core with several docking ports to which Salyut and/or Kosmos 1443 type modules would dock. The concept of such a station has been discussed by the Soviets for several years. At the end of 1983, rumors were rampant that a test launch of the Saturn V-class booster would come in 1984. If this proves true, then the larger space station could be in orbit by 1985 or so. Initially, a station composed of a core with 4 to 6 docking ports might accommodate up to 12 persons, although there has also been some discussion of slightly larger space stations housing 20 to 30 people.[27] Obviously the orbital complex discussed in *Pravda* would involve larger numbers of people, perhaps 100 or more.

[26] Paton, B. and Y. Semenov. For the Orbits of the Future. Pravda, Nov. 28, 1983. p. 7.
[27] Soviets Looking at 20 to 30 Man Space Stations. Defense Daily, Aug. 16, 1982. p. 243.

UNCHARACTERISTIC CANDOR

An interesting development in 1983 was an unusual amount of candor by the Soviets about their space program. As mentioned earlier, articles detailing Lebedev's thoughts while on his 211 day flight, and the Soyuz 33 and Soyuz T-8 docking failures were published. The Soviets admitted that they had had a launch failure on September 26, named the crew involved, and provided some details of what had happened only 2 weeks after the incident. They further conceded that there had been a fuel leak on Salyut 7, as the Western media had reported, and also affirmed that they are developing a reusable space vehicle. They also published articles describing their launch sites at Kapustin Yar and Plesetsk, which had not been previously discussed in the Soviet press.

Whatever the reasons for this new frankness on the part of the Soviet Union, it is certainly appreciated by Western observers of the Soviet space program, and it can only be hoped that such openness will continue to grow.

SPACE LIFE SCIENCES

In 1981, the only missions having any significant life sciences research associated with them were Soyuz T-4 which was launched in March 1981, and the succeeding launching of Soyuz 39 and Soyuz 40. All these manned missions ferried cosmonauts to the Salyut 6 space station.

Cosmonauts Kovalenok and Savinyk were aboard the Salyut 6 for 75 days. During this time they performed experiments on vestibular disturbances and changes in body mass, utilizing multifunctional clinical analysis systems (Polimov-2M, Rheograph and Beta). Cardiovascular analysis after 3 weeks in space indicated that their average pulse rate was 60 per minute and the arterial pressure was 120/63. By the end of the 7th week in space, the average pulse rate remained constant, however, the arterial pressure had decreased for one crewmember. This would suggest that though cardiac deconditioning was manifesting itself in one of the crewmembers, the other remained stable. The Soviets claim this stability was achieved by maintaining a vigorous physical exercise program, consisting of at least 2 hours of exercise per day. The physical conditioning regime utilized a bicycle ergometer, a running track, expansion equipment for strength building and springs to create a load on the muscoskeletal system. The crew also trained with the "Chibis" vacuum suit. Additional cardiovascular studies were performed by the Soyuz 39 crews.[28]

In addition to the aforementioned observations, the arrival of Soyuz 40 brought with it an experiment that evaluated the capacity of human lymphocytes to synthesize interferon.

The crew of Soyuz 40 also investigated possible countermeasures to the initial difficulties encountered in adapting to zero gravity. The crew wore special collars (Vorotnik) which created an artificial load on the cervical vertebrae and limited head movements. It was

[28] Vorob'ev, Ye. I. et al. Preliminary Results of Medical Studies Conducted During Manned Flights of Salyut 6 Program. Izvestiya Akademii Nauk. SSSR. Seriya Biologicheskaya 1, 1981, pp. 5-20.

hoped that this would reduce the incidence of space motion sickness. It is not clear whether the system was effective. Another experiment by means of a device called Pneomatik attempted to prevent the redistribution of blood to the upper torso. Other cardiovascular measurements on the righthand portion of the heart were made by means of a Kardiokassett.[29]

During this time interval, another series of experiments were being conducted on the growth of higher plants aboard the Salyut 6. Utilizing the Oazis apparatus discussed in chapter 4, the crews attempted to grow peas, onions, and orchids; unfortunately none were successful. They also evaluated the effect of heterogenous magnetic fields on the orientation of Crepsis sprouts.

On April 19, 1982, the Soviets launched Salyut 7. Like Salyut 6, the transfer compartment of the new station had a window designed to permit germicidal ultraviolet light to sterilize the interior of the station and transfer point continually. The Soviets also indicate that this permits the cosmonauts to maintain a well tanned skin. One should mention that the ultraviolet light might also facilitate vitamin D synthesis by conversion of 7-dehydrocholesterol to vitamin D. The latter in turn promotes calcium absorption from the intestines. Though not specifically mentioned in the Soviet literature, this might beneficially modify some of the demineralization occurring in bone tissue.

The first crew to visit Salyut 7 remained aboard the space station for the longest duration yet—211 days. Most of the biomedical information from the flight is still not available. Unconfirmed reports indicate that toward the end of their 211-day mission, Berezovoy and Lebedev were experiencing some psychological difficulties. However, prior to that time the condition of the cosmonauts was judged to be good. Unfortunately, on returning to Earth they did encounter some difficulties. They landed at night in the midst of a snow storm. Due to their physical deconditioning they were unable to get out of the Soyuz capsule. The first rescue helicopter sent to assist them from their capsule crashed on landing. The second rescue helicopter which carried medical teams aboard managed to reach the Soyuz capsule. However, it could not take off. Motor vehicles were then dispatched from Arkalek to the landing site and the cosmonauts spent the night in this vehicle. Upon reaching Dzhezkezgan, the two cosmonauts were transferred to Baikonur to undergo readaptation treatments.[30]

During their 211 days aboard Salyut 7, several significant events occurred. An attempt was made, by taking advantage of zero gravity, to purify a biological material, interferon, by electrical charge only, regardless of its molecular weight. Results were encouraging in that a 10 to 15 time greater purification was achieved than is possible on Earth. In addition, on June 24 a Soviet-French space crew arrived to monitor cardiac functions with the French-developed "Echograf," a method for ultrasonic echo-sounding and dopplerography of the heart and major blood vessels. This instrument permitted monitoring of the pumping and contractile function of the heart as well as determining the rate of blood flow in the blood

[29] Ibid.
[30] Ducrocq, A. The Terrible Return. Air Et Cosmos. Dec. 18, 1982, pp. 52-63.

vessels during the acute adaption phase in a weightless state. In that phase, the redistribution of body fluids to the upper torso occurs. By means of closed circuit television, both the crew and ground stations were able to monitor the heart and blood flow visually. One observation was that the heart is displaced upward in the chest cavity due to zero gravity. Blood circulation was measured through the heart, aorta and veins. The rate of blood flow as well as the movement of the heart walls, valves and heart shape were also observed during weightlessness.[31] Using the "Echograf," the crew also evaluated countermeasures in order to normalize blood circulation.

The second female cosmonaut was sent into space August 19, 1982. One of the major reasons given for the mission is that the Soviets believe there is a psychological advantage to having a woman as part of a space crew. The Soviet space medical staff also are trying to gain more information as to the female response and adaptation to space environment. Based on some of these observations, perhaps some of the physiological problem areas encountered by man in space might be modified from data obtained from female cosmonauts.[32]

A modest success in the general area of reproduction was recorded by the Soviets. After numerous failures, they succeeded in germinating and growing wallcress (arabidopsis) from a seed and having the latter subsequently seed.

This latter accomplishment may in the long run be a significant advancement in the development of ecological system for sustaining man in extended space missions.

On June 27, 1983, the Soyuz T-9 was launched. The program called for docking with the orbiting complex Salyut 7 and Kosmos 1443. The crew performed medical and biological experiments that are presently being analyzed.[33] The adaptation of cosmonaut A. Alexandrov to conditions of weightlessness was reported to be somewhat complicated by familiar symptoms of blood pooling in the head during the first few days of the flight. Alexandrov also had difficulty sleeping and suffered a mild loss of appetite during this period. Cosmonaut Lyakhov's adaptation reportedly went more smoothly.

On December 14, 1983, Kosmos 1514, the latest Soviet biosatellite similar in design to the Vostok spacecraft used for early manned missions, was launched. It carried NASA instrumentation for an experiment involving two monkeys, "Abrek" and "Bion", in addition to small laboratory animals and fish. The growth dynamics of plants was also studied. The primary mission of Kosmos 1514, which remained in orbit for only 5 days, was to study specific circulatory mechanisms of physiological adaptation to weightlessness. One of the most complicated problems of manned spaceflight is physiological adaptation to weightlessness in the first hours and days of flight. In these early stages of spaceflight, a number of physiological and circulatory shifts take place, occasionally result-

[31] Nikitin, S. A. Biomedical and Technical Experiments in Flight of Soviet-French Crew. Priroda No. 9 September 1982, pp. 6-9.

[32] Gubarev, V. Rationale for Selection of Female Cosmonauts. Pravda, Aug. 20, 1982, p. 3.

[33] Moscow. Tass June 29, 1983.

ing in discomfort for astronauts and cosmonauts in the form of temporary space sickness and a feeling of fullness of the head. The Kosmos 1514 mission was designed to measure the dynamics of these changes in monkeys. Despite its short duration, the mission was considered to be a success and data are being analyzed.[34] In another experiment, pregnant rats carried aboard Kosmos 1514 apparently gave birth to normal young after the flights. The results of the flight are still being analyzed.

[34] Moscow Tass International Service, Dec. 20, 1982.

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TABLE 2.—SUMMARY OF U.S. AND SOVIET MAN-RELATED SPACEFLIGHTS 1981-83

Mission	Launch date	Crew (No. of flights)	EVA (hr/min)	Ship duration (hr/min)	Crew duration (hr/min)	National cumulative person hours	Comments
Progress 12	Jan. 24, 1981						Unmanned resupply ship.
Soyuz T-4	Mar. 12, 1981	Kovalenok (3), Savinykh	None	1,794:38	1,794:38	50,482:10	Docked with Salyut 7. 75 day flight. Visited by Soyuz 39 and 40.
Soyuz 39	Mar. 22, 1981	Dzhanibekov (2), Gurragcha	None	188:43	188:43	50,859:36	Gurragcha first Mongolian cosmonaut. Docked with Salyut 6.
STS-1	Apr. 12, 1981	Young (5), Crippen	None	54:21	54:21	22,612:31	First U.S. flight of reusable space shuttle.
Kosmos 1267	Apr. 25, 1981						Prototype space station module. Docked with Salyut 6 on June 19, 1981. Deorbited with space station on July 29, 1982.
Soyuz 40	May 14, 1981	Popov (2), Prunariu	None	188:41	188:41	51,236:58	Prunariu first Romanian cosmonaut. Docked with Salyut 6.
STS-2	Nov. 12, 1981	Engle, Truly	None	54:13	54:13	22,720:57	Mission terminated early because of fuel cell failure.
STS-3	Mar. 22, 1982	Lousma (2), Fullerton	None	192:05	192:05	23,105:07	Landing delayed one day and switched to White Sands, N.M. because of bad weather at primary landing site (Edwards AFB, Calif.)
Salyut 7	Apr. 19, 1982						Unmanned space station. Occupied by Soyuz T-5, T-6, T-7, and T-9 crews.
Soyuz T-5	May 13, 1982	Berezovoy, Lebedev (2)	5:06	2,549:06	5,073:05	61,383:08	Docked with Salyut 7. Established new record of 211 days. Both performed 2 hr. 33 min. EVA on Aug. 2. Returned in Soyuz T-7 capsule, landed in blizzard.
Progress 13	May 23, 1982						Unmanned resupply ship.
Soyuz T-6	June 24, 1982	Dzhanibekov (3), Ivanchenkov (2), Chretien	None	189:51	189:51	61,952:41	Chretien first French spationaut. Docked with Salyut 7.
STS-4	June 27, 1982	Mattingly (2), Hartsfield	None	169:10	169:10	23,443:27	Final test flight of space shuttle. Both SRB's lost at sea. First primarily military shuttle payload.
Progress 14	July 10, 1982						Unmanned resupply ship.
Soyuz T-7	Aug. 19, 1982	Popov (3), Serebov, Savitskaya	None	2,712:51	189:52	62,522:17	Savitskaya second woman cosmonaut. Docked with Salyut 7. Returned in Soyuz T-5 capsule.
Progress 15	Sept. 17, 1982						Unmanned resupply ship.
Progress 16	Oct. 31, 1982						Unmanned resupply ship.
STS-5	Nov. 11, 1982	Brand (2), Overmyer, Allen, Lenoir	None	122:14	122:14	23,932:23	First operational shuttle flight. First 4 man crew.
Kosmos 1443	Mar. 2, 1983						Unmanned multipurpose space vehicle (cargo delivery and return, space tug, modular extension or free flyer). Docked with Salyut 7 from Mar. 10, 1983 to Aug. 14, 1983. Descent module returned 350 kg of material on Aug. 23, 1983.
STS-6	Apr. 4, 1983	Weitz (2), Bobko, Musgrave, Peterson	7:44	120:24	120:24	24,413:59	Deployed NASA's TDRS satellite. Musgrave and Peterson performed 3 hr. 52 min. EVA.

Soyuz T-8	Apr 20, 1983	V. Titov; Strekalov (2); Serebrov (2).	None	48:18	48:18	62,667:11	Could not dock with Salyut 7 because rendezvous radar did not deploy.
STS 7	June 18, 1983	Crippen (2); Hauck; Ride; Fabian; Thagard.	None	146:24	146:24	25,145:59	Ride first American woman in space. Was to make first shuttle landing at Kennedy Space Center, but switched to Edwards AFB because of bad weather.
Soyuz T-9	June 27, 1983	Lyakhov (2); Alexandrov	11:30	3,585:46	3,585:46	69,838:43	Docked with Salyut 7/Kosmos 1443 complex. Both performed 2 EVA's (Nov. 1 for 2 hr. 50 min.; Nov. 3 for 2 hr. 55 min.) to install additional solar panels. First time cosmonauts performed 2 EVA's on 1 mission.
Progress 17	Aug. 17, 1983						Unmanned resupply ship.
STS-8	Aug. 30, 1983	Truly (2); Brandenstein; Thornton; Bluford; Gardner.	None	145:09	145:09	25,871:44	First night launch, first night landing of shuttle. Bluford first American black astronaut. Thornton oldest space traveler (54).
(Soyuz T-10A)	Sept. 26, 1983	V. Titov (2); Strekalov (3)					Fire erupted in launch vehicle seconds before liftoff. Crew rescued using emergency abort system. Would have docked with Salyut 7 and probably replaced Soyuz T-9 crew.
Progress 18	Oct. 20, 1983						Unmanned resupply ship.
STS-9	Nov. 28, 1983	Young (6); Shaw; Parker; Garriott (2); Lichtenberg; Merbold.	None	247:47	247:47	27,358:26	First Spacelab mission. Merbold (W. Germany) first non-American to fly on U.S. mission. First 6 person crew. First payload specialists (Lichtenberg and Merbold).

Chapter 3

Soviet Manned Space Programs: 1957–80

From 1976 to 1980, the Soviets launched a total of 19 crews. All but one of these were intended to dock with a Salyut space station; three were unable to dock. Two space stations were launched, the second of which (Salyut 6) introduced the second generation of stations with two docking ports. A new variant of Soyuz optimized for cargo-carrying and refueling functions was introduced and called Progress. Eleven of these unmanned spacecraft were launched to resupply Salyut 6 through the end of 1980. In 1979, the Soviets introduced the Soyuz-T spacecraft, an upgraded manned version of the Soyuz, and announced that Soyuz would no longer be used after Soyuz 40 in 1981.

There were also several flights whose missions are not completely understood, but which may be related to development of new manned vehicles. Included in this category are three pairs of spacecraft (Kosmos 881–882, 997–998, and 1100–1101) and a single flight (Kosmos 929). In addition, there were several flights assumed or known to be related to the development of the Progress and Soyuz-T variants of the Soyuz spacecraft.

The following chapter includes information on all known or suspected man and man-related flights, with the exception of biosatellites which are treated in chapter 4. The discussion of flights prior to 1976 is excerpted from earlier editions of this study; for more detailed discussions, the 1971–75 edition should be consulted.

THE EARLY YEARS OF SOVIET MANNED SPACEFLIGHT

Sounding Rocket Flights

Throughout the 1950's, the Soviet Union launched a series of vertical probe (sounding) rockets from Kapustin Yar using a variety of specially adapted military rockets ranging from modified version of the German V-2 to medium range surface-to-surface missiles which are designated the SS-3 (Shyster) in the West. This vehicle was the immediate forerunner of the SS-4 (Sandal) booster used for launching small payloads from Kapustin Yar and Plesetsk.

While the United States made tests with monkeys and apes, the Soviets concentrated on dogs and occasionally sent smaller animals. By 1952, the Soviet Union claimed to have sent 12 animals up in 18 flights to an altitude of 96 km. The effort improved to the point that in the spring of 1957, a single rocket with a payload of

2,195 kg carried five dogs. That June, the Soviets announced that dogs would participate in the Soviet part of the International Geophysical Year (IGY) program.[1] The use of sounding rockets continued even after satellites were introduced.

On August 27, 1958, the dogs Belyanka and Pestraya were flown to 452 km as part of a 1,690 kg payload. On July 2, 1959, as part of a 2,000 kg payload, Otvazhnaya and another dog were flown to 241 km. On July 10, 1959, Otvazhnaya and several other dogs were flown to 211 km; the payload weight was 2,200 kg. Otvazhnaya made yet another flight on June 15, 1960, this time accompanied by another dog and a rabbit. This rocket had a payload of 2,100 kg and was flown to 221 km. These and other repetitive flights provided opportunities for testing a variety of life support component systems and for linking the behavior of animals, even if briefly, to the hazards of rocket accelerations, radiation, micrometeorites, weightlessness, and recovery. They are summarized in table 3.

TABLE 3.—SOVIET VERTICAL PROBES RELATED TO BIOLOGY LAUNCHED AT KAPUSTIN YAR[1]

Date	Launch vehicle	Payload weight (kg)	Altitude reached (km)	Remarks
1946–52			96	18 flights carried 12 animals.
May 16, 1957	SS-2	2,196	211	5 dogs on a single flight
Aug. 27, 1958	SS-3	1,690	452	Dogs Belyanka, Pestraya
Sept. 19, 1958	SS-3	1,515	473	
Oct. 31, 1958	SS-3	1,515	473	
July 2, 1959	SS-2	2,000	241	Dogs Otvazhnaya, Snezhinka; rabbit Marfusha.
July 10, 1959	SS-2	2,200	211	Dogs Otvazhnaya, and (unnamed).
June 15, 1960	SS-2	2,100	221	Dogs Otvazhnaya, and (unnamed), and rabbit.
June 24, 1960	SS-2	2,100	212	
Sept. 16, 1960	SS-2	2,100	210	
Sept. 22, 1960	SS-2	2,100	210	

[1] The list of flights is incomplete, but includes those announced by Tass or reported in available scientific reviews, including those flights in a longer list which were specifically labeled as related to biology. Most of the other flights not included in the table carried geophysical experiments.

Sources: Tass bulletins. See also Wukelic, George. Handbook of Soviet Space Science Research. New York, Gordon and Breach, 1968.

SPUTNIK AND KORABL SPUTNIK

The Soviets launched the first satellite, Sputnik 1, on October 4, 1957. Only 1 month later, they launched Sputnik 2, which carried the first animal into space. This was followed by five flights in the Korabl Sputnik series, which were precursors to the manned Vostok flight. These carried television cameras to permit real-time observations of the reaction of dogs to spaceflight. These flights are summarized in table 4.

[1] The IGY is discussed in more detail in the space science chapter in volume III. Essentially, it was an international effort from July 1, 1957 to December 31, 1958 to study the Earth and its environment and served as a focal point for the launch of the first satellites. Both the first Soviet and the first U.S. satellites were launched as part of the IGY effort.

TABLE 4.—KORABL SPUTNIK FLIGHTS AS PRECURSORS TO VOSTOK AND VOSKHOD (PLUS SPUTNIK 2)

Flight[1]	Launch		Recovery		Flight duration (hrs:min)	Apogee (km)	Perigee (km)	Inclination (degrees)	Period (min.)	Weight (kg)	Remarks
	Date	Hour	Date	Hour							
Sputnik 2	Nov. 3, 1957	0224	Apr. 14, 1958	0155	3,888:00	1,671	225	65.3	103.7	6,508	Carried dog Layka, with no recovery intended. Net payload weight was 508 kg
1	May 15, 1960	0000	Oct. 15, 1965	2121	47,508:00	369 675	312 290	65.0 65.0	91.3 94.3	4,540	Carried dummy cosmonaut. When braking rocket was fired on May 19, 1960, the orientation was incorrect, and the payload climbed to a higher orbit. The service module decayed on Sept. 5, 1962, at 0951, while the cabin decayed as shown in 1965.
2	Aug. 19, 1960	0838	Aug. 20, 1960	1102	26:24	339	306	65.0	90.7	4,600	Carried dogs Strelka and Belka, 2 rats, 40 mice. This was the first successful recovery from orbital flight.
3	Dec. 1, 1960	0726	Dec. 2, 1960	0912	25:46	265	188	65.0	88.6	4,563	Carried dogs Pchelka and Mushka. Too steep an angle at reentry caused the ship to burn, killing the dogs.
4	Mar. 9, 1961	0629	Mar. 9, 1961	0816	1:47	249	184	64.9	88.5	4,700	Carried dog Chernushka and dummy cosmonaut. Successfully recovered.
5	Mar. 25, 1961	0600	Mar. 25, 1961	0747	1:47	247	178	64.9	88.4	4,695	Carried dog Zvezdochka and dummy cosmonaut. Successfully recovered.
6	Apr. 12, 1961	0607	Apr. 12, 1961	0755	1:48	327	181	65.0	89.1	4,725	This was the last of the original series, and was given the new name Vostok. Carried Gagarin, and was successfully recovered. Details on Vostok 1 through 6 are carried in other tables.
Kosmos 47	Oct. 6, 1964	0712	Oct. 7, 1964	0730	24:18	413	177	64.8	90.0	5,320	Precursor to Voskhod 1; no Soviet announcement on payload or results of flight. Apparently successfully recovered.
Kosmos 57	Feb. 22, 1965	0741	Feb. 22, 1965	1042	3:01	512	175	64.8	91.1	5,682	Precursor to Voskhod 2; no Soviet announcement on payload or results of flight. Something went wrong, for the payload was exploded in orbit, with debris reentering the atmosphere.

[1] The flights listed by number alone were all called Korabl Sputnik, with the numbers 1 through 6. In the West, these were misidentified as Sputnik 4, 5, 6, 9, and 10 (plus Vostok). Launch date and recovery date (if any) are from Tass. Time of day estimates are from the Royal Aircraft Establishment. Orbital elements and weights are from Tass, or estimated if so marked. Payload details for the most part are from Tass.

Sources: Tass bulletins, and Royal Aircraft Establishment, revised table of Earth satellites, v. 1: 1957 to 1968: Farnborough, Hants, 1 January 1979.

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SPUTNIK 2

The first spacecraft to carry an animal—the dog Layka—into space was Sputnik 2, launched on November 3, 1957. The payload itself weighed 508.3 kg, but it remained attached to a much larger spent rocket casing so that the total weight was probably on the order of 6.5 metric tons.

Layka was kept in a cylindrical cabin, hermetically sealed with a regenerating system for air, a thermal regulation system, and food. She had trained over a period of time in preparation for the flight, including exposure to vibration, and spending periods up to several weeks in a sealed cabin of small dimensions. Layka was placed in a "spacesuit" which permitted scientists to connect her to sensors which sent back data for 1 week on her pulse, respiration, blood pressure, and electrocardiograms to show her reaction to weightlessness, launch conditions, radiation, and temperature changes.

Layka withstood the launch and flight environment successfully, and a considerable amount of useful data was returned. The ship was powered only by chemical batteries and was not designed for recovery, however, so after 1 week, she was killed by an injection of poison.

KORABL SPUTNIK 1

By adapting the A-1 vehicle, used earlier for direct ascent flights to the Moon, the Soviets were able to create an Earth orbital system capable of carrying up to 4,700 kg to low Earth orbit. This was first used successfully on May 15, 1960 with the launch of Korabl Sputnik 1 which was described as weighing 4,540 kg. This included 1,477 kg of instruments and equipment plus a self-sustaining biological cabin weighing 2,500 kg. The cabin contained a dummy of a man, designed to check the operation of the life support system and stresses of flight. The ship sent back both extensive telemetry and prerecorded voice communications. The Soviets some years later related that they wanted to avoid Western claims that they had flown a man on this mission and lost him, so rather than taping a pilot's voice sending typical flight data, they installed the tape of a singing Russian choral group.

After 4 days of flight, the reentry cabin was separated from its service module and retrorockets were fired. Unfortunately, the orientation was incorrect, and the cabin moved to a higher orbit instead. It did not decay for 5 years.

KORABL SPUTNIK 2

On August 19, 1960, the Soviets launched Korabl Sputnik 2, carrying the dogs Strelka and Belka. This time, the flight duration was reduced to 1 day to minimize the risks of equipment malfunction, and recovery was successfully accomplished, for the first time in history. The two dogs became national heroes and were put on display, obviously healthy despite their experience.

KORABL SPUTNIK 3

The next in this series of spacecraft was launched on December 1, 1960, and apparently was a repeat of the previous flight except that the perigee was lowered to insure automatic decay within the reserve capacity of the life support system. After 1 day, retrofire was ordered, but the angle may have been too steep, for the cabin burned beyond successful recovery. The dogs Pchelka and Mushka became the first important casualties of orbital flight.

KORABL SPUTNIK 4

Launched on March 9, 1961, Korabl Sputnik 4 carried both a dummy cosmonaut and the dog Chernushka. Successful recovery was made after a single orbit.

KORABL SPUTNIK 5

On March 24, 1961, the fifth and last time in this series of flights was launched, again carrying a dummy and a dog, Zvezdochka. As with the previous mission, recovery was made after one orbit.

VOSTOK

By 1961, the Soviets had a considerable amount of data from the short sounding rocket flights, Sputnik 2, and five actual manned precursor flights, three of which were recovered, including four of the six dogs used. A ship in excess of 4,500 kg was both fairly commodious and provided a fair amount of redundancy. The dogs not only provided telemetered data and usually were available for postflight tests, but all the Korabl Sputniks had provided live television coverage from orbit, permitting further examination of their state during flight. Rumors were strong that manned flights were about to begin.

The Vostok spacecraft that appeared was designed to make maximum use of automatic devices, with manual override to be used only in emergencies or experimentally. This feature prevailed throughout later Soviet manned programs as well, and all new manned spacecraft have been fully tested in an unmanned mode before committing crews to the new hardware. Vostok also became the basis for military recoverable payloads in the Kosmos series. Observations by Alan Pilkington, formerly of Scarborough Planetarium in England, revealed that Vostok and the Kosmos photographic recoverable spacecraft were of the same dimensions and brightness. (Similarly, Soyuz became the basis of a new generation of military recoverable payloads later in the decade.)

VOSTOK 1

On April 12, 1961, Maj. Yuriy Alekseyevich Gagarin became the first man to orbit Earth. His ship, Vostok 1 (code name Kedr) made a single orbit from Tyuratum and was recovered in Kazakhstan. The electrifying news produced the same kind of shock waves in the world as Sputnik 1 had, despite the advance notice which should have been gleaned from the Korabl flights.

Vostok 1 (see figs. 6 and 7) was launched by an A-1 rocket, and the spacecraft consisted of a near-spherical cabin covered with ablative material, with three small portholes for vision, and external radio antennas. The capsule contained a life support system, radios, instrumentation, and an ejection seat both for escape on the launch pad and as a part of the optional recovery system. The manned cabin was attached to a service module resembling two truncated cones base to base, with a ring of gas pressure bottles on the upper cone close to the cabin. This module carried a considerable weight of chemical batteries, orientation rockets and the main retro system, plus added support equipment for the total system.

On launch, all five engines of the booster rocket fired, and then the four outer sets of tankage and engines fell away, leaving the central sustainer engine still burning. This stage also was abandoned suborbitally, and the upper stage then fired to place itself and the payload in orbit. After burnout, this stage was separated from the payload, and continued in its own orbit, a derelict, to decay after a few days.

The payload was allowed to tumble slowly to even out heat loads, but could be stabilized on command for observation of the Earth, signal transmission, and most importantly for correct retrofire on reentry. As on the precursor flights, television was transmitted from the ship.

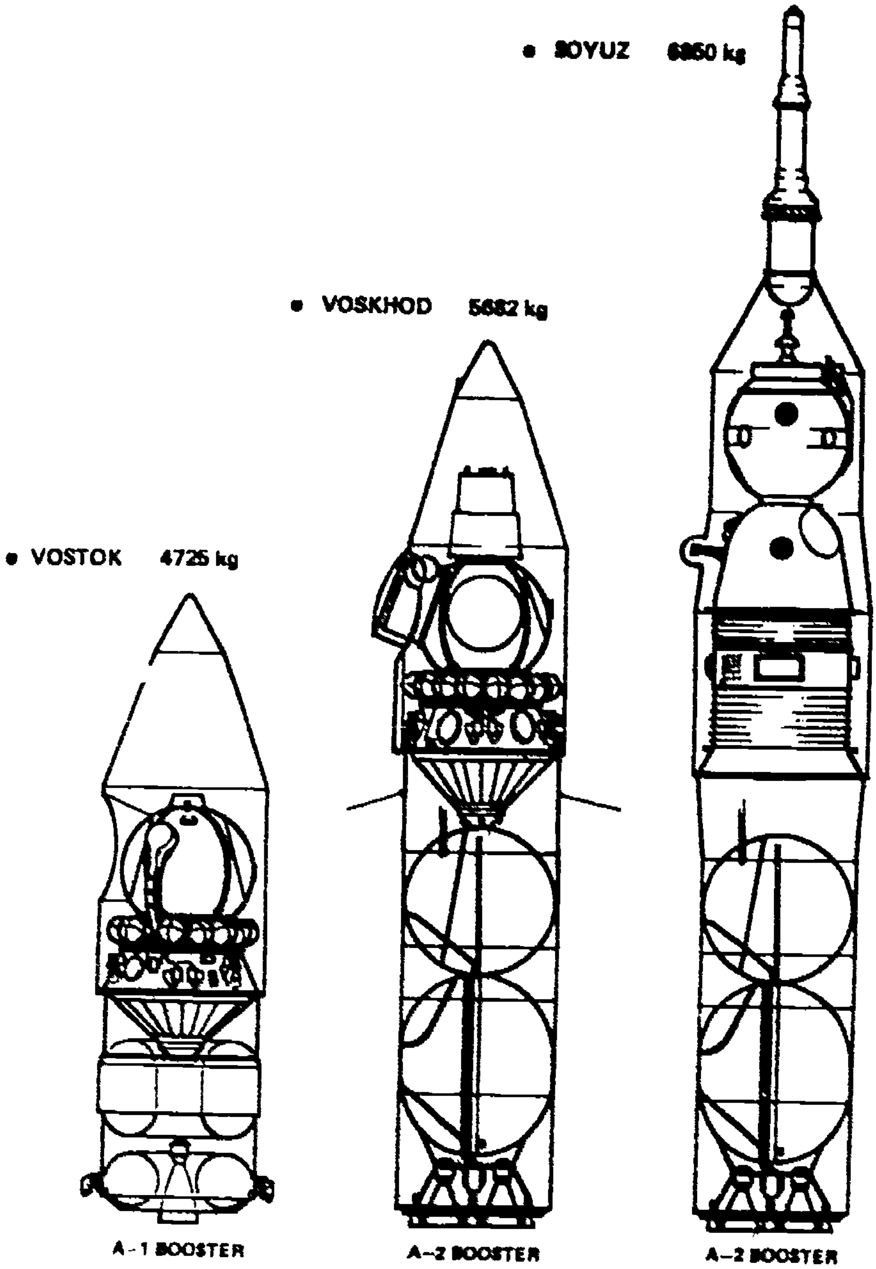

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FIGURE 6.—Soviet Manned Launch Spacecraft. Variants of the A-booster have served as the basic launch vehicle for three generations of Soviet manned launch spacecraft. Six Vostok spacecraft, carrying one cosmonaut each, carried the first man into orbit, the first woman, and conducted the first tandem flights. The two Voskhod mission carried the first multimanned crew (3) and conducted the first extra-vehicular activity (EVA). The third generation series, Soyuz, which entered service in 1967, serves as the current Soviet manned launch spacecraft.

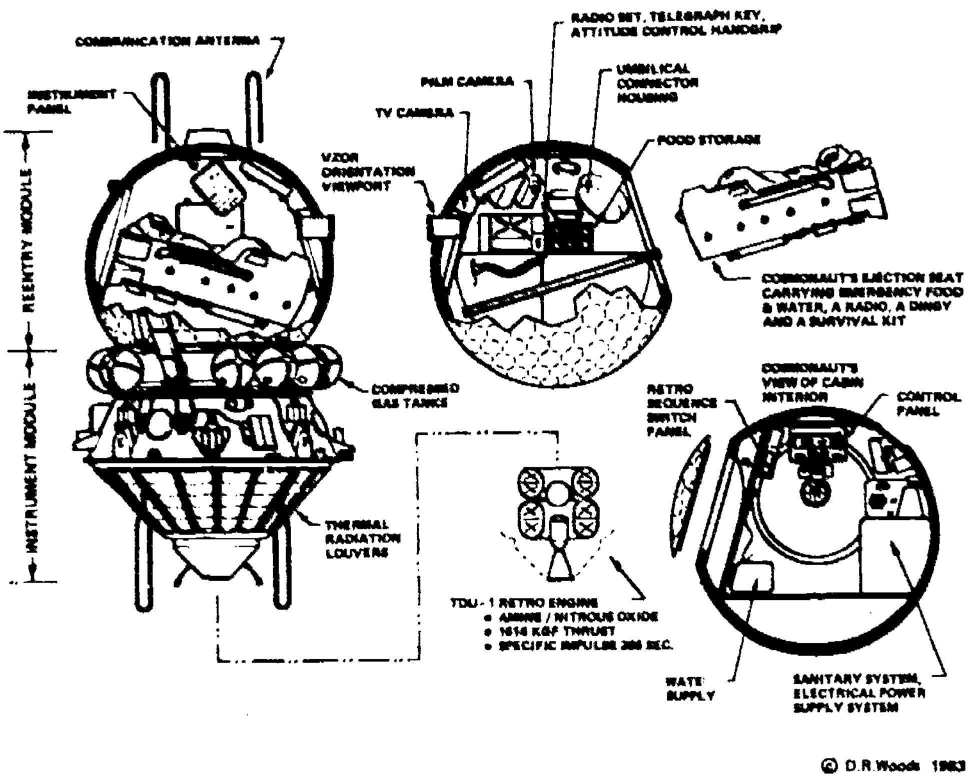

FIGURE 7.—Vostok Spacecraft. The successful launch of the first Vostok spacecraft marked the beginning of manned orbital flight. Vostok consisted of two modules: a spherical reentry module for launch and recovery of the cosmonaut and an instrument module for control during orbital flight.

VOSTOK 2

Maj. German Titov became the second man to reach orbit on August 6, 1961, remaining up for a day to complete 17 orbits. In most respects the flight was like that of Vostok 1. There is some inconsistency in Soviet accounts with regard to the final phase of recovery in the Vostok program. The implication, although contradicted by other reports, is that Gagarin rode in his ship all the way to the surface of the Earth. But it seems clear that from Titov on through the rest of the Vostok program the cosmonaut fired open the hatch at 7,000 meters and then used the ejection seat to come down separately from the main cabin. The cabin, after being slowed by air pressure and protected by ablative material, apparently still struck ground hard enough that even a cosmonaut in a contoured couch would not enjoy the landing. Like the dogs which preceded them, most of the cosmonauts were fired out free from the main ship on their seat, which was mounted on rails pointed toward an escape hatch. After coming well clear, the cosmonaut would then free himself from his seat and come down on a personal parachute (see figs. 8 and 9).

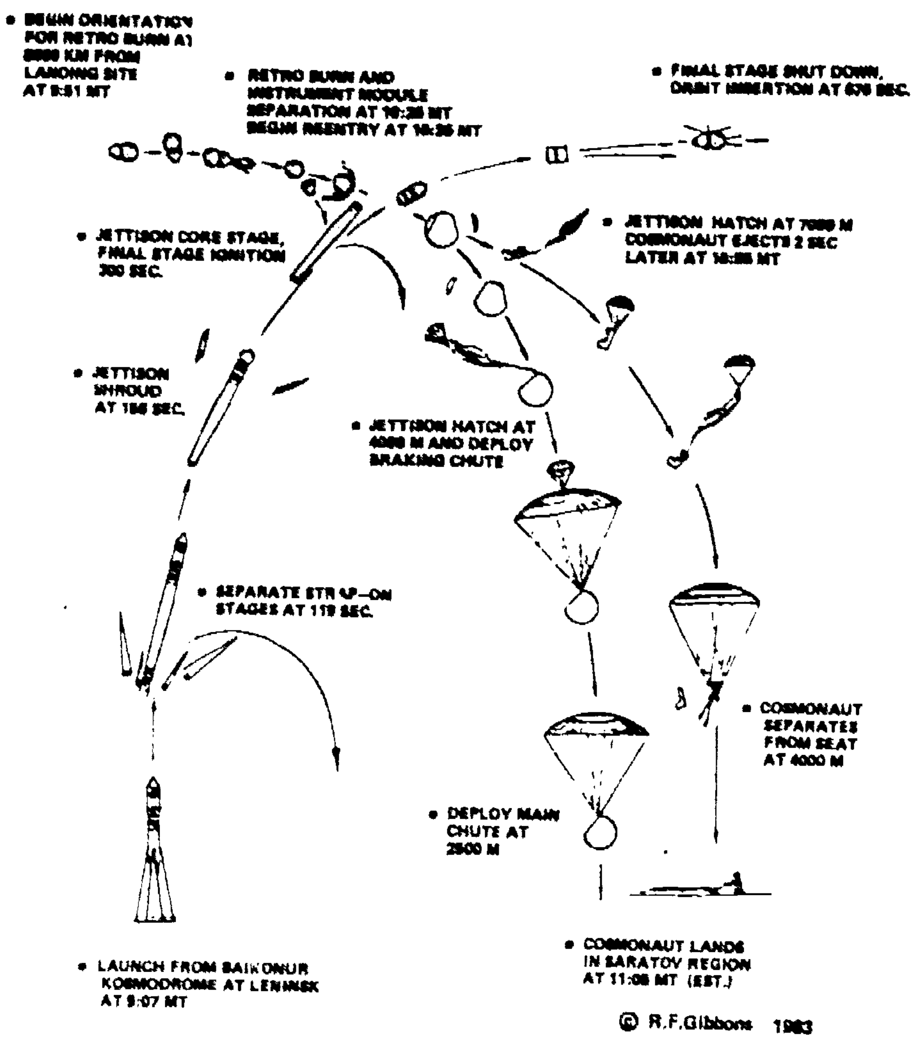

FIGURE 8.—Mission Profile for Vostok. Vostok 1 was launched into Earth orbit on April 12, 1961; man's first orbital flight. The mission was a simple one orbit of the Earth, lasting a total of 108 minutes. Accounts vary as to whether Cosmonaut Yuriy Gagarin ejected from his cabin for a parachute landing, or landed with the ship. In subsequent Vostok flights the cosmonaut ejected from the capsule and landed with a separate parachute.

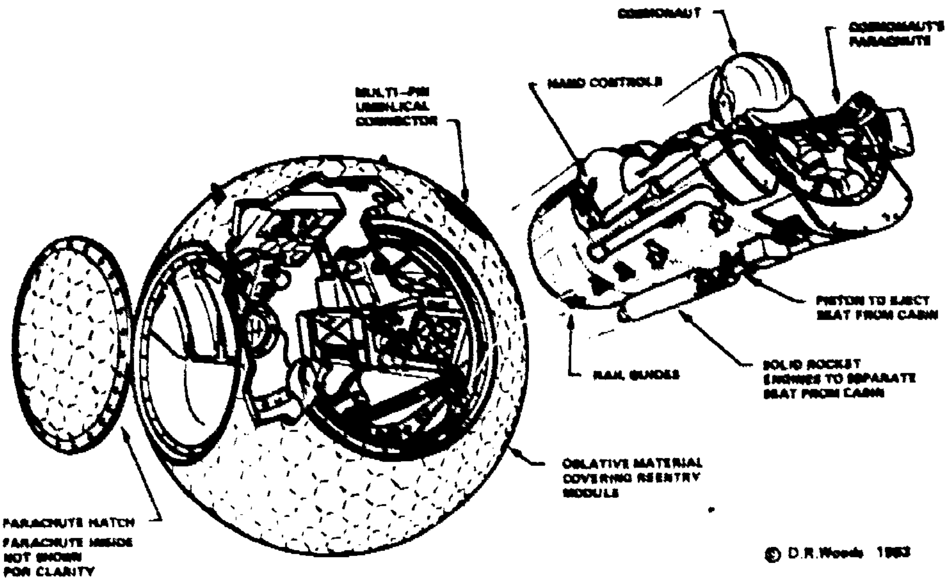

FIGURE 9.--Vostok Spacecraft Ejection Seat. Soviet spacecraft have always landed on hard ground and not water. At least five of the six Vostok cosmonauts ejected from the reentry module for a separate landing.

VOSTOK 3

Maj. Andriyan Nikolayev was launched on August 11, 1962, for a flight which lasted 4 days. It can be noted that a flight of similar duration had already been made by a Kosmos military observation satellite using essentially the same hardware, but without a life support system; and Korabl Sputnik 1 with the complete Vostok equipment had flown for 4 days when retrofire occurred. All the Vostoks flew in orbits which would experience natural decay in less than 10 days. From the outset every flight carried air, water, food, and electricity to last for 10 days, even though no flight lasted that long.

VOSTOK 4

Lt. Col. Pavel Popovich was launched August 12, just a day after Vostok 3, into a close coorbit so that the two ships approached within 6.5 km of each other in clear visible range. This was impressive both in terms of the ground support at the launch site in readying the facilities for so quick a turnaround (unless two pads were used), and also for the accuracy in timing the launch and controlling the flight parameters to guide the second ship to the same location as the first. This group flight was heralded as a portent of future dockings.

VOSTOK 5

On June 14, 1963, Lt. Col. Valeriy Bykovskiy was launched into orbit for 5 days of flight, matching the time of a predecessor Kosmos military observation satellite. This set a Soviet manned duration record of 119 hours, 6 minutes—not exceeded until Soyuz 9.

VOSTOK 6

It is possible that this launch was a day late, because it went up on June 16, 1963, and on an orbit which would not permit a sustained rendezvous with Vostok 5. The orbit did, however, permit a brief pass at a distance of only 5 km. The pilot was Valentina Tereshkova, the first woman to fly in space, and she remained in orbit for 3 days. In contrast to the other cosmonauts who were experienced military test pilots, Ms. Tereshkova had worked in a textile factory, took up sports parachuting, and then was trained for her flight. Although she did not have the background or experience common to her Russian and American counterparts, she gained more orbital experience in flight time than all the U.S. Mercury astronauts combined.

Kosmos Precursors to Voskhod

On October 6, 1964, Kosmos 47 was put into an orbit 177×413 km and after just 1 day was retrofired to come back to Earth, while its carrier rocket flew for 8 days. Just 6 days later a manned flight (Voskhod 1) was launched with orbital elements of 178×409 km and also stayed up for 1 day.

On February 22, 1965, Kosmos 57 was put into an orbit 177×512 km. This time something went wrong, for the payload was exploded in orbit. Voskhod 2 did not follow as closely after this precursor as had happened the previous fall. One can surmise that it required a little time to determine that whatever went wrong with Kosmos 57 would be unlikely to occur in the manned flight to follow. Hence the followup flight was delayed 24 hours and then entered a 173×495 km orbit.

Voskhod

VOSKHOD 1

Voskhod 1 was launched on October 12, 1964, and based upon information released after the fact, it was determined that it was put up by an A-2 launch vehicle, which permitted increasing the payload weight from the 4,700 kg range to 5,320 kg. Voskhod seemed to be only a modified Vostok.

The principal modification of this first flight was removal of the heavy ejection seat on its rails. Then, within the approximately 2.5 meter sphere of the cabin, it was possible to place three seats side-by-side with the center seat raised. By this time such confidence had been gained in the reliability of the basic system, that the cosmonauts did not wear cumbersome protective space suits and helmets, but comfortable coveralls. This practice was followed until the Soyuz 11 tragedy, when the three-man crew died due to a pressure leak in their cabin. Without ejection seats, the landing of the ship with crew on board was eased by use of a final breaking rocket.

Voskhod 1 was the first multimanned flight. The crew was led by Col. Vladimir Komarov, accompanied by a military physiologist, Lt. Boris Yegorov, and a civilian technical scientist, Konstantin Feoktistov. Although the flight lasted only 1 day, the special crew made it possible to obtain much more comprehensive medical data and to operate more complex checks on the payload systems and external experiments. The flight also returned live television pictures from orbit.

There is an interesting political sidelight to this mission. While in orbit, Premier Khrushchev sent congratulations to the crew and promised to see them on the reviewing stands in Moscow on their return. They landed less than 24 hours later, but when they reached Moscow, Mr. Khrushchev had been replaced by Party Secretary Brezhnev and Premier Kosygin.

VOSKHOD 2

Still another variant of the original Vostok hardware was provided by this flight whch was launched on March 18, 1965 (see figure 10). Again the A-2 vehicle was used, and the payload weight was raised to 5,682 kilograms. Although no pictures of the actual payload have been released, the shroud view in the assembly building showed a large bulge well forward. This flight carried only two seats, and added instead an extendable airlock to permit egress into space without evacuating the main cabin of air.

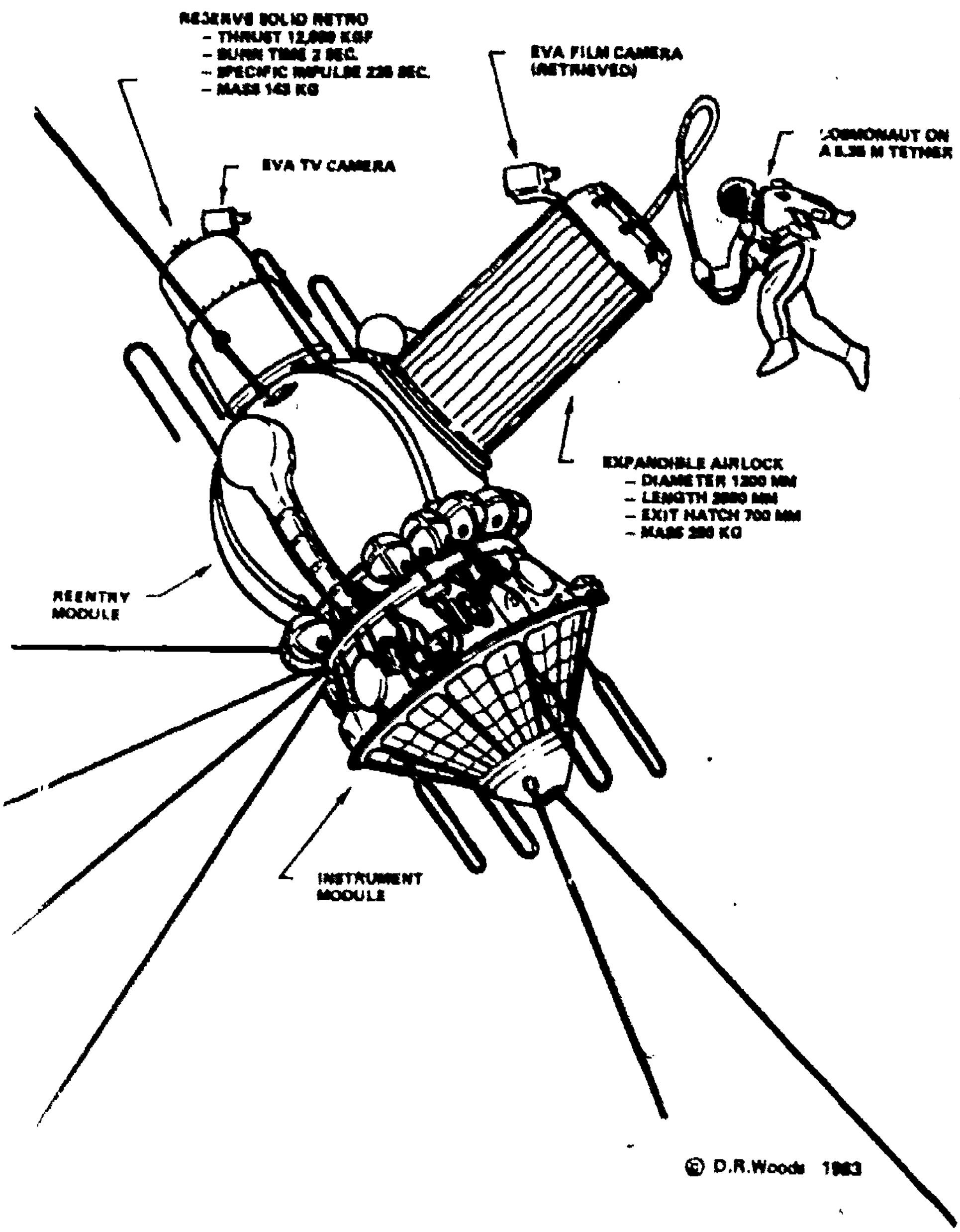

FIGURE 10.—Voskhod 2 Spacecraft. The basic Vostok spacecraft was modified for two multimanned missions. The ejection seat was removed to make room for the crew and a back-up retro rocket added for additional reliability. An airlock was added for the second mission, to permit cosmonaut Aleksey Leonov to conduct the first manned extravehicular activity (EVA).

The ship was commanded by Col. Pavel Belyayev, the first cosmonaut with a naval air force background, accompanied by Lt. Col. Aleksey Leonov. Leonov won a place in history by becoming the first man to perform extravehicular activity (EVA). During flight he donned a completely self-contained life support system backpack. Having switched to a supply of air enriched with oxygen in order to purge much of the nitrogen from his blood, he then entered the extendable airlock, sealed the hatch behind him, and then after depressurization opened the second hatch to look out into space. Finally he pushed free to float at the end of a tether line in the weightless, airless medium of space, with his eyes shielded from the Sun by a special visor. Beneath him in a few minutes passed a good part of the Soviet Union.

The event was recorded by a preplaced external television camera, and he also took along a handheld motion picture camera. As might be expected, his physiological indicators showed he was under considerable stress. In general, his suit was so cumbersome that he could do little more than float awkwardly at the end of his tether and wave for the cameras. Leonov moved away from and back to the ship four times, and "checked the ship for stability; as it turned out, blows can made it rock." He was supposed to photograph the spacecraft, but did not because he could not reach the device to move the camera which was attached to his thigh.[8] The whole event amounted to about 20 minutes exposure to the vacuum conditions of space, of which about 10 were outside the ship on the tether. Leonov explained later that he had some difficulties in his big suit getting back in without losing his camera, and Colonel Belyayev had to repeat the orders to get him to come in, as he not only experienced the tension of being the first to go out, but the same euphoria several American EVA astronauts displayed. He also reported that he could not get back in feet first, and had to enter the airlock head first and then turn around.

As had happened after previous Soviet flights, the claims of Leonov's EVA came under some dispute in the West. Complaints centered around analyses of the Soviet-released pictures which included not only blurred views, and the better motion pictures, but a number of sequences to fill in with simulation what would have been harder to provide during the real event. This explains the question "Who was holding the camera for the clear shots of his emergence from the airlock?" and also some process shots taken either in a watertank or with guide wires in another view. One can dispute particular pictures, but the total evidence that EVA occurred is reasonably compelling.

While preparing for reentry after 16 orbits, the crew discovered that the automatic orientation devices necessary for retrofire were malfunctioning, so they were authorized to orbit one more time and then make a manually controlled reentry. This moved the landing site into European Russia instead of Kazakhstan, and for some reason reentry was delayed long enough to carry the ship hundreds of kilometers north to Taiga where they landed amidst pine forest. It took several hours for the recovery team to locate the ship, and about a day for ground parties to cut through the forest to reach the cosmonauts and bring them home. As wolves howled nearby, the crew kept close to their capsule for protection.

Kosmos 110

After Voskhod 2, there were a number of statements which suggested that further manned flights would occur. One can only speculate whether fiscal economies led to a cancellation of these mis-

[8] Leonov, Aleksey. The Friendly Solar Wind. Komsomol'skaya Pravda, Mar. 18, 1983, p. 4.

sions, or whether it was decided to apply the existing stock of launch vehicles to other programs while engineering a new manned ship. However, it appears that at least one more Voskhod flew, but it carried dogs rather than people.

Designated Kosmos 110, the spacecraft was launched on February 22, 1966, into a 904×187 km orbit by an A-2 vehicle and carried the dogs Verterok and Ugolek. A television monitor sent back pictures of the dogs, while telemetry from biological and cabin environment sensors reported other information. The flight set a duration record of 22 days, following which the dogs were successfully recovered. Data from this mission considerably expanded Soviet information on the more prolonged effects of weightlessness and radiation.

SOYUZ DEVELOPMENT AND FREE-FLYING MISSIONS

Kosmos Precursor Missions and Development Flights for Soyuz

These missions are summarized in table 5.

TABLE 5.—KOSMOS FLIGHTS IN THE SOYUZ PROGRAM (OTHER THAN ASTP AND SOYUZ-T)[1]

Kosmos flight	Launch		Recovery		Flight duration (hrs:min)	Apogee (km)	Perigee (km)	Inclination (degrees)	Period (min)	Remarks
	Date	Hour (GMT)	Date	Hour (GMT)						
133	Nov 28, 1966	1101	Nov 30, 1966	1200	48:59	232	181	51.8	88.4	No mission details from Tass. First Soyuz
140	Feb 7, 1967	0322	Feb 9, 1967	0307	47:45	241	170	51.7	88.5	No mission details from Tass. Final check before Soyuz 1.
186	Oct 27, 1967	0931	Oct. 3, 1967	0820	94:49	235	209	51.7	88.7	The active partner in docking with Kosmos 188, at 0920 on Oct. 30, undocking the same day at 1250. First docking in orbit by automatic means.
188	Oct 30, 1967	0814	Nov 2, 1967	0853	72:39	276	200	51.7	89.0	The passive partner in a first orbit rendezvous.
212	Apr 14, 1968	0932	Apr 19, 1968	0815	118:15	239	210	51.7	88.8	The active partner in docking with Kosmos 213, at 1021 Apr. 15, undocking the same day at 1411. Final check before Soyuz 2-3 attempt.
213	Apr 15, 1968	0932	Apr 20, 1968	0948	120:16	291	205	51.7	89.2	The passive partner in a first orbit rendezvous.
238	Aug 28, 1968	1000	Sept. 1, 1968	0853	94:53	219	199	51.7	88.5	No mission details from Tass.
496	June 26, 1972	1453	July 2, 1972	1424	143:31	342	195	51.6	89.6	No mission details from Tass, but seemed to be a check after the mission failure of Soyuz 11.
573	June 15, 1973	0600	June 17, 1973	0712	49:12	329	196	51.6	89.6	No mission details from Tass. Final check before manned flights resumed with Soyuz 12.
613	Nov 30, 1973	0520	Jan 29, 1974	0712	1,441:52	295	195	51.6	89.1	No mission details from Tass. Long duration test of a Soyuz in powered-down condition.
						396	255	51.6	91.0	
656	May 27, 1974	0730	May 29, 1974	0712	47:42	354	194	51.6	89.7	No mission details from Tass, but probably a check before manned ferry flights resumed with Soyuz 14.

[1] Dates are from Tass and times from the Royal Aircraft Establishment, if not from Tass. Orbital elements are from Tass, except for the figures after maneuver on Kosmos 613.

Sources: Tass bulletins, and Royal Aircraft Establishment, revised tables of Earth satellites, Volumes 1 and 2, Farnborough, Hants, December 1978 and December 1979

KOSMOS 133 AND 140

When expectations that the Voskhod program would continue were not fulfilled, Western observers debated whether the Soviet Union had abandoned manned flight or whether they had paused in order to make much more fundamental changes in their systems. The pause was fairly long, almost 22 months, but at last on November 28, 1966, came a routinely announced Kosmos flight, 133, which had the telltale signs of low perigee, a fairly circular orbit, a radiobeacon frequency usually reserved for manned flights, and recovery after only 2 days of flight instead of the 8 typical of military recoverables.

Kosmos 140 was put into a similar orbit on February 7, 1967, and again stayed up only 2 days. Then rumors began to build that a manned flight was coming, and on April 24, Soyuz 1 was launched (see below).

KOSMOS 186 AND 188

Just in time to highlight the 50th anniversary of the Soviet State in early November 1967, the Soviet Union conducted a double space operation with unmanned Soyuz prototypes. On October 27, 1967, Kosmos 186 was put into a low circular orbit for a period of 4 days. While Kosmos 186 waited in orbit, Kosmos 188 was launched on October 30 for a 3-day period. This was a direct ascent, first orbit rendezvous launch, which brought it within about 24 km of Kosmos 186. At this point the ships were programmed to conduct a completely automatic close rendezvous and docking on the side of the world away from Soviet territory, later passing over the U.S.S.R. in docked configuration.

When the seeking devices on both ships found each other, they were oriented into a head-on position and Kosmos 186 became the active vessel, moving in until its docking probe was inserted into the receptacle of the other ship. Further automatic devices then completed a tight lock and made electrical connections so the two ships could operate as a single unit. They remained docked for 3.5 hours and after 2.5 orbits accomplished an equally automatic undocking over Soviet territory and resumed separate flights. A day later Kosmos 186 made a soft landing in the usual recovery zone and 2 days after that Kosmos 188 was recovered in a similar fashion.

This successful operation showed that modifications had been made in Soyuz and drawings were finally released to the public showing the approximate appearance of the two ships as they approached each other. (One must say approximately because it later developed that some essential elements of the design had been airbrushed out, and it was many months before the actual shapes became apparent.) The first drawings showed a cigar-shaped craft with docking collar and probe or receptacle at the forward end, and a propulsion unit at the other. Special acquisition and distance-measuring radars extended out from the ships on hinged lattice-structure arms. Most distinctive were the solar panels which unfold after orbit is attained and look like rectangular gull wings.

KOSMOS 212 AND 213

On April 14 and 15, 1968, Kosmos 212 and 213 respectively were placed in a low circular orbit, each remaining for 5 days. Prior to the second launch, Kosmos 212 made slight orbital corrections which brought it very nearly over the launch site to simplify rendezvous. At the time the carrier rocket was separated from the Kosmos 213 payload, the controllers on Earth had accomplished a first orbit, direct ascent rendezvous which brought Kosmos 213 to within 5 km of Kosmos 212, and the velocity difference was only about 108 km per hour. After mutual radar search and lockon, Kosmos 212 became the active partner and completed the exercise. Main propulsion which could be turned on and off was used for most of the closing, but when the ships were within a few hundred meters of each other, low thrust propulsion was employed, and the difference in their relative speed was between 0.5 and 1 km per hour. This time, by Soviet claim, docking was conducted over the Soviet Union (this is hard to reconcile with other Soviet data), but the followup rigid mechanical lock and the interlinking of electrical connections occurred some minutes later over the Pacific Ocean, 47 minutes after launch. On the next pass over the Soviet Union, external television cameras on the ships showed how they looked.

The ships remained linked together for 3 hours 50 minutes, and then undocked on radio command over the Soviet territory. Each ship then made further maneuvers repeatedly to continue group flight, but at a distance sufficient to avoid mutual interference.

KOSMOS 238

On August 28, 1968, still another flight was made which had the orbital path and radio frequency characteristics of a manned precursor. It was never commented on by the Russians after the initial launch announcement under the Kosmos cover name, but after 4 days in orbit it was called down. Apparently it represented a final check of onboard systems as a step in man-rating. Soyuz 2 and 3 were launched 2 months later (see below).

KOSMOS 496

After the long pause in man-related activities caused by the death of the Soyuz 11 cosmonauts, the Russians launched Kosmos 496 without announcing much more than routine parameters: An apogee of 342 km and a perigee of 195 km, at an inclination of 51.6 degrees. The flight was launched on June 26, 1972, and recovered after 6 days. Tass in Moscow noted that it used the 20.008 MHz frequency common to the Soyuz. On the basis of orbital calculations from Geoffrey Perry in the United Kingdom, Sven Grahn in Sweden was not able to find signals on 20.008 MHz, but did discover that each time the ship reached the radio horizon of Yevpatoriya in the Crimea, the ship sent signals on 922.75 MHz, which had been used in the manned program previously. There were three carriers with high-speed commutated telemetry sidebands. The strong inference was that the Russians were testing an improved

Soyuz to correct the problems of Soyuz 11. Further manned flights were expected, although none came for over a year.

KOSMOS 573

After the 1973 failures of Salyut 2 and Kosmos 557 to operate for extended periods and to be visited by manned crews, the Russians sent up another unmanned test craft. This was Kosmos 573, launched on June 15, 1973, almost a year after Kosmos 496, and flying in a very similar orbit. Tass announced it as having an apogee of 329.2 km, a perigee of 196.2 km, and an inclination of 51.6 degrees. Again, they announced that it used the 20.008 MHz frequency common to man-related flights. This time the ship stayed up only 2 days, the pattern Soyuz 12 was to follow.

KOSMOS 613

On November 30, 1973, Kosmos 613 was sent to a 295×195 km orbit inclined at 51.6 degrees. No purpose was given beyond the routine, but Western observers noted that it seemed like a Soyuz. Without announcement, the orbit was raised on December 5 to 396×255 km, still at 51.6 degrees inclination. Signals were found on 922.75 MHz, typical of man-related flights. On reaching the higher orbit, little was heard from it, and it appeared to be in powered-down condition. Then toward the end of the flight, it became electronically active again, and recovery was made after a total flight duration of 60.1 days on January 29, 1974.

With the advantage of hindsight, it now seems likely that this was a first long-duration test in powered-down condition for the flight of Soyuz 18 (see below).

KOSMOS 656

Kosmos 656 was launched on May 27, 1974, into a 354×194 km orbit. The mission lasted just 2 days, suggesting that it was like Kosmos 573 and Soyuz 12, probably ferry versions of Soyuz without solar panels.

SOYUZ 1: A TRAGIC BEGINNING

In April 1967, after a period of 2 years in which the Russians did not fly any manned missions and the Americans were establishing one record after another in their Gemini Program, rumors of the most ambitious and spectacular manned flight operation became very strong in Moscow. Thus on April 23, 1967, Col. Vladimir Komarov, the first Russian to make a second trip into orbit, was launched into space by an A-2 vehicle as part of a payload which probably weighed about 6,570 kg (see figures 11 and 12).

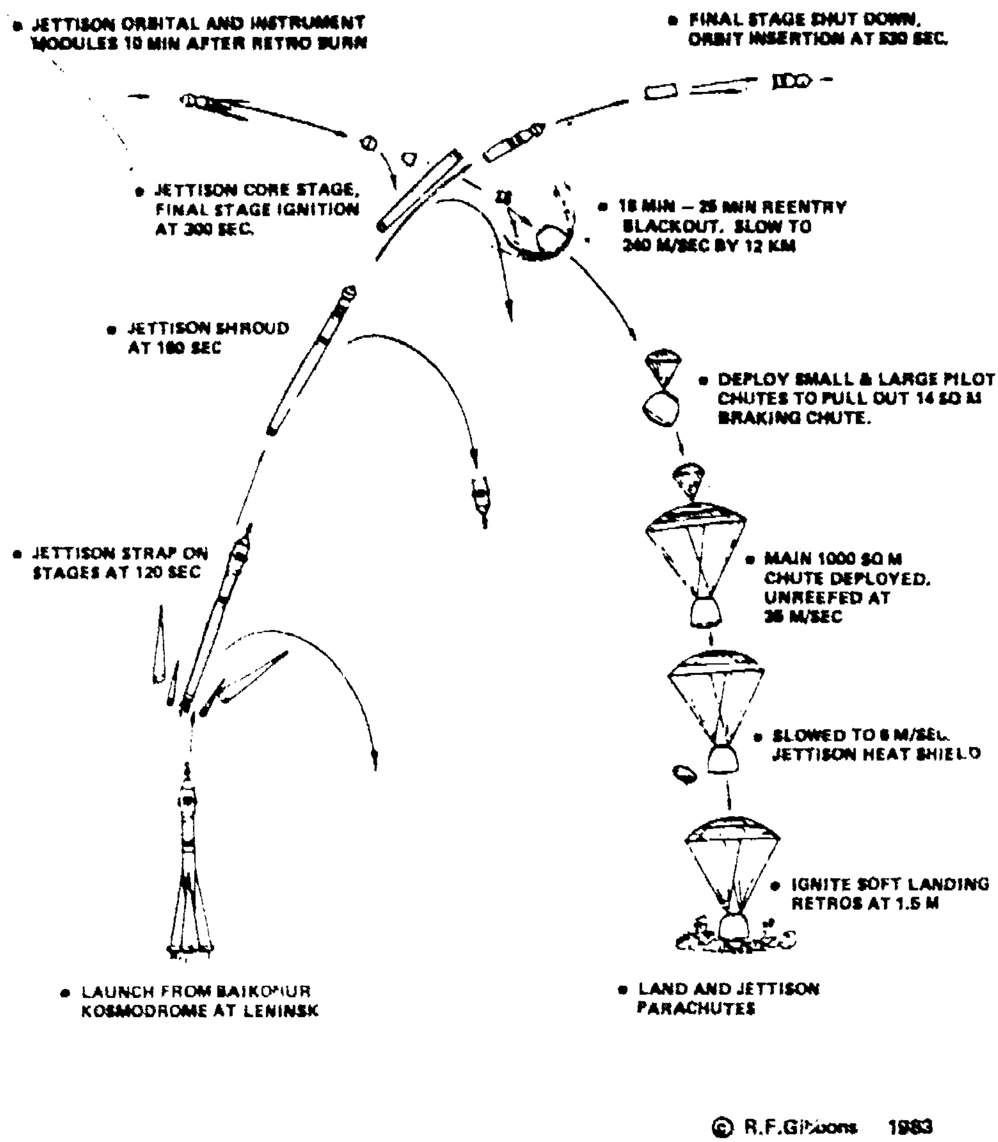

FIGURE 11.—Soyuz Mission Profile. The A-2 booster is used to place the Soviet spacecraft into Earth orbit. Reentry is initiated with a deorbit retro burn, followed by jettisoning of the orbital and instrument modules. A series of parachutes slow the descent module. Just before touchdown, a set of retro rockets fire to soften the impact of landing.

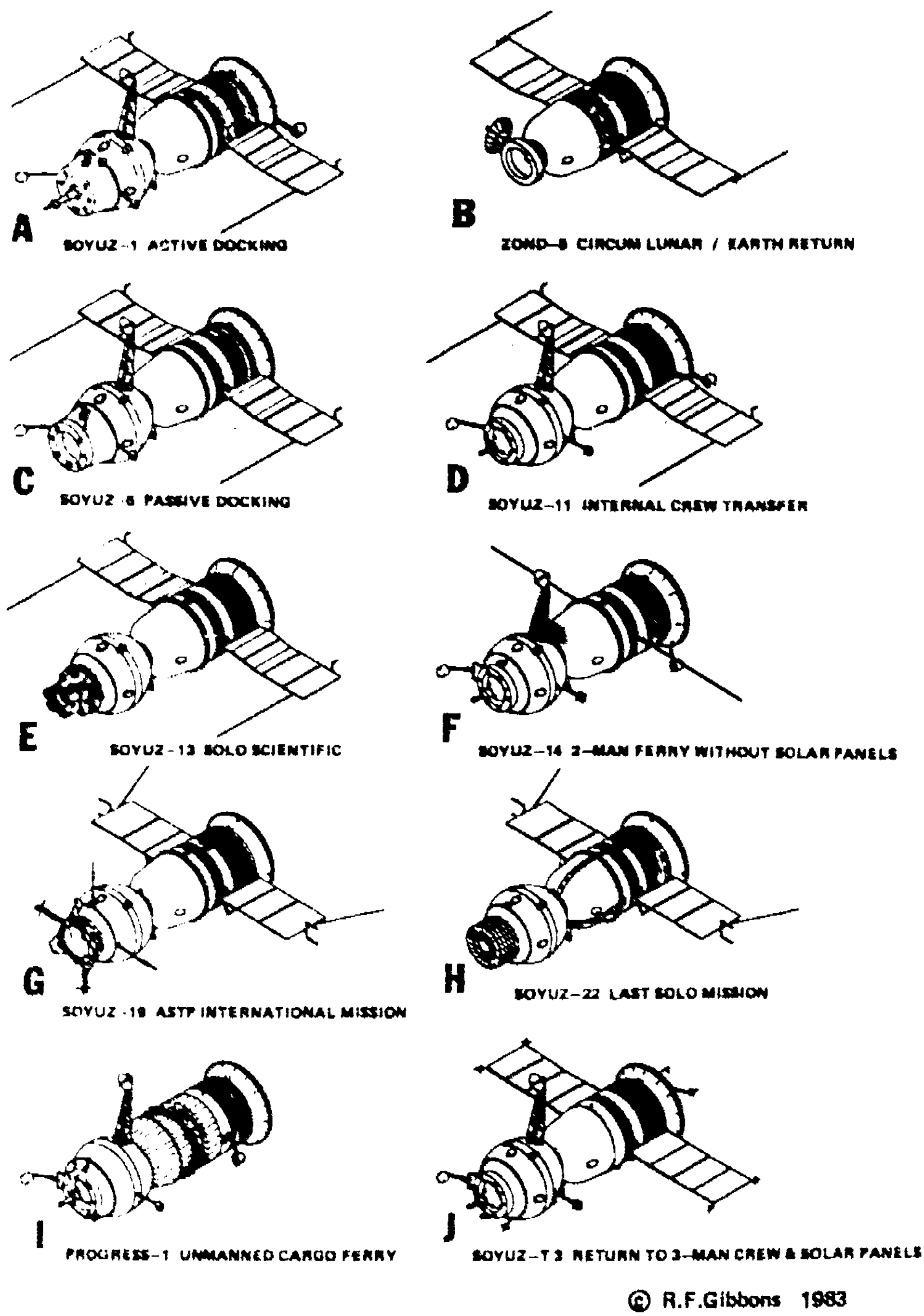

FIGURE 12.—Soyuz Variants. The current Soyuz series has been in service since 1967. In the years since, variants have flown circumlunar missions, conducted the first in-orbit crew transfer, participated in the first international mission, and matured into a standard ferry craft for missions to the Salyut space stations. An unmanned, nonrecoverable version called Progress serves as a cargo craft to resupply the current Salyuts.

Soviet reports indicated that all was going according to plan, their standard description, but one could infer the opposite when his ship was ordered to land after only 1 day in orbit with nothing spectacular to show for the flight. It is possible that another craft (Soyuz 2) was supposed to be launched and a docking obtained. In fact, the "crew" of the alleged second spacecraft has been identified by some Western Soviet space enthusiasts as Valeriy Bykovskiy, Aleksey Yeliseyev, and Yevgeniy Khrunov.[3] The precursor flights, Kosmos 133 and 140, were only 2-day flights, however, and a longer flight would probably have been in order if docking was the goal. The rumors of a spectacular flight could have alluded to the entire Soyuz program, not this particular mission.

Komarov accomplished retrofire on his 18th orbit, an unusual step since when recovery is planned after 1 day it normally occurs after 16 to 17 orbits in order to bring the ship down to the prime recovery area in Kazakhstan. However, the 51.8 degree inclination of the flight also brought the 18th orbit to the regular recovery area. One gathers that to this point the pilot was in no immediate danger, since Soviet spacecraft are equipped with backup safety features. (Data made available during the ASTP mission raised some safety questions, however.)

Retrofire and passage through the upper atmosphere where radio blackout occurs is said to have passed routinely. But what happened after that is still unclear, for in the last few kilometers of descent, the parachute system which should have given Komarov a steady ride down to the surface for a final rocket soft landing failed, remained furled and twisted with its lines, so that the ship and pilot were destroyed in the hard impact.

Speculation abounds as to what actually happened on Soyuz 1, and even after all these years, the Soviets still have shed no light on the accident. In the West, various hypotheses have been put forward. One possibility mentioned is that the aerodynamics of the spacecraft had not been tested sufficiently and stabilization problems arose. In fact, some have suggested that the spacecraft was spinning as it reentered, thus causing the parachute lines to tangle.[4] Others have speculated that the solar panels did not deploy, and Komarov had to work in a powered-down condition for the entire mission, and thus had problems orienting the ship properly for reentry, or that he had deliberately spun the spacecraft to free the solar panels and then could not get the spacecraft under control.[5] Another rumor was that while the ship was on the pad, water seeped into the parachute compartment, interfering with the system's operation. This seems unlikely since all manned payloads have a shroud until they are outside most of the atmosphere, a protective environmental blanket while on the pad, and a large escape rocket assembly on top of the Soyuz-class ships which should cover the parachute compartment. A useful summary of the rumors, speculations, and hypotheses connected with the Soyuz 1 accident has been prepared by James E. Oberg and published in *Spaceflight* magazine.[6]

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[3] See for example: Oberg, James E. Soyuz 1 Ten Years After: New Conclusions. Spaceflight, v. 19, May 1977. p. 188.

[4] Oberg, James E. Soyuz 1 Ten Years After: New Conclusions. Spaceflight, v. 19, May 1977. p. 188.

[5] Clark, Phillip S., and Ralph F. Gibbons. Evolution of the Soyuz Programme. Journal of the British Interplanetary Society, v. 36, Oct. 1983. p. 439. See also: Johnson, Nicholas. Handbook of Soviet Manned Space Flight. American Astronautical Society Science and Technology Series, v. 48. San Diego, Univelt, 1980. p. 142.

[6] Oberg, op. cit.

Komarov's death was, of course, a great shock to the Russians, especially since only 3 months earlier the United States had lost the crew of Apollo 1 in a pad fire as they were running tests a few days prior to launch. Although the Soviet Union sent a message of sympathy, it was coupled with claims that the U.S. accident was a direct outgrowth of a reckless race to be first on the Moon and the greed of U.S. private enterprise willing to cut corners in safety and quality, even for manned flights. The statements implied that such considerations were nonexistent in the Soviet Union.

Although the frailty of human planning was revealed in the Apollo fire, which only in retrospect became so clearly deficient in design, the Soyuz 1 accident showed that accidents are not tied to economic or political systems, but to design, quality control, and sometimes simply lack of knowledge or human error.

Just as the American manned space effort was delayed for almost 2 years for investigations into the Apollo fire, the Russian manned program waited for 18 months before seeing another launch.

Soyuz 2–9

SOYUZ 2

Soyuz 2 was launched without any immediate announcement on October 25, 1968 and was placed in the typical low parking orbit of the other Kosmos precursor flights. It remained in orbit for 3 days and was the target for the manned flight which followed. Despite its unmanned status, the mission was given a Soyuz name instead of the Kosmos designation for unknown reasons.

SOYUZ 3

On October 26, 1968, 18 months after the ill-fated flight of Komarov, the Soviet Union launched Soyuz 3 carrying Col. Georgiy Beregovoy. After achieving a co-orbit with Soyuz 2, the ship made an automatic approach to within 200 meters. After that, the pilot took over manual controls and made repeated approaches toward Soyuz 2, coming very close and reducing the differences in velocity to less than 1 kilometer per hour. For some unknown reason he was unable to accomplish actual docking although this was clearly his objective.[7] Television coverage of these operations was provided by external cameras.

More details about the ship itself emerged, revealing that there were two passenger compartments, a fact less clear from earlier drawings (see figures 13 to 17). Beregovoy slept in a separate work compartment, while piloting was done in the command module, which was also the recoverable part of the ship. The total volume of the two compartments, which were connected by an airlock, was about 9 cubic meters. The ship had a 30-day stay time capability and some versions could fly up to 1,300 km above the Earth. The descent portion had special aerodynamic qualities which permitted precise landings at preselected points, and the lift cut the G-load to between 3 and 4 G's compared with 8 to 10 G's for a ballistic re-

[7] Moscow Radio, Oct. 28, 1968, 0200 GMT.

entry, although the latter could still be used in an emergency to save time.

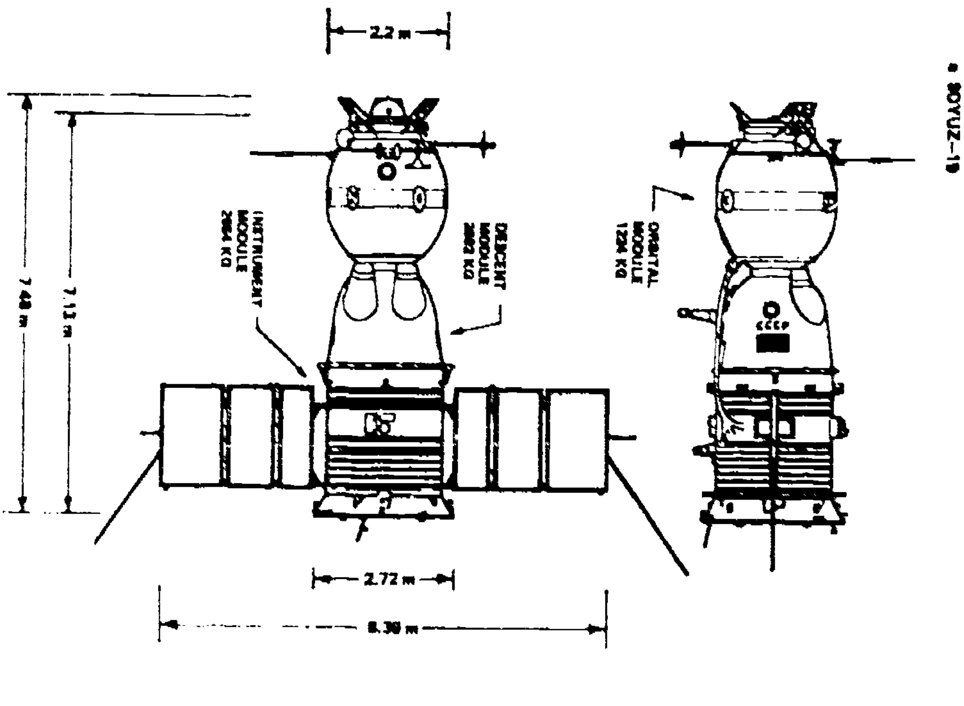


FIGURE 13.—Soyuz Spacecraft. The Soyuz spacecraft consists of three modules. The nonrecoverable orbital module is fitted with a docking collar for docking with other spacecraft (Soyuz, Salyut, and Apollo). The cosmonauts are launched and recovered in the reentry module. The nonrecoverable instrument module provides control, power, and propulsion during orbital flight.

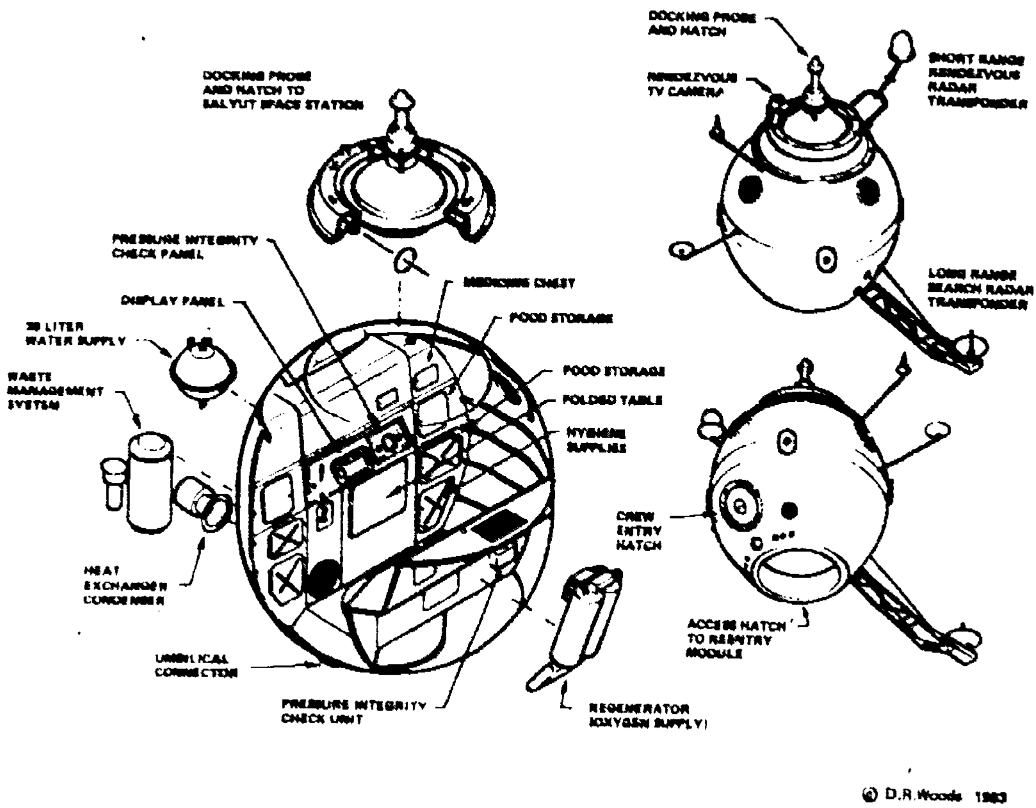


FIGURE 14.—Soyuz Orbital Module. The orbital module, weighing just over 1 metric ton, provides life support functions during independent orbital flight.

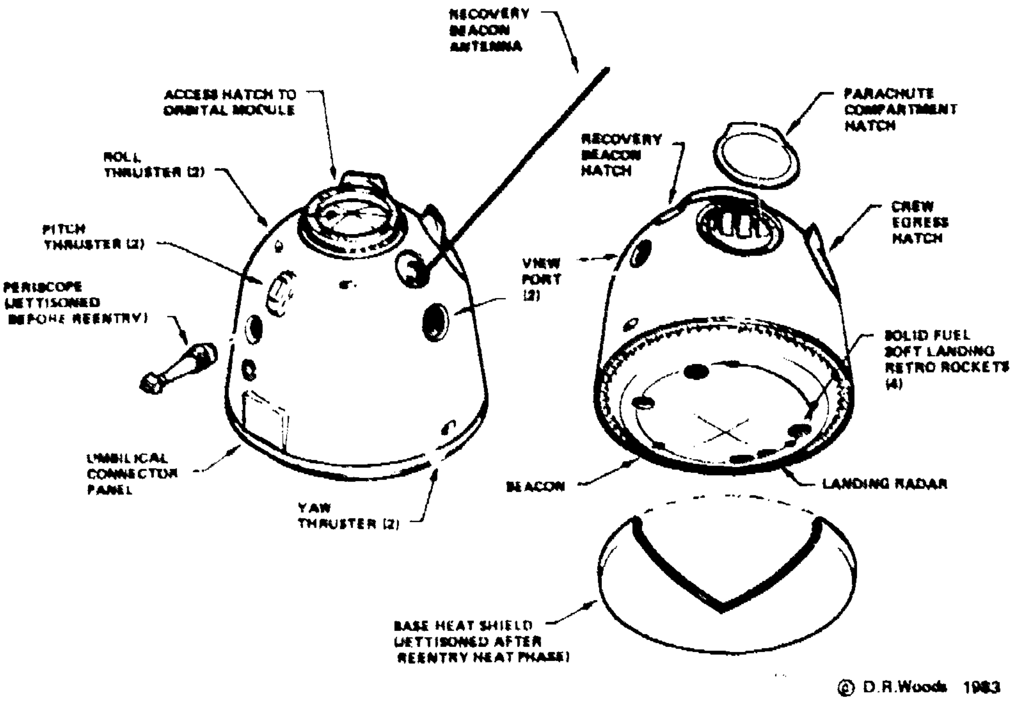


FIGURE 15.—Soyuz Descent Module—Exterior Details. The cosmonaut crew is launched and recovered in the descent module of the Soyuz. After successful reentry, the base heat shield is dropped away to expose a set of soft landing solid retro rockets that are ignited just moments before touchdown.

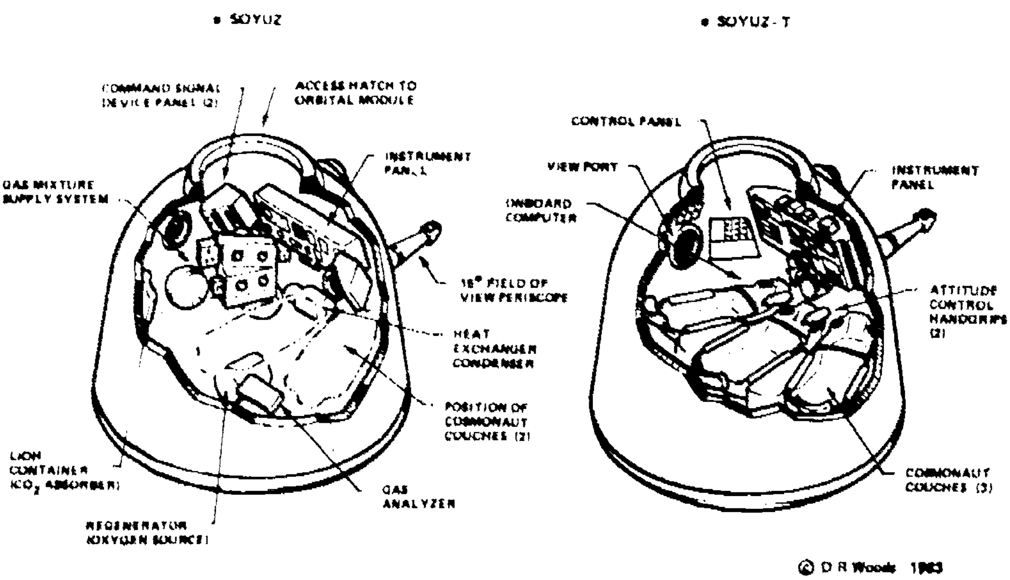


FIGURE 16.—Soyuz Descent Module—Internal Details. The Soyuz descent module was extensively modified following the loss of the Soyuz 11 crew. It remained a two-man craft until the introduction of Soyuz-T that again can carry a three-man crew.

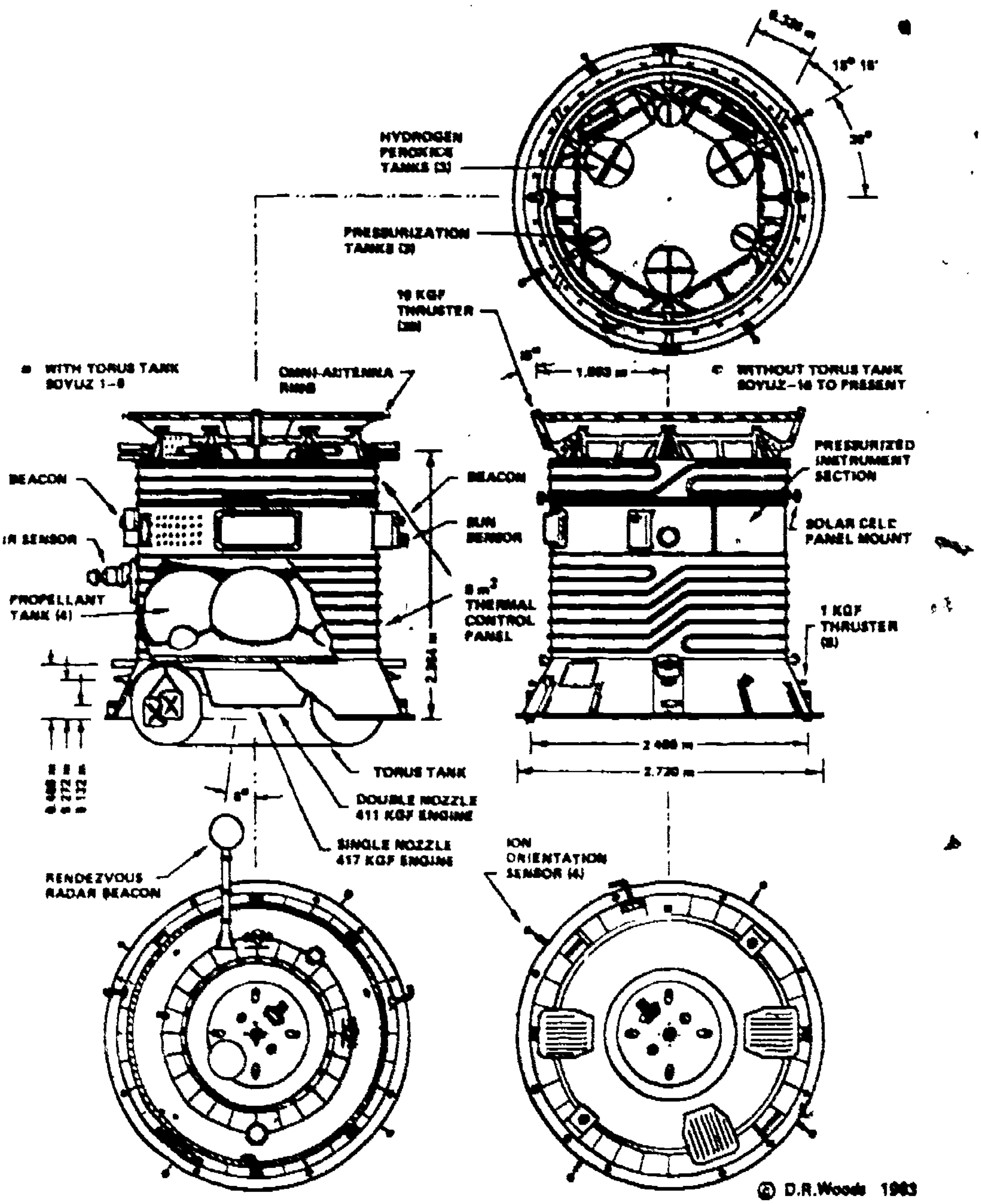


FIGURE 17.—Soyuz Instrument Module. The Soyuz instrument module provides electrical power, thermal control, attitude control and a maneuvering capability during orbital flight. The role of the torus tank carried on the first nine missions is not known.

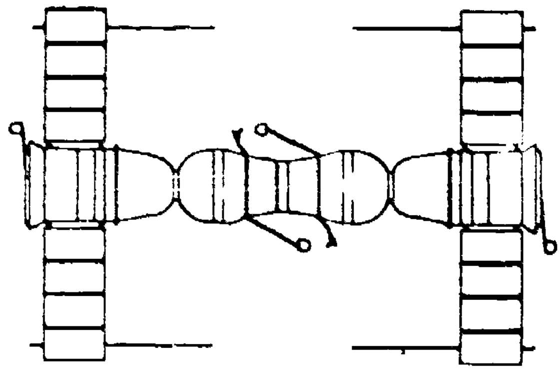
Retrofire was provided from a 400-kilogram-thrust liquid rocket engine with a completely duplicate engine in reserve. If both failed, normally the residual fuel of the orientation steering rockets would be sufficient to return a ship from orbit. On reentering, a drogue parachute was deployed at 9 km, followed by the opening of the main parachute, with a second parachute in reserve. Just before final touchdown, at a height of about 1 meter, a gunpowder rocket was fired as a final brake to soften landing.

During his 4-day flight, Beregovoy monitored the flight systems, gathered geophysical data, and took pictures of the Earth's surface for resource studies. Except for the strong implication (although explicitly denied) that docking was intended and failed, the flight was a good proving effort for the Soyuz hardware. At a much later date, a specific weight of 6,575 kg was filed for the ship.

SOYUZ 4 AND 5

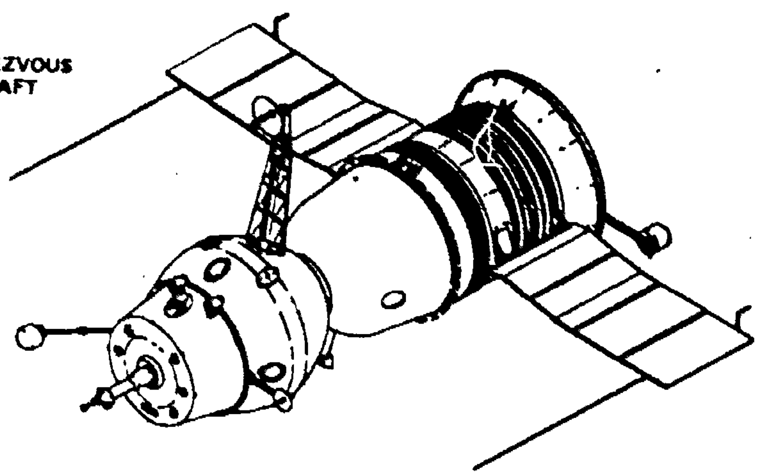
Soyuz 4 was launched on January 14, 1969, a novel launch time for the Russians since they had avoided the winter season when either an aborted launch or off-course landing might mean a delay in crew rescue under severe weather conditions. However, not only did the ship have an enhanced water-landing capability so a sea landing in the tropics could occur if necessary, but the Russians were fully confident of their systems. Put into the typical low Soyuz orbit, the ship was piloted by Col. Vladimir Shatalov. The next day Soyuz 5 was launched with a three-man crew: Lt. Col. Boris Volynov, commander; Aleksey Yeliseyev, flight engineer; and Lt. Col. Yevgeniy Khrunov, research engineer.

After a number of orbital corrections by both ships, the docking exercise began on Soyuz 5's 18th orbit, and Soyuz 4's 34th (see fig. 18). The automatic system brought the ships to within 100 meters of each other whereupon Shatalov completed a manual approach. On the 35th orbit of Soyuz 5, Khrunov and Yeliseyev donned pressure suits and self-contained life support systems, entered the orbital work compartment, sealed the inner hatch, then opened their outer hatch, and transferred to Soyuz 4, floating and using handrails on the outside of the crafts for assistance. Both men were outside for about an hour, with television cameras recording the entire affair and constant radio communications maintained. Khrunov made the transfer over South America while Yeliseyev did so over the Soviet Union. The orbital work compartment of Soyuz 4 served as an airlock.



• SOYUZ–4

ACTIVE RENDEZVOUS & DOCKING CRAFT



• SOYUZ–5

PASSIVE RENDEZVOUS & DOCKING CRAFT

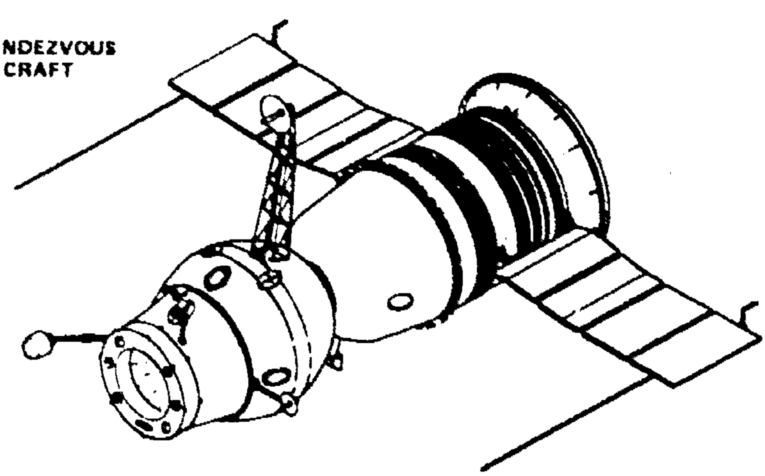


FIGURE 18.—Soyuz 4 and 5 Spacecraft Soyuz 4, carrying a one man crew and Soyuz 5, carrying a three man crew conducted the first crew transfer. Soyuz 4 returned with two of the cosmonauts from Soyuz 5.

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The ships remained docked for 4 hours 35 minutes. Soyuz 4 returned to Earth after 3 days, now carrying a crew of three instead of one, and Soyuz 5 landed after 3 days with only one man aboard instead of three. Soyuz 4 and 5 were later registered as weighing 6,625 kg and 6,585 kg respectively, for a total weight of 13,210 kg. As a result of maneuvers and usage of other expendables, their combined mass at the time of docking is estimated as being 28[illegible] kg lighter, or 12,924 kg.

The combined ships have always been hailed in the Soviet press as the world's first space station in which a total of four men were housed. Although the combination can be considered a station in that a fair amount of working space was provided by the orbital work compartments, the general view of a space station suggests a longer duration of usefulness and no need for EVA to go from one work compartment to another. The ships' orbit was low enough that it would have decayed in about 10 days, and the main life support systems, solar panels, and orbital adjustment rockets were in the after-service modules, separated from the orbital compartment by the command modules. Thus the "station" could not have been left behind in orbit for visits from other crews.

New pictures were released showing the true shape of Soyuz: A spherical work cabin at the front end separated by a hatch from a bell-shaped command module with its slightly convex reentry shield facing aft, and at the rear, the cylindrical service and propulsion module with its two solar panels.

SOYUZ 6, 7 AND 8

Launched on 3 successive days, Soyuz 6, 7 and 8 were to perform group flight with orbital assembly the prime mission. Soyuz 7 and 8 were meant to dock with each other for joint experiments, but Soyuz 6 was almost incidental to the mission since it could have flown any time after Soyuz 4 and 5. There are several reasons why the Russians might have waited. First, the possibility that the other projects had a higher priority for the tracking system and data central during the middle months of the year. Second, putting it up in conjunction with the next two Soyuz flights would reduce the cost of maintaining ocean tracking ships on station in all parts of the world. Third, by having three manned ships up at one time, the abilities of the computers and operations people to handle a much more complex data management system was given a good test. Fourth, having seven men up at once has a certain appeal as a portent of things to come.

The flights were terminated after 5 days each. There were rumors in the West that other ships were to have been launched and that the flight was to have run much longer, but it should be noted that before the first launch occurred, Moscow unofficial reports said that three ships would be involved with at least six cosmonauts, for a total period of 1 week.[8]

[8] First reported by Paris AFP on Oct. 9, 1969, naming three ships and docking; then reported on Oct. 10 by Moscow UPI as imminent; then stated on Oct. 13 by the Yugoslav agency Tanyug as being for 1 week. Apart from the docking, all these rumors were confirmed by events.

Soyuz 6

Launched on October 11, 1969, this flight was piloted by Lt. Col. Georgiy Shonin, who was accompanied by flight engineer Valeriy Kubasov. It not only tested the Soyuz systems, but also contributed to gathering Earth resources data. Its most important and significant experiment, though, dealt with alternate methods for welding in the high vacuum and weightlessness of outer space.

The Russians consider welding as necessary in future space operations if very large permanent stations are to be assembled and if such stations are also to be used for the assembly of expeditions to visit the planets. Thus they built into the Soyuz 6 workspace remote handling equipment to conduct welding experiments, after first opening the cabin to vaccum conditions. The welding unit, Vulcan, was controlled remotely by electric cable. They tested three methods: A low pressure compressed arc, an electron beam, and arc welding with a consumable electrode. Only the electron beam experiment was reported as categorically successful.

Soyuz 7

This launch occurred on October 12 with a crew of Lt. Col. Anatoliy Filipchenko, flight engineer Vladislav Volkov, and research engineer Viktor Gorbatko. The ship carried docking equipment and was meant as the passive target for Soyuz 8. Aside from group flight activities, its principal task was Earth resources and related research.

Soyuz 8

Launched the day after Soyuz 7, the flight was commanded by Col. Vladimir Shatalov, accompanied by flight engineer Aleksey Yeliseyev, both veterans of the Soyuz 4/5 operation. Design as the active partner in docking with the larger crew in Soyuz 7,[9] many maneuvers were made between the two ships but docking was never accomplished. Although Soviet accounts vary from outright denial of docking plans to evasion on this point, it seems likely that a pair of ships equipped with docking gear instead of other experiments are meant to dock. What is unclear is whether automatic docking routines would have been successful as in the double Kosmos missions, or whether a mechanical problem precluded either automatic or manual docking.

SOYUZ 9

Soyuz 9 was launched on June 1, 1970, with Col. Andriyan Nikolayev as pilot and Vitaliy Sevastyanov as flight engineer. This ship lacked rendezvous and docking systems and was sent on a solo flight to test, for a longer period of time than other flights, the capacity of both the hardware and the human crew. On the fifth orbit the ship was raised from its initial orbit to protect its orbital life from early decay. On the 17th orbit, the perigee was raised again to establish a still more durable circular orbit.

Medical-biological research effects of long-term exposure to space conditions were probably the primary mission of this flight, but it

[9] Tass, Oct. 15, 1969, 1846 GMT.

also afforded a good opportunity to enhance capabilities related to Earth resources observation. These concentrated on both visual observation and photographing geological and geographical objects, weather formations, water surfaces, snow and ice cover, and conducting other ground studies.

Onboard television cameras gave the ground controllers and Soviet public live coverage of activities on the ship during some orbital passes. The crew found the ship comfortable, and slept for 8 hours at a stretch on couches in the work compartment, using sleeping bags. A stove provided hot meals of a wide range of conventional foods, and shaving was accomplished with both the shaving cream method and a dry electric razor. Lacking a shower they resorted to twice-daily rubdowns. A vacuum cleaner was used to maximize the cleanliness of their living spaces.

As far as the ship itself was concerned, the Russians claimed that the 14 square meters of solar panels with chemical batteries were more reliable than the American fuel cells used in Gemini and Apollo. They also felt that their use of two cabins made it possible to provide a work and sleep area with no threat of clutter and interference to the flight and recovery observations conducted in the command module. Also, the pilot would have no need to put on a pressure suit if his companion(s) conducted EVA exercises through a hatch from the work module.

On the 14th day of flight, the orbit was lowered as a precaution for later recovery, particularly if retrofire should not be successful, but retrofire occurred as expected, and the command module separated from the work and service compartments for landing on June 19 in Kazakhstan The crew was immediately picked up and although they were in good condition, after 18 days in space they had a harder time adjusting to full Earth weight than American crews who had stayed up for 14 days. The men were taken to a new quarantine laboratory whose description sounded very much like the Houston lunar receiving laboratory. In the later Moscow celebrations, Nikolayev was promoted to Major General.

The following experiments were conducted:

(1) Medical

The crew made measurements of their condition before and after exercise, noting arterial pressure, pulse and respiration. They checked the contrast sensitivity of their eyes and made many tests of their vestibular sensitivity in weightlessness. Samples of air breathed before and after exercising were collected in plastic bags for analysis on Earth, with expectations that the ratio of carbon dioxide and oxygen would give a measure of energy expenditure. The dynamics of pain sensitivity were checked and maximum hand strength tested with a dynamometer.

During the 13th day of flight, a test of Sevastyanov's mental capabilities was made by exposing him to a simulated set of commands which had been preprogrammed into the onboard computer, as a comparison with his corresponding capabilities earlier in the flight.

(2) Other Biological

Experiments were performed relating to the micro and macro genesis of flowering plants, the division of cells of chlorella, the propagation of bacterial cultures in liquid media, and the propagation and development of insects.

(3) Earth Resources

On the fifth day, the crew watched a large tropical storm in the Indian ocean and observed surf on a continental shore. The next day they observed forest fires in Africa near Lake Chad.

They used both black and white and multispectral color film to photograph the Earth's surface, which was expected to throw light on problems of identification of different kinds of Earth rock and soil, the moisture content of glaciers, the location of schools of fish, and estimation of timber reserves.

The crew also made studies of aerosol particles in the atmosphere by observing twilight glow.

(4) Navigation

Astronavigation was practiced by locking onto Vega or Canopus and then using a sextant to measure its relation to the Earth horizon. Spectrographic measurements of the horizon were taken to define it better for navigation purposes. Arcturus and Deneb were later added as sighting targets for navigation tests.

On the 4th day, using onboard navigation and measuring equipment, the orbital elements were refined to three decimal places—that is, to an exact number of meters for apogee and perigee, to an exact number of thousandths of a minute for period, and to the exact number of thousandths of a degree in inclination.

(5) Astrophysical

In addition to observing celestial bodies, the cosmonauts made photographic studies of the Moon.

SOYUZ 12: FERRY CRAFT CONFIGURATION

Soyuz 12 (Ural) was the first manned flight by the Soviet Union after the tragic deaths of the Soyuz 11 crew in 1971 (see next section). The Russians launched several unmanned tests to check systems and spacecraft design to ensure the incident would not occur again. Soyuz 12 was primarily a test of the new designs, including introduction of a new launch escape rocket, so the only experiment scheduled was Earth photography. This flight introduced the ferry craft version of Soyuz without solar panels, which was used for taking crews back and forth to space stations beginning with Soyuz 14 (see fig. 19). In addition, it introduced the return to two-man crews in order to accommodate spacesuits and their associated equipment. Cosmonauts have worn spacesuits during launch and reentry since this time.

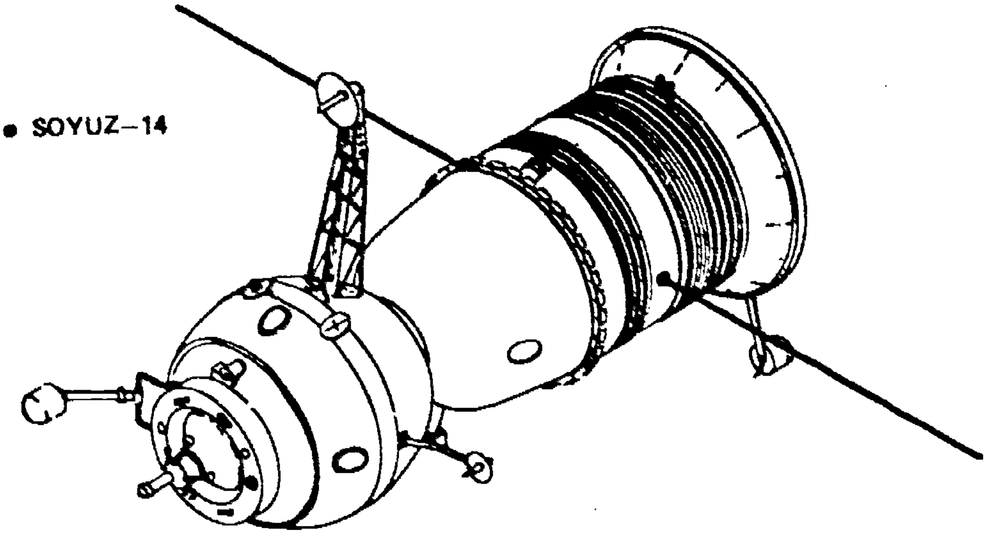


FIGURE 19.– Soyuz 14 Operational Two-Man Ferry Craft. Soyuz 14 was the first operational mission of the two-man ferry missions to Salyut space stations. Since independent flight was short, solar panels were removed to save weight.

Launched into an initial orbit of 249×194 km at 1218 GMT on September 27, 1973, the ship was piloted by Lt. Col. Vasiliy Lazarev and flight engineer Oleg Makarov. It was inclined at 51.6 degrees and had a period of 88.6 minutes. In a test of the control systems, the orbit was changed to 345×326 km, 91 minutes on the second day of flight. Sven Grahn suggested that this forecast higher altitudes for Salyut and his prediction was confirmed by Salyut 4.

Both days were devoted to checking onboard systems and photographing the Earth in various spectra, using a nine-objective camera. As the spacecraft photographed a region of the planet, airplanes simultaneously took pictures of the same area for comparison purposes to discover what distortions were introduced by the atmosphere.

Soyuz 12 landed Septemter 29, 1973, at 1134 GMT, 400 km southwest of Karaganda, Kazakhstan.

SOYUZ 13: OBSERVATORY

Soyuz 13 was launched on December 18, 1973 at 1155 GMT and code named Kavkaz (Caucasus). Primarily conceived as an orbiting astronomical observatory (see fig. 20), the cosmonauts aboard, Maj. Petr Klimuk and flight engineer Valentin Lebedev, had undergone extensive training at the Byurakan Observatory in Armenia on the operation of the ast ronomical equipment on board (Orion 2). On the fifth orbit, Soyuz 1 was put into a 272×225 km orbit, inclination 51.6 degrees, period 89.22 minutes.

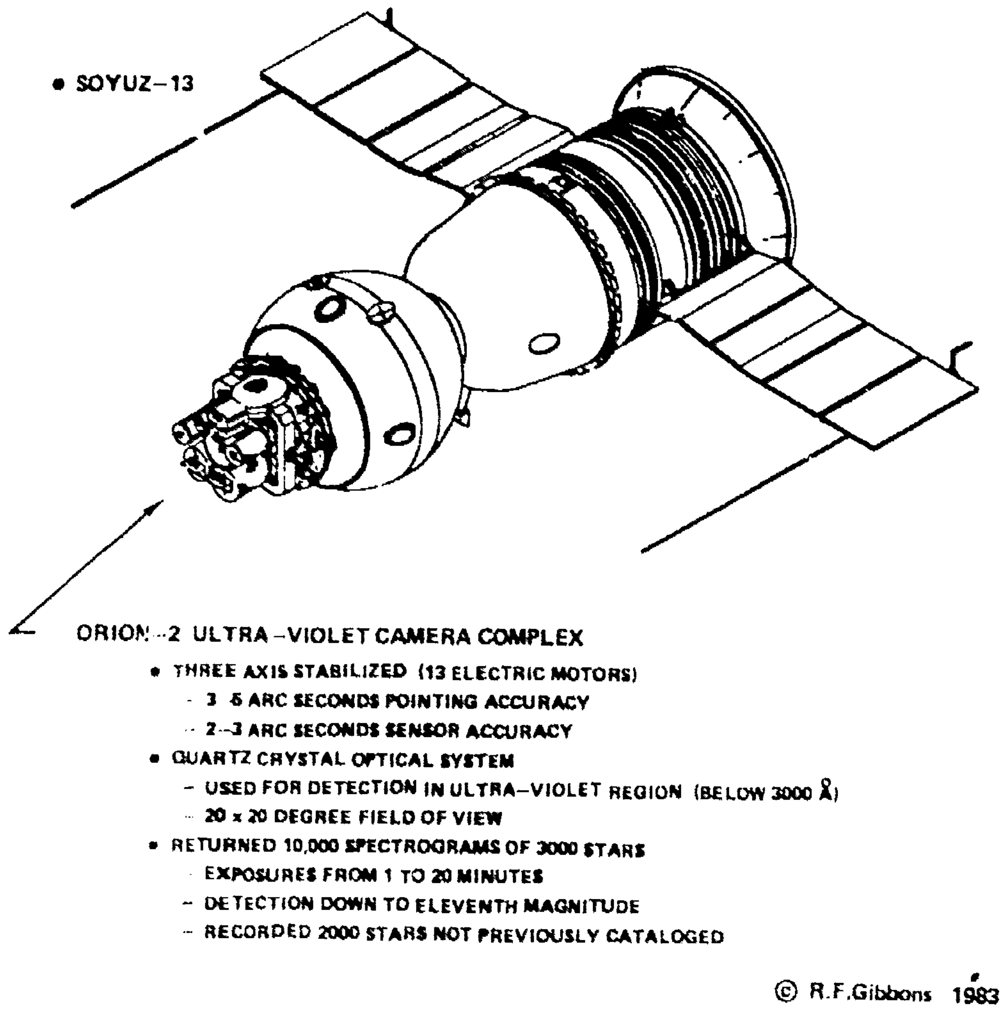


FIGURE 20. Soyuz 13 Spacecraft. Soyuz 13 was a solo flight. An astronomical observatory complex mounted on the orbital module was used for an extensive survey in the ultraviolet region of the spectrum.

Since the orbit was similar to that planned for the Apollo-Soyuz Test Project in 1975, some speculated that this flight was a demonstration mission. But Salyut 2 and Kosmos 557 had failed shortly before this flight and it is quite possible that the Russians decided to modify the Soyuz so that Salyut-like experiments could continue until another space station was orbited. Two modifications were made to the Soyuz ship: The addition of the Orion 2 system which was mounted outside the ship in the position of the docking assembly, and the orbital section was transformed from a place for rest and relaxation into a space laboratory.

Klimuk and Lebedev remained in space for 8 days, landing on December 26 at 0850 GMT, 200 km southwest of Karaganda, Kazakhstan. Five minutes later they were outside walking around.

The main projects for the mission were: Astrophysical experiments with Orion 2, research into the production of protein mass in space with Oazis 2 (both of these had predecessors on Salyut 1), experiments with higher plants, biomedical checks with the Levka apparatus, Earth observation, and navigation.

MEDICAL

The Soviets are especially interested in blood circulation to the brain in a weightless environment (blood tends to redistribute itself toward the upper body in the absence of gravity). In the Levka (Lion's Cub) experiment, the cosmonauts stretched a special expander with a force of 15 kg at a rate of 30 times per minute. The response in cerebral vessels was measured by electrodes on the cosmonauts and recorded by telemetric devices.

OTHER BIOLOGICAL

Oazis 2 consisted of two interconnected cylinders for the study of regeneration. One cylinder cultivated water-oxidizing bacteria which used hydrogen from water electrolysis for growth. Oxygen was formed and passed into the second cylinder containing urobacteria (which break down urea). The urobacteria absorbed the oxygen and released carbonic acid which in turn was passed back to the first cylinder and used for synthesis of biomass. Thus the waste products on one type of bacteria are the initial material used by other bacteria to accumulate protein mass: This is regeneration. During Soyuz 13's flight the biomass increased 35 times. This is important for long duration spaceflights where food, air and water might be regenerated so vast quantities of these perishables need not be carried on board.

Higher plants studied during this mission were chlorella and duckweed. Chlorella absorbs carbon dioxide and returns oxygen to the air, so the Russians want to see how well it grows in space, since animals, including people, exhale carbon dioxide and need oxygen to breathe. Duckweed is interesting because in the winter it goes into hybernation and exists in the form of turions, small bodies with inhibited vital activity. In the spring the turions multiply by division and again become duckweed. The cosmonauts put turions into a vessel and added kinetin to restore the vital activity. They then added a nutrient to see how the duckweed would assimilate it.

EARTH RESOURCES

The cosmonauts again studied natural formations on the surface of the planet as well as the atmosphere. For the former, a nine-lens camera which exposed three strips of film simultaneously photographed several areas of Earth. Two of the films were sensitive to visible light, the third to infrared. Each lens had color filters so many spectra could be taken and selection could be made as to which are the most valuable for specific missions.

An RSS-2 spectrograph studied the atmosphere by photographing day and twilight horizons. In addition, the spectrograph recorded the reflection of solar radiation from natural formations on Earth.

ASTROPHYSICAL

Orion 2, unlike Orion 1, was mounted entirely on the outside of the ship and had a wide field meniscus telescope which could cover an area 20 degrees square. A canopy surrounded the telescope to protect it from temperature extremes as the ship travelled into and out of the Earth's shadow, and the optical components were made of crystalline quartz. A window in the canopy opened during observation, with exposure times ranging from 1 to 20 minutes.

Designed by Grigor Gurzadyan of Armenia, the telescope was mounted on a three-axis platform which stabilized the system with an accuracy of 2 to 3 seconds of arc. This was vital for successful observations. Pointing was accomplished by positioning the spacecraft within a few degrees of the area to be studied. The two reference stars were then found, whereupon Orion 2 itself took over with an automatic pointing system accurate to 3 to 5 angular seconds. The instrument had 13 electric motors for drive. Although some of the Orion 2 system was automatic, both cosmonauts were needed for these experiments; one to orient the ship, the other to work Orion.

Also mounted on the Orion system was an instrument for studying X-ray emissions from the Sun. These studies were done on the 65th orbit. The camera had several channels and took photographs simultaneously in several ranges of the X-ray band, and has a 70 degree field of view. Observations were carried out at the same time from Earth for comparison purposes.

During the mission, the cosmonauts made 10,000 spectrograms of more than 3,000 stars in the constellations Taurus, Orion, Gemini, Auriga, and Perseus. The spectrograms were in spectral classes from 2,000 to 3,000 angstroms (these cannot be studied from Earth since the atmosphere absorbs emissions less than 3,000 angstroms) and the stars were of the 10th magnitude generally, although the cosmonauts were able to photograph some even of the 12th. Special sensitive film was supplied by George Low of NASA for this project.

NAVIGATION

Experiments were continued into autonomous navigation, specifically to determine the accuracy of control systems and the testing of new instruments for orientation using the Earth and stars.

THE APOLLO-SOYUZ TEST PROJECT

In 1972, the United States and Soviet Union agreed to conduct a joint manned mission in 1975 in which an American Apollo would dock with a Soviet Soyuz. A total of four Soviet flights were made in connection with ASTP: Two unmanned test flights (Kosmos 638 and 672), a manned test flight (Soyuz 16), and the mission itself (Soyuz 19). These flights are summarized in table 6.

TABLE 6.—APOLLO-SOYUZ TEST PROJECT MISSIONS [1]

Flight	Launch Date	Launch Hour	Recovery Date	Recovery Hour	Flight Duration (hr:min)	Apogee (km)	Perigee (km)	Inclination (degrees)	Period (min)	Remarks
Kosmos 638	Apr 3, 1974	0730	Apr 13, 1974	0448	237:18	325	195	51.8	89.4	Later identified by Tass as ASTP related. Adjusted orbit
						390	268	51.8	89.8	
Kosmos 672	Aug 12, 1974	0625	Aug 18, 1974	0448	142:23	239	198	51.8	88.6	Do.
						238	227	51.8	89.1	
[illegible] 16	Dec 2, 1974	0940	Dec. 8, 1974	0804	142:24	223	177	51.8	88.4	Dry run for ASTP, including docking exercise. Adjusted orbit.
						225	225	51.8	88.9	
Soyuz 19	July 15, 1975	1220	July 21, 1975	1051	142:31	220	186	51.8	88.5	Apollo docked with Soyuz 19 at 1609 July 1[illegible] undocked at 1202 on July 13 Then Soyuz 19 docked with Apollo from 1220 to 1532 on July 19.
						225	223	51.8	88.9	

[1] The flights known to be directly related to Apollo-Soyuz Test Project (ASTP) are included. Basic data on launch and orbital parameters are from Tass, with adjusted orbits from the Royal Aircraft Establishment. Time is GMT.
Sources: Tass bulletins, and Royal Aircraft Establishment, revised table of Earth orbital satellites, volumes 2 and 3, Farnborough, Hants, December 1979 and January 1980.

KOSMOS 638 AND 672

Kosmos 638 was launched on April 3, 1974 into a 325×195 km orbit inclined at 51.8 degrees, the same orbit intended for ASTP. The spacecraft stayed up for 10 days and was then recovered. The Kettering Group found signals at 20.008 MHz.

Kosmos 672 was launched on August 12, 1974 into a 239×198 km orbit, inclined at 51.8 degrees. The orbit was adjusted to the ASTP position when the apogee was moved to 238 km and perigee to 227 km. Later, as with Kosmos 638, the Soviets confirmed that it was an ASTP test flight.

SOYUZ 16

Soyus 16 (Buran or Snowstorm), announced as a precursor flight for the Apollo-Soyuz Test Project, was launched December 2, 1974, at 0940 GMT and piloted by the prime ASTP backup crew, Col. Anatoly Filipchenko and Nikolay Rukavishnikov. It was a test of the new systems installed for the joint mission and most importantly, the docking procedure. Some biological and photographic experiments were aboard, including some to be repeated on ASTP.

Modifications to the Soyuz included the docking gear, flight and attitude controls, radio communication systems, the addition of new controls and consoles in the orbital module, addition of an automatic gas analyzer, and changes in the life support system to enable it to handle four people (two cosmonauts and two astronauts). Tests were made of the changes in pressure and air composition that would be used during ASTP. The Russians operate in space under normal atmospheric pressure (760 mm Hg) and a nitrogen-oxygen air content. The United States, however, worked in a pure oxygen atmosphere at low pressure (260 mm Hg). In order to minimize the amount of time required for adjusting in the docking module airlock, the Soviet engineers agreed to reduce their pressure to 520 mm Hg and increase the percentage of oxygen to about 40 percent. These alterations were practiced during Soyuz 16 and the cosmonauts suffered no ill effects.

NASA was told in advance that this would be an ASTP test, but did not know the exact date and time of launch, since the Russians insisted such information be secret and NASA refused to keep the news from the press. Once the launch was announced, joint tracking exercises were conducted at the following locations: Bermuda and Tananarive (NASA operated); Antigua, Grand Turk, Eastern Test Range, Canton Island, Kaena Point (Hawaii), Kwajalein and Ascension (DOD operated). Mission control in Houston did not operate for this exercise.

The Russians have never announced the initial orbit for Soyuz 16, but NORAD stated it was 352×254 km. On the fifth revolution this was altered to 223×177 km, with an inclination of 51.8 degrees and a period of 88.4 minutes. As an ASTP test, the craft had to achieve a 225 km circular orbit, and this was accomplished by two more burns: To 240×190 km at an unspecified time, and on the 17th and 18th orbits to the final 225×225 km, with a period of 88.9 minutes. Although the Russians stated that these corrections were part of the planned program in order to test fully Soyuz's systems, some speculate that the initial orbit may have been a trajectory error. Others argue, however, that the "error" was deliberate, and the Soviets meant to demonstrate to the Americans that if the ASTP spacecraft was inadvertently placed in an incorrect orbit, they would be able to correct it.

Docking exercises were of primary importance for Soyuz 16. A special practice imitating ring attached to the ship was moved away so Soyuz could maneuver and dock with it (the ring was pulled onto Soyuz with a force equal to that of Apollo). The docking equipment incorporated some of the Soyuz/Salyut gear, for example a spring-mechanical type of shock absorber as opposed to the hydraulic type used by the United States. Some 20 technical operations were carried out to test coupling, link-up and hermetic docking, beginning in the 32d orbit. The tests were successful.

Filipchenko and Rukavishnikov landed 300 km north of Dzhezkazgan at 0804 GMT on December 8 after 6 days in orbit. Other experiments carried out during the mission included:

Earth resources

Photographs of the Earth were taken for the study of natural resources, and of the horizon to determine the composition and limits of the atmosphere.

Astrophysical

Photography of the Sun and stars was carried out in preparation for an ASTP experiment which used Apollo to block out the Sun and create an artificial solar eclipse for Soyuz.

Biological

There were five biological experiments.

(1) The growth of microorganisms in space. Microbes were put in a nutrient medium the first day in space and the cosmonauts watched for their growth. There was a lag for the first few days, but the microbes soon became adjusted to the environment and grew normally.

(2) A determination of what direction sprouts would grow in without the Sun's rays.

(3) The study of fish. In previous experiments, scientists discovered that adult fish lost their sense of spatial orientation in a gravity-free environment. On this mission, Danio rerio fish eggs were brought along. When the fish hatched they exhibited no orientation problems as the earlier fish had.

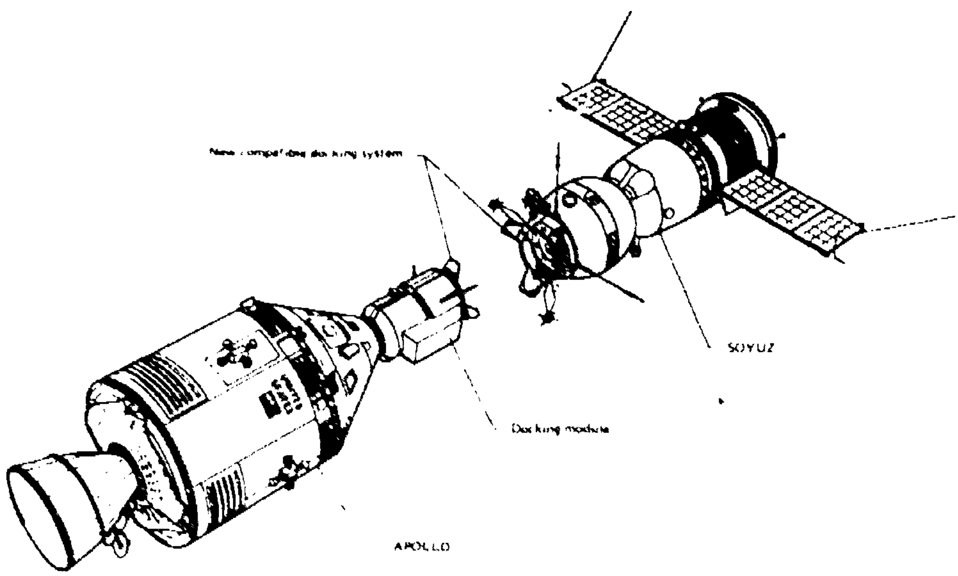
(4) Samples of microbes were taken from different parts of the Soyuz craft and from the cosmonauts themselves (hair and skin) to test microbial transfer. This was repeated on the ASTP mission to determine if any contamination occurs when one space crew is visited by another, as might happen in long-duration space stations.

(5) Zone-forming fungi were studied for two reasons. First, these fungi develop a new growth ring every 24 hours on Earth and scientists wanted to see how often one would grow in space where a "day" is only 90 minutes long. In addition, the fungi were placed inside a device called "Ritm" which had a dosimeter mounted on the outside to measure the amount of radiation entering the flask to see if it had any effect on the fungi. During ASTP, fungi were flown on both ships to see how different amounts of radiation in

various areas of space would affect the organisms, since Apollo and Soyuz travelled in different parts of the sky except for the time they were docked together.

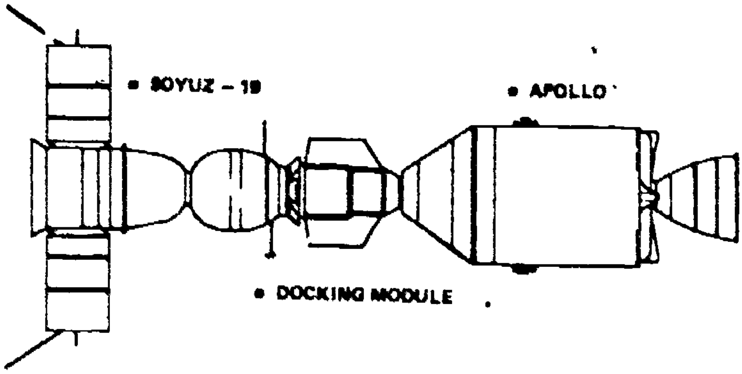
SOYUZ 19 (ASTP)

Soyuz 19, the Soviet half of the Apollo-Soyuz Test Project, was launched on July 15, 1975 at 1220 GMT carrying Col. Aleksey Leonov and Valeriy Kubasov (see figs. 21–24). The Soviets had provided a complete backup Soyuz launch vehicle and capsule ready on the pad in case there was an abort with the primary launch, and backup crews for both the prime crew (Leonov and Kubasov) and the prime backup crew were named. The launch occurred nominally, placing the spacecraft in a 229×188 km orbit. On the 4th and 17th orbits, the crew raised the ship so it would be in a circular 225 km orbit.



SOURCE SOVIET ASTP PRESS KIT

FIGURE 21 – ASTP International Mission The Apollo Soyuz Test Project (ASTP) was the first international space mission. U.S. and Soviet project personnel had to overcome a multitude of technical problems before the mission could be conducted These included different systems of measurement, different languages and alphabets, and different spacecraft atmospheres and composition.



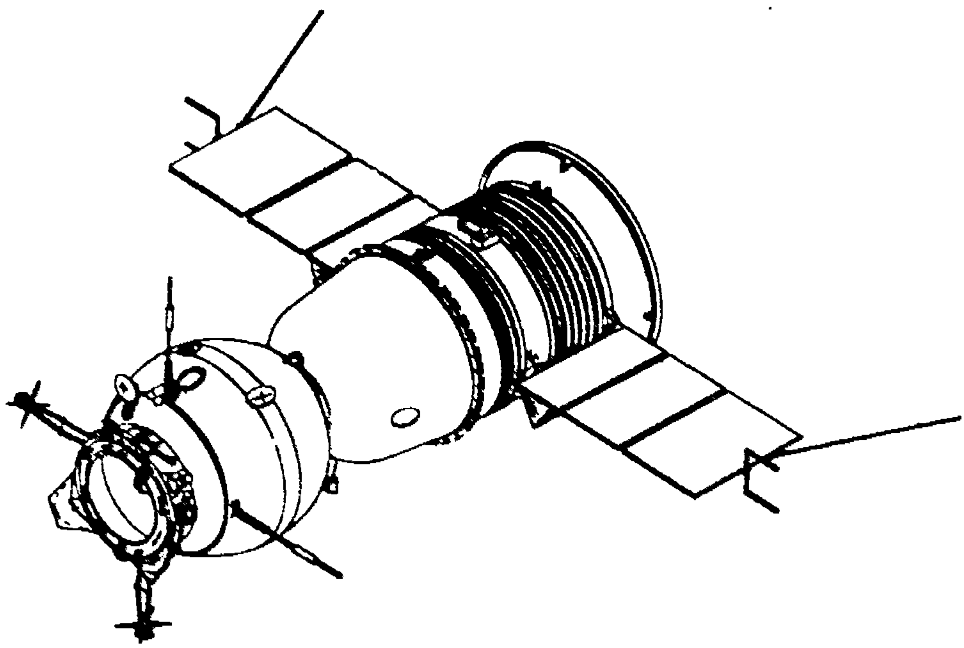


FIGURE 22 --Soyuz 19 ASTP Spacecraft. The Soyuz 19 spacecraft was fitted with a special docking collar to permit it to dock with the Apollo docking module.

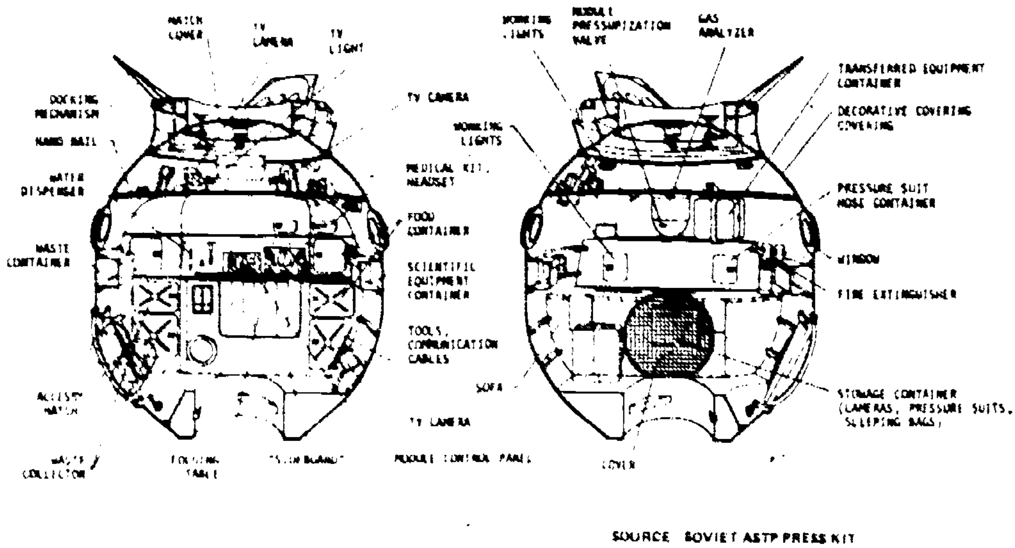


FIGURE 23 Soyuz ASTP orbital module. The Soviets provided extensive details of the orbital module to be used for the ASTP mission. This figure provided in the Soviet ASTP press kit shows the layout that is generally common to all Soyuz spacecraft

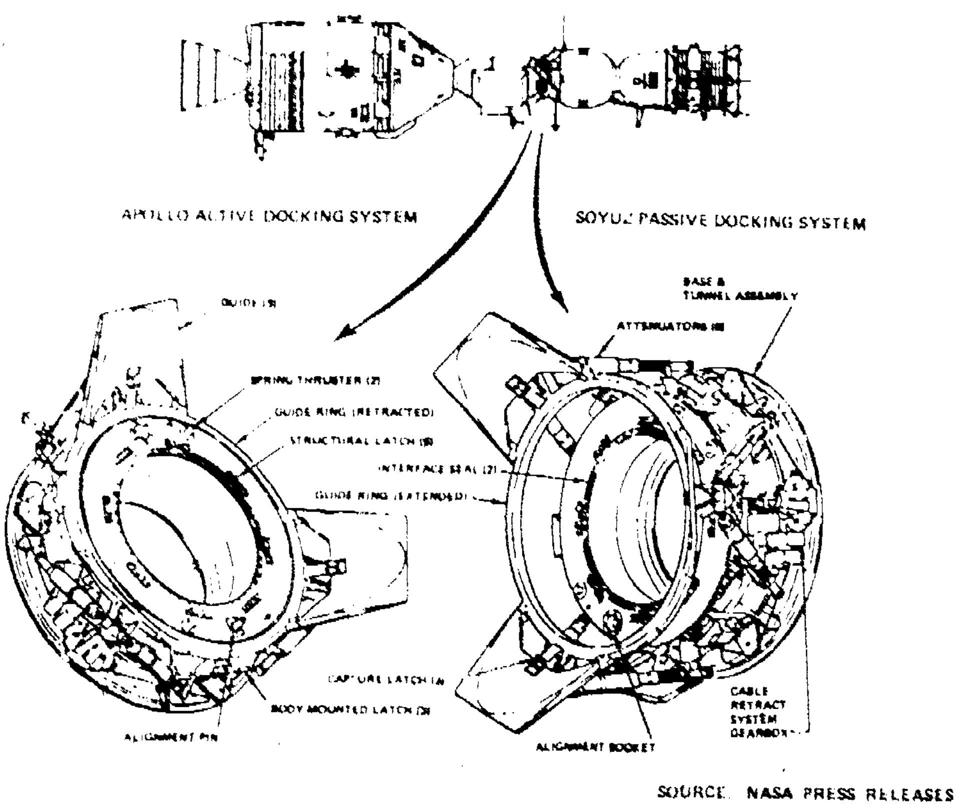


FIGURE 23 ASTP Docking Units. The Soyuz and Apollo docking module were each fitted with a special docking collar to conduct docking during the first international space mission.

At 1950 GMT, the U.S. Apollo spacecraft was launched with its crew of Gen. Thomas Stafford, Vance Brand, and Donald (Deke) Slayton. (The United States had named a single backup crew.) The Apollo was placed in an initial orbit 173×155 km. Approximately 1 hour after attaining orbit, the American crew began transposition and docking with the docking module which had been specially designed for joining the two dissimilar ships. The Apollo orbit was then circularized to 172 km. Another burn was made to change the oribit to 234×173 km on July 16, and the next day it was circularized at 229 km.

Rendezvous and docking of the two ships was accomplished at 1612 GMT on July 17 (Apollo was the active ship), and the ships remained docked for 2 days, conducting joint experiments and exchanging national mementos. At 1623 GMT, Soviet Premier Brezhnev relayed congratulatory messages to both crews, and the first handshake between Stafford and Leonov took place at 1919 GMT when the ships were approximately over Metz, France (5° 47′ 37″ E, 49° 10′ 12″ N).[10] President Ford spoke with the Apollo and Soyuz crews, offering his congratulations. Several crew exchanges were made, national flags were exchanged, and international certificates were signed.

After the 2 days of docked flight, the ships completed an undocking and redocking maneuver, separating for the last time at 1526 GMT on July 19. Soyuz 19 landed near Arkalyk at 1051 GMT on July 21. The Apollo remained in orbit to conduct additional experiements, splashing down in the Pacific at 2118 GMT on July 24.

ASTP preparation

Prior to the conduct of ASTP, the astronauts and cosmonauts and support personnel visited each other's space centers to become familiar with the spacecraft of the other country. The first visit was by the Soviet crew to NASA's Johnson Space Center in July 1973, followed by a U.S. crew visit to Moscow in November 1973. In late April and early May 1974, the Soviet flight crews returned to Johnson Space Center, and the U.S. crews went to Moscow in June and July 1974. The Soviet crew made a third trip to the United States in September 1973 and came for the fourth and last time in February 1975. The U.S. crews visited the Soviet Union in late April and early May 1975 and became the first Americans to see the launch facilities at Tyuratam on April 28, 1975.

Three simulation sessions were conducted between flight controllers and the ASTP crew in Houston and Moscow on May 13, 15, and 18, 1975, involving communications links between the two control centers and fully manned control center facilities. A final simulation was conducted from June 30 to July 1, 1975.

One of the most difficult problems to overcome was that of language. To alleviate this as much as possible, the Americans learned Russian and the Soviets learned English. It was found that the best

[10] Press reports at the time stated that the handshake had taken place over Amsterdam, Netherlands, but analysis by the Kettering Group has shown that Amsterdam was not on the ground track of the spacecraft when the handshake occurred, and that in fact the ASTP crews were over the Strasbourg area when they shook hands.

scenario was for the Soviet to speak English and the Americans to speak Russian.

Objectives and experiments

According to NASA, the main objective of ASTP was "to develop a compatible docking system and rendezvous and crew transfer procedures that might be appropriate for future international manned missions." [11] Since it was well known by this time that this would be the last flight for Apollo, and that the utility of the docking system would end after this flight, it seemed a less than convincing argument.

An additional objective, according to NASA, was scientific investigations, and a number of experiments were carried out by both crews separately and jointly. A discussion of the U.S. experiments can be found in United States Civilian Space Programs.[12] In the following paragraphs, experiments designated "S" were conducted by the Soviet Union, and those labled "J" were conducted jointly.

(1) Photography of the solar corona and zodiacal light against the background of the night sky (S)

A number of shots of the night and dusk sky and the Sun at different angles behind the Earth's horizon (conditions of solar eclipse by the Earth) were taken in an attempt to find coronal rays at large angular distances from the Sun.

(2) Investigation of refraction and transparency of the upper layers of the atmosphere (S)

Atmospheric refraction was determined from solar disc image flattening in photographs taken of the Sun as it rose and set behind the Earth's horizon. Photographs were also taken of setting stars.

(3) Photography of daytime and dusk horizon (S)

Visual observation and photography of light effects in the vicinity of the spacecraft were carried out in an attempt to determine the characteristics of light-scattering by atmospheric air, investigate various layers of aerosol, investigate certain types of clouds, and analyze the dependence of altitude aerosol distribution on geographical and meteorological factors.

(4) Microorganisms' growth (S)

To study the effects of weightlessness and space radiation and the Earth's magnetic field on the growth of microorganisms, a culture of proteus vulgaris was placed in a thermostatically controlled capsule known as a "Biokat" and observed.

[11] NASA. Apollo-Soyuz Test Project. Preliminary Science Report. Washington, U.S. Government Printing Office, 1976. p. xi

[12] U.S. Congress. House. Committee on Science and Technology. United States Civilian Space Programs 1958-1978. Volume I. Washington, U.S. Government Printing Office, 1981. See Chapters Six, Ten, and Eleven

(5) Fish embryonic development (S)

To study the growth and development of amphibians under space conditions, aquarium fish as well as their fertilized eggs were inserted into "Biokat" aquaria for observation.

(6) Genetic experiments (S)

In order to study the effects of weightlessne[illegible] cell division and mutation in biological organisms, various typ[illegible] of seeds were placed in one of the "Biokats" and observed.

(7) Artificial solar eclipse (J)

A series of on-board photographs taken from the Soyuz of the solar corona "atmosphere" around the Apollo while it eclipsed the Sun provided a record of the first solar eclipse produced by man. This experiment was of particular interest to scientists because of the relative infrequency of naturally occurring solar eclipses.

(8) Ultraviolet absorption (J)

To measure the concentrations of atomic oxygen and nitrogen in space at the altitude of the mission, different types of mass-spectrometers were used on board. The method of resonance absorption within the ultraviolet spectrum was employed to determine the densities of these components of the outer atmosphere.

(9) Zone-forming fungi (J)

In order [illegible] study the effects of space flight factors on biological rhythms, tw[illegible] cultures of the Pushchino strain of Actinomyces levories (fungi) were observed. Each had been cultivated in different time zones (United States and Soviet Union) approximately 9 hours apart, 7 days prior to launch.

(10) Microbial exchange test (J)

Microbial samples were taken from cosmonauts and astronauts before, during, and after the flight to determine the character and conditions of microbial exchange among men confined in a sealed compartment.

(11) Furnace system experiments (J)

This series of joint "multipurpose furnace experiments" was conducted in order to determine the effects of weightlessness on some metallurgical and chemicrystallization processes in metals and semiconductors.

Political issues

Beyond its merits as a scientific and technical project, ASTP was a highly political and somewhat controversial mission, acclaimed by some as a major contribution to U.S.-U.S.S.R. detente, while assailed by others as an expensive waste of time. Politics affected both sides, both jointly and separately, at various stages of the project development. In question were such issues as the value of the mission in relation to detente, the Soviet safety record and its effect on U.S. confidence, and the feasibility of future U.S.-U.S.S.R. cooperative space endeavors.

(1) Contributions to detente

The Apollo-Soyuz Test Project's political achievement in strengthening the atmosphere of detente between the United States and the Soviet Union may be judged by historians as the most significant aspect of the mission. Certainly the demonstration of meaningful cooperation between these two historically competitive powers was a positive step in this direction. Both sides demonstrated that they had considerably changed their attitudes since the early days of the so-called "space race."

(2) U.S. doubts—Senator Proxmire and the CIA

In light of several Soviet Soyuz mission failures, doubts about Soyuz hardware safety and reliability were raised by some U.S. critics prior to the mission. In particular, the Soviet "April 5th Anomaly" (discussed in section E) prompted Senator William Proxmire to call for a briefing by Central Intelligence Agency officials on Soviet space program capabilities. A closed hearing before the HUD and Independent Agencies Subcommittee of the U.S. Senate Appropriations Committee was held June 4, 1975. A summary of the classified testimony of Carl Duckett, CIA deputy director for science and technology, reported that "I do not think they (the U.S.S.R.) are in good shape to handle two missions at once from the command point of view." [13]

Based upon this testimony, Senator Proxmire released a statement July 2, 1975, urging NASA to postpone the July 15 Apollo-Soyuz Test Project mission "until the Soviet Union brings back to Earth the Russian (Soyuz 18/Salyut 4) cosmonauts already in space." [14]

NASA responded to this statement July 2, 1975, concluding that "the Soyuz 18/Salyut 4 mission does not constitute a hazards to ASTP." [15] NASA also noted that their calculations indicated a tracking overlap of the two missions would occur in only two instances, one lasting about 30 seconds, the other about 90 seconds.

ASTP was not postponed, and the joint mission went smoothly and according to plan.

Summary

In summary, it may be said that the successful completion of the Apollo-Soyuz Test Project mission was a step toward the realization of the goals set forth in the May 24, 1972, agreement between the United States and the Soviet Union on cooperation in the exploration and peaceful uses of outer space. The technological cooperation between engineers and scientists and crew members afforded an opportunity for *individuals* really to work together on a personal level. The preparations for the joint mission were perhaps as important as the flight itself from the standpoint of developing attitudes. History will be the ultimate judge of its success or failure, but it would appear that the Apollo-Soyuz Test Project made a significant contribution to the strengthening of detente, and laid the

[13] Summary Report of CIA testimony. Remarks of Senator Proxmire, Congressional Record, v. 121, July 14, 1975, "CIA Report on Apollo-Soyuz Mission."
[14] Press release from the Office of U.S. Senator William Proxmire, July 2, 1975.
[15] NASA Statement to Aerospace Daily, v. 74, No. 3, July 3, 1975, p. 18.

foundation for possible future joint efforts between the United States and the Soviet Union.

Soyuz 22: The MKF–6 Multispectral Camera

The most recent free-flying Soyuz mission was Soyuz 22 (Yastreb), launched at 1248 Moscow Time on September 15, 1976 (see figure 25). Since that time, all Soyuz flights have been made in connection with space stations, and are discussed later.

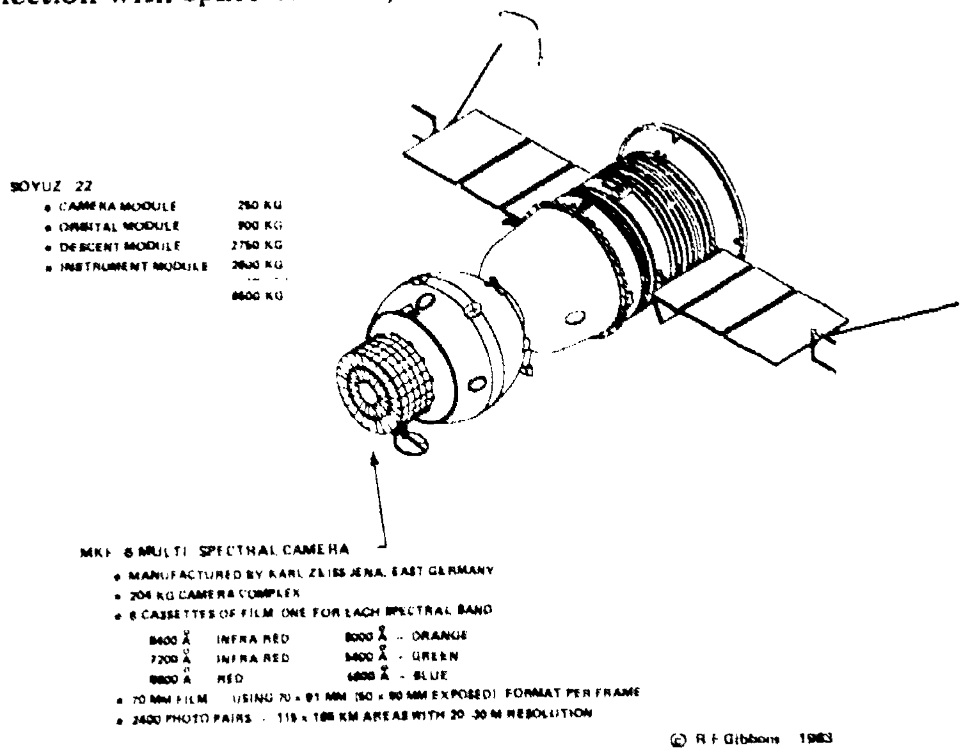


Figure 25.—Soyuz 22 Spacecraft. Soyuz 22, a scientific solo mission, carried a prototype of the East German MKF–6 multispectral camera that is now a standard on the Salyut space station series.

The mission was commanded by Col. Valeriy Bykovskiy and Vladimir Aksenov served as flight engineer. The mission was primarily concerned with testing an East German multispectral camera (MKF–6) for Earth resources photography. It was the first time foreign-made equipment was flown on a Soviet spacecraft, perhaps explaining why it was done on a free-flying mission. Tests with the camera were very successful and a slightly modified model was flown on Salyut 6. The camera simultaneously took photographs in six bands (four visible, two infrared). Each picture covered an area 80×55 km. Resolution is thought to have been as good as 10 meters, but the Soviets have not released information on this aspect of the instrument. During the mission, ground and aerial photography was taken at the same time for comparison purposes. The flight engineer took the pictures while the commander oriented the ship. The experimental program was called "Raduga" (the Russian word for rainbow).

Other experiments conducted on Soyuz 22 included work using seeds and fish in the "Biokat" experiment. Many of the biological investigations had begun on ASTP, and the spacecraft itself was the backup for that mission. The docking mechanism was removed and the camera installed in its place.[16]

The Soviets wanted to fly over East Germany, since MKF-6 was an East German experiment, so the inclination of the orbit initially was 64.75 degrees, the only time such an inclination was used for Soyuz. After two firings on the fourth revolution, the spacecraft was in a 280×250 km orbit inclined at 65 degrees. Some observers noted that the timing of the mission also permitted the Soviets to study NATO maneuvers taking place in Sweden at that time.[17] The ship landed at 0742 GMT on September 23, 150 km northwest of Tselinograd.

Soyuz T and Related Development Flights

In December 1979, the Soviets introduced a new, improved version of the Soyuz spacecraft, designated Soyuz T.[18] At least three unmanned precursor flights (Kosmos 869, 1001, and 1074) had already been flown, and the first Soyuz T flight so identified was also unmanned. Two additional flights, Kosmos 670 and 772, may also have been related to the development of Soyuz T. These flights are summarized in table 7.

[16] Pravda, Sept. 16, 1976.

[17] Spaceflight, Feb. 1977, p. 62.

[18] The T stands for Troika to indicate that it is a third-generation spaceship. Soldat und Technik, No. 8, Aug. 1981, p. 453.

TABLE 7.—SOYUZ T MISSIONS

Flight	Launch Date	Launch Hour	Docked Date	Docked Hour	Undocked Date	Undocked Hour	Landed Date	Landed Hour	Apogee (km)	Perigee (km)	Inclination (degrees)	Period (min)	Revolutions
Kosmos 670	Aug 6, 1974	0014					Aug 9	0000	307	217	50 6	89.5	48
Kosmos 772	Sept. 29, 1975	0419					Oct 2	0448	320	201	51 8	89 4	48
Kosmos 869	Nov 29, 1976	1605					Dec. 17	0936	390	268	51.8	91.1	281
Kosmos 1001	Apr 4, 1978	1507					Apr 15	1200	315	308	51.6	90 7	174
Kosmos 1074	Jan 31, 1979	0907					Apr. 1	1200	383	364	51 7	92.0	944
Soyuz T 1	Dec 16, 1979	1230	Dec 19	1405	Mar. 23	2104	Mar 25	2147	382	370	51 6	91 6	1,595
Soyuz T 2	June 5, 1980	1419	June 6	1558	June 9	0920	June 9	1240	316	267	51.6	90.2	62
Soyuz T-3	Nov. 27, 1980	1418	Nov. 28	1554	Dec 10	0610	Dec 10	0926	260	255	51.6	89.6	204

NOTES

1 The hypothesis is that the Soyuz T program evolved over a period of years as more and more improved systems were introduced into the Soyuz design Most other Kosmos precursors of Soyuz can be linked to the main series of flights These were the obscure ones left over, but seem a best fit for this program

2 Hours for the Kosmos flights are the estimates of the Royal Aircraft Establishment, which are rounded to 14.4 minute increments. Hours for Soyuz T flights are as announced or estimated by the Kettering Group (G. E. Perry)

3 The orbital elements listed are the highest known to have been attained, as reported either by TASS or by the Royal Aircraft Establishment

4 The number of revolutions listed are as calculated by the Kettering Group (G. E. Perry)

5 The Soyuz T flights all docked with Salyut 6. Soyuz T 2 and T 3 carried a two-man and a three-man crew respectively

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KOSMOS 670

Kosmos 670 was launched on August 6, 1974, into a 307×217 km orbit, and was recovered three days later. It was unique in that its inclination was 50.6 degrees, never before used on a flight launched by an "A" class vehicle, and was, in fact, close to that which Western rumors had predicted would be used for the big "G" class vehicle. Otherwise, its external flight parameters seemed close to military recoverable observation flights. There was speculation that this might be a test of a ferry vehicle to a new large space station which would be orbited using the "G" vehicle at some future time. With hindsight, it has been classified here with the Soyuz T precursors.

KOSMOS 772

On September 29, 1975, the Soviets launched Kosmos 772 into a 320×201 km orbit, inclined at 51.8 degrees. Soyuz-type telemetry on 20.008 MHz was monitored in Kettering and Akrotiri, Cyprus. Like the Soyuz ferry ships, Kosmos 772 had no solar panels, but remained in orbit for 3 days like Kosmos 670, a day longer than most other missions of its kind, suggesting either greater battery capacity or lessened electrical loads. There was speculation that this might be a system test for returning to a three-person crew.

KOSMOS 869, 1001, AND 1074

On November 29, 1976, the Soviets launched Kosmos 869 into an orbit 307×202 km at an inclination of 51.8 degrees. The spacecraft made several orbital maneuvers during its 18 days in orbit, raising perigee to 299 km. Kosmos 1001 was launched on April 4, 1978 into an initial orbit of 249×205 km at 51.6 degrees inclination. This was later raised to 315×308 km. It was deorbited on April 15. Kosmos 1074 was launched on January 31, 1979 into a 258×203 km orbit inclined at 51.6 degrees. This was later raised to 383×364 km. The spacecraft remained in orbit for 60 days, reentering on April 1. All of these are now considered to have been related to development of Soyuz T.

SOYUZ T-1

Finally, at 1230 GMT on December 16, 1979, the Soviets launched Soyuz T-1 (see figure 26). This was an unmanned test of the new spacecraft and at 1405 GMT December 19, the craft docked with Salyut 6. Unlike previous dockings, the Soyuz T rendezvoused from above and in front of Salyut, rather than catching up with the station from behind,[19] and it docked at the forward docking hatch. Geoffrey Perry of the Kettering Group has determined that Soyuz T overshot Salyut on the second day (rev 32) and had to be maneuvered back for a rendezvous and docking on the third day (rev 50). This is the only time 3 days have been required for a rendezvous with a space station (a manned Soyuz normally takes 1 day while unmanned Soyuz and Progress missions take 2). At 2104 GMT on March 23, Soyuz T-1 undocked from Salyut 6. After 2 more days of

[19] Spaceflight, Nov-Dec 1980, p. 344

autonomous tests, the spacecraft landed on March 25 at night in Kazakhstan (2150 GMT).

• SOYUZ–T3

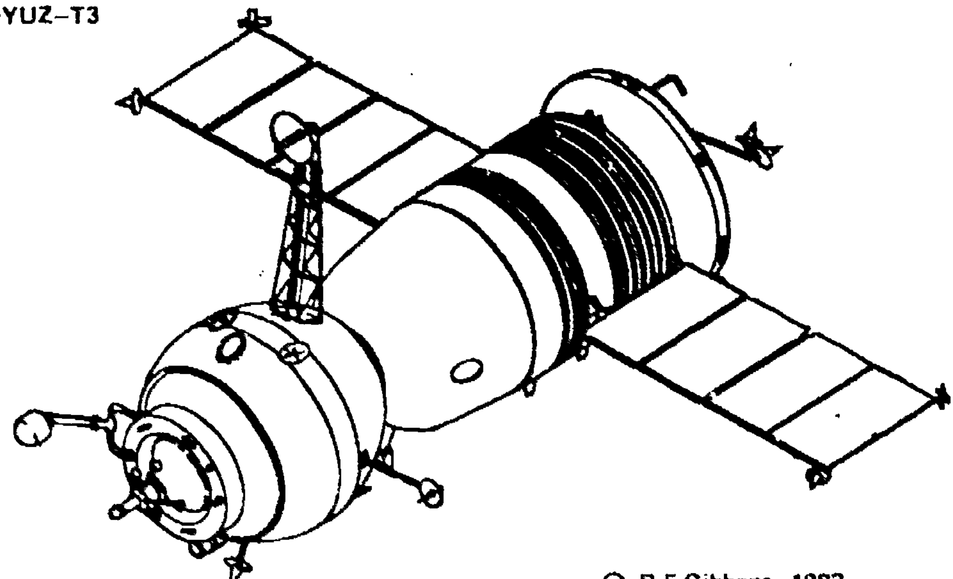


FIGURE 26. Soyuz T Ferry Craft. The Soyuz T variant of the Soyuz spacecraft series has been extensively redesigned internally to permit carrying up to a crew of three to the Salyut space stations.

Following this flight, more information became available about the new craft. Externally, Soyuz T is the same as the original Soyuz: 7.6 meters long, 3 meters in diameter, with a launch weight of 6.5 tonnes. A number of modifications have been made to the ship, however.

One significant change is the return to the use of solar panels. As noted earlier, the solar panels were removed beginning with Soyuz 12 on the theory that the ship would only have to remain in a free flying mode during the journey up to and down from a space station. Thus battery power would be sufficient, and the panels could be removed to allow a greater weight margin for payloads. After several docking failures (Soyuz 15, 23, 25), however, the Soviets apparently saw the need to give the Soyuz a longer lifetime on its own to deal with contingencies. In addition, once the spacecraft docks with Salyut, the two solar power systems are combined to provide additional power for space station operations.

The fuel system has been redesigned so that the main engine and all four attitude control thrusters can use the same fuel supply, meaning that the attitude thrusters can serve as a backup to the main engine in an emergency. Previously, a faulty manuever could exhaust the supply of fuel in the orientation system while the main engines had plenty,[20] and in the original Soyuz, the main engines used hydrazine, while the attitude control thrusters used hydrogen peroxide.[21] The new unified system, which is also used on Salyut

[20] Moscow World Service in English, 0700 GMT, June 6, 1980.
[21] Air & Cosmos, Jan. 26, 1980, pp. 46–47.

and Progress, also results in higher thrust and maneuvering capability. Two changes made in the descent/landing phase are: (1) the orbital module separates before retrofire instead of after as had been the case with Soyuz, thus saving 10 percent of the fuel since there is less mass to decelerate; and (2) the landing engines have more thrust to provide for a softer landing.

Among the changes in avionics is the introduction of a digital computer called the Autonomous Onboard Computing Complex which can fly the mission without human involvement. The computer has a CRT display unit, and analog sequence control devices previously used on Soyuz have been removed, while the number of indicator panels has tripled. A periscope is still used for the cosmonauts to orient themselves in space.[22] Soyuz T also has improved telemetry rates and channels for more reliable communications with the flight control center and tracking ships.

The rescue system mounted on the nose of the spacecraft has been improved, too, so that if a malfunction occurs during launch and initial flight, the launch vehicle main engines are automatically switched off, the spacecraft is separated from the booster, and the rescue rocket engines are ignited for a controlled emergency landing.

The interior has been redesigned to accommodate three spacesuited cosmonauts, and the first mission to carry three was Soyuz T-3, nearly 10 years after the ill-fated Soyuz 11 mission. The commander sits in the center, with the flight engineer to his left and the research engineer to his right.

For all its advances, the Soyuz-T still has some hurdles to overcome. On the first manned flight of the vehicle, Soyuz T-2, the cosmonauts had to abort the computer-controlled docking and take over manually starting at 180 meters from the station.[23] Soyuz T-3 was more successful.

THE FIRST GENERATION SPACE STATIONS—SALYUT 1-5

First Generation Design

The first generation of Soviet space stations spanned the years 1971 through 1976 and encompassed the successful launch of three stations, while two others were failures. The design of the station changed somewhat during this period, both externally in terms of the placement of the solar panels, and internally to allow for different experiments Each had a single docking port. (See figures 27-28.)

[22] Soldat und Technik. No. 8, Aug. 1981, op. cit.

[23] Aviation Week and Space Technology, Oct. 13, 1980, p. 18. In 1982, the Soyuz T-6 crew had an especially hard, and early, docking, because the computer failed, and on Soyuz T-8 in 1983, the mission had to be aborted because of a failure in rendezvousing with Salyut 7, due to the failure of the antenna mast to deploy

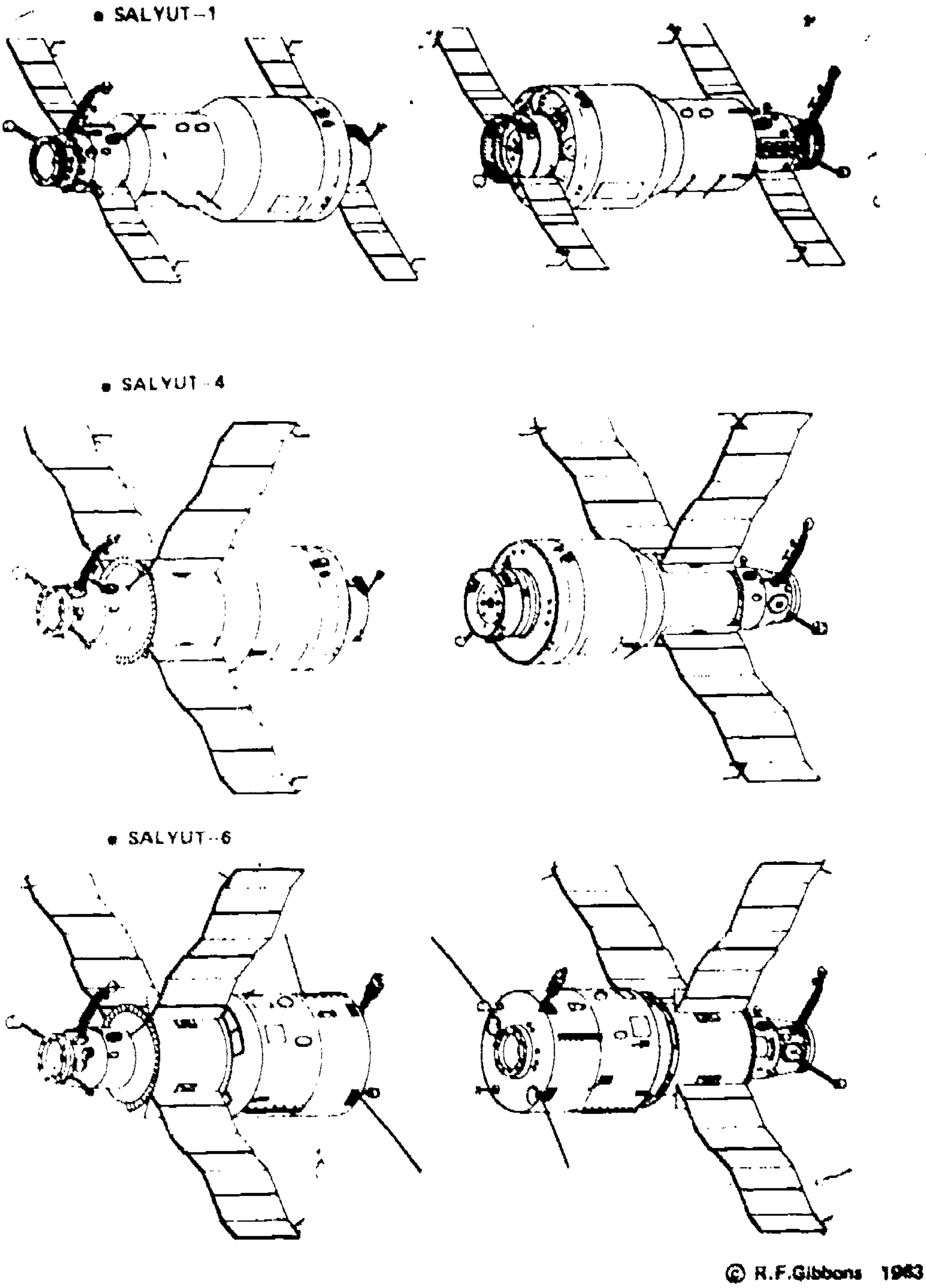


FIGURE 27.—Salyut Variants. Three variations of Salyut space stations have been flown since 1971. Salyut 1 carried 2 sets of solar panels fore and aft. By Salyut 4 they had been replaced by 3 panels mounted on the central cylinder. By Salyut 6, the small diameter aft propulsion module had been increased in diameter to match the maximum body diameter.

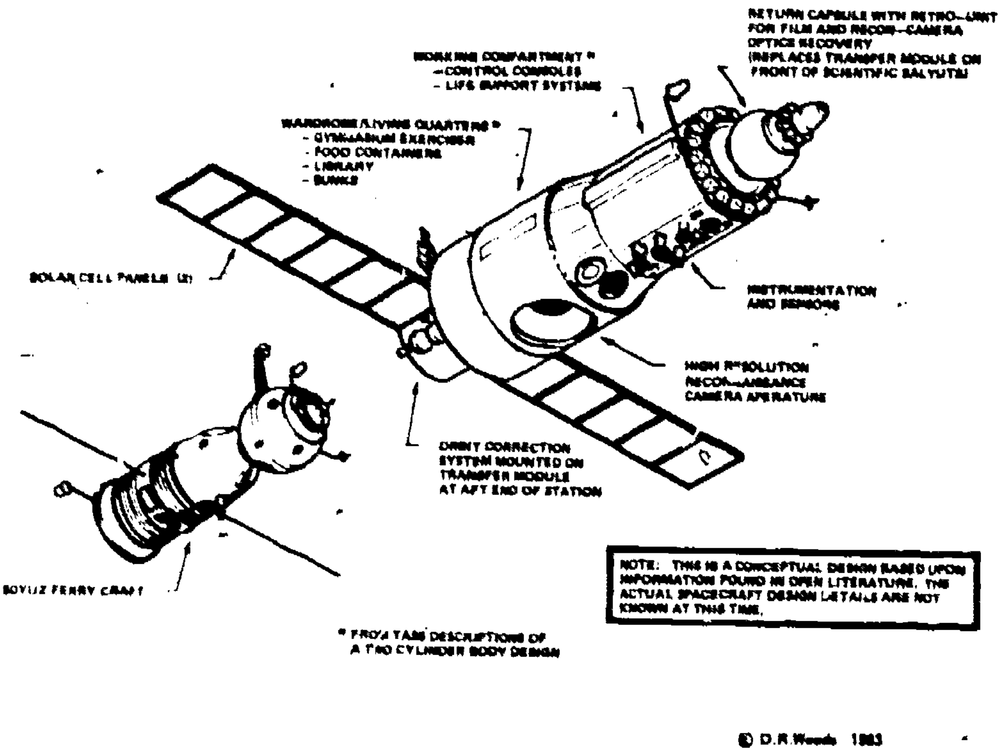


Figure 28.—Salyut Military Space Station Configuration Concept. Salyut 3 and 5 appear to have had military rather than scientific missions. Configuration details have not been released, but the Soviets have described them as having two, rather than three cylinders. Each released a return capsule after the last crew left. While the exact configuration is not known, they may have resembled this concept.

As each space station in this series was launched, more details became available about its design. In the case of space station dimensions, the information seemed contradictory since apparently in some cases external attachments such as radio antennas were included in the dimensions and in other cases they were not. It is assumed here that the basic station dimensions, including those of Soyuz ferry craft (which is 7.5 meters long) docked at one end, did not change and were length—21 meters (23 meters if antennas are included); maximum diameter—4.15 meters; interior volume—100 cubic meters; weight—25 metric tons. Without Soyuz, the stations weighed 18.6 to 18.9 metric tons, and were 13.5 meters long. The most significant change to Salyut externally was the change from four solar panels on Salyut 1, to three larger, individually rotatable solar panels on Salyut 3 and 4. Figure 27 shows these different configurations in comparison with the second-generation space station Salyut 6.

MILITARY VERSUS CIVIL STATION DISTINCTION

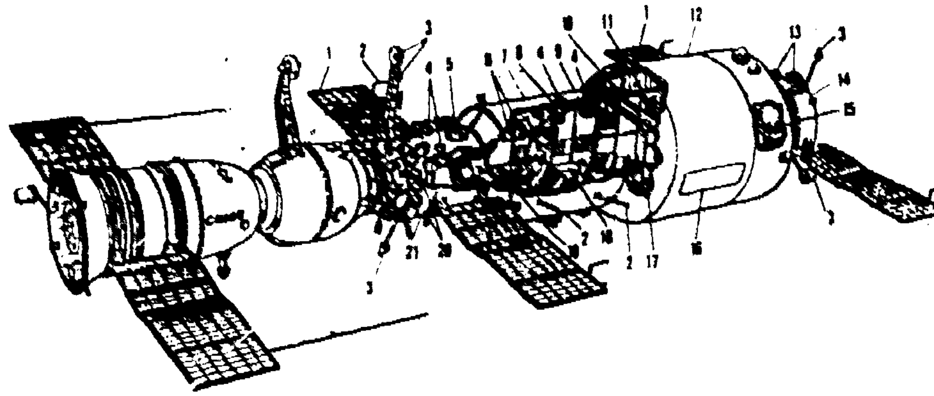
During this time, Western experts generally thought that the Soviets had two space station programs: one optimized for civilian space experiments, the other for military.

The distinction was drawn when Salyut 3 was lanuched in 1974. This station was placed in a lower orbit then Salyut 1, the crews sent to the station were all military, rather than mixed civil/military as had been the case on Salyut 1, and when the crew entered the station, they switched to military telemetery. When the next space station, Salyut 4, was launched it was placed in a Salyut 1-type orbit and the crew was again mixed military/civil, and remained on the civilian telemetry channels. Salyut 5 paralleled the Salyut 3 mission profile. In addition, both Salyut 3 and 5 ejected capsules after the departure of the crew which were recovered, as is the practice with military reconnaissance satellites. With hindsight, the conclusion was reached that had they been successful, Salyut 2 would have been the first military space station and Kosmos 557 would have been civilian, thus giving an alternating civil-military-civil-military pattern to launches.

The Soviets never admitted to such a dual program, insisting that all were for continuing the scientific exploration of space. Western observers, however, count Salyut 1, Kosmos 557, and Salyut 4 as civilian space stations, and Salyut 2, 3, and 5 as military stations performing a reconnaissance function.

SALYUT 1 DESIGN

On April 19, 1971, the Soviets launched the world's first space station, Salyut 1 (see figure 29). The station initially was described by the Soviets as 20 meters long with a maximum diameter of 4 meters, and weighing 25 metric tons with Soyuz attached.



1. Solar panels (2 pairs)
2. Telemetry antennae
3. Rendezvous antennae
4. Portholes
5. Orion stellar telescope
6. Atmospheric regenerat on equipment
7. Forward section of working compartment
8. Movie camera
9. Photographic camera
10. Apparatus for biological research
11. Food refrigeration unit
12. Aft section of working compartment
13. Attitude control engines
14. Propulsion compartment and main engine
15. Propellant tanks
16. Micrometeorite detector
17. Treadmill
18. Work table
19. Central control post
20. Compressed gas spheres
21. Docking/transfer compartment

FIGURE 29.—Salyut 1 Interior Details. Salyut 1 marked the beginning of the Soviet space station program. The body of the vehicle made up of four cylinders. The forward transfer module served as an airlock for crewmembers transferring from Soyuz to the station. The work module was made up of largest two cylinders. Finally, at the back was the propulsion module. Drawing reprinted with permission from Handbook of Soviet Manned Flight, Nicholas L. Johnson, vol. 48, Science and Technology, 1980, a publication of the American Astronautical Society.

The station had several compartments, which were subsequently designated the assembly, transfer and work areas. The transfer tunnel from the ferry craft to the station was 3 meters long and 2 meters in diameter. The main habitable portion of the station, or work compartment, was divided into three sections: A small cylinder 3.8 meters long and 2.9 meters in diameter; a large cylinder 4.1 meters long and 4.15 meters in diameter; and a cone connecting the two which was 1.2 meters long. The unpressurized assembly module completed the station and was 2.17 meters long and 2.2 meters in diameter.

Pictures of Salyut 1 showed eight chairs, seven at work stations, and 20 portholes, some unobstructed by instruments to give a good view of the Earth and outer space.

Externally, Salyut 1 had two double sets of stationary solar panels, placed at opposite ends, extending like wings from the smaller diameter compartments. Heat regulation system radiators, orientation and control devices, and some scientific instruments were also mounted externally.

SALYUT 3 DESIGN

After the Salyut 2 and Kosmos 557 failures discussed below, the Soviets finally succeeded in launching Salyut 3 on June 25, 1974. Salyut 3 is generally considered to have been the first operational military space station. The Soviets announced that Salyut 3 was 21 meters long with the same 100 cubic meter interior volume as Salyut 1. Changes to the station included miniaturized circuitry in the control loops; more efficient power and life support systems, including better thermal control; solar panels which were capable of rotating 180 degrees (unlike the stationary ones on Salyut 1) so the station itself did not have to constantly face the Sun, with three larger panels instead of the four on Salyut 1; and a general redesign of the interior. In addition, the docking port was located at the aft end of the station.[24]

The 4-meter diameter working compartment was described as being subdivided into control, working, and living sections, with a corridor to the left side of the ship, from front to back, connecting the various sections to each other. The floors and ceilings were painted different colors (dark for the floors, light for the ceiling) to make the cosmonauts feel more at home, and the floor was covered with a Velcro-type material to assist with walking.

The living quarters, in the front portion just forward of the control compartment, had four windows; a special sofa for medical experiments; one fixed position and one swinging bed (coming out from the bulkhead to conserve space); hot and cold water sources; a table for eating; storage space for clothes, linen, and entertainment gear (which included a tape recorder for music, a chess set, and a small library); and a shower and toilet.

SALYUT 4 DESIGN

Launched on December 26, 1974, Salyut 4 was announced as being 23 meters in length, with the same volume and weight as the other Salyuts. It is considered by Western experts as a civil space station (see figure 30).

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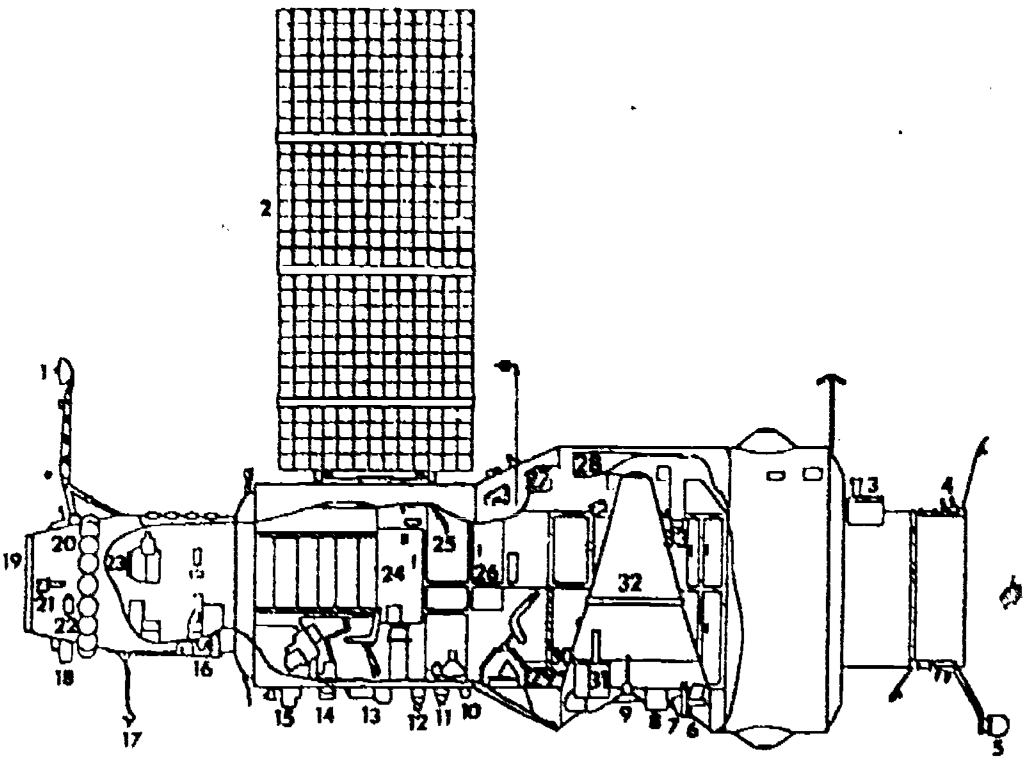
[24] Soviet Launches of More Military Salyuts Expected. Aviation Week and Space Technology, Dec. 4, 1978, p. 17. See also: Clark, Phillip S. The Design of Salyut Orbital Stations. Spaceflight, v. 23, Oct. 1981, p. 257-8.



1. Rendezvous antenna
2. Solar panel
3. Filin-2 X-ray spectrometric telescope
4. Attitude control jets
5. Rendezvous transponder
6. RT-4 X-ray telescope
7. KDS-3 diffraction spectrometer
8. KSS-2 solar spectrometer
9. Delta autonomous navigational orbital radioaltimeter
10. Prismatic laser reflector
11. Solar sensor
12. Infrared vertical sensor
13. Television star-direction finder
14. Optical orientor
15. Horizon sensor
16. Spektru apparatus
17. Radiator of the thermal control system
18. Television equipment
19. Soyuz docking port
20. Compressed gas spheres
21. Ion sensor
22. Neytral apparatus
23. Photographic camera
24. Water regeneration system
25. Velergometer (bicycle)
26. Medical and movie camera equipment
27. Silya-4 spectrometer
28. MMK-1 micrometeorite detector
29. Treadmill
30. Chibis medical device
31. ITS-K infrared spectrometric telescope
32. OST-1 orbital solar telescope
33. Freon experiment

FIGURE 30.—Salyut 4 Interior Details. The interior of the Salyut 4 space station was dominated by the OST-1 solar telescope, housed in the large cone structure in the large diameter cylinder of the body. Drawing reprinted with permission from Handbook of Soviet Manned Flight, Nicholas L. Johnson, vol. 48, Science and Technology, 1980, a publication of the American Astronautical Society.

Further information on the solar panels was released: They were individually rotatable, with a total area of 60 square meters producing 4 kilowatts of power. The panels turned automatically on signals from solar gauges indicating what position the Sun was in at any moment. A third bank of solar batteries was also added.

The Soviets also announced that the tation had a micrometeorite monitoring system (MMMS) with 4 square meters of panels serving as sensors. Further details of the thermal control system were also described. The Salyut walls were made of "screen-vacuum" heat insulation which precluded heat exchange between the station and space, and were made of many layers of snythetic film sprayed with aluminum. To heat the station, an intricate system of radiators was used which both collected solar heat and radiated surplus thermal energy. Three or more backup systems were available.

The interior of the station was described in much greater detail. The unpressurized assembly area was said to contain the fuel tanks and orbital and orientation engines. The transfer area contained two of the seven work stations (for navigation and scientific observations) plus the "Raketa" vacuum cleaner and a long sleeve of rubberized fabric which extended into the ferry craft to provide fresh air. The work compartment was described as consisting of two cylinders connected by a conical bridge. The smaller one was 2.9 meters in diameter and 3.8 meters long with the solar panels attached to the outside. The large cylinder was 4.15 meters in diameter and 4.1 meters long with a cone-like structure containing scientific instruments and equipment (for example, a telescope). To the left and right of the cone were refrigerators for storage. The conical bridge was 1.2 meters long. Walls were painted in soft greens, yellows, and blues.

The Soviets gave the following walkthrough description of Salyut 4 from front (near the transfer tunnel) to back.

The main control panel (housing navigation instruments, clocks, radio communications monitors and controls, the Globus navigational indicator, and two keyboard command signalling devices) faced the transfer tunnel. To the left of the main panel were the life support controls with regeneration cylinders for purifying the air on both sides of the panel. On the right was a scientific work station, and a medical research work station was located in the conical bridge section.

Behind the main command post, in the center, was the eating table, with direct feeds for hot and cold water. To the left, looking from the transfer tunnel, and behind the panels was a small cupboard for plates and other utensils. Beyond the table on the side panels were grids covering the cooling-drying assembly, with fans to circulate the air.

Farther back was the medical area with a swivel chair for vestibular studies, and a closet for medical instruments. At the right was the exercise equipment and above that, a shelf for the tape recorder. At the end of the cylinder was the sanitary-hygiene area, which was separated from the rest of the room and had forced ventilation. There was no shower on this station.

SALYUT 5 DESIGN

Launched on June 22, 1976, Salyut 5 is considered a military Salyut and of similar design to Salyut 3, i.e., the docking port was at the rear. The Soviets released a few more details about the space station. For example, on this station, the entire instrument compartment was covered with blue fabric with a soft interlayer to protect the sharp corners of the instruments. According to the Soviets, this change was made on the recommendation of the crews that had occupied previous stations.

Otherwise, the station was essentially the same as previous stations, although the cosmonauts did test a new attitude control device. The Soviets also announced that there was an onboard computer to direct the operation of instruments without human interaction.

Salyut 1 With Soyuz 10 and 11

Salyut 1 was launched on April 19, 1971 and deorbited on October 11, 1971. Two crews docked with the space station, although the first (Soyuz 10) was not able to enter the station possibly because of a hatch malfunction. The second crew (Soyuz 11) spent 3 weeks on the station (setting a new duration record), but died after separation of the Soyuz modules during reentry.

Soyuz 10: So Near and Yet So Far

On April 22, 1971 at 2354 GMT, Soyuz 10 was launched carrying the crew of Col. Vladimir Shatalov, flight engineer Aleksey Yeliseyev, and Nikolay Rukavishnikov, described as being responsible for operation of Salyut systems.

To accomplish rendezvous, the Salyut was maneuvered four times, while Soyuz made three major maneuvers. After 24 hours, the two spacecraft docked, with manual control being exercised by Shatalov once they were 180 meters apart. The crew said they were not able to see the space station until it was only 15 km away. The docking apparently was somewhat nerve-wracking, with Shatalov steering while his colleagues monitored various instruments on system status. The Soviets announced that new telemetry, and rendezvous and docking equipment was used for this mission.

After 5.5 hours, the ships undocked, without the crew ever entering the station. The Soyuz then flew around the station to take pictures (none of which have been published in the West) and returned to Earth. The flight lasted just under 2 days, and for the first time, a predawn landing was made (other missions had been recovered during the day).

The early recovery of Soyuz 10, and the failure of the crew to enter the space station, suggested that the mission had not met all its objectives although the Soviets said only that the flight had been scheduled very tightly for the research and testing tasks which were successfully accomplished.

There were several possible signs of trouble. First, the fact that the crew failed to enter the station once they had docked, especially since Rukavishnikov was a specialist in Salyut systems. Either the hatches or air locks were not functioning properly, or there was some threat of trouble which might have required a quick disconnect and return to Earth. Second, the crew returned to Earth at the very first opportunity to do so and still return in the usual recovery area, even though it meant landing in the dark. This suggested either trouble in Soyuz 10, or such dependence on Salyut systems that when these were unavailable, there was no point in

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prolonging the mission. Third, if all previous Soyuz flights are plotted on a graph to compare hour of launch with number of days in flight until recovery, a very linear relationship is found. On the basis of this type of estimate, the predawn launch of Soyuz 10 suggested a 30-day flight, but it only remained in orbit for 2 days.

While it is reasonable to accept the Soviet statement that the mission achieved the objectives associated with the new telemetry, docking, and control systems, it seems likely that the total mission fell short of its engineering capabilities and Soviet hopes.

SOYUZ 11: A SECOND SPACE TRAGEDY FOR THE SOVIETS

The Soyuz 11 crew was launched on June 6, 1971 at 0455 GMT and consisted of Lt. Col. Georgiy Dobrovolskiy, flight engineer Vladislav Volkov, and Salyut test engineer Viktor Patsayev.

The crew successfully docked with Salyut 1 on June 7 at 0745 GMT. Patsayev entered the station first, followed by Volkov and Dobrovolskiy.

The cosmonauts conducted various experiments (see below) during their 24 days on the space station, and on June 29, prepared for return to Earth, loading scientific specimens, film, tapes, and other gear aboard Soyuz 11. The ships undocked at 1828 GMT and retrofire occurred at 2234 GMT. The normal routine of detaching the work compartment and service module was accomplished, and using its automatic systems, the ship oriented itself and steered to the intended recovery area.

Radio communication with the crew came to an abrupt end at the moment of separating the work compartment, probably at 2247 GMT, even before the normal ionospheric blackout period. The drogue and main parachute systems functioned nominally, and a landing was made at about 2317 GMT on June 29.

Upon reaching the capsule, the recovery team was horrified to discover the three cosmonauts dead on their couches. Although the Soviets did not release information concerning the cause of death for quite some time, in 1973 U.S. negotiators for the Apollo-Soyuz Test Project pressured them into releasing the first detailed explanation.

Soyuz is equipped with two valves that open for spacecraft descent venting, the first at about 5,300 meters, the second at about 4,350 meters. One of the valves failed as the work module separated from the descent module. It appears that venting took about 40 to 50 seconds to reach the point where the ship's atmosphere could no longer support life. The crew would have become aware of the leak both because they could hear the pressure leak, and the discharge of air would have resulted in a spacecraft attitude change, causing an automatic thruster to fire. The crew tried to close the leak with a crank, but were unable to do so before losing consciousness, and subsequently died of pulmonary embolisms. The Soviets had done away with the practice of wearing spacesuits during launch and reentry by this time, primarily because the Soyuz could not accommodate three space-suited cosmonauts, and suits were no longer considered necessary.

SALYUT 1 EXPERIMENTS

Once the Soyuz 11 cosmonauts were safely aboard the space station, the Soviets announced that the objectives of the mission were as follows: Checking and testing the space station's design, units, onboard systems, and equipment; trying out the methods and autonomous means of the station's orientation and navigation; studying geological-geographical objects on the Earth's surface, atmospheric formations, the snow and ice cover of the Earth with the aim of developing methods of using these data in the solution of economic tasks; studying physical characteristics, processes, and phenomena in the atmosphere and outer space in various spectral bands; and conducting medical-biological studies to determine the possibilities of performing various jobs in the station and to study the influence of space flight factors on the human organism.

Health monitoring and exercises for the crew continued throughout the mission. Other biological specimens and a hydroponic farm for growing plants were carried and used in experiments. Work related to Earth resources and weather monitoring was extensive, the detailed astronomical observations began midway through the mission, and the ship's systems and instrumentations were tested extensively. The crew also made fairly regular television broadcasts to Earth.

On June 17, a change in the reports on the crew occurred. No reports were made of scientific work or television transmissions, and only "minor correction work" was mentioned, with the comment that the ship was equipped with tools, spare parts, and safety devices. At first, some Western observers concluded that a problem had been encountered, but the mission continued for 2 more weeks with a resumption in scientific experiments and TV transmissions, so either the problem was corrected or it was simply a day of rest for the crew as announced by the Soviets.

SALYUT 2 AND KOSMOS 557: SPACE STATION FAILURES

As detailed in the previous section of this chapter, following the Soyuz 11 tragedy the Soviets launched two manned free flyers, Soyuz 12 and 13. Two space stations, Salyut 2 and Kosmos 557, were launched in 1973, and both failed.

SALYUT 2

On April 3, 1973, Salyut 2 was launched into a 260×215 km orbit, with a period of 89 minutes and an inclination of 51.6 degrees. The next day, Cosmonaut Yevgeniy Khrunov announced that cosmonauts were engaged in preparations for new flights, supposedly to link up with Salyut, and on April 6 Victor Louis of the London Evening News reported that a Soyuz spacecraft was ready for launch. Thus when no launch followed Salyut 2, there was speculation that the Soyuz launch had failed. On two occasions the space station was in a position for rendezvous, but no launch occurred. When, on April 8, Salyut 2's orbit was raised to 268×248 km, above an appropriate rendezvous orbit, experts concluded that whatever had delayed the Soyuz launch was more serious than originally thought. Some suggested that solar flare activity on

April 4 and 5 prevented the launch rather than equipment failure, but when April 11 came and there was still no launch, general opinion was that either Salyut or Soyuz was having major difficulty.

Spaceflight magazine reported that Salyut 2's initial orbit was higher and more elliptical than Salyut 1's, possibly due to poor performance of the D–1 booster. Numerous fragments detected in the orbital path suggested the D–1 had exploded, although in retrospect it seems likely these early pieces of debris were no more than the routine releasing of equipment and window covers.

The real trouble came on April 14 when Salyut was reported to have undergone a "catastrophic malfunction" which ripped off the solar panels and boom-mounted rendezvous radar and radio transponder, leaving the vehicle tumbling in space without telemetry return. The craft may have separated into many pieces, some large enough to be tracked, but most were rather small and decayed quickly. Either an explosion or a misfiring thruster was blamed, although the most widely held theory was that the D–1 upper stage had exploded with its debris damaging the space station.

On April 28, Tass reported that Salyut "had concluded the programme of flight," and although the official statement said it had completed its mission, the word "successfully" (used in the most nominally successful flights) was omitted. This suggests that the Russians wrote the mission off as a failure. The main body of the station decayed through airdrag on May 28, 1973, and reentered near Australia.

Noting that the telemetry transmissions from Salyut 2 were similar to those used by Soviet reconnaissance satellites, *Aviation Week and Space Technology* concluded that the mission was not a Salyut at all, but that the Russians were simply trying to mislead the Soviet press and information agencies. The manned Salyut 3 a year later, however, used the same telemetry and suggests that Salyut 2 was the first of the military Salyuts.

KOSMOS 557

On May 11, 1973, shortly after the failure of Salyut 2, the Russians launched Kosmos 557 into a 226×218 orbit inclined at 51.6 degrees and with a period of 89.1 minutes. Speculation abounded as to its purpose, since virtually no information was reported in the Soviet press. Its telemetry resembled Salyut 1, typical of the manned programs, rather than Salyut 2, typical of the unmanned military reconnaissance program.[25] (It was not until a year later that the discovery was made that these military frequencies could be used for a manned station dedicated to military uses.)

Western experts thought there was a good chance that this was another Salyut, possibly of a different design, that failed so early in its mission that it was listed as a Kosmos. Tracking ships deployed for the expected manned flights to Salyut 2 were reported heading back for their home ports "before Kosmos 557 decayed"[26] during

[25] Kettering Group. Spaceflight, v. 16, Jan. 1974, p. 39–40.
[26] Kosmos 557 Decay. Aviation Week and Space Technology, May 28, 1973, p. 25.

the week of May 21. Whether they realized early on that no manned missions would be sent up, or whether there was no intention of sending men to it is unclear. However, no unmanned tests of Salyut stations had been conducted previously, if for no other reason than cost, so if one assumes Kosmos 557 was a Salyut, one can conclude that manned flights to it were planned, but that the station failed.

Other theories did prevail about the nature of Kosmos 557, though. Thomas O'Toole of the *Washington Post* reported it as an unmanned Soyuz sent to investigate and photograph the damaged Salyut 2, stating that its orbit was "almost identical to the Salyut orbit."[27] *Aviation Week and Space Technology*, while agreeing that it was an unmanned Soyuz, said that the two craft were too far apart for it to be an inspection mission, that there was "no way of Kosmos 557 approaching Salyut 2 without major orbital change."[28] (The difference in interpretations can probably be explained by noting that the NORAD data cited by both sources did give similar orbital elements (apogee, perigee, inclination, and period) for the two craft, but took no account of the fact that they were in widely separated orbital planes.

With the passage of time and the experience with 1974 Salyut flights, it is now reasonably safe to conclude Salyut 2 and Kosmos 557 were parts of parallel but different space station programs, one military and one civilian.

Salyut 3 With Soyuz 14 and 15

Salyut 3 was launched on June 24, 1974, and deorbited on January 24, 1975. Two crews were launched to dock with the space station. The Soyuz 14 crew spent 2 weeks on board, but the second crew (Soyuz 15) was not able to dock. As noted previously, this is considered the first operational military space station, and a capsule was ejected from the station and recovered on September 23, 1974.

SOYUZ 14: 16 DAY MISSION

Soyuz 14 was launched on July 3, 1974 at 1851 GMT. The mission was commanded by Col. Pavel Popovich, while Lt. Col. Yuriy Artyukhin served as flight engineer. The ship soft-docked with Salyut 3 on July 4 at 2100 GMT, followed by hard docking and pressure verification. The crew entered the station at 0130 GMT on July 5.

Soyuz 14 was the first operational use of the reconfigured Soyuz for serving as a space station ferry craft, that is, without solar panels. Soyuz 12 had tested the modifications, but had not docked with a space station. In theory, since the Soyuz was only meant to ferry crews to a space station, battery power would be sufficient. By removing the solar panels, the ship was lighter and more maneuverable, allowing more payload weight. Two interesting aspects of Soyuz 14 were that the Soviets announced that Soyuz had a water recovery capability, and it was the first mission to be in con-

[27] O'Toole, Thomas. Craft Sent To Inspect Crippled Salyut. Washington Post, May 15, 1973, p. A16.
[28] Soviets Try To Salvage Salyut Mission with Unmanned Vehicle. Aviation Week and Space Technology, May 21, 1973, p. 16.

tinuous communication on all channels (voice and telemetry) with the flight control center near Moscow. Western observers doubted the latter claim, however, since during several communications sessions the crew was heard to use the call sign for the *Gagarin* or *Komarov* tracking ships rather than that of the flight control center, and at one point Popovich said he would relay greetings from the *Komarov* to Moscow.

The crew worked aboard the station for 16 days, establishing a pattern of 8 hours of work, 8 hours of sleep, and 8 hours of exercising, rest, cleaning and making log entries. Soyuz 14 undocked from Salyut 3 at 0903 GMT on July 19, and landed at 1221 GMT.

SOYUZ 15: FAILED DOCKING ATTEMPT

Launched on August 26, 1974, at 1958 GMT, Soyuz 15 was reportedly a continuation of the scientific research and experiments started by Soyuz 14. Its initial orbit was 230×180 km.

Altering the orbit to 275×254 km with a period of 89.6 minutes and an inclination of 51.6 degrees on the second day of flight, the mission almost immediately ran into trouble when attempts to dock with Salyut 3 were unsuccessful. The pilots Lt. Col. Gennadiy Sarafanov and Eng. Col. Lev Demin, made repeated approaches to the space station, but each time the ship came within 30 to 50 meters of its target, the automatic reaction control system aboard Soyuz made excessively long burns, causing it to close too fast. The first public report of the trouble was made by the Kettering Group after visual observations showed that the two craft were still separate after the time they should have docked, and monitoring of the telemetry which confirmed that no docking had occurred.

Since the ferry version of Soyuz does not have solar panels for energy but only chemical batteries, its life in space is limited to about 2.5 days. Thus Soyuz 15 was forced to land at night on August 28. The tracking ship *Morzhovets*, stationed in the Atlantic near St. Helena Island, reported the correct firing of the retrorockets and at 2010 GMT the cosmonauts landed 48 km southwest of Tselinograd in adverse weather conditions. Despite the emergency nature of the landing, rescue teams located the ship quickly and 17 minutes after touchdown reached the crew.

The official Russian version, according to General Shatalov, was that the mission of Soyuz 15 was to test the automatic docking system aboard Soyuz for future tanker spacecraft missions to space stations. Thus, when the automatic docking system failed there was no attempt to dock manually, although the cosmonauts could have done so. Usually Soyuz closes to within 100 meters of the space station and then manual control is activated. Shatalov stated that even if docking had been accomplished, the cosmonauts would then have undocked and repeated the exercise for practice, rather than enter the space station for an extended visit.

Western observers are skeptical of Shatalov's explanation if for no other reason than that to send a ship into space simply to practice docking techniques when an extended stay is possible is an extremely wasteful exercise. Also, the mission was announced as a continuation of Soyuz 14's work, and indeed both crewmembers were once again members of the military. So the Russian version that Soyuz 15 was only a docking exercise, and that the repeated approaches to Salyut were meant only to gain further information on the malfunction in the reaction control system, are viewed with a great deal of doubt.

SALYUT 3 EXPERIMENTS

Medical

With the Polinom-2M equipment, the cosmonauts studied blood circulation to the brain and blood velocity in the arteries before and after physical activity. They also took samples of exhaled air for study on Earth to determine the level of energy expenditures at rest and while active. For physical conditioning, a universal trainer was provided to mimic walking, running, high and long jumping, and weightlifting. These exercises were performed every morning and evening. The trainer consisted of a running track or treadmill and a special suit with elastic pulls attached to the belt. The other end of these pulls was attached to the track so that the crewmember was pulled onto the apparatus with a force equal to 60 percent of his body weight. This force was transmitted not only to the waist and legs, but to the shoulders as well, an improvement over the Skylab bicycle according to Russian medical experts, since all muscles were thus exercised.

Other biological

A microbiological cultivator was on board and the crew daily sowed bacterial cultures into a growth medium to show the development of bacteria in space.

Earth resources

Listed as one of the prime projects on this flight, the cosmonauts spent a great deal of time photographing the Earth's surface and atmosphere. This was described as Earth resources work (of a civilian nature) but the station's characteristics equally or better fitted military reconnaissance work.

The areas mentioned by the Russians as being photographed by the team were: Soviet central Asia, the Pamirs, the eastern coast of the Caspian Sea, the Caucausus, the Ustyurt Plateau, and the Atlantic Ocean where research into global atmospheric processes was being carried out in connection with the international Tropex-74 program (this area was simultaneously photographed by the Meteor satellite). *Aviation Week and Space Technology* reported that objects were placed outside the Tyuratam launch facility during passes by the space station to test the reconnaissance potential of the station.

Atmospheric

The crew made observations of the polarization of solar light reflected by the Earth and its atmosphere during the night, twilight and day horizons for studying the dynamics of the development of optical phenomena. There also was a spectral investigation of the atmosphere with an RSS-2 spectrograph to measure the global distribution of gas aerosol components and other atmospheric pollution.

Navigation

For autonomous navigation, there were measurements of the angular position of celestial bodies relative to atmospheric dust layers and the horizon. An improved Vzor of the type carried on Vostok and Voskhod was used for determining methods of orienting the ship in transitional lighting conditions (going in and out of the Earth's shadow), and orbital orientation when the Sun is low above the horizon and Earth is incompletely illuminated. If one marks the real horizon with a line marked on the instrument and the Sun is in a definite position on the screen, the ship will be oriented correctly.

System checks

Another major duty of this mission was the checking of ship's systems. The cosmonauts were assisted in evaluating the exterior of the station by an optical instrument hinged to the outside which could relay images to them and to Earth via a television system. They also checked life support systems, including the parameters of Salyut 3's atmosphere and the water regeneration block, thermoregulation systems, and radio communication.

Television

There were several television transmissions, one of the most interesting of which showed effects of vibration on various pendulum instruments. Since some high-precision instruments are affected by these vibrations, yielding incorrect readings, engineers were quite interested in this demonstration.

SALYUT 4 WITH SOYUZ 17, THE APRIL 5 ANOMALY, SOYUZ 18, AND SOYUZ 20

Salyut 4 was launched on December 26, 1974 and was deorbited on February 2, 1977, completing a total of 12,188 orbits of the Earth. This space station continued the civilian studies began on Salyut 1, and hosted two crews (Soyuz 17 and 18) for 30 and 63 days respectively, bringing the Soviets closer to the American record of 84 days on the 1973-74 Skylab 4 flight. Another mission was launched to dock with the station, but had to be aborted because of a launch vehicle malfunction and is listed as the April 5 Anomaly since it occurred on April 5, 1975. Soyuz 20, an unmanned spacecraft, also docked with the space station for tests.

SOYUZ 17: 30-DAY MISSION

The launch of Soyuz 17 came at 2153 GMT on January 10, 1975. The crew, Lt. Col. Aleksey Gubarev and flight engineer Georgiy Grechko, docked with Salyut 4 on January 12 at 0125 GMT. During their 30 days on the station, the cosmonauts conducted a wide variety of scientific experiments, following a pattern of 6 days of work and 1 day of rest. They typically ate four small meals each day, with ½ hour of exercise before breakfast, 1 hour between breakfast and lunch, and 1 hour between lunch and dinner. No shower was provided, so they washed themselves with gauze napkins moistened with lotion. During the flight, Gubarev lost 2.5 kg of body weight, while Grechko lost 4.5 kg. The latter was attributed to the fact that Grechko did extra work at the expense of sleep.

At 0608 GMT on February 9, Soyuz 17 undocked from the space station and landed at 1103 GMT. The landing took place in a blinding snowstorm, with wind velocities up to 20 meters per second, a visibility of 500 meters, and a ceiling of 250 meters. Despite the adverse weather, rescue teams were on the scene immediately, and within 10 minutes the cosmonauts were on board a helicopter.

THE APRIL 5 ANOMALY: ABORTED MISSION

The next mission launched to dock with Salyut 4 resulted in the first abort of a manned mission during launch.

On April 5, 1975, at about 1103 GMT, the Russians launched a spacecraft with the announced purpose of docking with Salyut 4 and continuing scientific experiments. A stage separation malfunction of the A-2 booster forced the mission to be aborted, however, and the crew, Col. Vasiliy Lazarev and Oleg Makarov, found themselves landing in cold, snowy Siberia southwest of the town of Gorno-Altaisk, 1,600 kilometers away from the launch site and only 320 kilometers north of the Chinese border. After the failure, the mission was renamed the "April 5th Anomaly" and the Soyuz 18 designation it would have received was given to the next craft in the series.

Tass did not announce the shot until 2 days later, presumably to give the crew time to be rescued and their health assessed. It is suspected that they spent the night at the landing site before recovery teams could meet them. They reportedly exited the spacecraft shortly after landing and built a fire.

The primary significance of this failure was its relationship to ASTP, scheduled to be launched only 3 months later. Konstantin Bushuyev, Soviet program director for ASTP, assured his American counterpart, Glynn Lunney, that the launch vehicle used in this instance was an old version of the one used in July, and that none of the systems in common were suspect in the malfunction. This raised a lot of eyebrows in the West for several reasons. First, there had been no suspicion that the A-2 vehicle had two versions, although experts were aware of differences in the Soyuz craft itself. Second, since the Soyuz's docking target, Salyut 4, was in a substantially higher orbit than that to be used for ASTP, it seemed unlikely that a less capable launch vehicle would be used. Third, the A-2 is used for unmanned as well as manned missions. Why the Russians would use the older version on a manned flight rather than using them up on unmanned missions is unclear.

NASA did not appear overly concerned with the failure, however. The Russians were preparing two complete sets of hardware for ASTP, so if one failed another would be ready on the pad. Also, a failure before reaching orbit would not affect the safety of the American crew.

Senator Proxmire, chairman of the Senate subcommittee dealing with NASA's appropriations, did not concur however, and called for a CIA briefin on the capabilities and safety of the Russian space program. Co .ments on this classified briefing are given in the section on ASTP.

SOYUZ 18: 63-DAY MISSION

On May 24, 1975, 6 weeks after the failure of the Soyuz flight, the Soviets launched Soyuz 18 at 1458 GMT. The mission was commanded by Col. Petr Klimuk accompanied by flight engineer Vitaliy Sevastyanov, and they docked with the space station on May 25.

During this 63-day mission, the joint ASTP mission took place and two communications sessions ensued between the crews of Soyuz 18 and Soyuz 19. The crew landed on July 26 at 1418 GMT after setting a new Soviet space endurance record, although it did not surpass the American record of 84 days.

SOYUZ 20: UNMANNED TEST FLIGHT

After the end of the Soyuz 18 mission, Salyut 4 remained in orbit, prompting speculation that a third crew might be sent to work on the station. This would have been a new accomplishment, since the lifetimes of Salyut 1 and 3 had been too limited for this, and each had actually hosted only one crew.

On November 17, 1975, the Soviets did indeed launch another Soyuz to Salyut 4, but it was unmanned. During the Soyuz 15 mission, the Soviets had indicated that they were developing a tanker spacecraft to refuel space stations in orbit, so preliminary speculation centered around the possibility that Soyuz 20 was the first such mission. There were many doubts, however, since there was no indication that Salyut was equipped with a docking port on the service module end, an assumed necessity for fuel transfer (as confirmed with the Progress/Salyut 6 flights).

On a post-ASTP mission to Houston, Soviet ASTP technical director Konstantin Bushuyev announced that Soyuz 20 was definitely not a refueling mission, and said that it would conduct rendezvous and docking tests and check out modifications to the Soyuz for that purpose. A few days later, on December 4, the Soviets announced that Soyuz 20 was carrying out parallel biological studies with Kosmos 782, and that it carried turtles, drosophila, cacti, gladioli bulbs, vegetable seeds, corn, and legumes. Soyuz 20 and Kosmos 782 had different microclimates for the specimens aboard, so comparison studies could be made. Kosmos 782 and the biological aspects of the Soyuz 20 mission are further discussed in the next chapter.

On February 15, the Soviets tested the Soyuz propulsion system, and the ship undocked from Salyut 4 the next day after 90 days, 11 hours, and 48 minutes of flight. The Soviets announced that important results had been obtained for perfecting and testing the design and onboard systems of both spacecraft. The length of the flight suggested that Soyuz 20's main objective had been a test of the spacecraft in a powered down condition to determine whether the systems could be successfully reactivated after that period of time. Thus, speculation centered on the prospect for even longer Soviet manned space station missions.

SALYUT 4 EXPERIMENTS

The Soyuz 17 and 18 crews carried out a wide variety of scientific experiments. They are discussed here by general categories.

Medical

The Polinom-2M apparatus was used to measure and predict the functioning of the cardiovascular system, tone of the blood vessels, venous circulation, and circulation of blood to the brain. The crew also checked the effects of decompression on the lower part of the body with a special (Chibis) decompression suit that was worn not only during exercises, but also for hours at a time while the cosmonauts performed routine daily tasks. Samples of blood and exhaled air were taken for analysis on Earth, as well as microbes from various parts of the ship. Vestibular reaction was checked by use of a swivel chair, and used a "Plotnust" device for ultrasonic measuring of changes in the composition of bone tissue. There also was an electric muscle stimulator, Tonus, which could send pulses to any specific set of muscles to exercise them.

Exercise equipment included the treadmill used on other flights (which was 90 cm long and 40 cm wide), and a new addition, a bicycle. This was described as a comfortable chair with pedals, turned alternately by the feet and hands, connected to a generator which stored the electricity that was produced. They followed a regime of 3 days of regulated exercises, and then 1 day where they could choose whatever they liked.

Although the Soviets reported that the Soyuz 18 crew required a "normal" amount of time for adaptation to weightlessness, they noted that this period was 10 days, somewhat longer than previous crews needed. In a new medical experiment, experts decided to adopt 10 days as an adaptation period in reverse, that is, use the 10 days before the end of the mission to begin preparing the cosmonauts for Earth conditions. Remarking that the Soyuz 17 crew found physical exercise inadequate, physicians place Klimuk and Sevastyanov on a high salt diet and encouraged them to drink a lot of water to increase body fluids. Although both reported feelings of dizziness such as those they had experienced during initial adaptation, after landing on Earth doctors reported the experiment was successful.[29]

Other biological

Experiments continued with microorganisms and higher plants, as well as with certain biological species. An experiment called "Oazis" involved growing leguminous plants, specifically peas, which sprouted in 3 weeks. The relationship between this "Oazis" and the Oazis-1 and -2 on earlier flights is unclear. Fruit fliles (Drosophila) and the embryos of frogs that developed in space were observed to check their biological development in a weightless environment.

Earth resources

The Soyuz 17 crew performed only a small amount of Earth photography covering the following areas: The Kurile Islands, the Caspian depression, Central Asia, the southern European portion of the Soviet Union, the Far East and Kazakhstan.

[29] Tass, Moscow, July 29, 1975, 0600 GMT. In a subsequent report (Tass, Sept. 18, 1975) the Russians make no reference to this report, and said that the cosmonauts needed only 4 days for adaptation.

A great deal of attention was given to Earth photography by Soyuz 18, so they could compare photographs of areas in winter with those taken in summer. Covered in this mission were: The European part of the Soviet Union, the Transcaucasus, northern Kazakhstan, republics of Soviet Central Asia, Primorye territory, Kurile Islands, Rostov and Volgograd regions, the Ukraine, Turkmenia, the Pamirs, Sakhalin Island, the eastern part of the Baykal-Amur railway, the Orenbert region, the Volga, maritime areas, mountains, sea currents, and shelves and deposits on beds of rivers at their mouths. All in all, over 8.5 million square kilometers were photographed.

Data from these observations led to the discovery of 25 faults and ring structures which might contain mineral deposits.[30]

Atmospheric

The "Emissiya" system was used to study the red line of atomic oxygen in the atmosphere at a height of 250 to 270 km. Spectrographs in the rear part of the space station scanned the Earth's horizon in areas where the electron system was active. These studies were used both for meteorology and for determining flight dynamics for satellites.

Experiments that had been conducted on previous flights into the nature of the space immediately surrounding Salyut were continued and given the name "Spektr". They involved investigations of the physical properties of the cosmic environment, specifically interaction between space vehicles and space. An analyzer on board the station oriented in the direction of flight measured the density, composition and temperature of particles striking the hull of the ship to see how they affected orbital decay.

Earth radiation

The Earth's radiation was studied with an infrared telescope/spectrometer (ITS-K). The telescope had a 300 mm diameter mirror, and the slit of the spectrometer was precisely in the telescope's focus. The radiation entering the device hit a fluorite prism. The apparatus received wavelengths from 1-2 to 7 microns and had a 10×20 minute field of view, and the spectrometer had a resolving power of 600 lines per millimeter.

Although the Earth's surface, the Moon, and the galactic planes were all studied by the infrared device, its main target was the Earth's atmosphere. Spectra of solar radiation which had passed through the atmosphere were recorded at sunrise and sunset. To do this, the slits of the spectrometer were placed parallel to the Earth's horizon. The information is needed for determining the temperature of the atmosphere as well as distribution of water vapor and rare gases such as ozone. The atmosphere can only be explored to about 35 km with aircraft, and although sounding rockets can travel higher, they leave vapor trails which do not permit close examination of some aspects of the atmosphere's characteristics.

In order for the readings to be accurate, the apparatus must be kept extremely cold. Until this mission, a conventional cold genera-

[30] Tass, 1655 GMT, May 8, 80.

tor with compressors was used, but a great deal of energy was required for this method, so an ice coat of solid nitrogen was used to maintain the proper temperature.

Astrophysical

Two X-ray telescopes were used to study radiation from various areas of the universe. A "Filin" set of spectrometers was mounted on the outside of the station to detect the radiation by sensors, and was linked in parallel with a set of two optical telescopes (70 cm long with a 6 cm diameter and 1 degree field of view) to identify exactly what object was emitting the radiation. They used two modes of observation: One with the axis of the telescope permanently fixed on one area of the sky, and the other where the ship's commander had been done with Orion-2. The Russians announced that for the first time an autonomous system of stellar orientation was used to train the telescope, but provided no further details. The second X-ray telescope RT-4, was used to study soft X-radiation carrying photons with energy less than 1 kiloelectron volt. It had a parabolic mirror with a diameter equal to 200 mm, and a photon counter, a system of gas filling, and an electron device for primary processing of information. It looked at known sources of radiation rather than scanning for unknown sources as the Filin spectrometer had done, and had an independent orientation system accurate up to 15 seconds of arc. The crew studied the constellations of Scorpio, Virgo, Cygnus, and Lyra, focussing especially on X-1 Scorpio and X-1 Cygni. The latter was suspected of being the everelusive black hole, although its correct classification now is a neutron star. Because of the atmosphere, exact readings on this object are not possible from Earth, and the Russians stated they could now measure its mass, size, luminosity, density and temperature.

Solar photography

A telescope made in the Crimea was used for studies of the dynamics of the Sun in the ultraviolet. The oribtal solar telescope (OST) was equipped with a KDS (for Krymskiy Difraktsionnyy Spektrometer—Crimean Diffraction Spectrometer) and it studied specific areas of the Sun, not the entire disc at one time. Although the Soviets announced that the telescope had operated for 2 weeks before the crew came aboard, they also reported that the pointing system had malfunctioned causing the Sun to blind the main mirror. (The apparatus had two mirrors, the main one 25 cm in diameter with a 2.5 meter focal length, and a rotating mirror.) To correct this and make the telescope operational for the remainder of the flight, experts at the Crimean Astrophysical Observatory decided to reposition the rotating mirror so that the Sun's rays would be reflected into the main mirror. To accomplish this, the cosmonauts had to position the ship so that the telescope's axis was pointing directly at the center of the Sun. This was no easy task, for the crew had to measure the time it took for the rotating mirror to move from one support to another in its normal mode of operation, so they could calculate where it had to be stopped to assist the main mirror. The only way to do this was by listening to the mirror's movements, which the crew did with a stethoscope from their medical kit. Not only did this make the device operational, but once again proved man's usefulness in space.

Although the main mirror was in a conical niche to protect it from micrometeorites, the cosmonauts had to resurface it by spraying a new reflective layer onto it. The Soviets were delighted that the process worked well, for it was a deciding factor in their astrophysical plans for future space stations. If the surface could not be recoated, there would be no use in sending up other telescopes for long duration exploration.

The Sun was quiet during the Soyuz 17 mission, but good photographs were taken of dim flocculi (light patches on the Sun barely discernible from Earth) which exhibited bright features. These areas were simultaneously photographed on Earth for comparison purposes.

Navigation

Two navigation systems for autonomous control of the station were mentioned, and their relationship to each other is vague. Reports stated that daily tests were made of the Kaskad (Cascade) autonomous navigation system, consisting of an onboard computer that made navigation measurements and determined orbital parameters. The Soviets hoped it would reduce fuel consumption for orienting the ship. The "Delta" system was described in much the same way, although it seemed as though this system was a functioning part of Salyut, not an experimental version like Kaskad.

A new tracking technique was tried out using lasers. The laser pulses were sent from Earth and reflected back by an optical corner reflector installed in the ship. These trials were successful.

Communications

A new method of communication was experimented with that utilized a teletype system called "Stroka." This time the crew only tested the system, so it was used primarily for personal communications from family and friends, press reports on the mission, and basic information on orbital parameters. The system apparently worked the same way as newspaper teletypes with the message coming out on a strip of paper. This had the advantage that a permanent record was provided of communications from Earth, relieving the crew of the need to be present when the message arrived.

Systems

The crew practiced thermal regulation and life support in various modes. They also used a freon installation to study how liquids are affected in orbital flight. The results were related to creating hydraulic systems for spacecraft.

Salyut 5 With Soyuz 21, 23, and 24

Salyut 5 was launched on June 22, 1976 and deorbited on August 8, 1977 after completing 6,630 Earth orbits. This is generally considered to have been a military Salyut and was placed into an initial orbit 260×219 km. A capsule was ejected, as one had been with Salyut 3, by Salyut 5 on February 26, 1977, the day after the last crew left. According to the Soviets, this contained "the materials of research and experiments,"[31] probably exposed film.

Three crews were sent to Salyut 5, one of which (Soyuz 23) could not dock and became the first Soviet spacecraft to (inadvertently) splash down in water instead of landing on solid ground. The other two crews, Soyuz 21 and Soyuz 24, remained for 48 days and 18 days respectively. There is some indication that the first crew returned earlier than expected.

SOYUZ 21: 48-DAY MISSION

Soyuz 21 (Baikal) was launched at 1309 GMT on July 6, 1976 carrying the crew of Col. Boris Volynov and Lt. Col. Vitaliy Zholobov. By 1800 GMT, the ships was in an orbit 253×193 kilometers. Maneuvers were made on the 5th and 17th orbits, followed by docking with Salyut 5 at 1340 GMT on July 7.

After 48 days of work onboard the space station, the crew undocked from the space station at 1512 GMT on August 24, and landed at 1833 GMT. Circumstances surrounding the landing led some Western experts to conclude that the cosmonauts had encountered a problem and returned early. Among the factors were the unusual landing time (just after midnight local time), the landing site (which was more than 300 km from the area where the 5 previous Soyuz craft were recovered), and the fact that the Soviet press had reported on August 17 and 18 that the cosmonauts were experiencing "sensory deprivation."[32] Aviation Week concluded that the cosmonauts were forced to return early because of an acrid odor from the Salyut 5 environmental control system.[33]

SOYUZ 23: FAILED DOCKING ATTEMPT

Soyuz 23 (Radon) was launched at 1740 GMT on October 14, 1976, with the announced mission of continuing work onboard Salyut 5. The crew was composed of Lt. Col. Vyacheslav Zudov and Lt. Col. Valeriy Rozhdestvesnkiy.

According to the Soviets, at 1858 GMT October 15 the ship was put in its automatic regime for docking, but the procedure had to be canceled because of an operational malfunction of the approach control system. It was unclear whether the ship did not have a backup manual rendezvous procedure, or if there was insufficient time to implement it. This was seen as a repetition of the Soyuz 15 docking failure with Salyut 3.

The crew landed at 1746 GMT on the surface of Lake Tengiz, 195 km southwest of Tselinograd, in a snowstorm with temperatures which fell to −20 degrees C. The craft landed approximately 2 km from the northern shore, and the shore itself was described by the Soviets as a "quagmire" into which a spacecraft could sink. Rafts with recovery crews were dispatched but they encountered ice and could not reach the spacecraft. Helicopters were then used to tow the craft to shore, which despite its consistency, was able to support both the ship and the recovery teams. After emerging from

[31] Tass, March 1 and 2, 1977.
[32] Izvestiya, Aug. 17, 1976; Pravda, Aug. 18, 1976.
[33] Aviation Week and Space Technology, Oct. 18, 1976, p. 13.

the spacecraft, one observer commented wryly that with such large steppes in Kazakhstan the cosmonauts had "to go and land on purpose in a lake," to which Zudov jokingly replied that it was appropriate, since out of the entire cosmonaut corps his flight engineer was "the one seaman." [34]

The Soviets did not state how long the recovery operation took, but since the Tass announcement of the recovery was not made until 10 hours after they had splashed down, there was some speculation that it had taken quite some time.

SOYUZ 24: 18-DAY MISSION

Nearly 4 months elapsed before the Soviets made another attempt to dock with Salyut 5. The Soyuz 24 (Terek) crew, Col. Viktor Gorbatko and Lt. Col. Yuriy Glazkov, was launched on February 7, 1977 at 1612 GMT. Orbital corrections were made on the 4th, 5th, and 17th orbits and docking was achieved on February 8. Docking was accomplished manually rather than using the automatic system that had previously failed, and no docking time was announced. They entered the station at 0546 GMT on February 9.

After 16 days on the station, the crew returned to Earth on February 25, landing 36 km northeast of Arkalyk. The Soviets did not announce the time of landing, but it must have been 0938 GMT based on other data published by the Soviets.[35] There was speculation that the crew had returned so quickly because the military data they had obtained was needed.[36] If true, this might also explain why the unmanned reentry capsule was separated from the space station only 1 day later. The Soviets had announced on February 16 that the cosmonauts were halfway through their mission, however, so the return was expected.

The Soviets reported that the cosmonauts tried a new system for changing the atmosphere in the station. The system was described as a "multifunctional combined system" which could supply compressed air to control the station's stabilization system and compensate for leaks in the compartments when necessary. The reference to changing the atmosphere in the station lent some credence to the previous speculation that the Soyuz 21 crew encountered some sort of odor in the station forcing their early return, although the Soviets announced the air had been quite satisfactory and the test was related simply to future missions where such an exchange might be desired. With hindsight, it seems likely that this was a test of procedures to be used on Salyut 6 for replacing air lost when airlocks were opened, for EVA or garbage disposal, with air brought up by Progress. A 1983 article in Krasnaya Zvezda described the operation as being complex and requiring the development of torqueless nozzles to prevent the station from losing its orientation while the air is being vented into space.[37]

The Soviets also reported that the cosmonauts had fixed an onboard computer and replaced other units in the station.

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[34] Izvestiya, Oct. 19, 1976, p. 2.
[35] A 1982 Russian book, "Kosmos," contains a table listing the duration of all manned spaceflights, from which landing times can be calculated. The book was published in Leningrad.
[36] Aviation Week and Space Technology, Mar. 7, 1977. p. 20.
[37] Krasnaya Zvezda, Sept. 17, 1983, p. 3.

SALYUT 5 EXPERIMENTS

As noted earlier, Salyut 5 is classified by most Western observers as a military Salyut, suggesting that its primary mission was reconnaissance photography. The Soviets, however, discussed other experiments onboard the station, with a great deal of emphasis on Earth resources photography, a close cousin of reconnaissance.

Medical

Tests using the Polinom apparatus continued on these missions. Tests of the cosmonaut's taste perceptions were conducted, along with many others, including: An experiment called Impul's for comparing the threshold of sensitivity the vestibular apparatus to electrical irritants on Earth and in space to "improve methods of selection and training of cosmonauts"; use of a mass meter to determine the crew's mass while in space; an experiment called Levkoy for studying the effects of weightlessness on blood circulation; use of an autonomous blood analyzer for studying changes in blood components during flight (Soyuz 24 only, during the Soyuz 21 flight, reports were that blood was collected for analysis back on Earth); measurements of the heart's bioelectrical activity, blood pressure, and temperature; and measurements of respiration rate and the depth of breathing, the respiratory capacity, and pulmonary ventilation.

After returning to Earth, the Soyuz 21 crew took a few days to readapt to Earth's gravity. After 4 days, they were reportedly still "resting" and that each day they felt better, and that for the first time their schedule included "setting-up exercises, three walks, and even a fishing trip." The Soyuz 24 crew stayed up for a comparatively short time, and had reportedly fully adjusted to Earth's gravity after 1 day. They commented that they wished they had had a "back expander" since the body had a tendency to bend forward.

Other biological

The cosmonauts sprouted crepis seeds and the sprouts were fixed for subsequent genetical research on Earth. They studied the effects of zero G and radiation on plants, mushrooms, and animals. The station had an aquarium with two guppies and Danio rerio fish, and the behavior of the fish was filmed. In addition, experiments were conducted with the Danio rerio fish, which were carried to the station as eggs and born there, to study the formation of the vestibular apparatus in weightlessness.

Earth resources

According to Soviet press reports, the cosmonauts took pictures of the Earth's surface to find areas of likely mineral deposits, to study seismic activity, explore the danger of mud currents in mountains, explore areas where hydroengineering structures were to be built, and study areas adjacent to the eastern section of the Baykal-Amur railway line then under construction. They used both black and white, and color film.

During the period between the Soyuz 21 and 24 flights, the station automatically took pictures of the Earth "in the interests of science and the national economy."

33-865 O—84——9

The Soviets reported that a total of 65 million square kilometers were photographed during the Salyut 5 missions.

Atmospheric

The crew used an improved, handheld spectrograph to make photographs of the Earth's daytime horizon to study atmospheric constituents. This was the RSS-2M, which replaced the RSS-2 and RSS-1 used on earlier flights.

An infrared telescope-spectrometer was used to study the atmos~~phere over ocean areas, and to look at the Sun and the area near~~ the Sun. The cosmonauts also observed the formation of storms and hurricanes.

Materials processing

A number of materials processing experiments were performed on Salyut 5. The *Kristall* (Crystal) device was used to study crystal growth in weightlessness, and it was later reported that alumino-potassic alums had been grown. The *Sfera* (Sphere) experiment studied the melting and hardening of molten metals in zero-G. The cosmonauts tried soldering stainless steel with a manganese-nickel solder in the *Reaktsia* (Reaction) experiment, and the results were reported to have been of high quality. On the Earth, solder does not spread evenly over the seam and it was hoped that in space this problem would be alleviated. Using the *Diffuzyia* instrument, the cosmonauts tried to produce an alloy of dibenzyl and tolane [38] more homogenous than on Earth.

The *Potok* (Flow) device was used to evaluate the possibility of building capillary pumps in space for liquids without using electricity. The experiment consisted of two interconnected vessels which were used to study the flow of liquid from one to the other through a narrow channel under the influence of capillary and surface tension. This was thought to be related to the development of space tankers (probably the Progress series).

SALYUT 6—A SECOND GENERATION SPACE STATION

STATION DESIGN

Salyut 6 was the first space station to have two operational docking ports, and was designed to last 1.5 years. Launched on September 29, 1977, by the end of 1980, it had passed the 3-year mark and appeared in good shape for future utilization.[39]

DOCKING PORTS

Salyut 6 is depicted in figures 31-37. As noted above, it has two passive docking ports (the active systems are on the Soyuz or Progress ships). The forward docking port is used for Soyuz, while the aft docking port can be used either for Soyuz or Progress. The restriction for Progress is that the fuel lines which permit in-orbit refueling are located only at the aft port. If a Soyuz is located at

[38] Tass, 1624 GMT, Aug. 11, 1976. The correct word is probably toluene.

[39] In fact, it was used for manned crews through part of 1981, and was deorbited in the summer of 1982 after a year of operations with the unmanned Kosmos 1267 spacecraft, a test of a modular space station design.

the aft port and a Progress mission is needed to resupply the station, the crew dons spacesuits, enters the Soyuz and undocks from the aft end, the Salyut station is rotated by the groundcrew around one of its transverse axes [40] so that the forward end is facing the Soyuz, and the crew redocks.

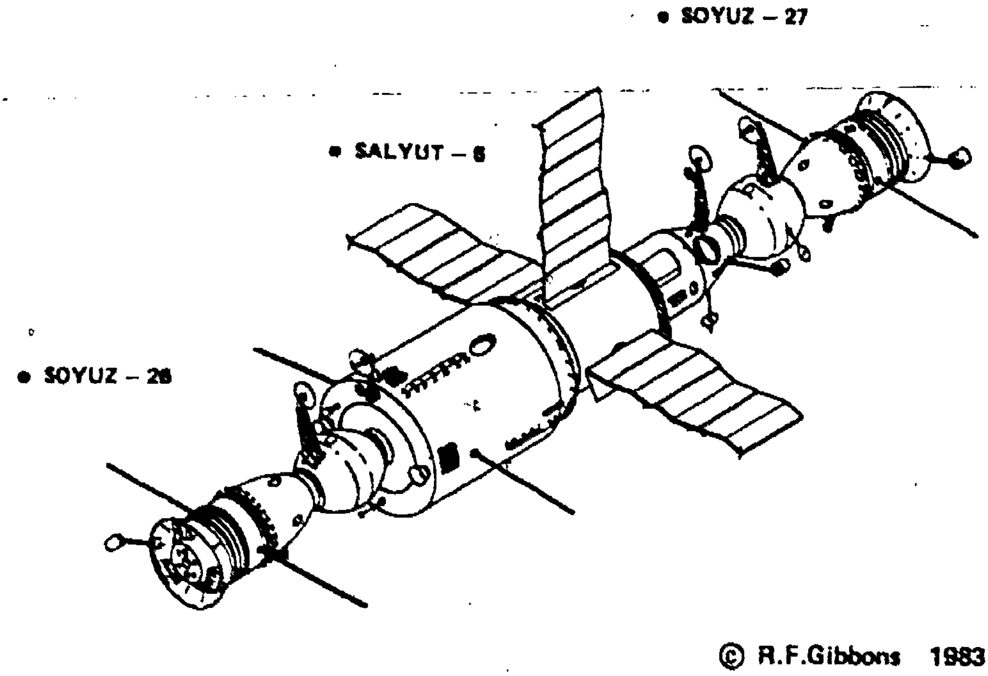

FIGURE 31.—Salyut 6 Multiple Docking Ports. Salyut 6 was the first Soviet space station to feature two docking ports. Soyuz 26 and 27 marked the first multiple docking. Here, as with some of the later missions, the short duration visiting crew returned in the older craft, leaving the newer craft for the long duration crew.

[40] In different accounts, it has been reported as a pitch or yaw maneuver. It may be that either can be used depending on what orientation the station already is in at the time of the undocking-redocking activity.

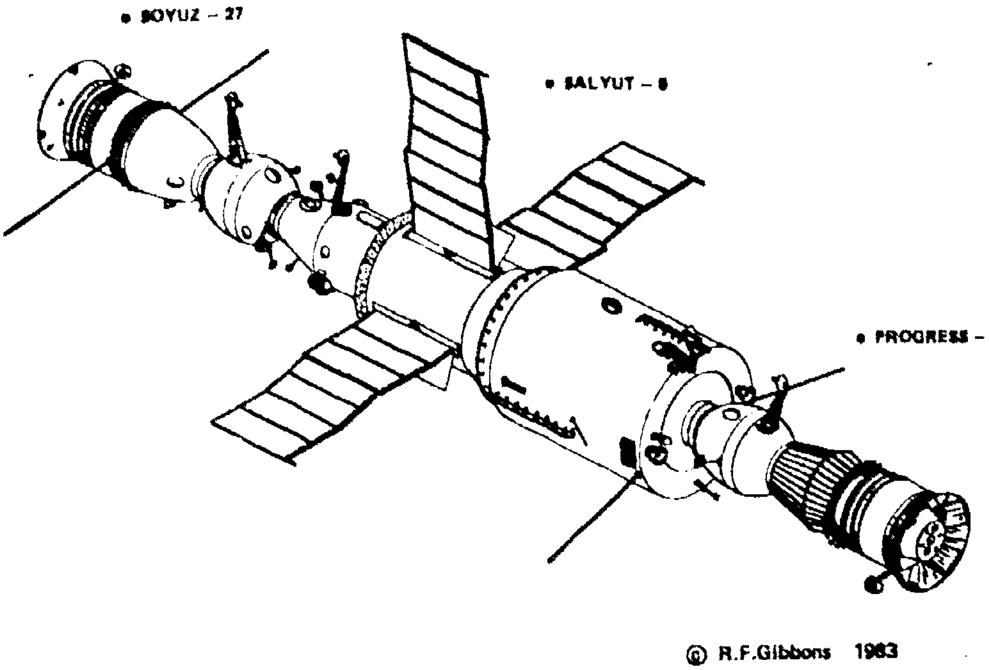

FIGURE 32.—Salyut 6 Resupplied by Progress Spacecraft. After the departure of Soyuz 26, Soyuz 27 was moved to the front docking port, freeing the rear port for Progress 1. The Progress spacecraft are unmanned, nonrecoverable variants of Soyuz, used to resupply the Salyut. Progress 1 delivered 1.0 metric ton of propellant and 1.3 metric tons of cargo to Salyut 6.

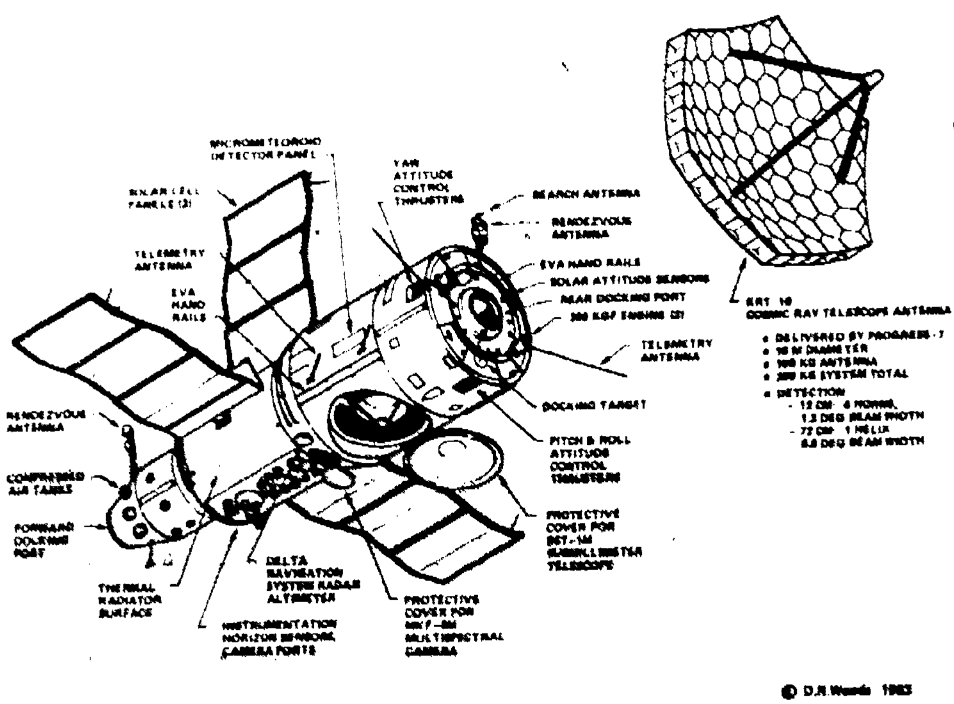

FIGURE 33.—Salyut 6 Exterior Details. The Salyut 6 exterior was fitted with a variety of instrumentation and equipment. Hand rails permitted travel over the entire surface during EVA exercises. One such exercise was necessary to completely detach the KRT-10 antenna when it caught on a station structure.

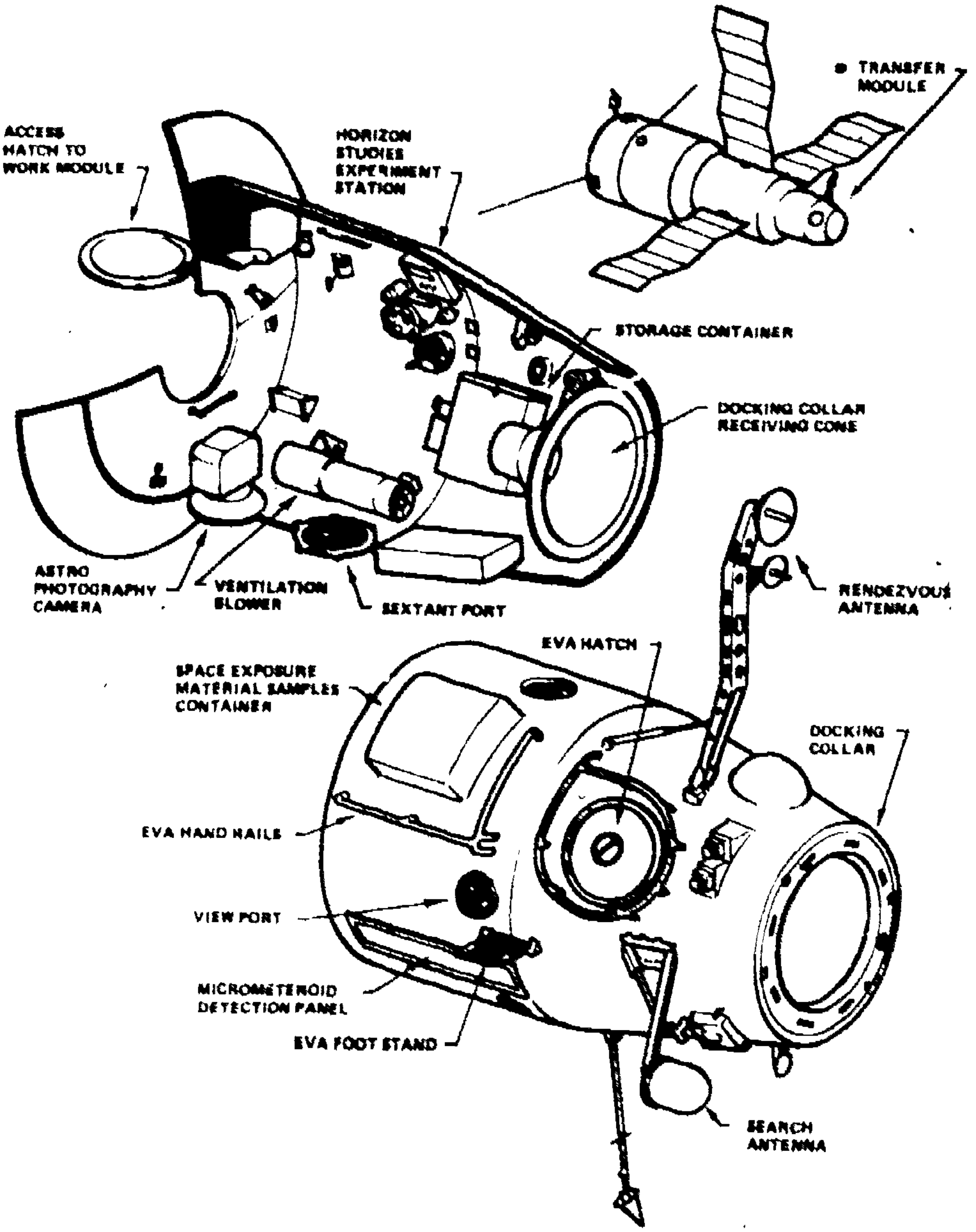

FIGURE 34.—Salyut 6 Transfer Module. The transfer module on Salyut 6 served as an airlock between the main work module and attached Soyuz spacecraft, as well as a small depressurization, repressurization chamber for EVA exercises.

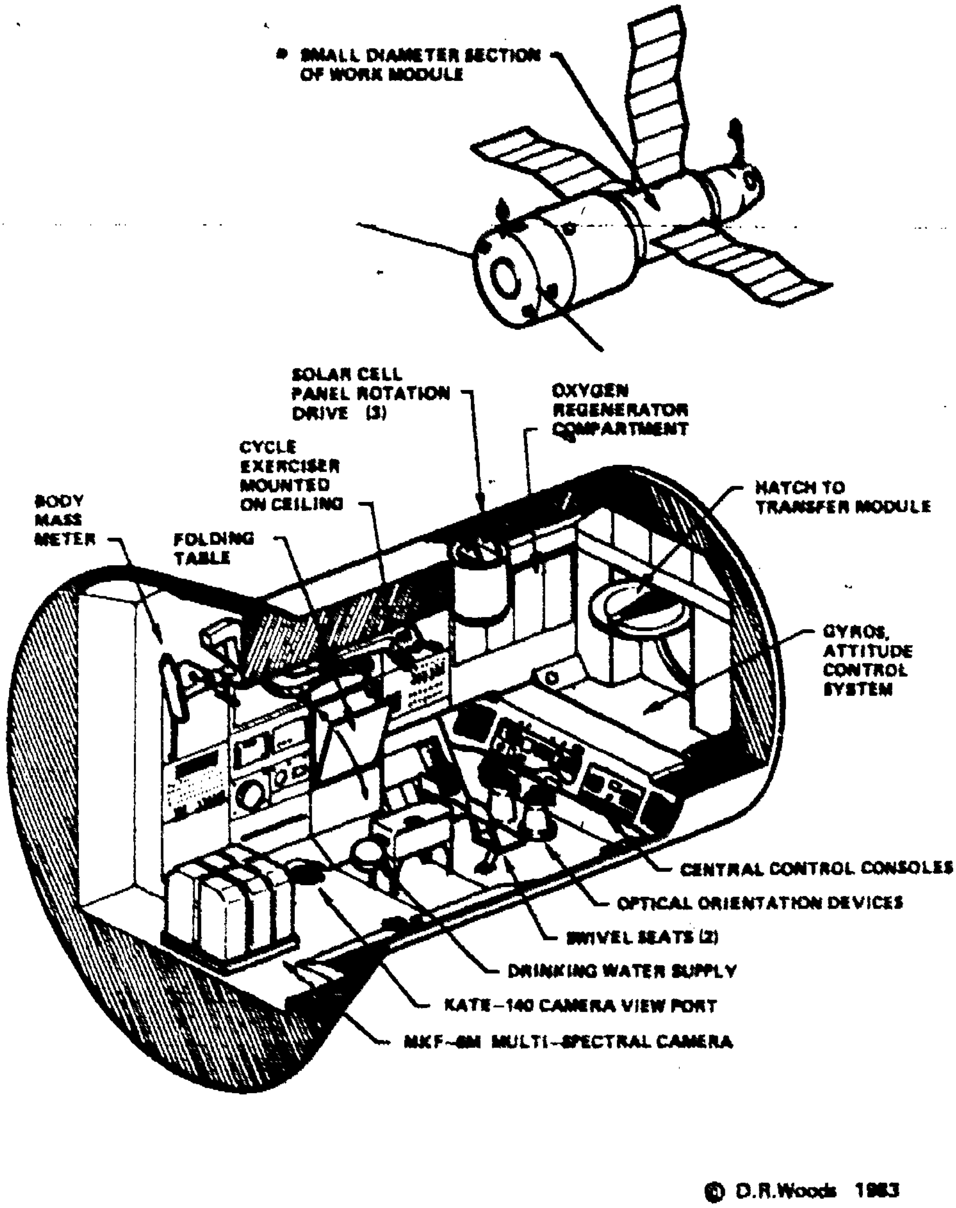

FIGURE 35.—Salyut 6 Small Diameter Cylinder of the Work Module. The small diameter section of the work module contained the main station control consoles. View ports on the floor could be fitted with various cameras for Earth resources or astronomical photography. The side walls contained oxygen regenerators in the front and specialized control panels toward the rear. A cycle exerciser was mounted on the ceiling.

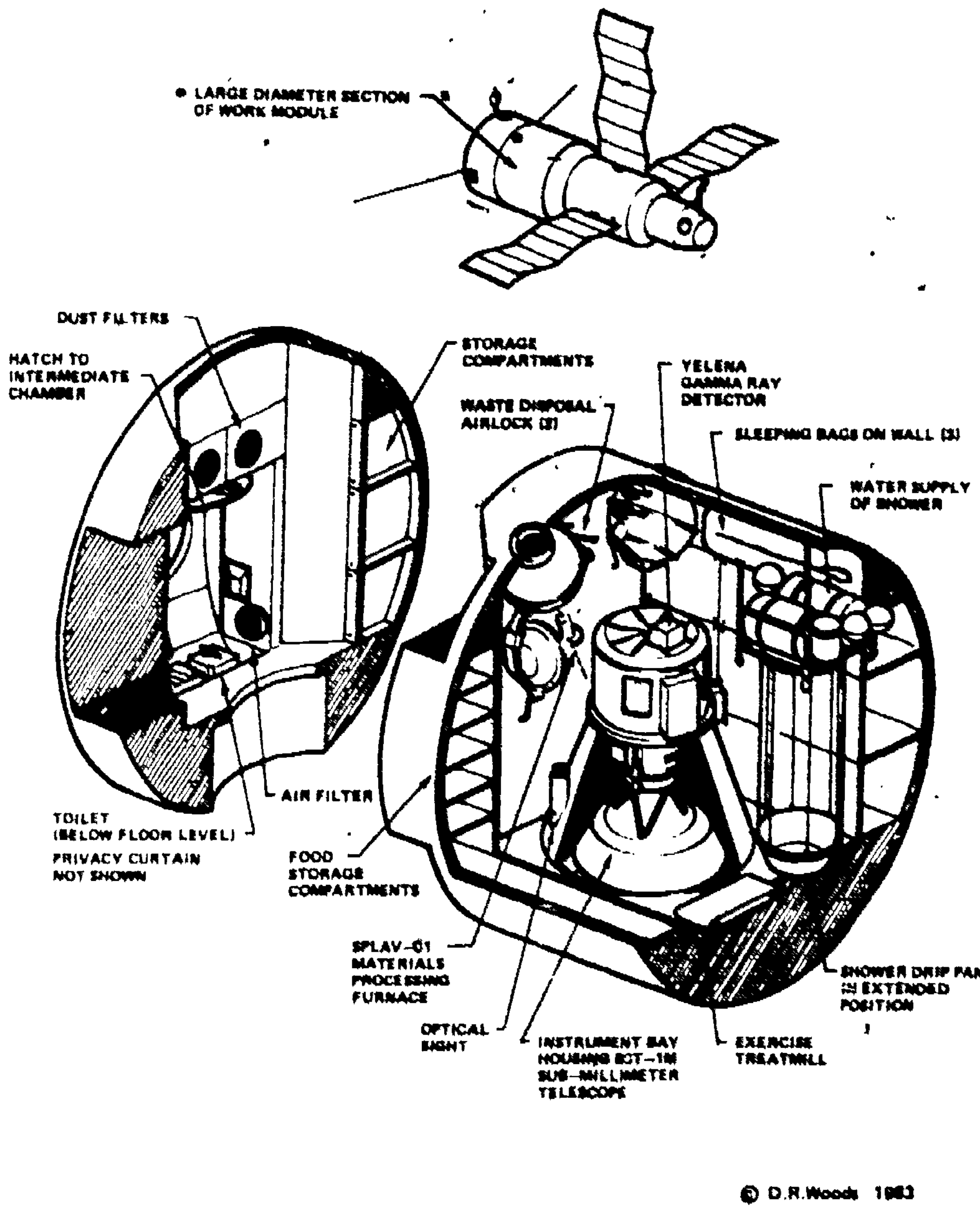

FIGURE 36.—Salyut 6 Large Diameter Cylinder of the Work Module. The cone structure in the work module on Salyut 6 contained the BST-1 submillimeter wavelength telescope. The walls contained storage compartments for food and supplies. Small spherical airlocks on the ceiling permitted disposal of waste material. The Splav-01 furnace could be fitted in one of the airlocks to operate in the vacuum of space.

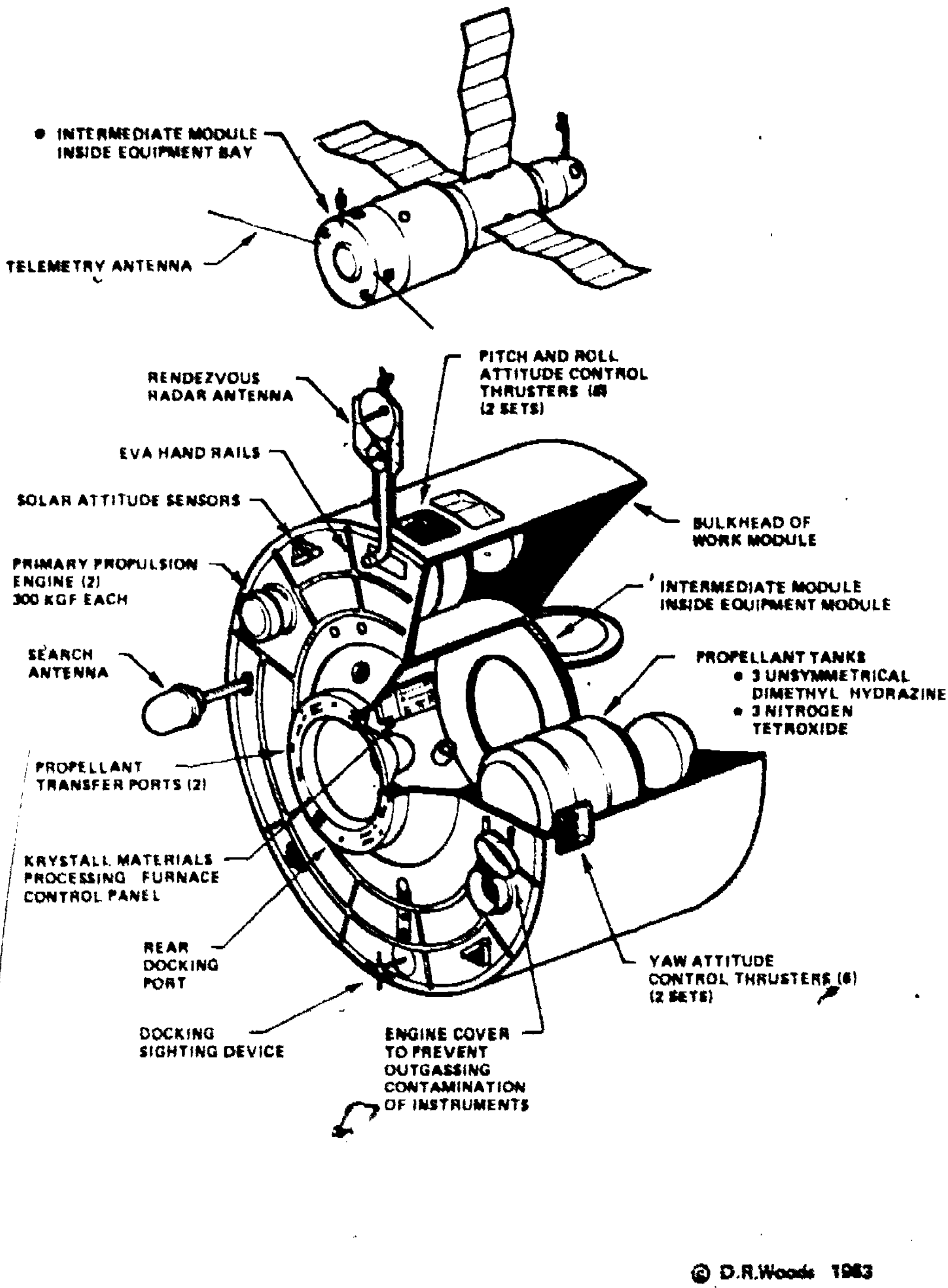

FIGURE 37.—Salyut 6 Intermediate Module. The intermediate module on Salyut 6 served as an airlock between the main work module and an attached Soyuz or Progress spacecraft. Six cylindrical propellant tanks, around it, supplied minimum contamination of station instruments from combustion residual products.

STATION STATISTICS

Basic station dimensions are the same as for the previous space stations. Including one Soyuz spacecraft, the space station is 21 to

23 meters long,[41] has a maximum diameter of 4.15 meters, an internal volume of 100 cubic meters, and weighs 25,600 kg. Without Soyuz, it is 13.5 meters long, has an internal volume of 90 cubic meters, and weighs 18,900 kg.

The three individually rotatable solar panels have a total area of 60 square meters, and produce 4 kilowatts of direct current. DC-AC inverters convert the electricity to alternating current. Salyut has a "wing span" of 17 meters with the solar panels and is made of aluminum.

A TOUR OF THE SALYUT 6 INTERIOR

The interior detail is also much the same as on previous space stations. Arriving through the transfer compartment, the cosmonaut enters an area with a volume of about 8 cubic meters. Pressure suits and airlock control panels are located there. Next is the working compartment with walls that are removable and covered with soft, bright-colored cloth. On this space station, the internal sound insulation layer was increased by 50 percent to lessen the noise of the equipment onboard in response to complaints from the crews.

Almost immediately in front of the access hatch is the station's central control post. Behind that is a table for working and eating, and nearby, a water tank. Cupboards for storing food are located to the left and right of the working compartment.

Past the table is the scientific equipment area containing, among other things, a cone which protects the BST-1m infrared telescope. The shower is located to the right of the equipment compartment on the "ceiling" and close to that are two airlocks for disposing of garbage.[42] One of these airlocks is also used for materials processing devices (Splav or Isparitel, depending on which one is in use at a given time).

On the "floor" of this section are the MKF-6M and KATE-140 cameras and infrared sensors for determining the local vertical positions of the station for the navigation system.

Behind the scientific equipment compartment is the toilet, with a soft door with a zipper fastener. Past that is the hatch into the intermediate chamber which leads to the aft docking hatch.

There are 20 portholes in Salyut for visual and photographic observations on Earth. Problems have been encountered with the optical quality of the portholes over a period of time as dust collects on them, and in a few cases, they have been scratched by what appear to be meteorites.

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[41] As noted in previous sections, the length of Salyut depends on whether external fixtures such as radio antennas are included. Konstantin Feoktistov has stated that Salyut 6 was 13.5 meters long by itself (Moscow, Novoye v Zhizni, Nauka, Teknika, Seriya 'Kosmonavtika, Astronomiya, No. 3, 1980), and since Soyuz is 7.5 meters long, the docked combination, should be 21 meters. The Soviets usually list the length as 23 meters, however, so it is assumed that antennas are included in the latter length.

[42] All types of refuse are placed in the garbage containers, including body waste from the toilet. The garbage containers decay naturally from orbit after about 1 month, burning up completely as they enter the dense layers of the atmosphere. They do not present a significant "space pollution" problem.

Pipes carrying a liquid heat transfer agent are welded along the inside walls of the station (but behind the panels which the crew sees) for thermal regulation.[43] This is especially important not only for the well being of the inhabitants, but because the station, as described by the Soviets themselves, is a "sieve" with openings to allow electrical and hydraulic leads to connect equipment on the outside of the station (such as the solar panels) with the interior.[44] Rubber gaskets are used to seal the holes, and correct temperatures must be maintained in order for them to maintain their elasticity and strength.

Heat generated inside the station (by the crew and equipment) is retained by using a multilayer thermos material made from metallized film. Excess heat is radiated into space with the thermal regulation system. When no crew is onboard, an electric heater is used to maintain proper temperatures.

Atmospheric regenerators consisting of nonreusable chemical cartridges are used to maintain the proper air composition (atmospheric pressure—700-960 mm Hg; partial oxygen pressure—160-240 mm Hg; partial carbon dioxide pressure—no more than 7-9 mm Hg.) The system also has pressure sensors to warn the crew of unplanned drops in pressure. (Some drops in pressure are "planned" in that they occur when the crew opens an airlock for EVA or disposing of garbage. The air is replenished by Progress cargo ships.) Fans are used to circulate the air.

Sitting in front of the control panel at work station 1, a crewmember sees a globe (called "Globus") in the upper corner which indicates the position of the ship relative to Earth. Next to it is a control panel with lights indicating the status of onboard systems (green), that orders are about to arrive from the ground or that the crew itself has given during the process of controlling the station (yellow), and emergency signal indicators (red). Two command signal systems are located to the left and right of the central post. On the left is the control panel for life support systems, and on the right, the refueling control panel.

There are six other work stations in Salyut 6. Station 2 is used for manual control of the station and has a panel, communication gear, astronomical instruments, and a control handle; station 3 is the control panel for the BST—1m telescope and its cooling systems, and also has communication gear, a viewer, and control handles; station 4 is for medical-biological equipment and the exercise equipment is located nearby; stations 5 and 6 are in the transfer compartment; and station 7 is for the water regenerating systems.

Salyut 6 has two main engines (300 kg thrust each) and 32 orientation engines (14 kg thrust each) positioned in four clusters 90 degrees apart. These are located around the outside of the aft docking port. Fuel is brought up by Progress cargo ships. Additional aspects of the fuel system are described in the next section on the Progess refueling operation.

[43] It is this system which the Soyuz T-3 crew had to repair at the end of 1980 by replacing four pumps. See p. 638 (Soyuz T-3).

[44] Semenov, Yu. and L. Gorshkov. "Salyut 6" Orbital Station: Home, Laboratory, Vehicle. Nauka i Zhizn, Apr. 1981. pp. 44-58, 125.

Salyut has a water regeneration system which removes water vapor from the air produced by breathing and perspiring and recyles it for consumption. Additional water is brought to the station on Progress cargo ships. Despite popular reports to the contrary, the Soviets have specifically stated that there are no provisions for water regeneration from urine on Salyut 6.[45]

Salyut 6 has an orientation and motion control system which the Soviets refer to as SOUD. It automatically orients the station for scientific observations and experiments, and docking manuevers, performs trajectory corrections, and allows for orienting the station via manual controls from the crew. The Kaskad system tested on Salyut 4 is part of SOUD and is used for "economical orientation" and consists of gyroscopes, a mathematical electronic memory, and two sets of sensors: One measuring infrared radiation from the Earth to determine position relative to the planet; the other measuring the flow of the ionic wind to determine orientation with respect to the station's velocity vector.

The Delta autonomous navigation system uses an onboard computer which receives data from a radio altimeter, radial velocity meter, and sunrise/sunset sensors. It can forecast the station's position 24 hours in advance, and compute the times when the station will be within range of tracking sites and automatically turns the communications equipment on and off as appropriate.

There is some question as to how well the navigation systems worked on Salyut 6. There were frequent references to the crews conducting navigation tests, and several Progress missions brought up replacement components. Some of the repairs would be expected considering the length of time the space station was in use, and some of the navigation exercises were probably related to gaining experience with how to best orient the station for certain tasks. Still, the repeated references raise questions about the system's reliability.

SALYUT 6 DESIGN CHANGES

Despite the similarity between Salyut 6 and its predecessors, there were significant changes to this second generation space station. The main difference is the addition of the second docking port, which required redesign of the main engine assembly. Originally the main engines were located in the center of the aft end, with orientation engines around the outside. On Salyut 6, the engine compartment was widened from 2.2 meters in diameter to the 4.15 meter maximum diameter of the station,[46] and the main engines as well as the orientation engines were mounted on the rim, with the docking port in the center.

The engines themselves were redesigned to be pressure fed, instead of turbine driven as on previous Salyuts, and hydrazine was used to fuel all the engines. Previously, on Salyut and Soyuz spacecraft, hydrogen peroxide was used for attitude control engines and to power the turbines for pumping oxidizer and fuel to the main engines; while hydrazine was used for the main engines. The

[45] Semenov and Gorshkov, op. cit.
[46] Kidger, Neville. The Salyut 6 Space Station. Spaceflight, April 1979, p. 178.

change to a unified fuel system simplified the number of propulsion lines and tanks needed. (Soyuz also switched to a common fuel system with Soyuz T, and Progress uses the same system.) Nitrogen is used to pressurize the fuel system. Salyut 6 has three oxidizers and three fuel tanks; one of each type is a reserve.

Progress Cargo Ships

To facilitate resupplying the Salyut space stations, the Soviets developed an unmanned cargo ship named Progress which is based on the Soyuz spacecraft. Progress is a one-way spacecraft—it takes material up to the space station, but it is not designed to survive reentry, so cannot bring anything down.

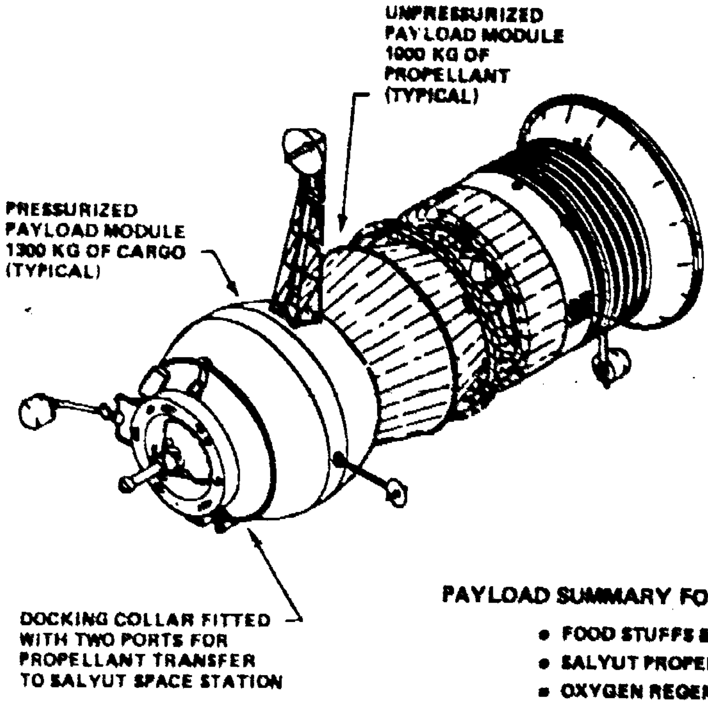
From 1977 to 1980, 11 of these ships were launched, each docking at the aft end of Salyut 6 where special fuel lines are located to enable refueling of the space station from Progress. These ships are not designed to dock at the forward end, thus if a spacecraft already occupies the aft docking port (such as when a visiting crew exchanges ships with the long duration crew), that ship must be moved to the forward docking unit. This has required a number of "do-si-do" maneuvers as described in the previous section.

The Progress spacecraft bring up fuel, air, water, food, clothing, experiments, and replacement parts for the space station. All these are critical for maintaining long term crews and long term space stations. They also bring personal items to the crew, including mail and parcels from their friends and family, newspapers and other periodicals, and special items the cosmonauts request—for example, Ivanchenkov asked that his guitar be sent up and it was delivered by Progress 3. The Soviets have found that the crews use 20-30 kg of expendable items each day, almost is a ton per month or 10 tons per year.

The following section summarizes the 11 Progress flights made from 1977 to 1980. Since most of them have refueled the space station, the process is only described once. Table 8 lists the pertinent statistics for these flights.

PROGRESS DESCRIPTION

The Progress spacecraft is a modified version of Soyuz. (See fig. 38.) Since it is an unmanned cargo craft, all life support systems have been removed as has the heat shield and parachutes, since it is not intended to survive reentry. This allows additional room and weight for cargo. The solar panels have also been removed.



PAYLOAD SUMMARY FOR PROGRESS 1–10

• FOOD STUFFS & WATER	11,375 KG
• SALYUT PROPELLANT	4,670 KG
• OXYGEN REGENERATORS	425 KG
• SPARE PARTS	870 KG
• RESEARCH EQUIPMENT	980 KG
• CAMERA FILM	225 KG
• AUXILIARY EQUIPMENT	115 KG
• PERSONAL EFFECTS	1,305 KG
	19,975 KG

FIGURE 38.—Progress Supply Spacecraft. Unmanned, nonrecoverable Progress spacecraft have resupplied the Salyut space stations to permit missions with durations measured in years rather than months. The first 10 Progress vehicles delivered a total of nearly 20 tons of cargo to Salyut 6; approximately equal to the station's launch weight.

Progress can carry 2,300 kg of equipment, materials, fuel, water, and gas. The total mass of the spacecraft is 7,020 kg,[47] compared to 6,557 kg for Soyuz.

Progress has an independent flight capability of 8 days, and although the Soviets announced that it had a flight duration of 1 month when docked to a space station when Progress 1 was launched, Progress 11 stayed attached to Salyut 6 for more than twice that long. Progress docks with Salyut after 2 days, instead of 1 day in the case of the manned Soyuz craft, since this requires less fuel to achieve the rendezvous and there is no hurry since no crew is aboard. The 2-day rendezvous also results in slower closing speeds, which simplifies docking operations since there is no crew on board to make final adjustments.

Since all systems are automated, the instrument compartment was enlarged and additional systems were installed. The Soviets report that Progress is slightly longer than Soyuz (8 meters instead of 7.5 meters), but it seems likely that the difference in length

[47] Gordon Hooper uses 7,005 kg for the Progress mass.

again is a matter of including the length of the antennas. The basic spacecraft is probably unchanged. A radar rendezvous system is used for docking, and the docking unit has warning systems to ensure that plumbing and docking latches are connected properly.

There are three compartments in Progress: Freight, refueling components, and instruments. The hermetically sealed freight compartment contains all the dry cargo, which is mounted on a special frame. The cargo is fastened with rapid release catches and special bolts which release the material with only a quarter turn. The hatch to Progress can be opened automatically or manually.

The refueling compartment has 4 fuel tanks and spherical containers filled with compressed air and nitrogen, plus requisite pneumatic and hydraulic systems. The total weight of fuel and gases that can be carried is 1,000 kg.

In the instrument compartment, there is almost twice as much instrumentation as with the Soyuz. Radio antennas, rendezvous apparatus, sensors and orientation engines are mounted externally. There are three lights and two television cameras to help with docking, which is controlled by the space crew, ground controllers, or both. One television camera is aligned along the longitudinal axis of the spacecraft while the other is perpendicular to it. Data on the motions made by Progress are sent both to the space station and ground controllers.

The docking assembly has additional automatic hydraulic connectors to ensure hermetic coupling of the main hydraulic lines of Progress with those of Salyut for the refueling operations.

There are 14 engines for docking and orientation, each with 10 kg thrust, and 8 precision orientation engines, each with 1 kg thrust. All operate on a unified fuel system, as does the Salyut space station and Soyuz T.

In addition to refueling Salyut, Progress is also used to boost the orbit of the Salyut/Soyuz/Progress complex itself by firing its own engines. Thus, the Soviets claim that it is as much a space tug as a space truck.

After the crew has emptied Progress of its cargo, they fill it with trash and old equipment, all of which burns up during reentry over the Pacific.

THE REFUELING OPERATION

When a Progress spacecraft docks with Salyut, it is done in a way so that their main pipelines are automatically coupled. There are two refueling units, one for propellant (hydrazine) and the other for the oxidizer. On Salyut there are 6 tanks, 3 for propellant and 3 for oxidizer. Progress has 4 tanks, two for each. (The third set of tanks on Salyut is held in reserve.)

The Salyut tanks have an accordion type device in the middle. When the tanks are full, the accordion is flat; as they empty, nitrogen is forced into the accordion to force fuel into the engines. Thus the first task in refueling is to remove the nitrogen from the fuel tanks and pump it back into its storage tank. This is accomplished by a special compressor that has a 1 kw, 3 phase electric motor powered by the solar panels via an AC inverter. Since the power required for this operation is considerable, the procedure is staggered over six shifts.

Once the nitrogen is removed from the fuel tanks, pumping of propellant is done first, followed by the oxidizer. Compressed nitrogen at eight atmospheres is used to force the fuel from Progress into Salyut. After these operations are completed, all the fuel lines are bled and compressed nitrogen is forced through to ensure that no excess fuel contaminates the atmosphere near the space station or the surface of the spacecraft.

Frequently after the refueling operation (and sometimes before), the Progress engines are used to raise the orbit of the complex. Then Progress undocks, tests are conducted of the navigation system using Progress as a target, and then the Progress engines are fired one last time for reentry.

THE DE-ORBITING OF PROGRESS SPACECRAFT

Progress spacecraft are not designed for recovery. The standard Tass announcement of the termination of a Progress mission following a period of autonomous flight after undocking from the space station states that the spacecraft has been put into a descent trajectory and "entered the dense layers of the atmosphere over a predetermined area of the Pacific Ocean and ceased to exist." Nothing more specific has been disclosed about the Pacific location, apart from a reference in a radio interview with an unnamed scientist at the end of the first Progress mission. He said that reentry into the atmosphere had occurred "over an unpopulated region of the Pacific—that special region in which such unmanned spacecraft which have done everything asked of them are usually dumped . . . The region is distinguished by the fact that it has hardly any inhabited islands and there are very rarely any ships there, so safety is completely guaranteed there; and I think that any parts, any pieces of metal of any size or weight, if they did in fact reach the surface of the ocean . . . are now resting at a depth of 7 km."[48]

No times were given for the first three deorbit burns, but the time for Progress 4 was given as 1928 Moscow time.[49] Taking this time as a starting point, Robert Christy and Phillip Clark made estimates of the times for the other missions in letters to the editor of *Spaceflight.*[50][51]

Clark's approach, based on his "optimum launch window" technique, suffered from a lack of access at the time to the two-line orbital elements distributed by NASA's Goddard Space Flight Center, and consequently took no account of postundocking maneuvers of the Progress spacecraft. Christy's treatment, based on two-line orbital elements, assumed that approximately 20 minutes elapses between retrofire and reentry and predicted reentry times and a location "somewhere near 140° E, 10° N." This may somewhat underestimate the time between de-orbit burn and final destruction. Figure 39 shows the descent ground-tracks for Progress 8 and Progress 11.

[48] Radio Moscow Home Service, 1900 GMT, 8, Feb. 1978.
[49] Moscow World Service in English, Oct. 26, 1978.
[50] Christy, R., Spaceflight, 21, 430-431, 1979.
[51] Clark, P.S., Spaceflight, 21, 432, 1979.

These two spacecraft had extreme values of ascending nodes for their destruction orbits of 12° E and 67° W respectively. All other destruction ground-tracks fall between these two paths. It will be seen that, in the latter case, a northern hemisphere demise would occur over land, long before the Pacific Ocean would have been reached. Thus the region of the Pacific Ocean between latitudes 35° and 52° S seems a more probable location than Christy's early estimate.

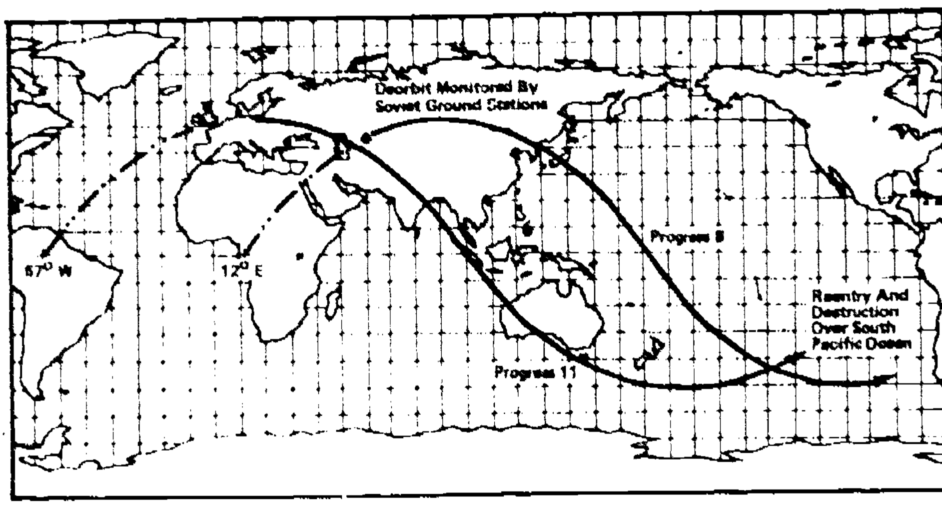


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FIGURE 39 —Progress Spacecraft Reentry Profile. Progress spacecraft are discarded at the end of their missions, and retrofired for a destructive atmospheric reentry. Andrew Driver and Geoffrey Perry of the Kettering Boys School have monitored the missions and found that the retro burns occur over the Soviet Union to insure destruction over the South Pacific where any surviving debris will sink harmlessly in the ocean. The Progress 8 and 11 ground tracks shown here are the extremes of all reentries to date.

Times for the de-orbit burns of those Progress spacecraft which have not been announced shortly after the end of the mission are contained in a book by Kravchenkov.[52] It seems strange that the times for Progress 1, 2, 3, and 5, all suggest that the burn was made deep in the southern hemisphere, far away from the Soviet Union. In all cases for which de-orbit times were promptly announced they are found to come between 15 and 23 minutes after the ascending node and while above the radio horizon of the Soviet Union. (Goddard data for Progress 7 was not available and that flight is not considered in this analysis.)

Thus, it would seem that after the Progress spacecraft is undocked from the Salyut 6 space station, it is allowed to slowly drift away from the station until it reaches a distance at which its engine may safely be fired to lower the orbit to a height close to 200 km from which reentry can be commanded. Then, while over the Soviet Union, it is oriented for retrofire. Following retrofire, it can be tracked from ground stations within the Soviet Union to

[52] Kravchenkov, Il, et al. Pilotiruyemyye Mezhdunavodnyye Polety Po Programme "Interkosmos" SSSR-SRV (Manned International Flights of the Interkosmos Program USSR-SRV. Izd. Novosti, Moscow, June 23, 1980.

ensure that it is on a suitable descent trajectory. It eventually burns up over the South West Pacific Basin.

PROGRESS 1 WITH SOYUZ 26/27

The first Progress launch was made on January 20, 1978, at 0823 GMT. Maneuvers were made on revolutions 4, 17, and 31 before final approach to the space station on revolution 33.[53] The launch came 4 days after the Soyuz 27/26 crew left Salyut, to bring supplies to the long-duration Soyuz 26/27 crew still on board.

Progress docked with Salyut 6 on January 22, and in this case the crew was not required to move to the Soyuz for safety, since the docking of Soyuz 27 (when they did wait in Soyuz until the other ship had docked) had gone so well. On January 23, the crew opened the hatch and began unloading the craft, which takes a certain amount of skill, since items have to be moved around in such a way so as not to upset the stability of the complex. The first items taken from Progress 1 were, of course, the mail and newspapers sent up by friends and family. Next, equipment for routine work, air purification filters, carbon-dioxide absorber units, and safety straps for chairs were removed. Food, water and scientific equipment came next, followed by bed linen, and new weighted training suits for the crew. New clothing, including underwear, was also delivered.

Air was also brought up by Progress to replace that which is lost each time the crew opens a hatch either for EVA or for disposing of garbage. In all, the crew unloaded 1.3 tons of material. After emptying the Progress, the crew filled it with refuse.

The first fuel transfer in space was accomplished on February 2 under the control of the space crew and ground controllers. Three days later, the Progress engines were fired to raise the orbit of the complex, later described by the Soviets as the first space tug operation.[54]

Among the specific items delivered by Progress 1 were a new set of "pickups" for the orientation and movement control system, and the Splav electric furnace for materials processing experiments.

Progress 1 undocked from Salyut 6 at 0553 GMT on February 6, after 15 days of joint operations with the space station. It reentered 2 days later, for a total lifetime in space of 19 days.

PROGRESS 2, 3, AND 4 WITH SOYUZ 29/31

The 140 day mission with Vladimir Kovalenok and Aleksandr Ivanchenkov was resupplied by three Progress spacecraft.

Progress 2 was launched at 1126 GMT on July 7, 1978 and placed in an initial orbit of 262×193 km. It docked with Salyut 6 at 1259 GMT on July 9 to bring fresh supplies after the visit of the Soyuz 30 crew. Among the cargo was mail, 200 kg of water, 100 kg of film for the cameras, 250 kg of food and equipment, 600 kg of fuel and oxidizer, and a new Globus instrument panel. Included in the

[53] Time of launch and orbital maneuvers taken from Hooper, Gordon. Spaceflight, November 1978, pp. 373, 375.

[54] Despite the Soviet characterization of this as the first tug operation, that distinction might more properly belong to the Agena stages which were used to boost Gemini X and Gemini XI into higher orbits in July and September 1966 respectively.

equipment was the Kristall furnace for materials processing experiments. The refueling process was controlled entirely from the ground this time to save the crew's time.

Progress 2 undocked from Salyut 6 on August 2, and reentered on August 4. It had spent 28 days in space (24 docked to Salyut 6).

Only 2 days after Progress 2 reentered, the next in the series was launched. Progress 3 lifted off at 2231 GMT on August 7,[55] and docked with Salyut 6 on August 10 at 0000 GMT. In this case, no fuel was carried and the ship stayed docked with the space station for only 12 days, long enough to bring supplies for the visit of the Soyuz 31 crew, which arrived 8 days after Progress 3 undocked.

The launching was done a little differently this time in that it was launched to achieve orbit 68 minutes after Salyut 6 passed overhead, instead of 44 minutes as had been done with the previous Progress missions. Docking still occurred at the usual ground elapsed time of 49 hours 30 minutes. This change provided the Soviets with a longer launch window and thus more opportunities to launch resupply missions.[56]

Progress 3 delivered cassettes containing materials to be processed in Splav and Kristall, an East German camera for Earth photography, other equipment for biological and medical experiments, 280 kg of food, 190 liters of water, and 450 kg of oxygen. Among the food items were strawberries and fresh milk. In addition, Ivanchenkov's guitar was brought up to him, and fur boots.

Although no fuel was transferred, the Progress 3 engines were used to raise the complex's orbit on August 17 to 359×343 km. Progesss 3 undocked from Salyut 6 on August 21 after approximately 12 days of joint flight. It reentered on August 23 after a total of 16 days in space.

The third and final resupply mission for the Soyuz 29/31 crew was Progress 4, launched on October 4, 1980. It docked with Salyut 6 at 0100 GMT on October 6, bringing fuel, food, regenerators, water, photographic materials and other supplies following a heavy workload by the crew and visits by other crews. Tass noted that fuel was needed because the fuel expenditure has been particularly great during the previous month because of experiments which required the space station to be oriented in specific directions, such as Earth photography and work with the telescopes on board.

Reflecting the experience they had gained with the procedures, the crew unloaded Progress 4 in half the time allocated for this activity.

On October 20 and 21, the Progress 4 engines were used to raise the complex's orbit. Ordinarily this procedure would be accomplished in 1 day, but the Soviets announced that this time they wanted to define the orbital parameters more accurately after the first burn, so that the second burn could be carried out more precisely.[57]

Progress 4 undocked from Salyut 6 at 1307 GMT on October 24 after 18 days of joint flight, and reentered on October 26 after a total of 22 days in orbit.

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[55] 0131 on August 8, Moscow Time.
[56] Aviation Week and Space Technology, August 21, 1978, p. 18.
[57] Moscow Domestic Service, 1130 GMT, 20 Oct 78.

PROGRESS 5, 6, AND 7 WITH SOYUZ 32/34

The 175-day mission of Vladimir Lyakhov and Valeriy Ryumin was also resupplied by three Progress flights.

Progress 5 was launched at 0547 GMT on March 12, 1979, and docked with Salyut 6 at 0720 GMT on March 13, just 2 weeks after the crew arrived. The ship delivered 2,300 kg of cargo, including 1,000 kg of fuel. Included were six signal detectors which were place in various areas of the space station to alert the crew to concentrations of carbon dioxide (and doubled as smoke detectors), a new tape recorder, a walkie-talkie for the crew to use with each other (called "Koltso" or ring), film, ampules for the materials processing experiments (including 10 developed by French scientists), a linen dryer, bath shampoo, clothes, food (including five types of bread, fresh vegetables, apples, onion, and at the crew's request, honey and fresh dried strawberries).

Three important pieces of equipment were a black and white television set for two-way visual communications with Earth (and to allow the crew to watch regular television programs), an "improved" Kristall furnace, since the first one had stopped working, and the Biogravistat plant centrifuge. Also included in the equipment cargo was a new clock and new command signal devices to properly sequence automatic commands, and a new science instrument control panel.

The Progress 5 engines were used to correct the complex's trajectory on March 30, placing it in a 357×284 km, 90.6-minute orbit. A second firing on April 2 placed it into a 91.4-minute orbit.[58] The Progress craft undocked from Salyut 6 on April 3 at 1610 GMT, and reentered on April 5. It had been in space for 24 days (20 of which it was docked to Salyut 6).

Just over a month after Progress 5 left, and following the aborted docking attempt of Soyuz 33 which would have brought some supplies and experiments, Progress 6 docked with the space station. Launched on May 13 at 0417 GMT, it docked with Salyut 6 on May 15 at 0619 GMT. Among the cargo was a new panel for the navigation system,[59] small amounts of fuel, air, food, air regenerators, sleeping accessories, electric bulbs, a Stroka teletype machine, and a tulip which had almost blossomed. Scientists wanted to find out how it would blossom, and also thought that it would bring the crew a touch of spring.

The Progress engines were used to raise the orbit on May 23 to 352×333 km. Refueling of the space station was completed on May 28, and another trajectory correction was made on June 4 and 5, leaving the complex in an orbit of 371×358 km. Progress 6 undocked from Salyut on June 8 and reentered over the Pacific on June 10. The ship was docked to the space station for 4 days, and was in space for 28 days.

The final resupply craft for the Soyuz 32/34 mission, Progress 7, was launched only 3 weeks later, at 0926 GMT on June 28. It

[58] The Soviets stated only that the engines were fired on April 2. The information on the 91.4-minute orbit is taken from: Spaceflight, February 1980, p. 57.

[59] There was no mention of this panel in the Tass announcement on Progress 6, but shortly after the cargo ship arrived, the fact that the crew was replacing the panel was mentioned by Tass (1332 GMT, 30 May 79).

docked with the space station at 1118 GMT on June 30, bringing 500 kg of fuel, 50 kg of food, photographic material, clothes, equipment for the life support system, new gravity suits, indoor plants, mail, the vaporizer (Isparitel) and resistance experiments, and most importantly, the KRT-10 radio telescope. It also brought a book called "The Moscow Area" to remind the crew of the forests, fields, and streams back home. An orbital correction was made on July 4, placing the complex in an orbit of 411×399 km, an orbit higher than the space station had been during its entire 2 years in space.

The deployment of the KRT-10 radio telescope is described in more detail on p. 598, so will not be repeated here except to say that when Progress 7 undocked from Salyut on July 18, it did so using springs instead of its engines so as not to damage the radio telescope. It then stationkept at a short distance from the station to enable television broadcast of the unfurling of the radio antenna. Progress 7 reentered on July 20 after 18 days of joint flight (22 days in space).

PROGRESS 8 WITH UNOCCUPIED SALYUT

Progress 8 was launched at 1853 GMT on March 27, 1980, during a period when Salyut was unoccupied. It was launched 1 day after Soyuz T, which had been attached to the space station for a 100-day test, returned to Earth.

The cargo craft docked on March 29 at 2001 GMT, and its engines were used to raise the station's orbit on April 2 to 360×328, 91.4 minutes in preparation for the next Soyuz launch (Soyuz 35) which docked with the space station on April 10. Progress 8 was used to refuel the station, and another orbit correction was made on April 24, placing the complex in a 368×340 km orbit.

Progress 8 undocked from Salyut 6 on April 25, and reentered on April 26, after 30 days in space (approximately 26 of which were spent docked to Salyut 6).

No mention was made of any provisions or equipment on Progress 8, although during the course of the early days of the Soyuz 35 mission, Tass reported on a number of maintenance activities being conducted by the crew, and the supposition can be made that much of that material was brought to the space section by Progress 8. This would include new storage batteries, a new control desk, air regenerators, and part of the temperature control system that needed replacing.

PROGRESS 9, 10, AND 11 WITH SOYUZ 35/37

The 185-day Soyuz 35/37 mission with Leonid Popov and Valeriy Ryumin was resupplied by three Progress ships in addition to Progress 8 which, as noted above, was docked with the space station when they arrived. Progress 11, the last of these, remained docked to the station after the crew left and accomplished the first fuel transfer while the station was unoccupied.

Progress 9 was launched only 1 day after Progress 8 reentered, at 0624 GMT on April 27, 1980. It docked with Salyut 6 at 0809 GMT on April 29 and delivered the usual items such as scientific equipment (including a new motor for the Biogravistat centrifuge), material for the life support system, air, and mail. There was no fuel transfer with this mission, and it was used to stock the space station for the imminent visit of the Soyuz 36 and Soyuz T-2 crews.

Progress 9 undocked at 1851 GMT on May 20, and reentered 2 days later after 25 days in space (21 docked with the space station). The Soyuz 36 crew arrived a week later.

Five weeks later, Progress 10 was launched at 0441 GMT on June 29. It docked with Salyut 6 at 0554 GMT on July 1 and brought fuel, food, and equipment in preparation for the visit of the Soyuz 37 crew. Tass reported that 30 percent of the dry goods had been specifically requested by Popov and Ryumin. Included in the supplies were an American-made Polaroid instant camera and film, a new 25 cm color television (to replace the black and white model they had been using), cassettes of pop music, onion, dill, parsley, cucumbers, radishes, canned fish, new flower seeds for the hydroponic garden, new intensifiers for the BST-1m submillimeter telescope, and a device to rectify a problem with the Bulgarian-made Duga instrument which was producing inverse images.

Refueling of the Salyut tanks was accomplished on July 8. Progress 10 was used to raise the complex's orbit on July 8 (no new orbital parameters were announced, however), and on July 17 when it was left in an orbit at 355×328 km. It undocked from Salyut 6 on July 18 after 17 days of joint operation, and reentered on July 19 after 21 days in space. Five days later, Soyuz 37 was launched.

The final resupply mission for the Soyuz 35/37 crew, and for the 1977-80 time period, was Progress 11, launched on September 28. The relatively long hiatus between resupply flight was occasioned, apparently, by the fact that they overstocked Salyut 6 with the previous three flights. In mid-September, the space station reportedly had 2.5 tons of cargo on board, more than when the Soyuz 35 crew arrived.

Progress 11 docked with Salyut 6 on September 30 at 1703 GMT, delivering fuel, water, food, and regenerators. On October 8, an orbital correction was made using the Progress engines, but no new parameters were announced.

The Soyuz 35/37 crew left the space station on October 11, but Progress 11 remained. On November 16, while the station was unoccupied, the fuel transfer was accomplished automatically via commands from the ground. This was another first for the Soviet program.

Progress 11 remained docked with the space station until after the Soyuz T-3 crew docked in November, finally undocking on December 9 after 70 days of joint flight. It reentered on December 11 after a total of 74 days in space. Originally, the Soviets had stated that the Progress lifetime was only 30 days; this obviously proved that the ship was more capable than they envisioned.

TABLE 8.—SUMMARY OF PROGRESS CARGO MISSIONS 1977–80

Name	Launch date	Docking date	Undocking date	Days docked	Days lifetime	Comments
Progress 1	Jan 20, 1978	Jan. 22, 1978	Feb. 6, 1978	15	19	First use of Progress resupply craft. First in-space refueling. Raised Salyut's orbit once. Delivered Splav furnace.
Progress 2	July 7, 1978	July 7, 1978	Aug. [illegible], 1978	24	28	Delivered Kristall furnace. Refueled space station.
Progress 3	Aug. 8, 1978	Aug. 10, 1978	Aug. 21, 1978	12	16	B[illegible]ght supplies, but no fuel. Raised station's orbit once.
Progress 4	Oct 4, 1978	Oct. 6, 1978	Oct. 24, 1978	18	22	Brought supplies and fuel. Raised station's orbit once, but over 2-day period.
Progress 5	Mar 12, 1979	Mar. 14, 1979	Apr. 3, 1979	20	24	Delivered supplies and fuel. Brought b/w television set. Raised station's orbit twice.
Progress 6	May 13, 1979	May 15, 1979	June 8, 1979	24	28	Delivered supplies and fuel. Brought tulip that had almost blossomed. Raised station's orbit twice.
Progress 7	June 28, 1979	June 30, 1979	July 18, 1979	18	22	Delivered supplies and fuel. Brought KRT–10 radio telescope. Raised station's orbit to altitude higher than when it was launched.
Progress 8	Mar 27, 1980	Mar 29, 1980	Apr. 25, 1980	26	30	Docked with unoccupied space station. Delivered fuel and supplies for crew about to arrive. Raised orbit twice.
Progress 9	Apr. 27, 1980	Apr 29, 1980	May 20, 1980	21	25	Delivered fuel and supplies.
Progress 10	June 29, 1980	July 1, 1980	July 18, 1980	17	21	Delivered supplies, including color television, but no fuel. Raised station's orbit twice.
Progress 11	Sept. 28, 1980	Sept. 30, 1980	Dec. 9, 1980	70	74	Delivered supplies and fuel; refueled station for first time when it was unoccupied. Set new duration for Progress craft. Raised station's orbit once.

Interkosmonaut Missions

As detailed later on (see pp. 618–37), several of the flights to Salyut 6 involved cosmonauts from countries other than the Soviet Union. The Soviet attitude toward international cooperation in space, including flights of representatives of other countries, is discussed in part 1, chapter 3 of this study (see pages 272–282) and will not be repeated here.

The term "Interkosmonaut" is used here to denote cosmonauts from the other Interkosmos countries (Bulgaria, Cuba, Czechoslovakia, East Germany, Hungary, Mongolia, Poland, Romania, and Vietnam). From 1978–80, representatives from all but Mongolia and Romania flew into space, and all but one (Ivanov of Bulgaria) docked with Salyut 6. The Bulgarian cosmonaut was on Soyuz 33 which was unable to dock because of an engine failure. (Mongolian and Romanian cosmonauts voyaged into space in 1981.)

Each country selected two men to train as cosmonauts, one prime and one backup. Training occurred over a 2-year period at Star City where they worked closely with their Soviet colleagues. The final crew was composed of a Soviet commander and a "cosmonaut-researcher" from the Interkosmos country. Each successful flight lasted for just under 8 days, and involved a wide variety of experiments conducted on board the space station, many of which were developed jointly by Soviet scientists and those of the participating country. These experiments are described both in the section one Salyut 6 experiments (p. 585) and Manned Missions to Salyut 6 (p. 609).

A summary of the Interkosmonauts and their backups is provided in table 9. It is not expected that the backup will make a flight.

TABLE 9.—SUMMARY OF INTERKOSMONAUT MISSIONS 1977–80 [1]

Country	Prime crew member	Backup crew member	Flight	Launch date	Comments
Bulgaria	Lt Col Georgi Ivanov	Capt. Alexander Alexandrov	Soyuz 33	Apr 10, 1979	Unable to dock because of engine failure
Cuba	Col Arnaldo Tamayo Mendez	Capt Jose Armando Lopez Falcon.	Soyuz 38	Sept. 18, 1980	
Czechoslovakia	Capt Vladimir Remek	Maj. Oldrich Pelcak	Soyuz 28	Mar. 2, 1978	First non-Soviet, non-American in space.
East Germany	Lt Col Sigmund Jähn	Lt. Col. Eberhard Köllner	Soyuz 31	Aug. 26, 1978	
Hungary	Lt Col Bertalan Farkas	Maj. Béla Magyari	Soyuz 36/35	May 26, 1980	
Poland	Lt Col Miroslaw Hermaszewski	Col. Zenon Jankowski	Soyuz 30	June 27, 1978	
Vietnam	Lt Col Pham Tuan	Capt. Bui Thanh Liem	Soyuz 37/36	July 23, 1980	

[1] Representatives of the other two Interkosmos countries, Mongolia and Romania, made spaceflights in 1981

The order in which the cosmonauts made their flights has been the subject of acute interest in Western circles, since it appeared in some cases to have reflected political relations between the various countries and the Soviet Union. For example, the decision to make the Romanian cosmonaut wait until last was seen as an indication of the cool relations between the two countries at the end of the 1970's. When the Vietnamese cosmonaut made his flight during the Moscow Olympics, this was seen in some quarters as trying to impress the Third World. Whether such motivations were in fact responsible for the order in which the Interkosmonauts were launched has obviously never been discussed in the Soviet literature.[60]

SALYUT 6 EXPERIMENTS

During the 3-year period that Salyut 6 hosted crews covered in this study, the station was occupied about half the time. This permitted a great number of experiments to be performed, ranging from medical/psychological studies, to technical experiments such as materials processing, to Earth observation/photography sessions. The following section describes the experiments that were conducted and, in some cases, the results of those experiments. Overall, however, the Soviets have released little information about many of their experiments on Salyut 6, particularly in the area of materials processing. This may be due to the length of time required for data analysis.

Medical/psychological experiments are discussed at length in chapter 4 and materials processing experiments and Earth resources observations are discussed in part 3 of this study in the chapter on space applications. Thus, only a brief treatment is accorded those topics here.

MEDICAL/PSYCHOLOGICAL

The equipment carried on Salyut 6 for monitoring the cosmonauts' health and for exercising was much the same as on previous space stations. The Chibis vacuum suit, Polinom-2 apparatus, and Beta rheograph were all used routinely.

Most of the new medical experiments were developed jointly with other countries, and generally were used only when an international crew was onboard. They included the following.

Cardioleader

Developed jointly by Soviet and Polish scientists, this was a device to measure the physical effort exerted by a cosmonaut when using the bicycle or running track in order to develop a controlled program of exercise in which the effort spent in physical exercise was proportional to the action of the heart of the person using the given piece of equipment. For this experiment, three electrodes

[60] At one time, there was a suggestion that the countries were simply being handled in alphabetical order according to the cyrillic alphabet. This does not hold true, since Poland even in the cyrillic alphabet appears later than Bulgaria, and the letter "ch" in cyrillic, which is the first letter of Czechoslovakia, the first Interkosmos country to send a cosmonaut into space, is the 25th letter of the cyrillic alphabet.

were attached to the cosmonaut's chest, while another wire linked the Cardioleader device to the exercise equipment.

Audio

This experiment studied noise levels and the frequency characteristics of the noise in the space station, about which there had been numerous complaints from crews.

Smak or Vkus

This "taste" experiment, in which taste buds were electrically stimulated, determined how taste changes in space conditions. Some of the cosmonauts had complained that food that once tasted wonderful began tasting like sawdust or ashes.

Vremya

The "time" experiment was designed to test the crew's ability to react speedily to commands given by man or machine.

Speech

The speech experiment was developed by East German scientists and required East German Cosmonaut Sigmund Jähn to repeat a phrase (the number 226 in German, a real tongue twister) during communications sessions with Earth to study tone, volume, rate and other characteristics of his speech to determine how he felt in weightlessness compared to how his voice sounded.

Balaton

This joint Soviet/Hungarian experiment concerned the intellectual and motor performance of the crew. The 420 gram instrument was held in the cosmonaut's hand with two of his fingers touching two sensor plates which recorded the electric conductivity of the skin. Pulse rate was measured from the forefinger simultaneously, as was the perspiration rate, to determine if the task had been solved easily or with difficulty. Tasks were presented in the form of flashing numbers on a display, with answers given by pressing a button. Eight questions were presented which could be solved in four ways, each with different levels of difficulty. The most difficult of the tests was when the numbers 1 to 4 flashed on the screen 16 times and the cosmonaut had to respond by pressing the button corresponding to the location value. If a correct answer was given, the display would flash more quickly, thus increasing the difficulty of succeeding tasks. The machine would measure response time. The cosmonaut was also required to listen to sounds with varying rhythms through earphones at the same time.[61]

Opros

The "questionnaire" experiment required the cosmonaut to answer nine questions about his eating and sleeping habits, leisure time activities, professional skills, vision, hearing, smell, posture, and need for medication, in order to assess his psychological adaptation to space. These questions were asked at different times

[61] The description of the Balaton experiment is adapted from Neville Kidger's account in the February 1981 issue of Spaceflight, p. 43.

throughout the missions. Each question had a value of 5, and the cosmonaut would list the value reflecting his condition at that time.

Support

The Support experiment was developed jointly by Cuban and Soviet scientists who theorized that changes to the arch of the foot might be partially responsible for the locomotory disorders experienced by cosmonauts during their first days in space. According to those scientists, the arch is always supported on Earth and is an important signalling device to tell a person what his spatial position is, so if it were given more support while in space, the adaptation period might be easier. In this experiment, the Cuban cosmonaut, Tamayo Mendez, wore a special shoe to test the theory.

Cortex

The Cortex experiment was also a Cuban/Soviet project, and involved obtaining electroencephalograms of the cosmonauts.

Anthropometry

A third Cuban/Soviet biomedical experiment was called anthropometry and was simply described as determining the dynamics of change of some anthropometric indices.

Perception

This experiment, as its name implies, studied perception changes in the cosmonauts.

Dose

The dose experiment was designed to measure radiation levels. Pencil-shaped detectors were placed on the cosmonauts' bodies and in various locations around the space station. Every 2 to 3 days, the detectors were placed inside the "Pille" (moth) device to obtain readings on how much radiation had been absorbed since the last reading. The device obtained measurements in the 10 mrad to 10 rad range. Pille weighed less than 1 kg, and required 3 to 4 watts of power.

BIOLOGICAL

Biological experiments (other than those associated with the cosmonauts themselves) included the growth of plants and microorganisms, and studying the behavior of tadpoles and drosophila.

Plants

The space crews propagated a variety of edible plants on Salyut 6, including onions, cucumbers, radishes, dill, parsley, garlic, fennel, and mushrooms (according to the crews, "really strange mushrooms . . . with curly stems"[62]). Apparently the quantity of some of these vegetables was insufficient, since several Progress ships also brought cucumbers and onions.

[62] Tass, 0827 GMT, 14 May 79.

Experiments with the Oazis device continued on Salyut 6, but attempts to grow peas and wheat were unsuccessful. The apparatus had three light sources, interchangeable growing pots with an ion exchange nutrient, a pneumohydroapparatus for supplying measured amounts of water, temperature monitors, and forced ventilation, but still the peas and wheat died in their formative stage.[63]

Attempts to get an Arabidopsis plant to go through an entire cycle, from seed and back to seed again, in the Fiton apparatus[64] were only partially successful. On September 16, 1980, the Soyuz 35/37 crew reported that "some plants have passed the complete cycle of development."[65] A later report clarified this to mean that the Arabidopsis flowered, but did not produce seeds.[66]

During the visit of the Vietnamese cosmonaut, experiments were conducted with the aquatic fern Azolla pinnata, a nitrogen-rich natural fertilizer for rice growing soil, which is native to Vietnam and has a short growing cycle. No further reports were made of how the fern responded to space conditions.

Progress 5 brought the Biogravistat apparatus to Salyut (a later cargo ship brought a new motor for the device which the crew installed after the original stopped working). Biogravistat had a rotating centrifuge and a stationary area on which plant seeds could be placed to determine how they would grow under those two different conditions. Tests showed that the roots of the seeds on the centrifuge grew twice as fast as those on the stationary part, and the root was directed along the radius in whichever direction the centrifugal force acted.

Progress 6, which docked with Salyut on May 15, 1979, brought a tulip that had almost blossomed to the Soyuz 32/34 crew. When the ship was launched, Tass reported that scientists were interested in how the plant would blossom in space, while noting that it would bring a breath of spring to the crew. No further mention was made of tulips until July 25, after the next Progress flight had departed. At that time, Tass reported that it had been found that tulips "produced a nearly halfmeter shoot, yet the buds refused to open."[67] Whether that was a reference to the Progress 6 tulip or another one brought up by Progress 7 or Soyuz 34 is unclear. What is obvious is that the plants were not behaving in the expected manner. After the Soyuz 32/34 mission, Tass reported that Soviet scientists were trying to find out "why plants in outer space conditions do not blossom and bear fruit," suggesting that they had no better luck later in the mission. Theories on why the plants would not blossom included: Lack of gravity; changes in the plant's mechanism of disposing of waste products so that the wastes "hang" in zero G; or the plant's metabolism stalls or discontinues entirely.[68]

The Soyuz 35/37 crew brought a special apparatus called "Malakhit" for growing orchids in space. The orchids were brought to

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[63] Nauka i Tekhnika, August 1981, pp. 12-13.

[64] During the Soyuz 38 and T-3 missions, an Arabidopsis experiment was carried out in an instrument called Svetoblock. Whether this is the same as Fiton or a different arabidopsis experiment is unclear.

[65] Tass, 1310 GMT, 16 Sep 80.

[66] Nauka i Tekhnika, August 1981, pp. 12-13. An Arabidopsis finally did complete a full seed-to-seed cycle on Salyut 7, however (Tass, 2150 GMT, 23 Sep 82).

[67] Tass, 1907 GMT, 25 Jul 79.

[68] Tass, 1245 GMT, 10 Sep. 79.

the space station in a flowering state, but once on board, the flowers almost immediately fell off. When the experiment was repeated, the flowers fell off again.[69] In another experiment, orchids were grown in space and although they developed normally for 177 days, they did not produce flowers at all.[70]

The chlorella algae experiments begun on previous space stations were continued on Salyut 6. These experiments are conducted in the hope that one day closed-cycle space stations can be orbited that will not require resupply missions from Earth.

Microorganisms

Several experiments were conducted on microorganisms. One was a joint Cuban/Soviet experiment called "Hatuey" for studying yeast growth. Yeast is a unicellular microorganism with a short life cycle, allowing research on numerous generations which develop on board the space station. The experiment was designed to study intracellular processes.[71]

Another experiment was called "Cytos" and was developed jointly by Soviet and French scientists to study the kinetics of cell division. Two types of protozoa were used for the experiment: The French chose Paramecium while the Soviets chose Proteidae. The samples were refrigerated until just prior to the launch of Soyuz 27. On the eve of the launch, the specimens were placed in a "Bioterm-8" device which maintained a temperature of +8 degrees C during launch and until docking with the space station. After docking, they were placed into the French device "Cytos" where they were "awakened" by warmer temperatures maintained at +25 degrees C. In 4 days, 8 consecutive generations were produced.

The Soviet/East German Soyuz 31 crew conducted an unusual experiment called "sewing of microorganisms," which was developed by the Aviation Medicine Institute in Koenigsbrueck. According to the Tass description, East German scientists reasoned that since gravity affects the geometry of formations such as floccules, which consist of microorganisms and organic polymers, the sewing of such polymers might help in obtaining new medical preparations.[72]

To study the effect of cosmic rays, flasks containing biopolymers were placed on the outside of the space station by the Soyuz 26 crew when they went out on EVA early in the mission, and were retrieved by the Soyuz 29 crew. Control flasks were kept inside the station for comparison purposes. This experiment was called "Medusa," and no further information was found on what results were obtained.

Tadpoles and flies

The droscphila experiments continued on Salyut 6. A new generation was born every 2 weeks for heredity studies. The flies had their own "thermostat house" which maintained a constant tem-

[69] Nauka i Tekhnika, August 1981, pp. 12-13.

[70] Chernyshov, Makhail. Salyut 6: From Holography to Space Plant Growing. Novosti Press Agency. Reprinted in Space World, March 1981, p. 24.

[71] A similar experiment called Multiplikator was also mentioned. It is unclear whether they are the same

[72] Tass, 1627 GMT, 29 Aug. 78.

perature of 24 degrees C. They were delivered to Salyut in containers, which were then transferred to the thermostat house, and later returned to Earth. These experiments continued throughout the various Salyut missions.

Another experiment was conducted with tadpoles to see how they would adjust to a lack of gravity. There were two groups of specimens, one born on board the space station and another brought from Earth. The Soyuz 26/27 crew found that the Earth-born tadpoles swam in a disorderly manner "for a whole fortnight" without knowing top from bottom, while those born in space swam in an orderly, spiral pattern.

EARTH RESOURCES

Observations of the Earth's atmosphere, land masses and oceans occupied 60 percent of the crew's time on these Salyut 6 missions. Four different cameras, a 15-band spectrometer, an electrophotometer, and visual observations (using binoculars in some instances) contributed to these studies. Atmospheric studies are the subject of a later subsection; Earth and ocean studies are discussed here.

During the course of the nearly 3 years of flights to Salyut 6 covered by this report, virtually every area of the planet within range of the space station was observed. To prepare for this role, cosmonauts were given lessons by geological and scientific experts in a TU-134 airplane.

By way of emphasizing the importance of this work, A.P. Alexandrov, president of the Soviet Academy of Sciences, commented that it takes only 10 minutes to photograph a million square kilometers from Salyut, which would take several years to accomplish with aerial photography.[73]

From 1977-80, 9,500 photographs of the Earth were taken by the MKF-6M multispectral camera and another 4,500 were taken with portable and stationary single-channel cameras. Additionally, 100,000 spectra of the Earth's surface and atmosphere were registered.[74]

According to experts at the Soviet Priroda center, the economic effect of Earth resources photography and observations from space from 1978 to 1981 "exceeded 56 million rubles in the Central Asia region alone, in addition to shortening the time required to create cartographic documentation by 75 to 80 percent." [75] (This would have included remote sensing systems other than Salyut, though. See part 3, chapter 4, for a description of the other satellite systems.) Several hundred organizations of 22 Soviet ministries and departments contributed to defining the Earth resources program conducted on Salyut 6.[76]

Despite all the remote sensing equipment on Salyut 6, visual observations were nevertheless a very important part of the research. Vladimir Lyakhov, a member of the Soyuz 32/34 crew, commented

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[73] Looking to Orbits of the Future. Izvestiya, July 14, 1981, p. 2.

[74] Tass, 0532 GMT. 12 Nov 80.

[75] Shnyrev, G. Multizonal Photography System Proposed for USSR State Prize. Izvestiya, 30 Aug 82, p. 2.

[76] Izvestiya, 14 July 81, p. 2

that after a period of time, looking at the ocean was like learning to see anew.

> Although the ocean's surface seemed at first to be monotonously homogenous, after half a month we began to differentiate the characteristic shades of one sea or another and different parts of the world ocean. We were astonished to discover that during a flight, it's as if a cosmonaut learns how to see all over again. At first the finest nuances of color elude you, but gradually you feel that your vision is sharpening and your eyes are becoming better, and all of a sudden the planet spreads itself before you with all its unique beauty.[77]

Binoculars were delivered to the crew to assist in the visual observations, and it was determined that 6× and 12× magnifications were the most convenient.[78]

The relationship between remote sensing activities in space and the Priroda center is described in part 3 of this report so will not be reviewed here. Rather, the types of equipment used and what the crews viewed during their missions will be summarized. Soviet media accounts of the flights do not always make clear whether observations were accomplished visually or using which piece of equipment. There were four different cameras on board the station, some for still photographs, others for moving pictures, and usually the various systems were used in concert with each other.

The MKF-6M and KATE-140 cameras were permanently affixed to the space station, while the others (Pentacon 6M and Praktica EE2) were portable, permitting photographs of areas that might not be in view of the two stationary cameras. During Earth observation sessions with the MKF-6M and KATE-140, the space station was oriented so the axes of the cameras pointed toward the nadir, an orientation maintained with the Salyut engines. This required a significant expenditure of fuel, partially accounting for the frequent Progress refueling missions.

MKF-6M multispectral camera

The first flight of the MKF-6 camera, developed by East Germany, was made on Soyuz 22 (see p. 532 of this chapter). The success of that mission led the Soviets to include a slightly modified version of the camera, designated MKF-6M, on Salyut 6. Its six spectral bands are: 0.46-0.50 microns, 0.52-0.56 microns, 0.58-0.62 microns, 0.64-0.68 microns, 0.70-0.74 microns, 0.78-0.86 microns.

Since the original camera was only designed to operate for about 2 weeks, the Salyut version had to be designed to last longer. Thus, designers "doubled the vital mechanical and electronic systems" and made the systems more "robust" to ensure that they could survive the loads associated with liftoff and dockings.[79] They also made the camera easier to handle, and it was reported that the first two crews "were able to do all the necessary operations with one hand, using the other if necessary, 'to hold on to something' in the space station." Changing film cassettes was also made easier by modifying the sprokets (each cassette weighed 13 kg and had 1,200 frames of film). The film was brought to Salyut by Progress mis-

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[77] Quoted in: Novikov, N. Sovetskiy Voin, No. 8, 1981, pp. 28-29.
[78] Grechko, G.M. et al. Issledovaniye Zemli iz Kosmosa, No. 1, Jan-Feb 1982, pp. 5-13.
[79] Hempel, Wilhelm. MKF-6 Multi-Spectral Camera in Space. Spaceflight, Mar. 1979, pp. 110-112.

sions, since keeping a supply on board would not only take up too much space, but cosmic rays might have exposed the film.

During the time that the camera was operated East German experts were available in flight control center to assist the crew if necessary. To facilitate space-ground communication about the instrument, two special devices were installed in the MKF-6M to telemeter information to the ground about whether the camera was on and if the film was advancing. In addition, an alarm on the control panel would warn the crew if the film broke. Altitude was recorded automatically.

One MKF-6M image shows an area of 225×155 km, or about 35,000 square kilometers. This is 84 percent more than when the camera was used on Soyuz 22 because of the higher altitude of the space station. The camera permits 60 percent overlap of adjacent areas, thus providing stereo images. The Soviets have said only that the spatial resolution of the MKF-6M is "tens of meters," [80] but it is thought to be about 20 meters on the Salyut 6 version, while it may have been as good as 10 meters when flown on Soyuz 22 because of the lower altitude.[81] A member of the East German Astronautical Society has stated that when the camera was flown on Soyuz 22, "in fine weather one [could] recognize even small weekend houses on the pictures—taken from a distance of 250 km."[82]

KATE-140

The KATE-140 (also referred to as the KT-140) is a wide angle, stereographic, topographical camera for making contour maps. One frame covers 160,000 square miles "with a high degree of definition." [83] The 85 degree field of view permits an image 450×450 km from the 350 km Salyut orbit. The camera could provide both single and strip photographs and had two film cassettes, each with a 600 frame film supply. It could be operated by the crew or on command from Earth.

Biosphere

The Biosphere experiments were done by visual observations assisted by binoculars and chromaticity atlases, and with hand held cameras, probably including the Pentacon 6M East German camera, although it was not specifically named. These experiments were conducted particularly when visiting Interkosmonauts were on board, at which time they would focus on the area around whatever country he was from.

The primary objectives of the Biosphere series were: To improve methods of space photography including selecting optimum angles for photographing specific natural objects in different states and selecting the best films, light filters and settings to best reflect actual land and water patterns; to clarify how well photographs reproduce

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[80] Arkhipov, V. V. and L. A. Ronzhin. Earth's Natural Resources in Manned Flights of Intercosmos Programs. Zemlya i Vselennaya, Mar.-Apr. 1982, pp. 20-28.
[81] Pirard, Theo. Salyut 6 Space Station: Three Years in Orbit and Still Operational. Space Age Review, September-October 1980, p. 3. Aviation Week and Space Technology, January 2, 1978, p. 11.
[82] Hempel, op. cit., p. 110.
[83] Moscow Domestic Service, 2004 GMT, 23 May 80.

the chromaticity of the underlying surface; to develop and improve methods of visual identification of objects and their state by the crews; and to investigate optical properties of the atmosphere in different conditions.[84]

Among the areas studied were geological formations (lineaments, circular, dome-shaped and crater-like structures), ocean basins (currents, ocean fronts, zones of upwelling, eddy formation, regions of biological productivity), meteorological phenomena, pollution (atmosphere, land, and water), and natural phenomena (cyclones, dust and sand storms, fires, floods, volcanoes).[85]

Spektr-15 spectrograph

The Bulgarian-made Spektr-15 instrument weighed 10.5 kg and was designed for spectroscopic surveys of the Earth's surface and atmosphere, and recorded light in 15 spectral bands to distinguish, for example, between crops that were ripe and those that were not, or to define the boundaries of ocean currents and plankton accumulations.

The Spektr-15 was used extensively during the Interkosmonaut missions, with experiment names varying with each country: Bulgarian—Balkan, Hungary—Pannoniya, Vietnam—Kyulong, and Cuba—Antiyas. The Bulgarian observations were made by the Soyuz 32/34 crew.

Land and ocean observations

The Soyuz 26/27 crew reportedly photographed the Central Asian Republics, Kazakhstan, the Altay region, the Volga region, and the Central Chernozen zone in January 1978, and Siberia and the construction site of the Baykal-Amur railway in February. Only 10 percent of the observation time was spent on photography for purely scientific purposes, while the remainder of the time was devoted to photographing specific features at the request of specialists.[86]

The next mention of the use of the MKF-6M was with the Soyuz 29 crew during the visits of Soyuz 30 and 31 when they took photographs of the Interkosmonauts' home countries, Poland and East Germany. The sessions were called "Ziemia" and "Syomka" respectively. In the case of the Ziemia observations, at least, simultaneous photographs were taken by aircraft.

By the end of the Soyuz 29/31 mission, "hundreds" of photographs had been taken and "hundreds of pages" of drawings and descriptions of atmospheric and surface phenomena had been made.[87] Among the areas specified as having been photographed were: The Crimea, the Caucasus, the southern Urals, the low-land on the coasts of the Caspian Sea, Kazakhstan, the Central Asian republics, Siberia, the Trans-Baykal region, the Far East, the European part of the Soviet Union, Belorussia, the Ukraine, and the Pamirs (in particular snow caps and glaciers). These observations led to the discovery of underground water in the Mangyshlak Pe-

[84] Koval, Aleksandr. "Salyut-6" and Cooperative Earth Resources Studies. Ekonomicheskoye Sotrudnichestvo Stran-Chlenov Sev. Mar.-Apr. 1982, pp. 30–32.
[85] Ibid.
[86] Tass, 1304 GMT, 19 Jan 78.
[87] Tass, 1110 GMT, 30 Oct 78.

ninsula area on the eastern coast of the Caspian Sea, which had been thought to be devoid of water even after geological prospecting.[88]

Special mention was made of taking pictures of the Rostov region, one of four "pivots" identified by specialists for studying the utility of space-based remote sensing. The others were: Preparing a geobotanical chart of the Balkhash Lake, mapping pastures in Turkmenia, and studying irrigated fields in Uzbekistan. The Rostov region has the "Salskiy" experimental lot where a wide variety of cereals, vegetables, and grasses are grown, and experiments focussed on whether the different crops could be distinguished from space.

The Soyuz 32/34 crew spent the first part of their mission making visual observations rather than using the cameras. Beginning in April, however, reports appeared that the MKF-6M and KATE-140 cameras were being used to study the Baykal area, the Caspian Sea, Kazakhstan, the Caucasus, and the Volga Delta. In early June, they studied the forests of the Far East at the request of specialists, and later that month focussed on the agricultural areas of the Ukraine, Urals and Kazakhstan. At the very end of June and beginning of July they photographed the southern part of the Soviet Union, the Altay region, Siberia, the Far East, the Ukraine, the Volga Delta, the southern Urals, and Kazakhstan. At that time, they observed a wide belt of plankton for 1,000 km near the Kurile Islands in the Pacific.[89]

At the beginning of the Soyuz 35 mission, the Soviets announced that Earth resources would be prominently featured during the flight and that the crew was specifically charged with studying the ocean and its biological productivity.

By request, the crew studied the areas around the Caspian Sea, central Kazakhstan, southern Siberia, and the eastern part of the Baykul-Amur railway. Geologists were especially interested in linear and ring structures, and the crew studied these types of formation from aircraft as part of their pre-launch training. One of the Salyut 4 crews (Romaneko and Grechko) had discovered 25 faults and ring structures that might contain mineral deposits.[90]

During the visit of the Hungarian cosmonaut, a great deal of Earth resources work was accomplished. In one experiment called "UTROF," MKF-6M photographs were made of Lake Balaton to assess its ecological state. Simultaneous observations were made from an AN-30 aircraft at 6-7 km altitude, an AN-2 aircraft at 1.7-2.7 km altitude which took multispectral data in four bands, and a helicopter at 1 km altitude which took infrared photographs. Meteorological data and soil and water samples were also recorded during the experiment.

Other experiments with the Hungarian included studies to determine the Kishkere Reservoir's effect on soil salination, observations of the Carpatian Basin and the Tisza River Basin, and the Biosphere series in which 100 photographs and observations were made of ocean and weather formations.

[88] *Tass*, 1937 GMT, 16 Aug 78.
[89] *Tass*, 1216 GMT, 6 July 79
[90] *Tass*, 1655 GMT, 8 May 80

When the Vietnamese cosmonaut visited later in the year, another intensive session of Earth resources work was held for agricultural, hydrological, geological and forestry investigations. Among the tasks were evaluating existing soil resources, finding the maximum boundaries of heavy floods, defining the inner boundaries of the penetration of tidal sea waters, and studying changes in the shape of sea coasts due to erosion and sedimentation.

After the Vietnamese/Soviet crew returned to Earth, the Soyuz 35/37 crew continued observations of the Krasnoyarsk region, the Trans-Baykal area, and the Far East, as well as Central Asia, and the Caspian and Aral seas. At the end of August, the crew conducted daily studies of the Soviet Union and the world's oceans, including the southern Ukraine, Central Asian republics, the Black and Caspian Seas, the Caspian lowlands, Kazakhstan, and Lake Baykal. These observations were made with handheld cameras, Spektr-15, and the RSS-2 spectograph. (This is the only time during these Salyut 6 missions than an RSS-2 spectrograph was mentioned.)

In mid-September, the crew was reportedly studying the dynamics of currents in the Indian Ocean and looking for dynamic formations in the Sargasso Sea, the Caribbean and the Gulf of Mexico. When the Cuban cosmonaut arrived later that month, the Tropic 3 set of observations was conducted for observing specific areas of Cuba.

By the end of the Soyuz 35/37 mission, more than 3,500 MKF-6M photos had been taken, and 1,000 images with the KATE-140. A total of 100 million square kilometers had been photographed.

Among the findings from the observations was the discovery by Popov and Ryumin of three lineaments of meridional orientation in Hungary. Oil and gas deposits were found to be connected with the central lineament. Space observations also showed that Cuba was covered with a dense network of geological faults intersecting each other, especially in the western and eastern edge zones.[91]

The above descriptions of the areas investigated by the Salyut crews are based on Soviet press accounts and translations of articles in scientific journals. It is reasonable to assume that they also spent a great deal of time looking at other countries that passed beneath them, not just the oceans. The Soviets do not mention this, however, stating only that the observations were in the interests of the national economy. Such a statement certainly does not preclude observations of, for example, the wheat growing regions of the world to assess what the yield, and therefore potential price, of wheat would be in a given year.

Some of the observations may also have served the military sector. This possibility is discussed below.

ATMOSPHERIC STUDIES

The BST-1m submillimeter telescope

One of the instruments used for atmospheric observations was the BST-1m telescope for recording data in the infrared (thermal), ultraviolet and submillimeter ranges. It was the largest instrument

[91] Arkhipov and Ronzhin, op. cit.

on the space station (650 kg in mass) and had cryogenically cooled receivers which had to be calibrated each time it is used. Because of the large expenditure of time and power (1.3–1.5 kilowatts) required for its operation, it apparently was not used as often as other systems such as the MKF–6M.

The telescope had a 1.5 meter diameter mirror and an optical sight with 12X magnification. The receivers were cooled by liquid helium (at −269 degrees C) which was prepared on board the space station.

One of the primary goals of the BST–1m was studying Earth's ozone layer, although other atmospheric studies were done as well, together with observations of planets (Jupiter, Mars and Venus), stars (Sirius and Beta Centaurus especially), galaxies, and the interstellar medium. It also observed the Moon during a lunar eclipse. At certain times, simultaneous measurements were made with balloonborne instruments to obtain comparison data.

One of the results of the BST–1m observations was the discovery of anomolously strong emissions in the submillimeter band in areas of thunderstorm formation.[92]

The Yelena gamma ray instrument

A second experiment on Salyut 6 (delivered by Progress 5) for atmospheric studies was the Yelena gamma ray device. Although there are several references to the various crews working with Yelena, there is little information on exactly what was involved. In general, they measured gamma ray emissions inside the space station and from Earth.

The instrument itself weighed 20 kg and its dimensions were 300×300×500 mm. The area of the input window was 50 sq. cm., the angle of view (aperture) was 30 degrees, it operated in the 30–500 MeV range, and required 10 watts of power. It could operate continuously for 20 hours.[93]

Yelena was composed of a gas Cherenkov counter, 8 scintillation counters, 16 photomultipliers, and electronic equipment consisting of 60 integrated circuits, high and low voltage power supply systems, 2 photographic information recorders, and control and signalling panels.

The Soyuz 35 crew encountered a problem with Yelena when a pin broke and they could not use the instrument until a new pin was delivered by the Soyuz 38 crew.

Balloon observations were made to obtain comparison data, and one of the balloons was lost when it landed. When it was finally recovered, some parts were missing (the parachutes and other pieces), although the data recorder was intact.[94]

At the end of the Soyuz 35/37 mission, 100 hours had been spent with the Yelena and BST–1m instruments. Data from Yelena showed an increased stream of high energy electrons in the South Atlantic anomaly. Overall, it was found that background fluxes are

[92] Kotel'nikov, V. Aviatsiya i Kosmonavtika, November 1982, pp. 22–23.

[93] Gal'per, A. The Gamma Telescope in the Space Laboratory. Aviatsiya i Kosmonavtika, November 1980, pp. 44–45. Interestingly, an earlier article by the same author lists the dimensions as 280×348×477 mm, with a weight of 22.5 kg. Zemlya i Vselennaya, No. 1, 1980. pp. 30–33.

[94] Aviation Week and Space Technology, Sept. 1, 1980, p. 48.

highly dependent on latitude, being least at the equator and increasing by a factor of 10 at the higher latitudes.

The Duga electrophotometer

Another instrument used on Salyut 6 for atmospheric studies with the Bulgarian-made Duga electrophotometer. Duga had two modules: The opticomechanical module including the optical telescope, dispersing system, and image converter; and a data recording module which included a digital tape recorder. The image converter had to be replaced because it was producing inverse images; the replacement part was brought to Salyut by Progress 10.

Duga measured the intensity of optical emissions in the upper atmosphere at 6300, 5577, 4278, and 6563 angstroms. A Cassegrain system was used to permit sighting by the cosmonaut, with the viewer located parallel to the optical axis of the telescope. The entire instrument was attached to one the station's windows with a flange.[95]

An "equatorial glow" was discovered using Duga. The optical intensity of the equatorial region was 10 times higher than outside that area, with the brightest emission in the red oxygen line with a wavelength of 6300 angstroms. The green line at 5577 angstroms was also bright, but 4 to 6 times less intense as the red line. No emissions at 4278 or 6563 angstroms were recorded, and since the former is associated with electron emissions and the latter with proton emissions, "the outpouring electron and proton fluxes are very small and cannot explain the equatorial glow."[96]

Other

Among the other atmospheric experiments conducted were "Refraction" and "Zarya," as well as observations of the solar corona, and the aurora borealis.

"Refraction" was described as consisting of two "Polarization" experiments conducted with the Bulgarian Spektr-15 and Duga instruments which involved studies of optical phenomena in the atmosphere and pollution near industrial areas. "Polarization 1" made spectrographic studies of sunlight refraction in the atmosphere, while "Polarization 2" made terrestrial horizon studies using light filters and the VPA-1 analyzer.[97]

"Zarya" involved spectrographic measurements of sunrise and sunset at various altitudes to study air density and temperatures in the stratosphere and troposphere.[98]

An April 1983 article by several Soviet authors (including Popov and Ryumin) discussed another refraction experiment in more detail, although it does not appear to be the same as any of those mentioned above. It was conducted on August 27, 1980. Using a composite forming lens, the Sun's image was projected onto a screen attached to the station, and moving pictures were taken of the image on the screen as it set below the horizon. Salyut was oriented such that the Sun's image was in the center of the screen on

[95] Balebanov, V. M. and A. V. Zakharov. Space Physics Studied in Intercosmos Program. Zemlya i Vselennaya. March-April 1982, pp. 15–20.

[96] Ibid. Wavelengths are often quoted in nanometers (nm). 1 nm = 10 angstroms.

[97] Kidger, Neville. Spaceflight, February 1981, p. 43.

[98] Ibid.

the lens' optical axis, and the stations' residual angular velocity was minimal. The Salyut engines remained off during this experiment. The value of the refraction angle could be determined by comparing the movement of any part of the image relative to a point on the screen. Moving pictures were taken directly of the Sun setting, in addition to the view on the screen. For the direct pictures of the Sun, 750 frames were processed; for the images from the screen, 700 were processed. Both were taken at approximately 24 frames/second. Analysis of these pictures showed strong refractive deformations of the Sun's limb in the form of steps, with refractive discontinuities of the image seen twice. The analysts concluded that both methods were reliable techniques of obtaining atmospheric refraction data.[99]

Experiments called Terminator and Atmosphere were mentioned while the Vietnamese cosmonaut was on board, but no details were provided.

The cosmonauts continued observations of noctilucent clouds in the polar regions to study pollution. These clouds are formed at about 80 km altitude from silicon or iron particles getting into the upper atmosphere from volcanic eruptions. Scientists are curious to know how they form, since clouds require water and there is none at those altitudes. Photographs and drawings by space crews have shown a clear division of the clouds into three layers differing in temperature from 130 degrees to − 150 degrees.

The crews also made observations of the solar corona, and the aurora borealis, as had been done on previous space station missions. Although reports on auroras were made by most crews, a special period of observation was held during the visit of the East German cosmonaut. Jähn made visual observations and drawings, and tape recorded his verbal descriptions. He observed diffuse shapes and arcs which were "sometimes uniform, sometimes radiant." The auroras were gray-green in color, and the brightness did not exceed 2 (a brightness of 1 corresponds to that of the Milky Way)[100]

ASTROPHYSICS: KRT-10 RADIO TELESCOPE

Although the BST-1m submillimeter telescope was occasionally used for observations of planets, galaxies, and other celestrial objects, the only intensive astrophysical activities conducted on Salyut 6 involved the KRT-10 radio telescope.

As described under Soyuz 32, the KRT-10 was delivered to the space station via Progress 7 and deployed out the aft docking unit (see fig. 40). Observations with the KRT-10 were conducted from July 18 until August 9, 1979. Both crew members were required to operate the instrument, and several days were required just to calibrate it.

[99] Gurvich, A. S., et. al. Measurement of Atmospheric Refraction on Board "Salyut 6" Orbital Station and Recovery of Temperature Profile. Izvestiya Akademii Nauk SSSR: Fizika Atmospfery i Okeana. Vol. 19, No. 4, Apr. 1983, pp. 425-427

[100] Balebanov and Zakharov. op. cit.

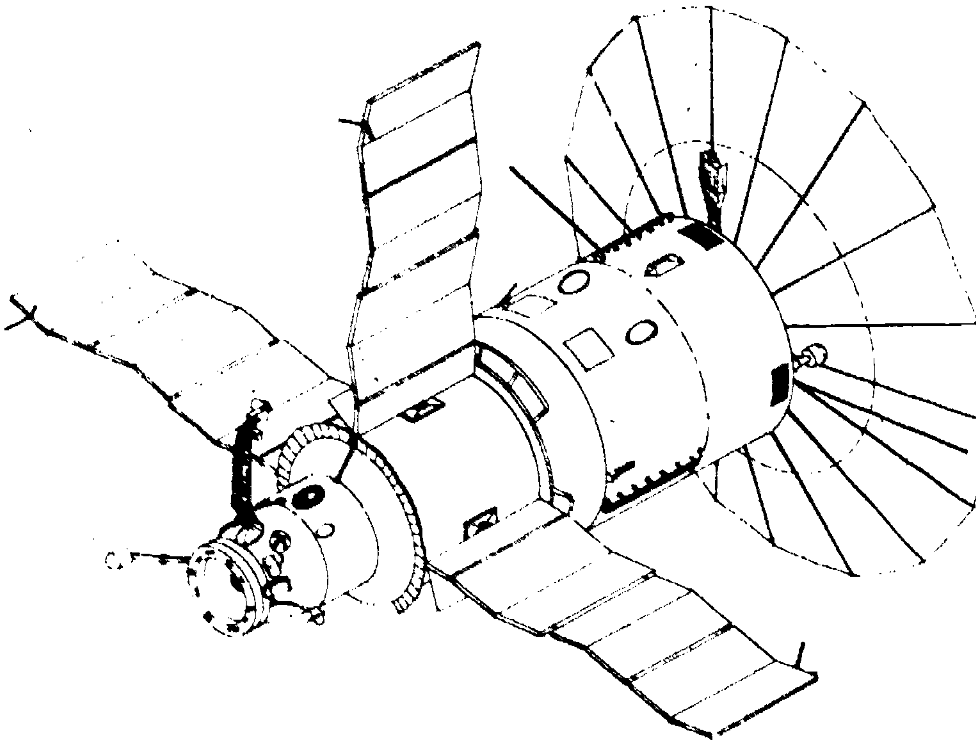

FIGURE 40 - Salyut 6 with KRT-10 radio telescope fully deployed. There is some indication that the antenna did not fully deploy, and hooked on an exterior projection of the space station during deployment rather than as it was being jettisoned, as claimed by the Soviets. (Drawing by R. F. Gibbons. Reprinted with permission from *Handbook of Soviet Manned Space Flight*, Nicholas L. Johnson, American Astronautical Society.)

The telescope was brought up into space in separate pieces: The antenna itself, the focal container with the irradiators (four horns in the 12 cm band and a spiral irradiator in the 72 cm band) with three extendable supports, and the device for attaching the antenna to Salyut. The entire assembly weighed 200 kg, half of which was for the antenna. When directed toward Earth, it had a 7 km resolution in the 12 cm band.[101]

Lyakhov and Ryumin assembled the device, attaching it to the edge of the docking unit with three special claws. They also mounted the control panel and timing device, and laid electrical communications lines.

Once everything was assembled, the crew closed the hatch, and automatic devices pulled the instrument up to the hilt inside the intermediate chamber of the space station, while the antenna remained inside the Progress. Then the Progress undocked (using spring pushers instead of its engines to avoid any damage to the telescope), and the antenna was exposed to open space. The antenna was folded like an umbrella and after Progress was a safe distance away, the restraints holding it in the folded position were released and it unfurled while the space and ground crews watched

[101] Arsent'yev, V. M. et al. KRT-10 Radio Telescope. Doklady Akademii Nauk SSSR. May 1982, pp. 588-591.

via the Progress 7 television cameras. Only a very few still photographs, of poor quality, have been released in the West.

Some of the experiments with the KRT-10 were done in conjuction with a 70 meter radio telescope located in the Crimea. The distance between the two telescopes varied between 400 and 10,000 km depending on the position of the space station. Two primary astronomical studies were conducted. In one, the space station was maintained in a stable orientation mode for observing Pulsar 0329. In the other, the station was rotated circularly around a transverse axis in order to map the Milky Way.[102] Observations of the Sun and the star Cassiopeia A were also made.

Extensive Earth-looking studies were conducted for geological and other purposes. The oceans were special areas of interest. Mount Etna erupted during this time and it was detected by the KRT-10.

When experiments with the telescope were completed on August 9, the crew attempted to detach it from the docking port in order to make way for future spacecraft. Vibrations developed, however, and the antenna caught on part of the space station that jutted out. The crew had to free it during an EVA.

There has been speculation in the West that the antenna actually caught on part of the space station while it was unfurling, not when the crew tried to release it, and that it never fully deployed. This hypothesis has been partially fueled by the lack of high quality photographs showing the KRT-10's deployment. Dr. Bernard Burke of the Massachusetts Institute of Technology has seen a plot of the data returned from the high frequency feed and found that it was much poorer than he would have expected. While agreeing that one explanation could be that the antenna did not deploy properly, he adds that it could have simpiy been a case of poor design of the feed itself.[103]

As mentioned, this radio telescope was 10 meters in diameter, and Soviet scientists immediately expressed the desire for larger telescopes, first 10 to 100 meters in diameter and eventually 100 to 300 meters. They feel these instruments would be useful both for studies of the universe and Earth, in the latter case providing data on humidity, snow cover, meteorological parameters, and oceans.[104] Nikolay P. Mal'nikov, director of the Central Scientific Research and Design Institute for Steel Construction of the Soviet Ministry of Construction revealed that work connected with the construction of large space radiotelescopes had been going on at his institute since the mid-1960's, and that design work was now proceeding for folding antennas with diameters of 30 to 100 meters. He predicted that some day there would be such antennas on the Moon and other planets.[105]

[102] Zagura, I. Institute Director Discusses KRT 10 and Other Space Antennas. Stroitel'naya Gazeta, 12 Apr 81, p 3

[103] Private communication, Oct 1983

[104] Tass, 0340 GMT, 20 July 79

[105] Zagura, I., op cit

MATERIALS PROCESSING AND OTHER TECHNICAL EXPERIMENTS

Technical experiments related to processing certain alloys and semiconductors on Salyut 6 are discussed in detail on Part 3 of this study. The following will briefly highlight activities of the various crews. Other technical experiments that do not quite fit the definition of materials processing (such as holography) are also discussed here.

Splav and Kristall furnaces.

There were two materials processing furnaces on Salyut 6: Splav (Alloy); and Kristall (Crystal). Some materials were processed in both devices.

During the materials processing experiments, the space station usually was placed in a gravity gradient mode so that the engines would not have to be used, since any vibration might affect the process. Many were done while the crew was asleep to further reduce interfering motions. Results (see subsection d) indicated that there were problems with vibrations on board the station during the course of the experiments, however. Since many of these took place over as many as 3 days, this is not surprising.

Materials processing work occupied a considerable portion of the crew's time on all the flights to Salyut, including the visits from Interkosmonauts. In most cases, a special materials processing experiment was devised jointly by Soviet scientists and those from the Interkosmonaut's country. A 1982 article by S.D. Grishin summarized the results of some of the Interkosmonaut materials experiments, and these are reported on p. 606.

A great many materials were the subject of experiments during the 3 years of Salyut described in this report, but the largest number by far were done on three combinations: cadmium-mercury-telluride, indium antimonide, and gallium arsenide.

The following is an alphabetical list of all materials identified by the Soviets as being used in materials processing experiments. K indicates the experiment was performed in Kristall; S designates Splav. A question mark indicates that it is unclear where it was performed. Some materials were used in both. If the experiment was developed jointly with another country, the name of the country and the name of the experiment is indicated. An asterisk indicates that multiple experiments were conducted.

Aluminum-antimony	S	
Aluminum-tin molybdenum	S	
Aluminum tungsten	S	
Bismuth antimony	S	(E. Germany, "Berolina").
Bismuth-tellurium-selenium	?	(Vietnam, "Halong").
Cadmium mercury-telluride*	S	(Mostly Soviet, but also Poland, "Sirena")
Cadmium mercury-selenium	K	(Poland, "Sirena").
Cadmium selenide	?	
Cadmium sulphide*	K	
Copper aluminum	S	(Hungary, "Bealuca")
Copper-indium	S	
Gallium antimonide	?	(Hungary)
Gallium arsenide*	K	

Gallium arsenide-aluminum	?	(Cuba, "Caribe")
Gallium arsenide-chromium	K	(Hungary, "Eotvos")
Gallium bismuth	K	
Gallium phosphide with varying trace elements	?	(Viet-nam, "Halong").
Gallium molybdenum	S	
Arsenide and antimonide of gallium and gallium bismuth	?	
Germanium*	K/S	(Mostly Soviet, but also E. Germany, "Berolina")
Germanium-antimony-sulphur	K	
Indium antimonide*	K/S	(Mostly Soviet, but also Hungary)
Indium antimonide alloyed with zinc and tellurium	S	
Indium arsenide*	K	
Lead-selenium-tellurium	K	(Poland, "Sirena).
Lead telluride	K/S	(E. Germany, "Berolina")
Lead-tin	K	(France)
Silver lead chloride and copper lead chloride	S	(Czechoslovakia, "Morava")
Sugar	K	(Cuba, "Zone, Sukhar")
Vanadium oxide	S	(France)

The Splav furnace was delivered by Progress 1 and was mounted in an airlock so the heat it generated would dissipate into space. It weighed 22 kg, and had three heating areas: A hot area which could maintain temperatures up to 1,100° C; a cold area with a maximum temperature of 600 to 700° C; and a gradient area capable of a linear temperature change from the maximum to the minimum. Molybdenum reflectors inside the furnace were used to focus the heat on the samples. The unit required 300 watts of power to operate.

Capsules 170 mm long and 20.6 mm in diameter containing the material to be processed were placed in each area, with each capsule containing three crystal ampules which would fuse together at high temperatures. Monocrystals would form in the gradient area, while three dimensional crystallization would take pace in the hot and cold areas; the ingots thus produced were returned to Earth for study. A computer maintained the correct temperature to within 5 K of the desired degrees C reading.

In one instance, the Soyuz 35/37 crew experimented with directional solidification with the Splav furnace, using Salyut itself as a centrifuge. On August 8, 1980, an ampule containing an unspecified substance was placed in Splav. The furnace was turned on and Salyut was then rotated around one of its axes (it was described as a "twisting motion" by the Soviet press) for several hours using the orientation engines. Acceleration was zero at the center of the station, increasing out towards the station's extremities. All other materials experiments had been conducted so as to minimize interfering motions, but in this case, scientists wanted to know how a certain amount of artificial gravity would affect crystal formation.[106]

The Kristall furnace was designed primarily for experiments with glass, and was delivered initially by Progress 2. This unit ceased functioning, however, and a replacement was brought up by

[106] Moscow Domestic Service, 0000 GMT, 9 Aug. 80.

Progress 5.[107] Unlike Splav which was placed in an airlock to facilitate radiating the heat it produced into space, Kristall was designed so that its exterior temperature would not rise more than 50 K above ambient temperatures, so it could simply sit inside the space station.

The temperature was varied differently in Kristall than in Splav. In Kristall, the materials would be brought to a steady state thermal zone where the temperature was between 400° and 1,200° C (but there was no gradient zone as in Splav). The capsules for Kristall were a little longer but much narrower than those for Splav (175 mm long and 9 mm in diameter) and passed through the hot zone at a speed of 0.188 and 0.376 mm/minute.[108]

The Cubans developed the Kristallograph for permitting observations and photographs of what transpires inside Kristall. The Vietnamese experimented with the "Imitator" device for determining the temperature profile in Kristall. The Bulgarians prepared the "Pirin" experiment that was later conducted by the Soyuz 32/34 crew for studying the growth of crystal faces, wetting under weightless conditions, and other processes. Using Kristall, the stability and structure of zinc crystals grown by a diffusion process were studied.

In Splav, a Bulgarian experiment was conducted to study foam metals. A quartz ampule with silumin, titanium hydride, and silicon nitride briquettes located in it was held at a temperature of 800° C for 10 minutes. A porous aluminum ingot was formed.

Ten French experiments were conducted with ampules delivered by Progress 5. The experiments focussed on studying the processes of diffusion during melting and subsequent cooling of metal alloys. Lead-tin and aluminum-copper were used. Other French experiments included some to study magnetic materials and metallic compounds. Tass reported that a magnetic material, "gadolinium-cobalt," was obtained on August 5, 1980, a material used in electronic computing.[109]

The Soyuz 29/31 crew performed the first experiments with glasses in Kristall. The report said only that optical glasses were melted and a monocrystal had been formed; the constituents were not identified.[110] The experiment was apparently a great success, for during the Soyuz 32/34 mission, the Soviets reported that on the basis of the work done on previous missions, scientists were most excited by the work done with optics, apparently for applications to fiber optic system. For these new applications, very pure glass is needed and in space it can be produced without coming into contact with any walls. They stressed that more experiments were required, though.

The first materials experiment on Salyut to use an organic substance, sugar, was performed when the Cuban cosmonaut visited, since sugar is the basis of the Cuban economy. The "Zone" and

[107] In his October 1981 *Spaceflight* summary, Neville Kidger reported that there were three Kristall furnaces: one used by the Soyuz 29/31 crew, a second one returned to Earth by the Soyuz 32/34 crew, and a third one used by Soyuz 35/37. The Soviet accounts of Progress flights and other missions to Salyut 6 scoured by this author reported only two Kristalls.

[108] Grishin, S. D. Production in Outer Space in Interkosmos Program. Zemlya i Vselennaya, Mar.-Apr. 82, pp. 28-32.

[109] Tass, 1112 GMT, 5 Aug. 80.

[110] Tass, 1213 GMT, 7 July 78.

"Sukhar" experiments were not described in detail, but the results were expected to be of great interest to Cuban scientists since they might have a bearing on the production of sugar on Earth.

The interest in cadmium-mercury-telluride was evidenced not only by the many experiments conducted on that material, but also by statements in the Soviet press. The Soyuz 26/27 crew was reported to have obtained a "triple-hard solution" of the substance for use in the manufacture of infrared receivers in medicine and geological prospecting.[111] In fact, an infrared scanning device using space-processed samples of the substance was used on a late Salyut 6 experiment to record the crews' body temperatures.[112] It should be noted that infrared detectors also have military applications.

Cadmium-mercury-telluride experiments were performed on each of the long-duration flights, and included a special experiment with the Polish cosmonaut, called "Sirena." The Warsaw Institute of Physics had been working on cadmium-mercury-telluride for more than 10 years, hence their interest.[113]

Isparitel (vaporizer)

Another set of materials experiments conducted on Salyut 6 involved the 24 kg Isparitel device and were begun by the Soyuz 32/34 crew. The results are expected to have application to the construction of future space stations. Isparitel occupied the same airlock as Splav and used the same control panel, so only one of the units could be operated at a time.

The device was designed to permit study of processes of evaporation and condensation of different materials in space, and was designed by the Yevgeniy Paton Electrical-Welding Institute of the Ukraine Academy of Sciences. In the experiments, coatings were sprayed onto metal, glass or plastic plates by vaporizing the coating material (silver, gold, or alloys containing aluminum, copper and silver) with two powerful electron guns. The vapor would condense on the plate over a period of 1 second to 10 minutes depending on the desired thickenss of the coating. The results of the experiments were expected to be important for future space station construction in terms of placing coatings on construction materials for thermal regulation, or protecting the spacecraft from the "destructive effects of the environment."[114] The first coating experiment had been successfully accomplished by the Salyut 4 crew when they put a new optical coating on the solar telescope.

The Soyuz 32/34 crew encountered difficulties with the device initially, and had to make some precise adjustments to it. These adjustments were successful, and the crew produced 24 samples. By August 1980, 186 Isparitel samples had already reached ground-based scientists, and that number would not have included the final batch done by the Soyuz 35/37 crew. The success of these experiments led Ukrainian scientists to conclude that "Soviet specialists can if necessary apply thermal protective, optical, and other

[111] Tass, 1724 GMT, 23 June 78.
[112] Kidger, Neville. Spaceflight, October 1981, p. 267.
[113] Hempel, Wilhelm. The Splav 01 Furnace. Spaceflight, Feb. 1979, p. 57.
[114] Tass, 1336 GMT, 1 Aug. 79.

coatings on various equipment in space as well as to obtain materials and articles by evaporation and condensation methods."[115]

Lotus

The Lotus experiment, which apparently was delivered by Progress 9, was described as attempting to improve the method of obtaining structures from polyurethane foam. No other details were released.[116]

Biological processing (interferon)

Three experiments on the production of interferon were conducted during the Soyuz 35/37 mission. The first experiment involved placing human white corpuscles and various interferon producing substances in test tubes with a two-way valve separating them. The white corpuscles were warmed to the average human temperature, and the valve was then opened and pistons pumped them into the interferon tube, thus influencing interferon production. The samples were then frozen and returned to Earth.

The second part of the experiment involved interferon pharmaceuticals which had been delivered to the space station in lyophilized gel and liquid states to assess the influence of space conditions on the antiviral effect of interferon production in pharmaceuticals. The third experiment simply involved taking blood samples from the crew to determine whether their stay in space had affected natural interferon production in their bodies.[117]

Holography

The Soviets experimented with holography on Salyut 6, using a device developed jointly by Cuban and Soviet experts. The device was supposed to be operated by the Cuban cosmonaut, but it was not ready in time, so instead was used by the Soyuz T-3 crew at the end of 1980.[118]

The 5 kg holographic camera used a helium-neon laser optical system and registering systems developed in Leningrad. Holography is extremely sensitive to vibrations, so the device was designed to be immune from such influences on Salyut. Vladimir Konstantinov, a research associate at Leningrad's Ioffe Physical-Technical Institute, reported that it had been successfully used to photograph a moving train during ground tests. "In fact, a portable holographic camera was obtained."[119]

On Soyuz T-3, the camera was trained on a salt crystal while it dissolved in a container. Study of the hologram was expected to show how the density of the crystal was distributed throughout the volume of liquid at zero gravity where there are no convection currents. Among the space applications of such a device are evaluation of the condition of the station's portholes (which has been a considerable problem for the crews), and measuring the velocity of gas expelled by the station's engines.

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[115] Tass, 1300 GMT, 27 Nov 80

[116] Tass, 1033 GMT, 20 May 80; Tass, 1034 GMT, 15 July 80.

[117] Kidger, Neville. Spaceflight, v. 23, Feb. 1981, p. 48.

[118] More intensive experiments were conducted by later Salyut 6 crews.

[119] Chernyshov, Mikhail. Salyut 6: From Holography to Space Plant Growing. Novosti. Reprinted in Space World, March 1981, p. 24.

Results of MPS experiments

By the end of 1980, 300 samples had been grown in 181 firings of the Splav and Kristall furnaces.[120] As previously noted, at least 186 Isparitel specimens were produced.

As early as the Soyuz 29/31 experiments, the Soviets were commenting that the goal of materials processing was "not only . . . creating future orbital factories to produce unique materials" but to perform technological experiments for the needs of space exploration itself. "Indeed, future wide-scale exploration is unthinkable without technological operations in orbit, such as welding, soldering and cutting metals."[121]

There has been little discussion of the results of the Soviet materials processing experiments in the Soviet literature, and a 1982 article commented that "the research process is a lengthy one . . . at the present time only the preliminary results are known."[122]

Among the preliminary results published were those involving the Czechoslovakian "Morava" investigations. It was found that compared to Earth samples, hardened melts of crystalline and glass forming materials were more homogenous. In one case, an ampule containing lead chloride and copper chloride was placed in Splav and heated "for several hours" to 500 degrees C, where the temperature was held for 20 hours, and then it was cooled at a rate of 10 degrees per hour. The lead crystals were larger and more perfect than those obtained on Earth, with the component distribution "quite homogenous," but they also had visible deformities (one had a helical surface), which were "obviously" connected with operation of other equipment on the space station during the lengthy period of the experiment.[123]

Kidger reports that in the beginning, only 5 to 10 percent of the cadmium-mercury-telluride crystals were satisfactory, but that the success rate had increased "many fold" by the end of the Soyuz 35/37 flight. In addition, all of the successfully formed samples are usable, and only about 50 mg is required for each infrared detector.[124]

The success that was achieved led the Soviets to exclaim that "Semiconductor crystals obtained in space are in quality immeasurably better than anything which can be made" on Earth.[125] At the end of the Soyuz 35/37 mission, the Soviets commented that they now had grounds on which to conclude that "weightlessness and vacuum can and will serve scientific and technological progress."[126]

From all indications, the Soviets definitely are planning to build orbital factories in the future. In their discussions of modular space stations, they frequently comment that one module might be devot-

[120] Tass, 0532 GMT, 12 Nov 80.
[121] Tass, 1724 GMT, 23 June 78.
[122] Grishin, S.D. and V.V. Savichev. Production in Outer Space in Intercosmos Program. Zemlya i Vselennaya Mar.-Apr. 1982, pp 28-32.
[123] Ibid.
[124] Kidger, Neville. Spaceflight, Oct. 1981, p. 267.
[125] Moscow Domestic Service, 0000 GMT, 9 Aug 80.
[126] Tass, 1613 GMT, 29 Oct. 80.

ed to factory type experiments. Future Soviet space plans are discussed further in a later section.

NAVIGATION

Salyut 6's navigation systems are described on p. 570. Throughout the 1977-80 time period, there were frequent references to the crew conducting navigation studies. The Soyuz 26/27 crew, for example, was reported to be performing tests related to "further mastering the system of orientation and stabilization of the orbital complex in various dynamic modes" and the Soyuz 32/34 crew tested new sensors for "promising systems of space navigation" and were "mastering methods of orienting the orbital complex by means of optical instruments." While some of these may have been related to assessing the best method of orienting the station for certain experiments or tests related to future navigation systems, the frequency with which navigation experiments were performed and the repeated references to the crew performing repairs on the navigation system suggest that there may have been significant problems.

SYSTEMS TESTS

Various systems tests were conducted by all the crews from 1977 and 1980. One was called "Resonance" and involved checks of the stability of the three spacecraft complex (Salyut with the main Soyuz craft plus either another Soyuz or a Progress vehicle).

For these tests, one of the cosmonauts would jump on the running track at precisely timed intervals (using a metronome) while instruments located in various parts of the complex would register the damping of the vibrations so produced. Following tests of Soyuz 26/27, it was reported in the Western media that some crew activities, such as running exercises, were restricted during the time that three spacecraft were docked together.[127]

A second systems test was called "Deformatsiya" to study the deformation of the exterior of the space station when one side was pointed toward the Sun for a long period of time. The information from these tests reportedly was used in helping to align optical instruments.

The "Illuminator" experiment was concerned with studying changes in the optical properties of the station's portholes. Examinations were conducted using the Bulgarian Spektr-15 spectrograph and the East German Pentacon 6M camera. The crew complained that they could not see clearly out the portholes because of dust.

The number of micrometeorite impacts on the station was measured using detectors attached to the outside of the station and retrieved during EVA's. The Soyuz 29/31 crew retrieved one of the detectors and found over 200 impacts, many more than expected. The Soyuz 26/27 crew found a 1.5 mm scratch on one of the portholes as well. Not all of the impacts may have been from micrometeorites since there is a considerable amount of space debris in orbit from previous spacecraft launches.

[127] Aviation Week and Space Technology, Aug. 7, 1978, p. 21.

Tests were conducted throughout the missions of noise levels in the station, since the crews had complained about the noise created by experiments and equipment.

MILITARY EXPERIMENTS

The Soviet Union does not admit to using space for military purposes at all, much less to conducting military experiments on board its space stations.

As noted earlier, during the early 1970's Western experts thought that the Soviets had two space station programs, one primarily for civil purposes (Salyut 1 and 4) and one for military observations (Salyut 3 and 5).

With the arrival of Salyut 6, such a distinction is virtually impossible to make. Using the same criteria as before, Salyut 6 would be classified as a civilian space station since the crew are mixed military/civilian personnel and civilian frequencies are used. The orbit, of course, varies, but most of the time is in the range used by Salyut 4. Whether the Soviets conduct military experiments on board is conjectural.

It should be noted, however, that there is a fine line between photographs of Earth that are used for agricultural, geological and hydrological studies, and those that have military value. The most important characteristic is the spatial resolution of the images obtained. Although any exact information is classified, it is thought that the resolution of military reconnaissance satellites used for looking at specific objects may be as good as 5 cm, while designed for broad area observations would probably require less spatial resolution, perhaps on the order of meters.

The resolution of the MKF-6M camera is thought to be about 20 meters when used in Salyut, which is probably more suited to Earth resources observations than military reconnaissance. The other camera systems are thought to have lower resolution than the MKF-6M.

Visual observations may have greater military utility, however. Looking at ships at sea to determine how easily they can be tracked is one potential military application. Another is observing bioluminescence produced by plankton when it is disturbed, which may give clues to submarine locations.

Materials processing experiments might also have military applications. As noted earlier, cadmium-mercury-telluride, which was the subject of many materials processing experiments, can be used for military infrared detectors, just as it can be used for civilian medical instruments, television components, or many other products. Using Salyut as a target for laser ranging experiments is another grey area which could have both civil and military applications.

So many experiments could have both military and civil applications that it is impossible to say that the Soviets do not conduct any military experiments aboard Salyut, but with the silence on the part of both the Soviet and U.S. Governments as to what these experiments might be, no definitive conclusions can be drawn.

Manned Missions to Salyut 6: 1977-80

INTRODUCTION

The following sections detail the missions of Soyuz 25 through Soyuz 38, and Soyuz T-2 and T-3, those manned missions to Salyut 6 that took place through the end of 1980. Only details of the missions not included in the previous sections is included, for example all information on Progress resupply flights are discussed in detail on p. 572. Experiments conducted by the crews are described on p. 585. Two other unmanned ships locked with Salyut 6 in the 1977-80 time frame: Soyuz 34, which is discussed here as a ferry craft to return the Soyuz 32 crew; and Soyuz T-1 which is discussed under the Soyuz development flights on p. 449.

With the long duration crews, ferry crafts were exchanged with those of visiting missions since the Soyuz has only been proven to be capable of being safely reactivated after a 90-day period of dormancy. Thus, the crew that went up in Soyuz 26 came down in Soyuz 27, and the crew that went up in Soyuz 27 came down in Soyuz 26. This makes mission designations difficult and confusing, since once the original Soyuz 27 crew had returned to Earth in the Soyuz 26 ship, the crew originally called Soyuz 26 was renamed Soyuz 27 even though it was the same crew. The call sign remains with the crew, not the ship.

In this report, missions where ships were exchanged are designated by two numbers: In this case, Soyuz 26/27 and Soyuz 27/26. The first number designates the original ship which brought the crew to the space station, while the second is the ship which returned them to Earth. Both ship duration times and crew duration times are listed in the table at the end of the chapter. In cases where the Soviets did not announce a landing time, it is calculated here based on a table of flight durations published in a Russian book "Kosmos" published in Leningrad in 1982.

In summary, during this period, 14 two-man crews and 1 three-man crew were sent to Salyut 6. Two of these (Soyuz 25 and Soyuz 33) did not dock. Five were long duration missions: Soyuz 26/27—96 days; Soyuz 29/31—140 days; Soyuz 32/34—175 days; Soyuz 35/37—185 days. Valeriy Ryumin participated in both the Soyuz 32/34 mission and the 35/37 mission, thus accumulating almost a year of time in space. The space station was occupied for approximately half the time it was in orbit (see tables 10 and 11).

TABLE 10.—OCCUPANCY OF SALYUT 6: 1977-80

Mission	Dates occupied	Number of days [1]
Soyuz 26/27	Dec. 11, 1977 to Mar. 16, 1978	96
Soyuz 29/31	June 16, 1978 to Nov. 2, 1978	139
Soyuz 32/34	Feb. 26, 1979 to Aug. 19, 1979	174
Soyuz 35/37	Apr. 10, 1980 to Oct. 11, 1980	184
Soyuz T-3	Nov. 28, 1980 to Dec. 10, 1980	12
Total time occupied		605
Total time of Salyut 6 in orbit	Sept. 29, 1977 to Dec. 31, 1980	1,188
Occupancy rate (percent)		51

[1] Note that days on board the space station are one day less than total mission duration, since one day is required for rendezvous and docking.

TABLE 11. —MISSIONS TO SALYUT 6: 1977–80

Mission [1]	Inclusive dates of entire mission [2]	Days onboard Salyut [2]
Soyuz 26 (crew)	Dec. 10, 1977 to Mar. 16, 1978	95
Soyuz 27	Jan 10, 1978 to Jan 16, 1978	[3] 5
Soyuz 28	Mar 2, 1978 to Mar. 10, 1978	7
Soyuz 29 (crew)	June 15, 1978 to Nov 2, 1978	139
Soyuz 30	June 27, 1978 to July 5, 1978	[3] 7
Soyuz 31 (crew)	Aug 26, 1978 to Sept. 3, 1978	[3] 7
Soyuz 32	Feb 25, 1979 to Aug 19, 1979	174
Soyuz 35 (crew)	Apr 9, 1980 to Oct. 11, 1980	184
Soyuz 36 (crew)	May 26, 1980 to June 3, 1980	[3] 7
Soyuz T 2	June 5, 1980 to June 9, 1980	[3] 3
Soyuz 37 (crew)	July 23, 1980 to July 31, 1980	[3] 7
Soyuz 38	Sept 18, 1980 to Sept 26, 1980	[3] 7
Soyuz T 3	Nov 27, 1980 to Dec 10, 1980	12

[1] In some cases, a crew would travel to Salyut in one spacecraft and return in a different one which had been left behind by a visiting crew. Missions in this column indicate the ship on which the crew was launched.

[2] It takes one day for the Soyuz to dock with the space station, so the days on the station are one day less than total mission duration.

[3] A visiting crew.

Source: Data taken from TASS announcements.

These missions to Salyut 6 represented a significant step forward for the Soviets in terms of extending man's duration in space. It was anticipated that the Soviets might try to institute a permanently manned space station with Salyut 6, which would have been possible if they had tried. Why they did not is unknown. They did demonstrate the capability of bringing up a new crew, however.

Also, as noted earlier, the advent of "visiting" crews opened opportunities for the Soviets to fly non-Soviet cosmonauts, and seven of the nine Interkosmos countries were represented during this time period (the other two were flown in 1981).

With the introduction of Salyut 6, the distinction drawn in the West between military and civil Salyuts can no longer be made. Using prior criteria, Salyut 6 would be classified as a civil space station, although there have been reports that the Soviets have conducted military experiments. If an assessment is made of press reports of activities, it can be determined that those civil experiments which are reported must account for the majority of the time spent working by the crew. It is always possible that unreported military experiments also take place, but probably consume less time than those for civil purposes. The one area in which a civil/military distinction is most difficult to make—Earth photography—occupies the largest percentage of reports, however. Thus, it cannot be estimated with any certainty how much time is devoted to military experiments.

Launch and landing opportunities

The rationale underlying the selection of opportunities for manned flights to Salyut 6 has been explained by British analysts Phillip S. Clark and Robert D. Christy. Clark deduced empirically, as shown in figure 41, that landings are chosen so that they take place during the 5 hours before sunset in the landing area. Thus, for a given mission duration, there is a small range of launch times which can give landing under the optimum conditions.[128] This enabled him to make accurate predictions of the launch and recovery times associated with Salyut 6. The ascending node of the Salyut 6 orbit precessed with respect to the Earth-Sun line approximately once in every 60 days, so there was a period of about 10 days at 2 month intervals during which a Soyuz landing could be made under optimum conditions. If the revolution on which landing was made was known, the landing time could be estimated with reasonable accuracy.

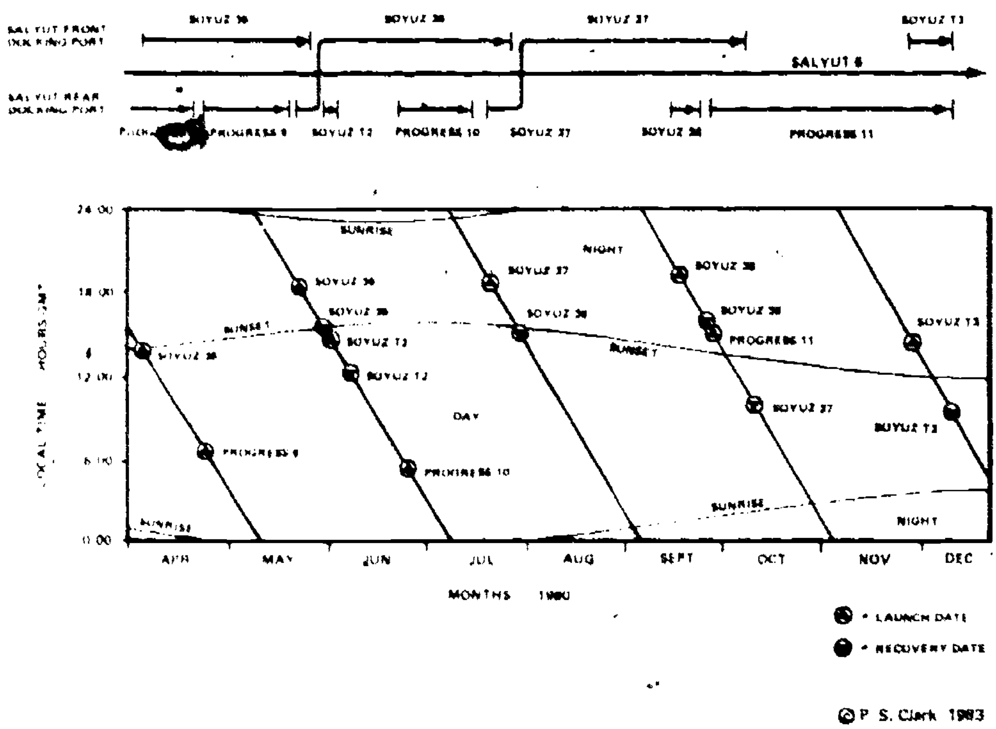

FIGURE 11 Soviet Spacecraft Launch And Recovery Constraints. The orbital plane of Salyut space stations precesses so that they repeat a given pattern of ground tracks once every 56 days. This chart, developed by P.S. Clark, shows a series of diagonal lines that represent the time of day, over a 9-month period, that the Salyut 6 ground track passed over the Tyuratam launch facility. Soyuz and Progress launches fall on these lines. Soyuz landings are in the same region so they fall on these lines as well. Progress reentries are over the Pacific, so they are not governed by these constraints.

The launch times and data for manned missions can also be calculated. For example, the visiting missions lasted for 8 days, so one could begin looking for a flight about 8 days before a recovery "window" opened. If the mission duration for the long duration crews was estimated, and therefore the most likely landing opportunities to be used, a calculation could be made as to launch opportunities.

Beginning with Soyuz 32, the long duration crews on Salyut 6 were launched during a landing opportunity in case Salyut proved unable to support the flight (so the crew could return to Earth

[128] Clark, Phillip S. Soyuz Missions to Salyut Station. Spaceflight, June 1979: 259-263.

under favorable conditions). Thus, the last three long duration missions lasted for approximately an integral number of Salyut orbital plane precessions.

Christy's [illegible] empirical approach [129] is based on two landing constraints which were revealed during preparations for the Apollo-Soyuz Test Project: (a) the landing must take place at least 1 hour before local sunset, and (b) for the purpose of manually overriding the automatic descent program, Soyuz must cross the terminator at least 8 minutes before retrofire.[130] The constraints must be fulfilled on the first pass over the landing site on the planned recovery day and the day after.

For a solo space mission like Soyuz 9, the choice of flight dates is completely open, but for flights to an already orbiting space station, recovery dates are dictated by whether or not the Salyut orbit obeys the constraints.

The second constraint may only be broken in the case of an emergency landing like that of Soyuz 33, but the first constraint may be waived if it conflicts with other mission requirements. This happened with some of the Interkosmonaut missions because one requirement of those flights was that citizens of the participating country be able to observe Salyut in the night sky while their cosmonaut was aboard. In cases where the countries were in the more southerly latitudes (Cuba and Vietnam), this could not have been achieved had the constraint been observed.

Typical mission features

All launches to Salyut 6 (like that of the space station itself) are made out of the facility at Tyuratam (see figure 43) into an orbit inclined at 51.6 degrees. Routinely, the Soyuz spacecraft will make orbital adjustments on revolutions 4 and 17, with docking on revolution 17-18. Docking occurs at approximately 25 hours and 40 minutes Ground Elapsed Time. On the crews with two cosmonauts, the pilot enters the space station first, followed by the commander.

At the end of the mission, the Soyuz lands approximately 3 hours and 20 minutes after undocking from the space station. Landing occurs in the area near Dzhezkazgan and Tselinograd (see figs. 42 and 43). The cosmonauts are given a preliminary physical examination at the landing site and then are flown to Tyuratam for varying lengths of time depending on the duration of their mission and subsequent readaptation to Earth's gravity. Sometime thereafter (the date is variable and may depend more on the schedules of the political personalities involved than anything else), the crewmembers are awarded the Hero of the Soviet Union title and/or an Order of Lenin. In general, a cosmonaut on the first and second flights will get Hero of the Soviet Union (and is thereafter referred to as "twice Hero of the Soviet Union") along with an Order of Lenin, and if he flies additional missions, will only be given the Order of Lenin. Cosmonauts whose missions have not been successful are frequently given only the Order of Lenin, unless the fault

[129] Christy, R. D. Safety Practices for Soyuz Recoveries. Spaceflight, v. 23, Nov. 1981: 321-322.
[130] Apollo-Soyuz Test Project—Launch Window Plan. ASTP Mission Document 40100-2, Oct. 1973.

clearly lay with systems and not their actions. Also with less-than-successful missions, the award ceremony may be delayed.

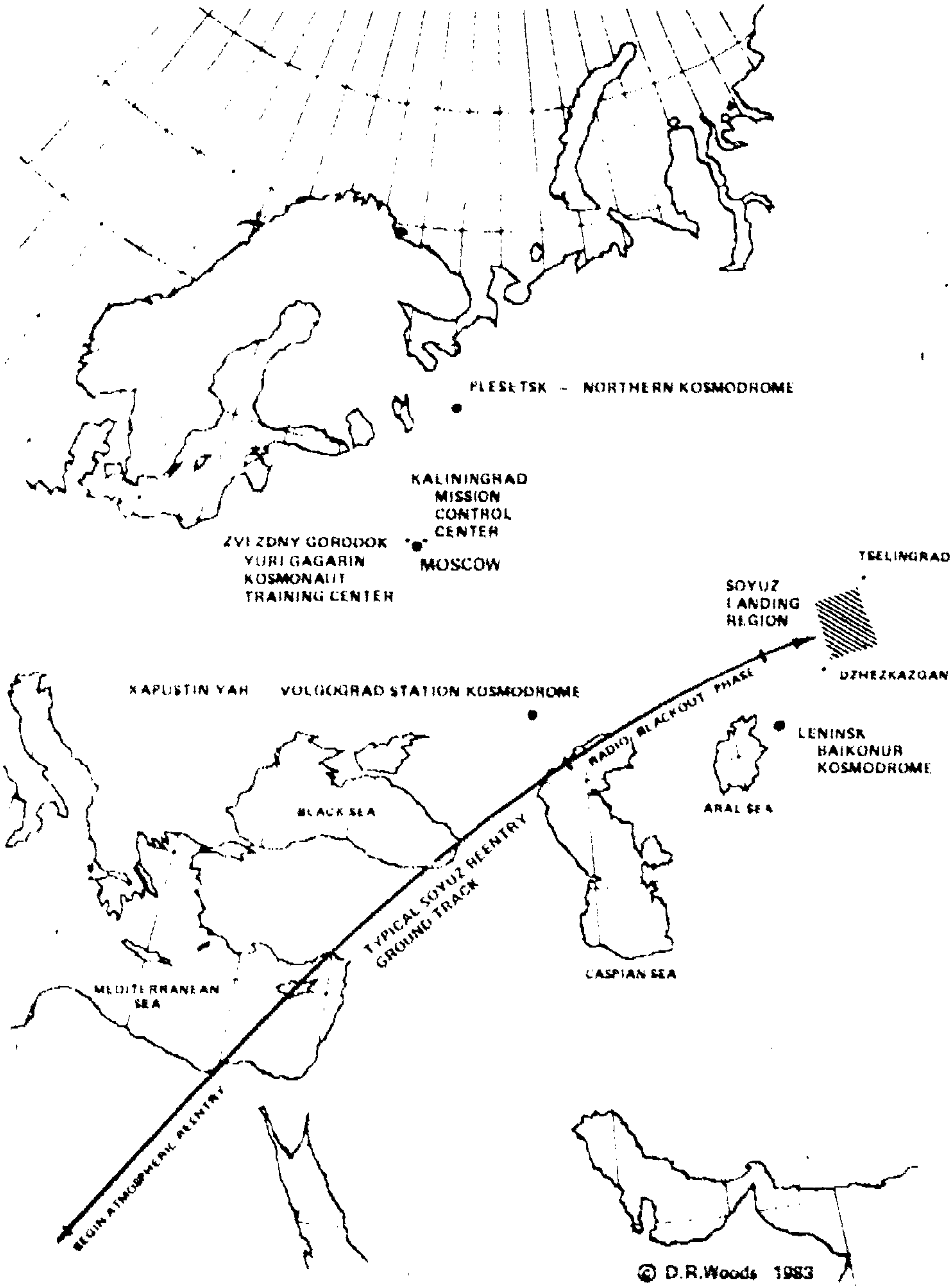

FIGURE 42.—Soyuz Reentry Profile. Soyuz retrofire occurs approximately at the equator over the Gulf of Guinea to assure a landing in the steppes of the southern Soviet Union. Atmospheric reentry starts over Egypt and continues through maximum heating and an ionization communications blackout near the Caspian Sea. Landings occur in a region bounded by the villages of Dzhezkazgan and Tselinograd, northeast of the launch site at Leninsk.

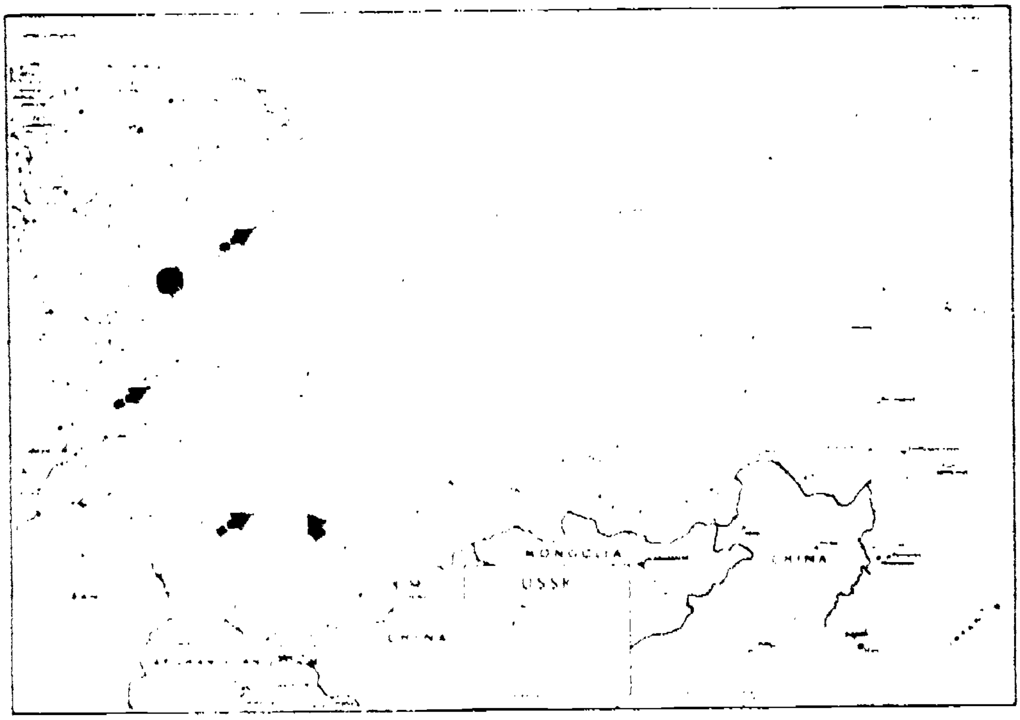

FIGURE 13.—Soviet launch and recovery sites. The primary manned launch site is at Tyuratam and the primary recovery area is to the east of that facility near Dzhezkazgan and Tselinograd. The primary military lanuch site is far to the north at Plesetsk. A small facility for various missions is located at Kapustin Yar, near Volgograd.

SOYUZ 25 OFF TO A BAD START

The first manned mission to the new Salyut 6 was a failure. The crew was unable to dock for reasons that remain unclear.

Soyuz 25 (call sign Foton) was launched at 0240 GMT on October 9, 1977 carrying the crew of Vladimir Kovalenok and Valeriy Ryumin. Tass announced the orbital parameters as 318 × 280 kilometers. On October 10, Moscow Domestic Service announced that "At 0709 [Moscow Time] today the automatic docking of the Soyuz 25 ship and the Salyut 6 station was begun. Then, from a distance of 120 meters, the docking was carried out. Due to deviations from the planned procedure for docking the linkup was called off." Pravda reported that the "final approach was conducted"[131] rather than "the docking was carried out," and later stated that the docking failed because of "an unexpected malfunction in the docking regime."[132] Tass later stated that the docking had been "put off" because of "off-design" operation of the approach and docking system.[133]

This left unclear whether the crew had not been able to dock at all, or had soft docked but could not attain a hard docking. The docking attempt had been at the transfer compartment end of the

[131] Pravda, Oct. 11, 1977, p. 1.
[132] Pravda, Oct. 11, 1977, p. 6.
[133] Tass, 1402 GMT, Dec. 20, 1977

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space station When Soyuz 26 was launched, the Soviets announced for the first time that Salyut 6 had two docking ports, and that Soyuz 26 had docked at the other side because "the first docking device . . . had become somewhat suspect." This furthered speculation that a soft dock had taken place but not a hard dock. When the Soyuz 26 crew inspected the forward docking port on EVA, however, Grechko reported that the "butt end is brand new as though just taken off a machine tool. There are no scratches, traces, or dents on it. All the docking equipment . . . is in full order. The receiving cone is also clear, without a single scratch." [134]

Gordon Hooper has reported that a second docking attempt might have been made, based on NORAD data which indicated that "for an unspecified time after revolution 23 the 2 craft were tracked as 1 object," and that "East European sources in Moscow said that they understood that the cosmonauts made three approaches in an attempt to dock with Salyut 6." [135] One might have expected the docking port to show some wear if any contact between the two ships occurred, so the question of exactly what went wrong remains unanswered. [136]

The docking failure surely was a disappointment to the Soviets, not only because it was the first mission to their new generation space station, but also because the flight had been timed to coincide with the 60th anniversary celebration of the October revolution, and also celebrated the new Soviet Constitution which had been adopted on October 7, 2 days before launch. According to the Soviets, it guaranteed the broadest human rights recognized anywhere. The Soviets announced that the Soyuz 25 crew had requested and received permission to carry a copy of the new constitution with them on the flight.

The crew landed at 0326 GMT on October 11, 195 km northwest of Tselinograd. Mission duration was 48 hours 46 minutes.

SOYUZ 26/27: 96-DAY MISSION

Despite the failure of Soyuz 25, the Soviets soon had another space mission to cheer about. The Soyuz 26 mission demonstrated the full range of capabilities of the new space station. The crew set a new duration record of 96 days, performed EVA to inspect the suspect docking port, received the first Progress transport craft and with it performed the first in-space fuel transfer, and was visited by two other crews (Soyuz 27 and 28) which included an exchange of ships (Soyuz 26 and 27), and the first non-Soviet cosmonaut.

Soyuz 26 (Tamyr) was launched on December 10, 1977 at 0119 GMT into an initial orbit 245×205 km. The crew was composed of Yuriy Romanenko and Georgiy Grechko. After several trajectory adjustments, the ship approached Salyut 6 and achieved a successful docking at the aft docking port at 0302 GMT on December 11.

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[134] Tass, 1402 GMT, Dec. 20, 1977.

[135] Hooper, Gordon. Spaceflight, March 1978, p. 120.

[136] Downlink voice communications monitored by the Kettering Group at 0550 GMT, Oct. 10, 1977, and hitherto undisclosed, revealed that one of the cosmonauts reported, "At the third attempt, our force was not sufficient—the contact light did not come on." The other cosmonaut interjected, "no, no, no, four," indicating that at least four attempts were made. [Information obtained following peer review.]

The docking led the Soviets to publicly announce that the space station had two docking ports.

On December 19,[137] the crew performed an EVA to inspect the forward docking port, as described under Soyuz 25. This was the first Soviet EVA in almost 9 years, the last having been performed on Soyuz 4/5 in January 1969. The hatch was opened at 2136 GMT and Grechko, wearing a new semi-rigid space suit with a built in autonomous life support system, moved out, attached by a tether. Romaneko was suited up, but remained in the hatch to supervise operations.[138]

In addition to inspecting the docking unit, Grechko also checked the outside of the station, assessing the condition of joints, sensors, and other surfaces, and apparently attached flasks containing biopolymers for the Medusa experiment to the surface of the space station[139] (see p. 585). He carried a mobile color TV camera with him so specialists on the ground could see for themselves what he was seeing. The cosmonauts spent 88 minutes in the "difficult conditions of outer space," although the space walk itself apparently only lasted 20 minutes. Gordon Hooper has observed that the exercise took place over the southern hemisphere, outside direct contact range with flight control center. When it began, the station was over the Cook Islands, with the Sun directly overhead, and ended 12 minutes before the station entered the Earth's shadow while they were over Santa Cruz in the Argentine.[140]

During the course of the mission, the cosmonauts lived on a schedule patterned after Moscow time. This was made possible by the increased use of ships for communication so that it didn't matter when certain activities (such as the EVA) occurred, and by storing information on recorders for later dumping when convenient.

The Soviets reported that Grechko was an "even-tempered" fellow, while Romanenko's personality was described as "volatile." Although distractions such as a ches t were available for the crew, Tass reported that the crew didn't use then very much, but that Grechko "fusses with a camera and sketch book near the port hole.: in the transfer compartment, the cosiest and darkest nook on board the station." while Romaneko spent most of his free time rechecking the operation of control systems.[141]

A New Year's tree and toys were provided to help the cosmonauts celebrate the beginning of 1978, and although no champagne was allowed on board, they toasted each other with orange juice.

By early January, press reports on crew activities did not indicate a high level of work. Tass reported that the crew had a "high capacity for work, enthusiasm" and had asked for additional as-

[137] Dec. 20, Moscow time

[138] In his book Red Star in Orbit (New York, Random House, 1981, p. 167), James Oberg reported that Romaneko couldn't contain himself and went out into space himself, but that he had not fastened his tether line and Grechko had to grab him before he permanently floated off into space. Oberg quotes Grechko for this information, but does not identify its source.

[139] Soviet media accounts of the EVA did not report anything about the Medusa experiment, but a January 7, 1978 newscast revealed that flasks containing biopolymers were attached to the outside of the station to study the effect of cosmic rays. It seems highly unlikely that they would have been installed prior to launch, so it can be inferred that the crew placed them there during the EVA.

[140] Hooper, Gordon. Spaceflight, June 1978, p. 231.

[141] Tass, 1730 GMT, Dec. 28, 1977.

signments. It could be that with such a long-duration mission, planners had decided to deliberately keep the workload low during the initial phase, or it could be that the cosmonauts were performing activities which were not publicly reported.

From January 11 to 16, the Soyuz 27 crew visited. The Soyuz 26 crew moved into their Soyuz ferry craft and sealed the hatch during the docking operation.[142] Whether this was a general safety precaution or represented concern that there still might be a problem with the forward docking unit is unknown. (As far as can be determined, the procedure was not used for subsequent dockings at either end of the station). The Soyuz 27 crew transferred their couches into the Soyuz 26 ship so they would return in the "old" spacecraft and leave their new one for the long-duration crew. The couches are individually contoured. The Soyuz 26 ship with the Soyuz 27 crew landed on January 16. Ship duration was approximately 37 days (898 hours, 6 minutes).

Returning in Soyuz 26 also freed the aft docking port for Progress 1, which docked with Salyut 6 on January 22. Operations with Progress took place through February 6, and are described above. Briefly, the crew accomplished the first fuel transfer on February 2, and on February 5 the Progress engines were fired to raise the altitude of the space station. The Soviets referred to this as a "tug" type of operation. Progress brought new life support system regenerators, which the crew later installed, and a furnace called Splav which was later used for materials processing experiments. Progress 1 undocked on February 6, after 15 days of being docked with the space station, and was used as a target for navigation studies before it reentered.

The third visit was that of Soyuz 28 from March 2-10. During this visit, at 0235 GMT on March 4, the Soyuz 26/27 crew broke the old endurance record of 84 days set by the U.S. Skylab 4 crew in 1974. The members of the Skylab crew relayed congratulatory messages to the new recordholders.

The Soyuz 26/27 crew returned to Earth on March 16, 1978 at 1119 GMT, landing 265 km west of Tselinograd. The crew's duration was 96 days, 10 hours (2,314 hours) exactly; the duration for the Soyuz 27 ship was approximately 65 days (1,558 hours 53 minutes).

Radio Moscow reported that during their first days back on Earth the cosmonauts tried to "swim" out of bed, and found it difficult to walk or even lift a cup of tea. They found standing possible, but were more comfortable lying down. By March 20, however, the men were taking walks, and by March 30, were reported to be regaining their preflight condition, and were doing remedial gymnastics and other exercises. Each had lost 5 kilograms while in orbit. In addition to breaking the duration record for a crew, Grechko broke the record for time spent in space by a single individual—3,023 hours 20 minutes (126 days) compared to 2,017 hours 16 minutes (84 days) for the members of the Skylab 4 crew.

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[142] Aviation Week, Jan. 16, 1978, p. 20. Also, Spaceflight, Nov. 1978, p. 371.

SOYUZ 27: FIRST "VISITING" CREW

The first crew to "visit" another in space was Soyuz 27 which docked with Salyut 6 while the Soyuz 26 crew was already on board.

Soyuz 27 (Pamyr) was launched on January 10, 1978 at 1226 GMT with the crew of Col. Vladimir Dzhanibekov and flight engineer Oleg Makarov. The initial orbit was 223×202 km. Docking occurred at 140 GMT on January 11, and the ship docked at the forward end of the station. The two crews met and shook hands for the television cameras in the working module. (As noted earlier, the Soyuz 26 crew waited in the Soyuz 26 spacecraft while the docking took place.) The visiting crew brought up letters, newspapers, books, and research equipment.

In addition to spending time switching couches from the two Soyuz crafts, the 4 cosmonauts also performed the Cytos and Resonance experiments (see p. 585). The latter had to do with the dynamics of the three-ship combination, and the Soviets reported that the assembly began to writhe like a snake with the different sections moving in different directions, although they emphasized that the movement was not visible to the eye.[143] The Soviet media reported that the Soyuz 27 crew adapted to weightlessness more quickly that the "old" crew, and attributed this partially to the effect of having experienced men on board who could reassure their colleagues that the sensations would pass.[144]

The crew returned in the Soyuz 26 spacecraft after 5 days on board the station (6 days in space). They landed on January 16, 310 km west of Tselinograd, and although the Soviets did not announce a landing time, it must have been 1119 GMT based on other data they have published. The crew reportedly got out of their spacecraft and walked over the snow covered field.

SOYUZ 28: FIRST "INTERKOSMONAUT" FROM CZECHOSLOVAKIA

The first non Soviet, non-American cosmonaut was launched into space as part of the Soyuz 28 (Zenit) crew on March 2, 1978, at 1528 GMT. Vladimir Remek of Czechoslovakia and Aleksey Gubarev docked with Salyut 6 and the Soyuz 26/27 crew at 1710 GMT on March 3 at the aft end of the station.

The Soviets reported that in preparation for the mission, Remek (who was single) lived with Gubarev and his family for 1 year. Remek, the son of a deputy defense minister in Czechoslovakia was 29 at the time, only slightly older than Gubarev's son; Gubarev himself was almost 47.

The two crews conducted several joint experiments including the Morava materials processing experiment using the Splav furnace to develop new electrooptical materials; a chlorella experiment; a test using an Oxymeter device for studying the oxygen regimen in weightless tissues; and the Extinctia experiment for studying the brightness of stars when they set behind the Earth's horizon.

The crew landed on March 10, 310 km west of Tselinograd after an 8 day (190 hours 17 minutes) mission. The Soviets did not an-

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[143] New Times, April 1978, p. 13.
[144] New Times, April 1978, p. 14.

nounce a landing time, but it must have been 1444 GMT based on other data they have published.

SOYUZ 29/31: 140-DAY MISSION

After the success of the 96-day flight, the Soviets decided to extend the space duration record even further. During 1978, the Soyuz 29/31 crew remained in orbit for 140 days, and maintained a very high work pace. They were visited by two other crews (one including the first Polish cosmonaut and the other, the first East German), the first of which arrived only 10 days after the main crew had boarded the space station. The crew also performed a 2-hour EVA to retrieve experiments from the outside of the space station, and unloaded three Progress resupply missions, two of which replenished the station's fuel tanks.

Soyuz 29 (Photon) was launched on June 15, 1978 at 2017 GMT. The crew consisted of Col. Vladimir Kovalenok and Aleksandr Ivanchenkov. By 0600 GMT on June 16, the Soyuz orbit was 314 × 270 km. The ship docked with Salyut 6 at the forward docking unit on June 17 at 2158 GMT.

It became apparent early in the mission that the scientific focus of the mission would be on materials processing. The first such experiment was conducted on June 23, shortly after the space station's systems had been reactivated.

Only 10 days after the main crew arrived at the station, they had their first guests. Soyuz 30, carrying Col. Petr Klimuk and Maj. Miroslaw Hermaszewski, the first Polish cosmonaut, docked at the aft port on June 27 and stayed until July 5. A variety of joint experiments were conducted, including the Soviet/Polish *Sirena* materials processing experiment for producing samples of cadmium-mercury-telluride. Special photographic sessions were held as part of the *Ziemia* joint experiment to observe portions of southern Poland which were simultaneously photographed by aircraft for comparative studies.

On July 9, 4 days after Soyuz 30 departed, Progress 2 docked at the aft port to deliver 2 tons of supplies. Included was 200 liters of fresh water, 600 kg of fuel and oxidizer for refueling the space station (which was accomplished on July 19), 100 kg of film, and 250 kg of food and equipment. A new "Globus" instrument panel was also brought up to the crew to replace one that had ceased functioning. Finally, Progress 2 delivered the "Kristall" furnace which joined the Splav device for conducting materials processing experiments. After 26 days of joint flight, Progress 2 undocked on August 2.

On July 29, during the time that Salyut 6/Soyuz 29 was docked with Progress 2, the cosmonauts conducted an EVA. Since the Soviets had announced during the previous mission that one task for Progress was delivering air to replace any that escaped while airlocks were open during excercises such as EVA's, it seems likely that the Progress remained attached so that it could replenish the air supply after the EVA.

The EVA was conducted in order to dismantle and partially replace scientific experiments installed on the surface of the space station for studying micrometeorite conditions and the effects of outer space on the properties of various materials that might be used for space construction. After several days of preparation, which included adjusting the EVA suits to their own heights, the crew was given permission to open the hatch at 0357 GMT on July 29. Ivanchenkov egressed first, while Kovalnenok assisted him from the hatch and relayed pictures back to Earth using a portable camera.

Since part of the EVA took place while the station was in the Earth's shadow, the crew used portable lamps to illuminate their work. The EVA began while the complex was over the Sea of Japan, which allowed 30 minutes of direct communication with the flight control center during predepressurization checks, although not for the EVA itself.

The crew retrieved an instrument for measuring the number of micrometeorite impacts, and samples of duraluminum, titanium, steel, rubber, glass, and ceramic materials which had been emplaced on the outside of the station to study the effects of space conditions on them. In addition, they retrieved the Medusa experiment left by the Soyuz 26/27 crew containing biopolymers. The crew installed a device for studying cosmic radiation (cosmic rays and X-rays).

The crew completed their assigned tasks earlier than expected, and were told that if they were finished they could get back inside. Kovalenok replied that "We would just like to take our time since it is the first time in 45 days that we go out into the 'street' to have a walk." [145]

The crew was in space conditions for 2 hours 5 minutes, although the actual time that they were outside the station has not been reported. Flight directors had envisioned as many as five EVA's during the course of the flight if gerequired,[146] but no further excursions were made.

On August 2, the crew's 46th day in orbit, the Soviet Union surpassed the United States in terms of cumulative person-hours in space for the first time since 1965.

On August 5, a trajectory correction was made using the station's engines, and 5 days later, on August 10, only 8 days after the departure of Progress 2, Progress 3 docked with Salyut 6 at the aft port. This resupply mission included no fuel, since the Salyut tanks had just been replenished, and instead brought samples for the materials processing experiments, an East German camera, biological and medical experiments, 280 kg of food (including strawberries, fresh milk, onion and garlic), 190 liters of water, 450 kg of oxygen, and personal items including mail, fur boots, and Ivanchenkov's guitar. After using its engines to raise the complex's orbit to an altitude of 359 × 343 km, Progress 3 undocked from the space station on August 21 after a comparatively short stay of almost 12 days.

The main crew had only 8 days to relax before they were visited again, this time by the Soyuz 31 crew, Col. Valeriy Bykovskiy and Sigmund Jähn, the first East German cosmonaut. Soyuz 31 docked at the aft port of the station on August 27 and remained until September 3. The joint crew conducted a wide variety of experiments,

[145] Tass, 1627 GMT, 29 July 78.
[146] Tass, 1627 GMT, 29 July 78.

particularly using the East German MFK-6M and KATE-140 cameras already installed on the station. A joint Soviet/East German materials processing experiment, *Berolina*, was conducted to produce lead-telluride and bismuth-antimony ampules.

It became evident that the Soviets were planning a very long duration mission for the main crew when they announced that the Soyuz 31 cosmonauts would return to Earth in the Soyuz 29 spacecraft, leaving their fresh Soyuz docked to the space station. The Soyuz 31/29 crew returned to Earth on September 3. The duration for the Soyuz 29 ship was approximately 80 days (1,911 hours, 23 minutes).

Since the Soyuz 31 spacecraft was docked at the aft end of the space station, the only one equipped to handle fuel resupply from Progress spacecraft, the Soyuz had to be switched to the other docking unit. On September 7, the Soyuz 29/31 crew entered Soyuz 31 and undocked, maneuvering the Soyuz so that it trailed the station by 100 to 200 meters. The space station was then commanded to do a 180° pitchover manevuer so that the forward end of the station would point toward Soyuz 31. The crew then redocked at the forward docking port. The Soviets announced that they had been able to complete the maneuver using a minimum of fuel because after Soyuz 31 undocked, they put the space station in a gravity gradient mode. Thus, the station began turning relative to Soyuz 31 and made half the turn just using the force of gravity, and the engines were required only for making the other half of the turn.[147]

For the next month, the crew had a period of relative calm in which they continued their extensive materials processing experiments as well as Earth photography and use of the BST-1m submillimeter telescope. At 0917 on September 20, they passed the old space endurance record of 96 days, and on September 26, Ivanchenkov celebrated his 38th birthday. They did not set a new duration record until late on September 29 when the old record had been exceeded by the 10 percent required by FAI regulations.

The third and final Progress flight for this crew, Progress 4, docked on October 6 at 0100 GMT. Noting that a considerable amount of fuel had been expended in order to correctly position the space station for various experiments (such as picture taking, work with the telescope, and the geophysical program), the Soviets announced that Progress 4 would refuel the space station, an activity performed around October 12.[148] In addition, the craft brought food, water, regenerators, and photographic materials. A total of 2 tons of freight were brought to Salyut 6, and the crew unloaded it in half the anticipated time.

On October 20 and 21, the Progress 4 engines were used to correct the station's trajectory. Ordinarily, this type of maneuver is done in a single day, but the Soviets announced that this time they wanted to more accurately define the station's parameters after the first burn, so that the second burn could be more precise.

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[147] Redocking of Soyuz 31 with Salyut 6. SWB. Sept. 13, 1978, SU/5915/C/2.

[148] The exact date was not announced. Radio Moscow, 2312 GMT, 10 Oct. 78 reported that oxidizer was being pumped out the fuel tanks, but Tass, 1234 GMT, 11 Oct 78, stated that only "the preparation of the capacities of the station have been completed for refuelling with fuel components." Tass 1233 GMT, 13 Oct 78 said that refuelling operations had been completed.

Progress 4 undocked from Salyut 6 on October 24 at 1607 GMT after 18 days of joint operations. It reentered 2 days later.

During the time that they were unloading Progress, the cosmonauts had little time for other experiments, particularly since they were beginning to prepare for their return to Earth which included extensive medical checkups. They began wearing the Chibis suits on October 15, and had an especially thorough physical check-up on October 18. The Kristall experiments continued up until the last minute, however.

Soyuz 29/31 undocked from the space station on November 2 and landed at 1105 GMT, 180 km southeast of Dzezkazgan. The crew had travelled 93 million kilometers in their 140 days spaceflight (3,350 hours, 48 minutes). The Soyuz 31 ship duration was 68 days (1,628 hours 14 minutes).

Ivanchenkov commented that when they landed "we were literally intoxicated by the fresh air," while Kovalenok said that "It was not easy . . . to bend and pick up a little lump of earth because of the Earth's gravitation, but I forced myself to do so. And this smell of the Sun-drenched steppe will remain with me forever."

As with the previous long duration crew, the two men wore special trousers after their return to assist in walking. They readapted more quickly than the Soyuz 26/27 crew, and were able to take a walk the second morning, the first time that the crew of a mission that had lasted over a month had included walks during the "acute" period of readaptation. The crew walked in a park, accompanied by their doctors, and took a total of 140 steps. Their pulse rates rose only 15 to 20 beats, which, according to the doctors, was the same amount as after a phone conversation or supper.[149]

Kovalenok lost 2.3 kg during the mission, while Ivanchenkov lost 3.9 kg. They were the first people to return with erythrocytes born in space. Erythrocytes, which carry oxygen to tissues, have a life cycle of 120 days, and those which were "space-born" were somewhat smaller than normal, but appeared to be functioning adequately.

By November 11, Ivanchenkov was playing a limited amount of tennis, although the physicians reported that "coordination is still suffering and there is fatigue at the end of the day." On November 14, the crew was permitted to return to home to Star City, and was welcomed by their international space visitors, Heramaszewski and Jahn.

SOYUZ 30: FIRST POLISH COSMONAUT

The first crew to visit Salyut 6 while the Soyuz 29 crew was aboard included the first Polish cosmonaut. Soyuz 30 (Kavkaz) was launched at 1527 GMT on June 27, 1978. At 1708 GMT on June 28, the two-man crew, Col. Petr Klimuk and Maj. Miroslaw Hermaszewski, docked with the Salyut 6/Soyuz 29 complex.

During the mission, Hermaszewski announced that he had brought a capsule containing soil from the Belorussian village of Lenino and from Warsaw, "earth made sacred by the blood of Soviet and Polish soldiers," and a medal dedicated to the first

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[149] Tass, 1710 GMT, 4 Nov 78.

Soviet/Polish spaceflight. He commented that "were it not for this earth and our friendship, there would be no space event today and today's festivities on Polish soil." [150]

After 7 days of joint experiments, the Soyuz 30 crew undocked and landed at 1527 GMT on July 5, 300 km west of Tselinograd. The crew brought back film, correspondence, trays containing biological materials, and capsules from the Splav furnace.

SOYUZ 31/29: FIRST EAST GERMAN COSMONAUT

Soyuz 31 (Yastreb), carrying the first East German cosmonaut, was launched at 1451 GMT on August 26, 1978. The crew consisted of Col. Valeriy Bykovskiy and Lt. Col. Sigmund Jähn. By 1200 GMT on August 27, the Soyuz 31 was in an orbit at 326×271 km. The crew docked with Salyut 6/Soyuz 29 at 1628 GMT on August 27.

The visitors brought gifts for their hosts, including a Russian doll, the traditional bread and salt, a toy Mishka bear (symbol of the Moscow olympics), a special issue of *Izvestiya*, and a souvenir watch for each of them made in East Germany. They also brought onions, garlic, lemons, apples, milk, soup, honey, pork, Bulgarian peppers, and gingerbread.

The two crews conducted a wide variety of joint experiments during the 7 day joint mission. In order to leave a fresh Soyuz spacecraft for the long duration crew, the Soyuz 31 crew returned in the Soyuz 29 spaceship which had been in orbit for 80 days. The crew landed 140 km southeast of Dzhezkazgan, and while the Soviets did not announce the time of landing, it must have been 1140 GMT based on other data they have published. Crew duration was 188 hours, 49 minutes. Among other things, they brought back 25 ampules from the materials processing experiments.

SOYUZ 32/34: 175-DAY MISSION

In 1979, the Soviets extended their manned space duration yet again, this time to 175 days. The main crew of Soyuz 32/34 did not receive any visitors because of an engine failure on Soyuz 33. Concern about the Soyuz engines led the Soviets to delay one manned flight and to replace the aging Soyuz 32 ship with a modified, unmanned Soyuz 34. Three Progress missions resupplied the crew, and the last of these delivered a space radiotelescope, the KRT-10. Difficulties in jettisoning the KRT-10 resulted in an unplanned EVA by the crew to detach it only a few days before the end of the mission.

Soyuz 32 (Proton) was launched on February 25, 1979 at 1154 GMT carrying the crew of Lt. Col. Vladimir Lyakhov and Valeriy Ryumin. The crew docked at the forward end of Salyut 6 at 1330 GMT on February 26, at which time the complex's orbit was 330×307 km. The crew used the Soyuz 32 engines to boost it into an orbit 338×308 km on March 5.

The crew spent a great deal of time during the first month reactivating and refurbishing the station. The Russian media emphasized that the station was now 1½ years old, and that it had been

[150] Tass, 2229 GMT, 30 Jun 78

designed so that various units could be easily accessed and replaced. Among the multitude of items identified by the Soviet as being replaced were: Ventilators in the thermal regulation system, lights, cables in the communications and television systems, components of the exercise cycle and running track, life support filters and regenerators, and the head on the videotape recorder. Regarding this latter item, the crew used a soldering iron which worked without tin. This was described as a considerable accomplishment since soldering creates discharges that have to be cleaned up before they float into critical equipment areas. The crew also checked the functioning and pressurization of the air lock.

On March 15, just over 2 weeks after the crew arrived on the station, the first cargo ship docked. Progress 5 carried the usual complement of food, clothing, and experimental devices, but its main task was refueling the station. This was more than a normal refueling exercise, however, because the Soyuz 29/31 crew had noticed a deviation in the parameters of one of the three fuel tanks' pneumatic lines. Mission planners had diagnosed the problem as damage to the mobile membrane which divided the liquid fuel and gaseous nitrogen in the tank. Mission planners had decided to take that one fuel tank off-line, since two were sufficient for station operations.

Thus, the first major task for the Soyuz 32 crew was to empty the malfunctioning fuel tank of remaining fuel. This was accomplished by rotating the space station around its transverse axis to separate the fuel and nitrogen by centrifugal force (the Progress engines were used to stop the rotation once the procedure was completed). Most of the fuel was transferred into another fuel tank, with the remainder going into an empty container on Progress 5. Remnants of the fuel were then vented into space. For the next 7 days, the tanks and the main lines were vacuumed, and finally a blast of compressed nitrogen was used to purge them. All operations during periods of radio visibility were controlled by the flight control center rather than the crew.

Progress 5 also brought up a new, improved Kristall furnace to replace the old one which had stopped working.[151] The crew installed the new one, as well as a two-way black and white television. The latter innovation was heralded by both the space and ground crews as a tremendous improvement. With it, the crew could look at diagrams, tables, and charts, as well as photographs they had taken which had been developed on the ground. The communications officer at the flight control center had two cameras, one pointed at him and the other at his desk to show the papers or photos. In addition, the crew could watch traditional television programs and reportedly received the first images of Cheburashka, a popular hero of children's cartoons, with "joyful exclamations."

The cargo ship also delivered six "signal" devices to alert the crew to carbon dioxide concentrations and which doubled as smoke detectors, a "Koltso" (ring) walkie-talkie for the crew, a linen dryer, and bath shampoo. Scientific experiments included the Yelena gamma ray instrument and the Biogravistat plant centrifuge.

[151] Pravda, 23 Aug 79, p. 2.

By March 21, it was reported that the crew was working faster than expected and the unloading of Progress 5 was completed. In fact, of the 33 tasks assigned to the crew during the first 4 weeks, almost all had been completed ahead of schedule. In addition, the crew was doing more physical exercises than previous crews, 2.5 to 3 hours a day. Ordinarily, crews had not exercised for that length of time until close to the end of the mission when they were preparing to return home, but based on the results of the previous long duration missions, doctors had decided to increase the amount of exercise throughout the mission.

On March 30, the complex's trajectory was raised to 357 × 284 km using the Progress 5 engines, and a further trajectory correction was made on April 2 (no new orbital parameters were provided, however). The cargo ship undocked on April 3. On April 6, the Soyuz 32 engines were used to further trim the orbit.

The next scheduled event for the crew was the arrival of Soyuz 33 bearing Nikolay Rukavishnikov and Georgiy Ivanov, the first Bulgarian in space. An engine malfunction forced the docking to be aborted, however (see next section).

The crew continued with the various experiments described on p. 585 with their time devoted extensively to materials processing, along with some work using the MKF-6M and KATE-140 cameras, and the BST-1m submillimeter telescope. During the May day festivities, the crew was given a 5-day vacation where they did not have to perform any scientific work, even though they had to keep up with their exercises.

From May 15 to June 8, joint operations were conducted with Progress 6 which carried more fuel and air, another control panel for the navigation system, a new Stroka teletype to replace the old one, and a tulip about to blossom. Prior to the docking, press reports made considerable mention of the tulip and how scientsts wanted to see how well it would blossom in space and referred to how it would bring a breath of spring to the crew. No further mention was made of the flower, however, suggesting that it did not blossom well. (Soyuz 34 also brought up a tulip as will be discussed later.)

Progress 6's engines were fired to raise the station's orbit to 352 × 333 km on May 23 to correct for precession in the orbit which had caused a shift in the crew's work schedule in order to maintain contact with the ground at optimum times. Refueling of the station's tanks was completed on May 28, after which the Progress engines were used twice more (June 4–5) to place the complex in an orbit of 371 × 358 km.

On June 5, the crew celebrated their 100th day in orbit and were congratulated by the Soyuz 29/31 crew. Reports from Hungary around this time indicated that the Hungarian cosmonaut had been scheduled to be launched on June 5 to dock with Salyut 6, but that the mission had been postponed because of concern about the Soyuz engines.[152] Technicians had apparently identified the problem on Soyuz 33, but did not want to commit a crew to a Soyuz until an unmanned test could be completed. Thus, the unmanned Soyuz 34 was launched on June 6. After 2 days of independent

[152] Washington Post, June 8, 1979, p. A 21. Spaceflight, March 1980, p. 110.

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flight to test out the modified engine, Soyuz 34 docked on June 8 at the aft of the station vacated only hours earlier by Progress 6.

Five days later, Soyuz 32 undocked and carried 180 kg of material down to Earth (since the Soyuz 33 failure precluded visiting missions, there was no other method of getting the experiment results back except with the main crew.) The ship landed on June 13 at 1618 GMT after a record 109 day [illegible] space. On board were 30 ampules from Splav and Kristall, film [illegible]ssettes, biological objects, old scientific equipment such as clocks from the control panel and light bulbs to be studied for wear after the long stay in orbit, a cast made of a hollow discovered on one of the docking units possibly from a meteorite impact, and the contents of the vacuum cleaner.

With Soyuz 32 gone, the crew's next task was to move Soyuz 34 to the forward docking unit to allow another Progress mission to dock at the aft entrance. The switch took place on June 15.

Until this time, there had been little description in the routine press reports of the flight on the scientific experiments being conducted by the crew. Mention was made of work with Kristall and observations and photography of the Earth, but the level of activity seemed somewhat less than on the previous mission. The reports indicated that the crew was in good health, and that for the first time, one of them (Ryumin) had actually gained weight (700 grams). This was attributed to better living conditions and better food, although it was also noted that Lyakhov had lost 4 kg, so other factors must have counted as well.

In an interview with former cosmonaut Feoktistov, the average day aboard the space station was laid out: 8 to 9 hours of sleep; 1.5 to 2 hours for eating; 2 hours of exercises; 1 to 1.5 hours for communications with the ground; perhaps 2 hours of free time; and the rest for experiments. Feoktistov noted that they were trying to develop spacecraft with systems which were more highly automated to free the crew's time for performing more experimental work.

On June 30, Progress 7 docked, bringing 1,230 kg of freight including a space radiotelescope, the KRT-10. The craft also delivered two new experiments, "resistance" to measure the ballistic resistance of the station in orbit, and "vaporiser" (Isparitel), a materials processing experiment described on p. 601. A book called "The Moscow Area" was also sent up to remind the crew of the forest, fields, and streams back home.

The KRT-10 was 10 meters in diameter when fully deployed, so obviously could not be brought up to space in an assembled condition. The dish had been folded like an umbrella, while the supporting structure was contained in three cylindrical containers. The crew mounted control panels in the Salyut and laid electrical communications lines. The base of the telescope was attached to the edge of the aft docking unit by three special claws, and was deployed out the docking port such that as Progress 7 pulled away on June 18, the structure was extended out with it. Then the restraints which held the dish in the folded position were released and the antenna deployed. So as not to damage the radiotelescope, the Progress used springs to separate from Salyut instead of using its engines. Progress maintained a stationkeeping distance from the station and relayed pictures of the KRT-10 unfurling.

The antenna weighed 100 kg by itself, with the remaining systems and structures adding another 100 kg to its mass. The crew had practiced deploying the structure on Earth, and found that it was easier in space. Both men were required to operate the instrument, and several days were needed just to calibrate it correctly. Operation of the KRT-10 was done in conjunction with a 70 meter radiotelescope in the Crimea. Further information on this experiment can be found on p. 598.

As the mission drew to a close, the cosmonauts had to jettison the KRT-10 in order to clear the docking port for future missions. This maneuver was attempted on August 9, but vibrations developed in the antenna and it hooked on a protruding part of the station. The crew tried to jerk it free by using the Salyut engines, but to no avail. Although the crew had been in space for close to 6 months, the decision was made (at the crew's insistent request) that they would do an EVA to free the instrument on August 15.

The hatch in the transfer compartment proved difficult to open, but after a few tries, Ryumin succeeded at 1416 GMT and exited. Lyakhov followed and they began to install handrails. At this time, the station passed into the Earth's shadow, so they waited until they could resume communications with the Earth. Meanwhile, the crew enjoyed the view, and Ryumin commented that the stars looked like "huge diamond pins on black velvet." Once communications were restored, Ryumin worked his way down the length of the station, while Lyakhov remained near the hatch, and cut the recalcitrant antenna loose with pliers and kicked it with his boot to send it away from the ship.[153]

Since they were already outside, the crew also brought in samples which had been left on the outside of the station by previous crews or had been there since the time the station was launched.[154] The crew's total time in space conditions was 1 hour 23 minutes, although the EVA had been scheduled for 2 hours. It was reported in the Western press that Ryumin had difficulty reentering Salyut because his spacesuit became entangled.[155]

On August 16, the Soyuz 34 engines were fired to place the complex in a correct orbit for descent (411×386 km, 91.4 min.). The crew landed on August 19 at 1230 GMT, 170 km southeast of Dzhezkazgan after 175 days (4,200 hours 36 minutes) in space. Both men had celebrated their 40th birthdays on the space station (Lyakhov on July 21, Ryumin on August 16), and Lyakhov, a smoker for 28 years, had managed almost 6 months in orbit without a cigarette.

The doctors were impressed with the cosmonauts' condition upon return stating that "not a single crew has ever returned from a

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[153] Oberg claims in "Red Star in Orbit" (op. cit.) that the crew was so worried about the potential danger of the mission that they packed the Soyuz spacecraft in advance and wrote letters to their families and left them on the couches in the ferry craft (on the assumption that it would have been returned automatically if they did not survive). Oberg bases this on an alleged copy of Ryumin's diary released after the flight. The diary has never been authenticated, so the Oberg account cannot be confirmed.

[154] There have been suggestions that the fact that the crew performed these additional activities meant that they were scheduled to perform an EVA anyway. It seems highly unlikely that an EVA would have been purposefully scheduled after the crew had been in space so long. Thus, it is assumed here that mission planners took advantage of the unscheduled activity to collect other samples.

[155] Aviation Week and Space Technology, Mar. 10, 1980, p. 9.

long space flight in such a medically ideal condition."[156] Ryumin had returned weighing the same as when he left, while Lyakhov lost a total of 5.5 kg,[157] and both showed a decrease in shin size. Heart rate and arterial pressure was reported to be virtually the same as preflight measurements. There were reports in the Western media that Ryumin initially had trouble articulating words upon return.[158]

The readaptation of the two men took 2 to 3 days less than had been anticipated, although it was different for both. Ryumin immediately asked permission to take a walk, and walked 800 meters the first day. During the first meeting with journalists the next day, he "entered at a brisk walk of a tennis player ready for a match." Lyakhov, on the other hand, "walked quietly into the room and settled in a deep chair."[159]

By the third day, Ryumin was jogging in the park and Lyakhov was doing gymnastics (how much was not mentioned). They joked that they were ready to patent the invention on how to give a haircut in orbit: Put the vacuum cleaner tube on the veloergometer, put your head under it and turn it on so your hair stands on end, and someone can cut it without a comb. Doctors were intrigued by the fact that in their whole time in orbit, neither had even a cold, which would be unusual on Earth for a similar period of time.

SOYUZ 33: A TENSE INITIATION FOR THE FIRST BULGARIAN COSMONAUT

The first crew scheduled to visit the Soyuz 32 crew on board Salyut 6 was that of Soyuz 33. Launched at 1434 GMT on April 10, 1979, Soyuz 33 (Saturn) carried the crew of Nikolay Rukavishnikov and Geogriy Ivanov, the first Bulgarian cosmonaut. Soviet reports said that the launch took place under the worst conditions of any manned launch, with winds gusting as high as 18 meters per second.[160]

Despite the weather, the launch was nominal, as were the five trajectory corrections required to place the spacecraft into a rendezvous orbit with Salyut 6. The approach to the space station began at 1854 GMT on April 11, but as Moscow Domestic Service reported: "During the process of approach deviations occurred in the normal operation of the approach correcting motors of the craft Soyuz 33 and the docking of the craft with the Salyut 6 station was aborted."[161]

As explained later by the crew, the main engine of the Soyuz had failed to fire correctly during its last maneuver prior to docking. The engine should have fired for 6 seconds, but shut itself off after only 3 seconds, and the thrust was uneven. Rukavishnikov commented that the ship had started shaking "I extended my hand and 'calmed' the control panel, holding on to it a little." He said that at that point he thought the control system was malfunctioning, not the engine.[162]

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[156] Tass, 1445 GMT, 20 Aug 79

[157] Tass, 1523 GMT, 23 Aug 79 A later report said that he lost only 4 kg (Tass, 1245 GMT, 31 Aug 79)

[158] New York Times, Aug. 21, 1979, p. C-1

[159] Tass, 1711 GMT, 21 Aug. 79

[160] Tass, 0905 GMT, 1[illegible] Apr. 79.

[161] Moscow Domestic Service, 0300 GMT, 12 Apr. 79

[162] Pravda, 29 Apr. 79, p 4.

After consulting with the ground, the Soyuz 33 crew tried to fire the engine again, but it shut itself down immediately. The crew was then told to discontinue operations and await further instructions.

Meanwhile, Ryumin reported from the space station that he had noticed an unusual lateral glow from the engines. After one orbit, the Soyuz 33 crew asked permission to try one more time, but ground controllers said no, that the docking was to be aborted and the crew should try to get some sleep.

Telemetry confirmed that the engine had shut itself off because the pressure sensor in the combustion chamber had been activated, indicating that the malfunction was serious. The backup engine on Soyuz was not suitable for rendezvous operations since it was designed for only a single burn at full thrust. Similarly, the docking engines were too small for the maneuver.

Rukavishnikov admitted that he could not sleep, and his mind wandered to Martin Caidin's book "Trapped in Orbit." [163] Not only was he concerned about the main engine, but if the glow noticed by Ryumin had hit the side of the spacecraft, it might have damaged the backup engine as well.

Both the space and ground crews considered the options. The crew would have to make a direct descent from their 346×298 km orbit using a single burn of the backup engine. Nominal burn time would be 188 seconds. If the engine burned for less than 188 seconds but more than 90 seconds, an additional manual engine burn could be made, but the landing spot could not be accurately predicted. If the engine burned for less than 90 seconds, "the vehicle would remain in orbit. Then . . . then there would be new possibilities."[164]

Another option was to use the Salyut engines to bring the space station and the Soyuz closer together, and then use the Soyuz docking engines, which presumably were still operational, to dock the two ships. Such a maneuver would require time-consuming ballistic computations, however, and the ships were separating at the rate of 100 km per hour, so it was rejected.[165]

Ivanvov tried to lighten the atmosphere in the spacecraft and suggested the two of them eat to divert their minds from the problems at hand. Rukavishnikov revealed that they decided to open a gift they had brought for the Soyuz 32 crew. "We opened the handsome red box tied with a multicolored ribbon and fortified ourselves. I had very little, Georgiy took a good drink."[166]

At 1547 GMT on April 12 the Soyuz 33 crew activated the backup engine. It fired for the full 188 seconds, but then did not cut off. After another 25 seconds, Rukavishnikov shut it down manually. The crew landed at 1635 GMT (local nighttime), 320 km southeast of Dzhezkazgan. Recovery teams saw the glow of the spacecraft as it reentered the atmosphere, so were able to locate it fairly rapidly once it landed.

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[163] This is apparently a reference to the book "Marooned," which may have had a different title for the translation Rukavishnikov read

[164] Krasnaya Zvezda, Apr. 2, 1983, p. 4.

[165] Ibid.

[166] Alcoholic beverages are strictly prohibited in space, even though the implication of this passage is that this was something other than orange juice.

The Soviets hailed the second successful ballistic reentry of Soyuz (the first having been the April 5 Anomaly in 1975 when the third stage of the A-2 did not function correctly and the mission was aborted prior to reaching orbit). The crew sustained G-forces of 8 to 10 G, compared with the 3 to 4 G encountered in a nominal Soyuz reentry.

Spacecraft designers were bewildered by what could have gone wrong. The engine had been fired 4,000 times in space and on Earth without failure, and the one part that was finally identified as causing the problem had been tested 8,000 times (the part itself was not specified.)[167]

With the Soyuz 33 crew safely home, mission planners turned their attention to Soyuz 32, which was docked with Salyut 6. They were concerned because the engine on that spacecraft had come from the same lot as the one on Soyuz 33. Thus, they decided to modify the engine and launch an unmanned test. If the test spacecraft worked, then it would replace Soyuz 32. Thus the Soyuz 34 mission was scheduled.

SOYUZ 34: UNMANNED TEST AND REPLACEMENT SPACECRAFT

The unmanned spacecraft Soyuz 34 was launched on June 6, 1979 at 1813 GMT into a 270×198 km orbit. For the next 2 days, it performed a series of maneuvers to check out the modifications made to its engine in light of the Soyuz 33 experience. Not only were the Soviets concerned about the health of the Soyuz 32 engines, but that ship had been in space past the 90-day period for which it had been rated for powered-down operations, and had to be replaced in order to bring the crew back to Earth.

When Soyuz 34 was launched, the Soviets announced that "For the sake of caution it was decided to implement the first flight without people on board, to test the spacecraft unmanned . . . and should it pass that test, it should be passed for manned flights. . . ."[168]

The tests were successful, and Soyuz 34 docked at the aft end of Salyut 6 on June 8 at 2002 GMT. The ship also served a resupply function, bringing the Soyuz 32/34 crew currant juice and more tulips.

As noted earlier, Soyuz 34 was subsequently moved to the forward docking unit on Salyut, and brought the Soyuz 32/34 crew home on August 19. The ship's duration was 74 days (1,770 hours, 17 minutes).

SOYUZ 35/37: 185-DAY MISSION

In 1980, the Soviets extended the duration of manned flight to 185 days, 10 days more than the previous record. Since records are officially established only when they surpass the previous record by 10 percent, this was not a new endurance record. In the course of the 185-day mission, the main crew was visited by three others and there were 2 ship exchanges. Four Progress ships resupplied the station: The first was docked to the station when the crew arrived,

[167] Moscow Domestic Service, 2000 GMT, 6 June 79.
[168] Moscow Domestic Service, 2000 GMT, 6 June 79.

and the last remained docked to it when the crew left, and transferred fuel into the station while it was unoccupied.

Soyuz 35 (Dneiper) was launched at 1338 GMT on April 9, 1980 carrying the crew of Lt. Col. Leonid Popov and Valeriy Ryumin who had returned from the 175-day Soyuz 32/34 mission only 6 months earlier. Ryumin had not been scheduled for this flight, but replaced Valentin Lebedev who had injured his knee. The decision to send Ryumin back into space so soon was premised on his knowledge of the Salyut space station. He had been the person to brief Popov and Lebedev on what repair work needed to be performed on the space station, which led mission planners to conclude that he "unarguably knows the station better than anyone else." [169]

The first task for the crew was unloading Progress 8 which had docked with Salyut 6 on March 29 while it was unoccupied. In addition, the crew's first 2 weeks were spent making prophylatic repairs and readying the station for a long period of occupancy. The crew synchronized the onboard clocks with those of the flight control center, installed new storage batteries, replaced the two blocks of the attitude control system of solar batteries and a conditioning block in the water regeneration system. Ryumin reportedly had an easier time adapting to weightlessness than he had on either of his two previous missions, and Popov was adapting more quickly than expected. Physicians commented that they had designed special cuffs for the crew to wear to distribute the blood in a manner similar to how it would be distributed on Earth.

Experiments were begun with the materials processing units, and with plants. The crew had brought a special, miniature greenhouse called "Malakhit" with them for growing orchids. Tass reported that the flowers would both provide needed scientific data, and provide "additional comfort and good spirits" for the crew.[170] Other plant experiments were continued using Oazis and Vazon.

On April 23, Salyut 6 completed 14,770 revolutions of Earth. The next day, the Progress 8 engines were used to raise the complex's orbit to 368×340 km, and the day after that, Progress 8 undocked. Two days later, on April 27, Progress 9 was launched and it docked with the space station on April 29. This cargo ship brought a new motor for the Biogravistat experiment which the crew subsequently installed, along with fuel and water. This time, 180 kg of water was pumped directly into the Salyut holding tanks using a system called Rodnik, instead of having the crew carry the water in 5 kg drums to the storage compartments. The Lotus device for molding parts from polyurethane was also delivered, as were new atmospheric regenerators which were smaller than previous models and which reduced the need for carbon dioxide absorbers (how was not specified). The Soviets explained that it was difficult to maintain the necessary oxygen-carbon dioxide balance in the space station, not only because the air has to be regenerated, but because they have to get rid of excess carbon dioxide. They said the definitive solution would be to create a biological closed cycle on board, and

[169] Philadelphia Inquirer, Apr. 20, 1980, p. 5E, quoting from Izvestiya.
[170] Tass, 1257 GMT, 12 Apr. 80.

that experiments to this end had already been conducted (particularly with chlorella), but that "as few anomalies do persist." [171]

Progress 9 was used to boost the station's orbit on May 16 to an altitude of 369 × 349 km, and it undocked 4 days later. On May 22, a further orbital correction was made using the Soyuz 35 engines.

No sooner had Progress 9 left than the first visiting crew arrived. On May 26, Soyuz 36, carrying Valeriy Kubasov, and Bertalan Farkas, the first Hungarian to travel in space, docked with Salyut 6/Soyuz 35. A total of 21 experiments were conducted by the joint crews, including three connected with studying the production of interferon in space, photography using the MKF-6M camera, and materials processing experiments. Many of these had been jointly designed by Soviet and Hungarian scientists. (SEe p. 585 for details).

The Soviet/Hungarian crew returned to Earth in the Soyuz 35 spacecraft on June 3, leaving the fresh Soyuz 36 at the aft end of the station. The Soyuz 35 ship had been in space for 55 days. On June 4 the main crew moved the Soyuz 36 to the forward docking port as had now become customary, leaving the aft end available for future dockings.

The next visit occurred only 2 days later when the Soyuz T-2 crew of Yuriy Malyshev and Vladimir Aksenov docked. This was primarily a systems test of the new Soyuz T spacecraft in its first manned flight, and the crew returned to Earth after less than 4 days in space, undocking from Salyut 6 on June 9.

Following the departure of the Soyuz T-2 crew, Popov and Ryumin finally had time to settle down to scientific experiments. On June 20, Tass reported that they were about to complete a 4-day cycle of comprehensive studies of the Earth, including photographs of vast regions of the middle and southern latitudes of the Soviet Union and Hungary. In addition, there were reports on continued plant growth experiments and materials processing.

On June 24, Salyut celebrated its 1,000th day in orbit. Another cargo ship, Progress 10, docked with the station on July 1 bringing the usual stores of consumables, plus a color TV to replace the black and white unit, remaining until July 18. While the crew unloaded Progress, they also continued other experiments, and completed experiments with the Isparitel equipment for spraying coatings on various materials. Tass announced that following the July 7th experiment, the Isparitel equipment would be dismantled from its airlock location and Splav would be placed there instead.

A manned launch was expected around this time because the Moscow Olympics were scheduled for July 18–August 3 and Western experts expected that the Soviets would want an international crew on board to speak to the spectators. When the Olympics opened, only Popov and Ryumin were on board, though, and they did make an address.

On July 23, Soyuz 37 was launched carrying the first Vietnamese cosmonaut, Pham Tuan, into space along with Col. Viktor Gorbatko. They docked with Salyut on July 24 and proceeded to conduct a wide variety of Earth resources, materials processing, and biomedical experiments. Included were experiments for growing a

[171] Moscow Domestic Service, 0000 GMT, 23 May 80

special fern, Azolla, which is native to Vietnam, the Halong materials processing experiment named after a Vietnamese bay, and atmospheric observations to learn more about typhoons and hurricanes, an area of special interest to the Vietnamese. Western media reported that the Soviets had announced that Earth photography and observations would focus on areas "devasted by U.S. defoliants" during the Vietnam War.[172]

The Soyuz 37 crew returned to Earth in the Soyuz 36 spacecraft on July 31, leaving their fresh Soyuz 37 docked at the aft end of Salyut. The Soyuz 36 ship had been in space for 66 days. Soyuz 37 was moved to the forward end of Salyut on August 1, the 115th day aboard for the Soyuz 35/37 crew.

The main crew continued conducting the now familiar range of experiments onboard Salyut, and practiced methods of orienting the ship on both the dark and light sides of the planet. On August 12, the crew completed 18 weeks in space, and 4 days later, Ryumin celebrated his second "space birthday" as he turned 41. Popov celebrated his 35th birthday 2 weeks later on August 31.

On September 5, the complex's orbit was corrected using the Soyuz 37 engines, placing the station in a 355×343 km orbit. More repair and preventive maintenance work was conducted during this period, while a high level of experimental activity continued. Tass reported that the crew would study the dynamics of changing the gas composition in the space station, and check the "serviceability of the station's automatic orientation and stabilization system."[173] The latter statement appeared to suggest that the crew continued to have problems with the navigation system.

The crew was left to perform these tasks in relative peace and quiet during August and early September. No Progress craft were launched because the three previous cargo ships had replenished the station more than adequately. In mid-September, 6 weeks after Progress 10 undocked, the Soviets announced that Salyut still had 2.5 tons of cargo aboard, more than when the Soyuz 35 crew was launched.[174]

Ventilation fans were replaced on September 12, and the Soviets later admitted that these fans were creating a problem because they had to be replaced so frequently because they become noisy after a while.[175] On September 16, another trajectory correction was made and the Soviets announced that they would test a "reserve engine that has not been in use for 2 years."[176] There was no apparent problem with the engines already in use, so this was probably just a test to see how the engine would respond after such a long time without use. The Soviets did not report on how well it functioned.

This orbital refinement left Salyut in a 91.4 minute orbit in preparation for another visiting crew. On September 19, Soyuz 38 was launched carrying the first Cuban cosmonaut, Arnaldo Tamayo-Mendez, and Col. Yuriy Romanenko, who returned to the space station 2 years after his last visit. He commented that since he was

[172] Aviation Week and Space Technology, Aug. 4, 1980, p. 23.
[173] Tass, 1048 GMT, 9 Sept. 80.
[174] Kidger, Neville. Spaceflight, Mar. 1981, p. 76.
[175] Moscow Domestic Service, 0755 GMT, 4 Oct. 80.
[176] Tass, 1310 GMT, 16 Sept. 80.

last there, a lot of the scientific equipment had been replenished and now totaled 2 tons, but otherwise the station had not changed. As usual, a large number of experiments were performed, including several jointly developed by Cuban and Soviet scientists. One was the "Support" experiment which required Tamayo Mendez to wear a special shoe to determine whether arch support could affect adaptation to weightlessness.

Two materials processing experiments involved sugar, the mainstay of Cuba's economy, which also marked the first time monocrystals of an organic substance were grown. In addition, the Cubans and Soviets developed a device for recording images of what takes place inside the furnace during these experiments. The crew also obtained electroencephalograms using the "Cortex" device. One Cuban experiment for holography was not ready in time for this launch, so was brought to the space station with the Soyuz T-3 crew later in the year.

Soyuz 38 returned to Earth on September 26. The fact that they did not switch ships with Soyuz 35/37 signalled that the main crew's mission was coming to a close. A final Progress cargo craft was sent to Salyut on September 28 and it docked on September 30. The space station had passed its third year in orbit on September 29, and had at that point made 17,000 revolutions of Earth and travelled 700 million kilometers. At 1414 GMT on October 1, the crew surpassed the old endurance record of the Soyuz 32/34 crew.

On October 6, the crew finished unloading the supplies delivered by Progress 11, and an orbit correction was made on October 8 using the Progress engines. No refuelling was done at that time. Progress 11 remained attached to Salyut after the crew left on October 11, and during November, completed the first refuelling of a space station while it was unoccupied.

On October 11, the crew undocked from Salyut at about 0630 GMT.[177] They later reported that they had conducted their last experiment--taking photographs of Earth—only 20 minutes before entering Soyuz.

The crew landed at 0950 GMT, 180 km southeast of Dzhezkazgan after 185 days (4,436 hours, 12 minutes) in space. The Soyuz 37 spacecraft had been in space for 80 days. The medical examination conducted at the landing site showed that the crew had "withstood well the long stay in weightless conditions."[178] Soviet physicians concluded that "no irreversible processes occur in the human organism in weightless conditions," and that the crew's good health was "indicative of the sufficient effectiveness of the methods and preventive means which they had used in weightless conditions.[179] After the flight, Ryumin revealed that on this flight, they had been given every fourth day off from performing exercises, which apparently did not harm them in terms of readaptation to Earth's gravity, and provided a significant psychological boost.[180]

Less than 24 hours after landing, the crew went for a 30-minute walk (about 1,500 paces) and their pulse rate quickened by 15 to 20

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[177] The Soviets did not announce a docking time. This information is taken from Neville Kidger's account of the mission in Spaceflight, Aug-Sept. 1981, p. 217.

[178] Tass, 1136 GMT, 11 Oct. 80.

[179] Tass, 1315 GMT, 11 Oct. 80.

[180] Tass 1112 GMT, 13 Oct. 80.

beats. Two days after landing, the two men participated in a press conference that had been scheduled by the physicians for 20 minutes but lasted over an hour. The press reported that the crew was eager to talk and were quick to respond to jokes. Both agreed that 185 days was not the limit for man's endurance in space.[181] Ryumin himself has now accumulated almost a year (362 days) in space on his three spaceflights.

For the first time both crew members gained weight (Ryumin about 10 pounds and Popov about 7 pounds), and grew (temporarily) about 3 cm. By October 15, both were playing tennis.

During the mission, Popov and Ryumin took over 3,500 photographs of Earth and 40,000 spectra of the atmosphere and its underlying surface, and obtained 100 specimens from 70 materials processing experiments. They reported that about 400 organizations in the Soviet Union were interested in the results of these experiments. Approximately 25 percent of their time was spent in repair and preventive maintenance tasks, and it was reported that the most commonly replaced items were (not surprisingly) those most frequently used, such as cables for the portable television camera, headsets, and ventilating fans. Neville Kidger also reported in *Spaceflight* that during one of their operations, the crew spilled 2.5 liters of water and cleaned it up by getting on either side of the huge globule and drinking it.[182]

Following the completion of the Soyuz 38 mission, Cosmonaut Yeliseyev was asked whether Salyut 6 would continue in operation after the Soyuz 35/37 crew returned. He replied that they would not know until after they came back and reported on the station's health, but it appeared that the answer would be in the affirmative. Only 2 months later, the next crew, Soyuz T-3, was launched to the station (its main task was making further repairs to the station).

SOYUZ 36/35: FIRST HUNGARIAN COSMONAUT

Soyuz 36 (Orion) was the first ship to visit the Soyuz 35 crew aboard Salyut 6. Launched at 1821 GMT on May 26, 1980, it carried Valeriy Kubasov of the Soviet Union and Bertalan Farkas of Hungary. The ship docked with Salyut 6 at 1926 GMT on May 27.

The two crews conducted 21 experiments, many of which were jointly developed by Hungarians and Soviet scientists. These included the "Eotvos"[183] experiments with Kristall for growing monocrystals of gallium arsenide alloyed with chromium, an experiment using Splav for alloying aluminum and copper called "Bealuca," two experiments involving atmospheric observations (Refraction and Zarya), biomedical/psychological experiments including "Capacity for Work" and "Audio," and Earth observations in general over Hungary. Most of the passes over Hungary were at night, but Farkas said that he could easily see the lights of Budapest, and on the few day passes they had, he could see the Danube, Tisza, and Carpathians. A total of 40 visual observation and Earth surface photography sessions were held.

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[181] Tass, 1142 GMT, 13 Oct 80.
[182] Kidger, Neville. Spaceflight, Jan. 1982.
[183] Named after the 19th century Hungarian physicist.

Farkas took his daughter's favorite toy rabbit along with him as a reminder "of what he treasures most in life."[184] Although he had a minor hot flush in the head about 1.5 to 2 hours after launch, he said he did not experience any of the disorders of sensation or orientation that had occurred with others, and that he personally had found the return to Earth to be the most difficult period. He lost 3 kg during the flight. Farkas also reported that during the mission, Ryumin's diary from his first long duration mission was published in Hungary in the form of a "minibook," which had pleased his space companion.

Farkas and Kubasov returned to Earth in the Soyuz 35 spacecraft, leaving their fresh Soyuz 37 for the long duration crew. They landed 140 km southeast of Dzhezkazgan at 1507 GMT on June 3 after 8 days (188 hours, 46 minutes) in space. The Soyuz 35 ship had been in space for 55 days.

SOYUZ T-2: FIRST MANNED LAUNCH OF SOYUZ T

The second crew to visit the Soyuz 35/36 crew (Popov and Ryumin) was the first manned test of the newly modified Soyuz T spacecraft. Launched on June 5, 1980, at 1419 GMT, Soyuz T-2 (Jupiter) carried the two-man crew of Lt. Col. Yuriy Malyshev and Vladimir Aksenov. They docked with Salyut 6 at 1558 GMT on June 6 after conducting several tests of the Soyuz T systems which may not have been entirely successful.

The crew approached Salyut automatically until they were 180 meters away, but then switched to manual controls, even though the advantage of the Soyuz T was supposed to have been its ability to dock automatically. The Soviets announced at the time that the procedure was "relatively complicated compared to what had been done before" and that Soyuz T-2 had come toward Salyut 6 aligned perpendicular to the station, instead of straight along its path. The crew executed a quarter turn to line up the two craft and docked.

Following the return of the Soyuz 38 crew in September, the Soviets released a few more details of what had happened with the docking. Yeliseyev stated that difficulties were encountered with the control of the craft's flight. He reported that the onboard computer chooses which of several different approaches to fly to the space station (as well as descent trajectories) and that they had been unable to practice all of them prior to this mission. When the Soyuz T-2 computer selected which "control method" it was going to use for the approach sequence, it was one which had not been practiced either by the ship's crew or ground controllers, so the cosmonauts decided to switch to manual control. Yeliseyev added that telemetric data indicated that if they had stayed in the automatic mode, the docking would have proceeded without incident, adding that "this is one of the tasks of experimental flights—to teach people how to fly the craft and to teach personnel how to control the craft."[185]

More details of the improved Soyuz T were reported, which are included in the description of Soyuz T appearing earlier in this

[184] Tass, 1412 GMT, June 12, 1980.
[185] Moscow Domestic Service, 0755 GMT, 4 Oct. 80.

chapter. When Soyuz T-2 returned from space on June 9 after a short 4 days (94 hours 19 minutes) in space, it was announced that the orbital compartment of the spacecraft had separated prior to retrofire, as opposed to after retrofire as had been the case with the other Soyuz flights. This reportedly saved 10 percent of the fuel, since there was less mass to be slowed for descent.

Malyshev and Aksenov landed 200 km southeast of Dzhezkazgan at a time that was not announced by the Soviets, but duration was 94 hours 19 minutes according to other Soviet sources, meaning that touchdown would have occurred at 1238 GMT.

SOYUZ 37/36: FIRST VIETNAMESE COSMONAUT

On July 23, Soyuz 37 (Terek) was launched at 1833 GMT carrying Viktor Gorbatko and the first Vietnamese cosmonaut, Lt. Col. Pham Tuan. The crew became the third set of visitors to the Popov/Ryumin crew on Salyut 6 when they docked on July 23 at 2002 GMT.

The launch took place during the Moscow Olympic Games and Western experts considered the choice of a Vietnamese to fly on this mission to be a "clear bid for support and prestige in the Third World." [188]

As had been the case on previous international missions, a number of joint experiments were conducted. In this case, these included experiments with growing the aquatic fern Azolla, which is native to Vietnam; Earth observations of Vietnam to find the maximum boundaries of heavy floods, the inner boundaries of the penetration of tidal sea waters, and other projects related to agriculture, hydrology, geology, and forestry; materials processing experiments including one called Halong (after a Vietnamese bay) which involved the growing of bismuth-tellurium-selenium, and gallium phosphide with varying amounts of trace elements, in Kristall; and the "Imitator" experiment for determining temperature profiles in Kristall.

The crew returned to Earth in the Soyuz 36 spacecraft, leaving their fresh Soyuz 37 for the long duration crew. They landed at 1515 GMT on July 31, 180 km southeast of Dzhezkazgan after 8 days (188 hours 42 minutes) in space. The Soyuz 36 ship had been in space for 66 days.

SOYUZ 38: FIRST CUBAN COSMONAUT

The fourth and last crew to visit Popov and Ryumin on Salyut 6 was the Soyuz 38 (Taymyr) crew which was composed of Col. Yuriy Romaneko and Arnaldo Tamayo Mendez, the first Cuban to fly in space. He was hailed in the Soviet media alternately as the first cosmonaut from Cuba, the Western Hemisphere, a non-aligned country, or Latin America. The spacecraft was launched at 1911 GMT on September 18, 1980, and docked with Salyut 6 at 2049 GMT the next day.

Among the joint Cuban/Soviet experiments conducted during the mission were several focussing on biomedical problems, including "Support," "Cortex," and "Anthropometry." Two experiments in-

[188] Christian Science Monitor, July 25, 1980, p. 3.

volving the growth of microorganisms were conducted, one called "Multiplikator" and the other "Hateuy" which involved studying yeast growth. No further details were provided.

Two materials processing experiments involving sugar were performed, which marked the first time such experiments on Salyut involved an organic substance. High temperatures were not required for these processes, so the Cubans had devised a piece of equipment called "Kristallograph" which allowed the crew to look at what was transpiring in the furnace and to photograph it. They also conducted a series of Earth observation sessions focussing on Cuba.

In all, 20 experiments were conducted in four fields: medico/biological, psychological, physico-technical, and Earth resources. Wilfredo Torres Yribar, President of the Cuban Academy of Sciences, stated that half of those experiments reflected the interest of the Cuban economy.[187]

The Cubans and Soviets had been working on a holographic experiment for this flight, but it was not ready in time. The Soyuz T-3 crew brought it into space with them in November.

Romanenko had been on Salyut 6, 2 years previously, and commented that little had changed except that there was more scientific equipment. The crew landed in their own Soyuz 38 spacecraft on September 26 at 1554 GMT, 175 km southeast of Dzhezkazgan after 8 days (188 hours 43 minutes) in space.

SOYUZ T-3: RETURN TO A THREE-MAN CREW

The last flight of 1980 was a 2-week demonstration of the capability of Soyuz T to carry a crew of three, and another test of the Soyuz T systems following the less than successful Soyuz T-2 mission. The last three man crew for the Soviets had been the ill-fated Soyuz 11 mission in which all three cosmonauts lost their lives. The Soviets referred to this three man crew as the "first space repair team"[188] since virtually all their time was spent making repairs to Salyut.

Soyuz T-3 was launched at 1418 GMT on November 27 with a crew of Lt. Col. Leonid Kizin, Oleg Makarov, and Gennadiy Strekalov. Progress 11 had remained docked with the space station after Popov and Ryumin left, and was attached when Soyuz T-3 arrived. Since Progress occupied the aft docking port, this crew docked at the forward end of Salyut 6 at 1554 GMT on November 28. The Soviet media stressed that this was "exclusively a test flight,"[189] and the ship linked up with the Salyut 6/Progress 11 complex "exactly on schedule."

The crew's main task aboard Salyut was a prophylatic examination of its systems and to continue the repairs started by the Soyuz 35/37 crew. They brought specially developed tools for these jobs. Since the mission was only planned for two weeks, the workload was intense. Two television broadcasts were cancelled as was one of

[187] Nature. 16 Oct. 80, p. 577.
[188] Apparently the Soviets forgot the activities of the U.S. Skylab 2 crew which repaired the badly damaged Skylab space station in 1973.
[189] Tass, 1920 GMT, 29 Nov 80.

the crew's free days. In addition, they were not able to exercise as much as they were supposed to.

The major repair job was adding a new hydraulic unit with four pumps to the thermal regulation system. This was a liquid-cooled system, so the crew had to be especially careful not to spill any of the antifreeze-like coolant. The task was complicated by the fact that station designers had not expected the Salyut to be used for such a long time, and since the pumps had a service life of 2 years and the station was only designed for 1.5 years, they had not made this one of the "serviceable" parts. Thus the Soyuz T-3 crew had to use a saw to cut through one of the metal supports to gain access to the pump area, while ensuring that all the "dangerous" metal filings were collected.[190]

That repair job was successfully accomplished, as were many more. To facilitate the repair activities, a direct communications link was established between the space crew and Popov and Ryumin who were vacationing in the Northern Caucasus. Among the other fix-it jobs were replacing a programming and timing device in the onboard control complex, an electronic unit in the telemetry system, and a transducer for one of the compressors in the refueling system (while Salyut was unoccupied, Progress 11 had automatically refilled the fuel tanks, at which time the problem was discovered).

A few experiments were also conducted during the mission, including: growing more monocrystals of cadmium-mercury-telluride in Splav; measuring the air circulation in the station to ensure that it was not becoming stagnant (called "Microclimate"); growing plants; and holography using the Soviet/Cuban holographic camera.

Progress 11 was used to make an orbital correction on December 8, placing the complex in a 370×290 km, 90.8 minute orbit. The Progress spacecraft undocked on December 9 and reentered 2 days later.

The Soyuz T-3 crew returned to Earth on December 10 at 0926 GMT after 13 days (307 hours 8 minutes) in space, landing 130 km east of Dzhezkazgan. Because they had not had time to do all their scheduled exercises, Kizim and Strekalov reportedly suffered from a certain amount of "stress" when they landed.[191] The successful repair activities of the crew were hailed as a "new accomplishment of Soviet cosmonautics [which] is a befitting gift for the forthcoming 26th Congress of the CPSU." [192]

In commenting on the crew's return as the last flight in the current Soviet 5-year plan, Cosmonaut Training Director Vladimir Shatalov stated that the manned space program was "an organic part of the economic plan of the USSR for 1976-1980" and that "every ruble invested into outer space exploration ensures a return of up to 10 rubles." [193]

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[190] Novikov, N. Sovetskiy Voin. No. 8, 1981, pp. 28-29.
[191] Kidger, Neville. Spaceflight. Jan. 1982.
[192] Tass, 1130 GMT, 10 Dec. 80.
[193] Tass, 1132 GMT, 11 Dec. 80.

SALYUT 6 STATUS AT THE END OF 1980

As 1980 drew to a close, Salyut 6 remained in orbit in good condition. On December 29, it was in an orbit of 349×308 km and had completed 18,720 revolutions of Earth. Ground crews continued to test onboard systems, and the control and functioning of station systems was being accomplished by commands from Earth and by means of the onboard automatic equipment. Three more crews (Soyuz 39 and 40, both of which carried cosmonauts from other countries, and Soyuz T-4) were to occupy the station before it was deorbited in July 1982.

SOVIET PLANS FOR A MANNED LUNAR PROGRAM

Although the Soviets still have not sent cosmonauts to the Moon, statements by Soviet authorities during the "Moon Race" period of the 1960's (see the 1971-75 edition of this report), certainly created the impression that they were trying to beat the United States to our nearest neighbor in space.

There was also empirical evidence that a manned lunar program was underway. Five Zond flights from 1968 to 1970 were identified by the Soviets as having been engineering tests related to development of a manned spacecraft to go the Moon, and it is generally concluded that this would have been for circumlunar flight (see table 12). One Kosmos flight in 1971 has been identified as having been a test of a lunar cabin, and it had similar orbital elements to two other flights prior to that time. The exact nature of these flights remains unknown, but they could have been testing propulsion systems and/or a module for landing on the lunar surface. A fourth flight in 1971 may have been a test of an orbiter and a lander (see table 13).

TABLE 12.—ZOND MAN-RELATED CIRCUMLUNAR FLIGHTS

Mission	Launch Date	Launch Hour (GMT)	Recovery Date	Recovery Hour (GMT)	Flight duration (hrs min)	Apogee (km)	Perigee (km)	Inclination (degrees)	Period (min)	Weight (kg)	Remarks
Zond 4	Mar 2, 1968	1830	Mar 9, 1968	1850	168 20	400,000				5,375	Test flight launched in the direction away from the Moon but to approximately lunar distance. No announcement of recovery was made, but probably made a ballistic return to the U.S.S.R.
Tyazhelyy Sputnik	Mar 2, 1968	1830	Mar 7, 1968?		96:00	206	190	51.5	88.4	18,000	Launch platform for Zond 4.
Zond 5	Sept 14, 1968	2142	Sept. 21, 1968	1608	162 26	400,000				5,375	Passed around the Moon at distance of 1,950 km on Sept. 18. Carried biological specimens. Took high quality photos of Earth and Moon. Returned over South Pole and made ballistic reentry into Indian Ocean.
Tyazhelyy Sputnik	Sept 14, 1968	2142	Sept 21, 1968	0800	34 19	219	187	51.3	88.4	18,000	Launch platform for Zond 5
Zond 6	Nov 10, 1968	1912	Nov 17, 1968	1410	162:48	400,000				5,375	Passed around Moon at distance of 2,420 km on Nov. 14. Carried biological payload and other experiments. Took high resolution photos of Moon. Returned over South Pole and performed skip-return reentry, landing in U.S.S.R.
Tyazhelyy Sputnik	Nov. 10, 1968	1912	Nov. 12, 1968	0658	35:46	210	185	51.4	87.9	18,000	Launch platform for Zond 6.
Zond 7	Aug 7, 1969	2349	Aug. 14, 1969	1814	162:25	400,000				5,375	Passed around Moon at a distance of 2,200 km on Aug. 11. Payload similar to earlier Zonds, but added color film to photograph Earth and Moon. Performed skip-return reentry to landing in U.S.S.R.
Tyazhelyy Sputnik	Aug. 7, 1969	2349	Aug. 8, 1969	1648	28:05	191	183	51.5	88.2	18,000	Launch platform for Zond 7.
Zond 8	Oct 20, 1970	1955	Oct. 27, 1970	1355	162:00	400,000				5,375	Passed around Moon at a distance of 1,120 km on Oct. 24. Took still pictures in black & white and color, and sent back TV pictures for 3 days. Returned over North Pole, probably made ballistic reentry into Indian Ocean.
Tyazhelyy Sputnik	Oct 20, 1970	1955	Oct. 26, 1970	1955?	144:00	223	202	51.5	88.7	18,000	Launch platform for Zond 8.

Sources: Dates and mission identifications, plus passes around the Moon and payloads, are from TASS. Specific hours and durations are from the Royal Aircraft Establishment, as are payload weights.

TABLE 13.—FLIGHT PARAMETERS OF POSSIBLE MANNED LUNAR DEVELOPMENT HARDWARE IN THE KOSMOS SERIES

Flight	Date (GMT)	Apogee (km)	Perigee (km)	Inclination (deg)	Period (min)	Remarks
Kosmos 146	Mar. 10, 1967	310	190	51.5	89.1	Launched with D-1-e at 1132 GMT. Orbital elements announced by TASS. 5375 kg? No further maneuvers were observed, but apparently on Mar. 11 the payload split into two parts, possibly the service module with solar panels, and the recovery module. Both decayed after 8-9 days in orbit.
Rocket	Mar. 10, 1967	150	150	51.4	88	Estimated data. Decayed first day. 4,000 kg?
Tyazhely Sputnik	Mar. 10, 1967	150	150	51.4	88	Estimated data. Decayed first day. 18,000 kg?
Kosmos 154	Apr. 8, 1967	232	186	51.6	88.5	Launched with D-1-e at 0901 GMT. Orbital elements announced by TASS. No further maneuvers observed. Decayed after two days.
Rocket	Apr. 8, 1967	170	157	51.4	88.5	Reported by RAE. Decayed after 2 days. 4,000 kg?
Tyazhely Sputnik	Apr. 8, 1967	170	157	51.4	88.5	Estimated data, not separately tracked. 18,000 kg?
Kosmos 159	May 16, 1967	60,600	380	51.8	1,177.0	Launched with A-2-e at 2144 GMT. Initial orbital elements reported by TASS; subsequent elements and decay by RAE. Lifetime, 3,832 days.
	May 16, 1970	58,470	2,502	53.4	1,174.1	
	Nov. 11, 1977 [1]					
Rocket	May 16, 1967	431	203	51.8	90.8	Carrier rocket for Kosmos 159, reported by RAE May 17. 2,500 kg?
Tyazhely Sputnik	May 16, 1967	395	208	51.7	90.5	Launch platform for Kosmos 159, reported by RAE May 18. 4,490 kg?
Torus	May 16, 1967	60,467	380	50.4	1,171.0	Discarded by Kosmos 159, reported by RAE June 13. 215 kg?
Kosmos 379	Nov. 24, 1970	253	198	51.6	88.7	Launched with A-2-m at 0515 GMT. Initial orbital elements announced by TASS. Subsequent elements reported by RAE. 7,495 kg?
	Nov. 25, 1970	1,210	190	51.6	98.7	
	Nov. 30, 1970	14,035	175	51.7	259.6	
	June 1, 1973	11,593	174	51.7	225.2	
Rocket	Nov. 24, 1970	214	189	51.6	88.5	Carrier rocket for Kosmos 379, reported by RAE on Nov. 24. 2,500 kg?
Tyazhely Sputnik	Nov. 25, 1970	1,198	187	51.5	98.6	Launch platform for Kosmos 379, reported by RAE on Nov. 27. 5,790 kg?
Kosmos 382	Dec. 2, 1970	5,040	320	51.6	143.0	Launched with D-1-m at 1700 GMT. Initial orbital elements announced by TASS. Subsequent elements reported by RAE. 10,380 kg?
	Dec. 7, 1970	5,072	1,615	51.6	158.9	
	Dec. 8, 1970	5,082	2,577	55.9	171.1	
Rocket	Dec. 2, 1970	5,045	409	51.5	144.1	Carrier rocket for Kosmos 382, reported by RAE Dec. 5. 4,000 kg?
Rocket	Dec. 7, 1970	5,081	1,590	51.5	158.7	Carrier rocket after second burn, reported by RAE on Jan. 1.
Tyazhely Sputnik	Dec. 7, 1970	5,084	1,614	51.6	159.1	Launch platform for Kosmos 382, reported by RAE on Dec. 14. 9,000 kg?

Kosmos 398	Feb 26, 1971	276	196	51.6	88.9	Launched with A-2-m at 0506 GMT. Initial orbital elements announced by TASS. Subsequent elements reported by or circumstantially implied from RAE.
	Feb 28, 1971	1,188	186	51.6	98.5	
	Feb 28, 1971	10,903	203	51.6	216.1	
Rocket	Feb 26, 1971	261	194	51.6	89.0	Carrier rocket for Kosmos 398, reported by RAE on Feb. 26 2,500 kg?
Tyazheiy Sputnik	Feb 28, 1971	1,188	186	51.6	98.5	Launch platform for Kosmos 398, reported by RAE Mar. 6. 5,790 kg?
Kosmos 434	Aug 12, 1971	285	197	51.6	89.0	Launched with A-2-m, at 0530 GMT. Initial orbital elements announced by TASS. Subsequent elements reported by or circumstantially implied from RAE.
	Aug 15, 1971	1,328	189	51.6	99.9	
	Aug 27, 1971	11,804	186	51.6	228.2	
Rocket	Aug 12, 1971	261	194	51.6	89.0	Carrier rocket for Kosmos 434, reported by RAE Aug. 12. 2,500 kg?
Tyazheiy Sputnik	Aug 16, 1971	1,328	189	51.6	99.9	Launch platform for Kosmos 434, reported by RAE Aug. 17 9,000 kg?

[1] Decayed from orbit

Note: Dates listed for events other than launch are approximate, as it may have taken varying amounts of time for Western sensors to locate some objects after they had moved to new orbits. Listed weights are quite uncertain, but generally reflect the lift capacity of the launch vehicles to the altitudes attained. RAE stands for Britain's Royal Aircraft Establishment. Data so noted are taken from RAE's Revised Tables of Earth Satellites, vols. 1 and 2, Farnborough, Hants, December 1978 and December 1979.

The most significant obstacle which the Soviets apparently could not overcome was development of a suitably powerful launch vehicle equivalent to the Saturn V rocket used in the U.S. Apollo program, the so-called "G" vehicle described in part 1 of this study.

Despite the prevailing wisdom that the race to the Moon was a race to be first, and once they lost, the Soviets put their plans aside indefinitely, it appears that they kept their plans alive at least for 2 years after that. The Kosmos flights related to development of a "lunar cabin" were launched in 1970–71, after the 1969 landing of Apollo 11.

THE ZOND MISSIONS AND RELATED KOSMOS FLIGHTS

From 1968 to 1970, the Soviets launched five missions, designated Zond 4 through 8, which were probes designed to test a spacecraft for circumlunar manned flight. (Zond 1–3 were related to other planetary targets, and are discussed in the space science chapter in Part 3 of this study.) There may have been unreported failures as well. For example, Newsweek magazine claimed that on November 22, 1967 and April 22, 1968, Zond flights to the Moon were unsuccessfully attempted. There are no official statements to prove or disprove that contention.

KOSMOS 146 AND 154

For many years, Kosmos 146 and 154, launched March 10 and April 8, 1977 respectively, have been thought to have been Zond precursors that failed.[194] Both were launched by D–1–e boosters, and never left low Earth orbit. There were four objects associated with each launch, two of which decayed after 1 day in the case of Kosmos 146, and three of which decayed after 2 to 3 days in the case of Kosmos 154. Two objects associated with Kosmos 146 and one with Kosmos 154 remained in orbit for several days.

The conclusion that these were failed Zond missions was questioned in a 1980 article by Sven Grahn and Dieter Oslender.[195] While acknowledging the temptation to place these in the Zond category based on orbital parameters of the shorter-lived objects, Grahn and Oslender ultimately conclude that the two spacecraft carried out missions different from each other based on their analysis of the frequencies used by, and the orbits of, the longer lived objects. Kosmos 146 used typical Soyuz frequencies, according to the authors, and could have been a complete test of the Soyuz propulsion system in preparation for the first Soyuz flight 5 weeks later. Kosmos 154 did not use Soyuz frequencies, per se, but did use the same frequency as Kosmos 133, often regarded as the first Soyuz precursor, and may have been another Soyuz test.

The real mission of these flights remains obscure, but since they were launched in successive lunar windows, they are listed here in the lunar-related category.

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[194] See Vick, Charles P. Soviet Super-Boosters-1. Spaceflight, v. 15, Dec. 1973; Oberg, James E. Russia Meant to Win the Moon Race. Spaceflight, v. 17, May 1975; Woods, David R. A Review of the Soviet Lunar Exploration Programme. Spaceflight, v. 18, July–August 1976.

[195] Grahn, Sven and Dieter Oslender. Cosmos 146 and 154. Spaceflight, v. 22, Mar. 1980: 121–123.

KOSMOS 159

Another ambiguous mission possibly related to the Zond program is Kosmos 159, launched May 16, 1967. Launched by an A-2-e vehicle, the main part of the spacecraft remained in orbit until Nov. 1977. Since it used a much smaller launch vehicle than Kosmos 146 and 154, it would have been limited to testing one or more subsystems.

Others have concluded that this mission was a test of the Soyuz propulsion system; its true nature remains unknown.

ZOND 4

On March 2, 1968, Zond 4 was launched and it is considered to have been a diagnostic engineering test for subsequent Zond flights. In 1971, a drawing was released which showed the ship to be virtually identical (externally, at least) to a Soyuz spacecraft without the forward work module (see fig 44). The Royal Aircraft Establishment estimated its weight at 4,820 kg, with a length of 5.3 meters and diameter of 2.3 meters.

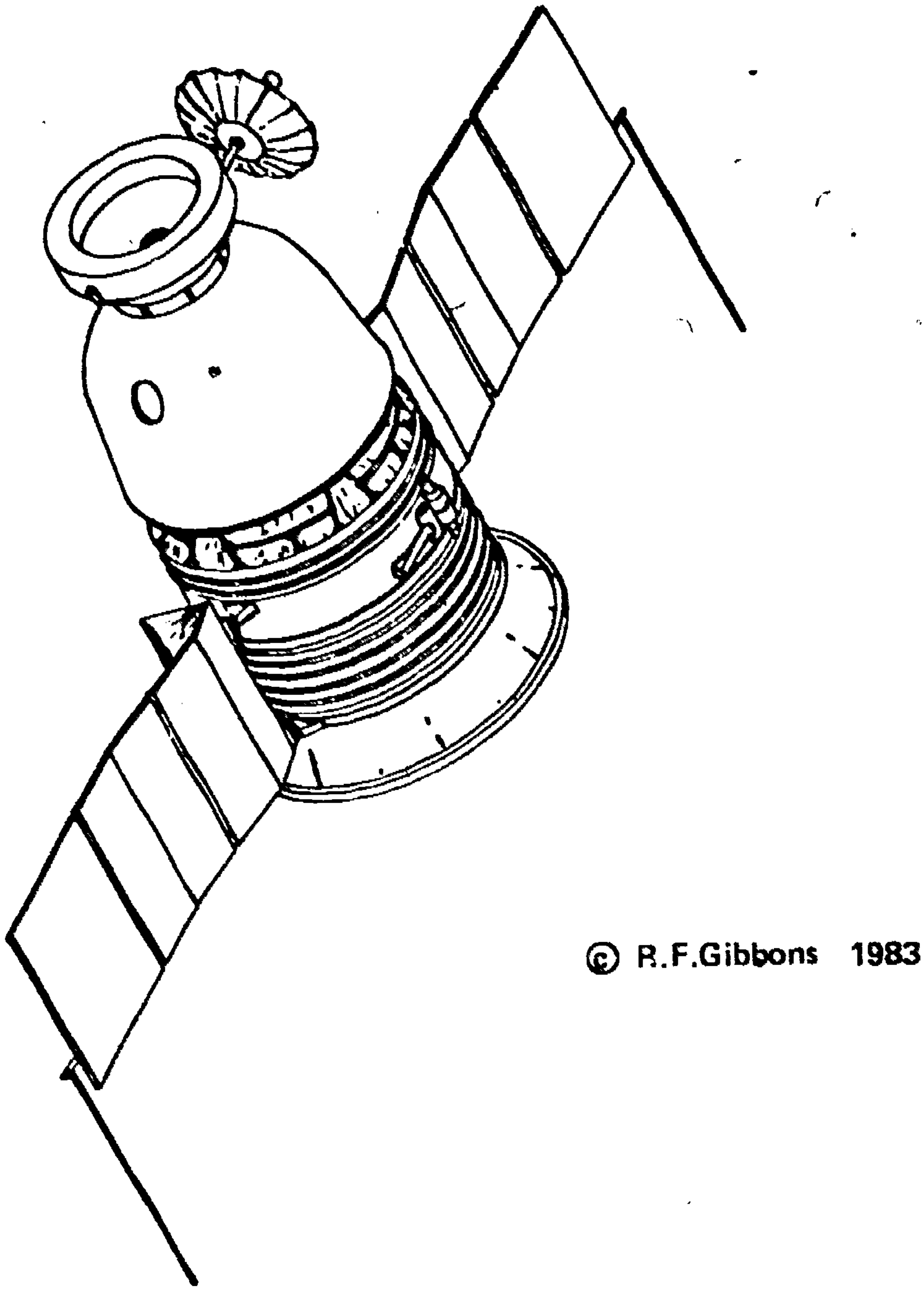

FIGURE 44.—Zond Circum-Lunar Spacecraft. The Zond-5 through -8 spacecraft were launched on circum-lunar missions between 1968 and 1970. After Zond-5, each spacecraft, after completing a loop around the far side of the Moon, plunged back into the Earth's atmosphere at a shallow angle that permitted a skip reentry.

Zond 4 was launched by a D–1–e booster one-half lunar month away from the ideal time to launch toward the Moon, and was sent in a direction opposite from the location of the Moon at that time. The Soviets stated that it had been launched to the "outlying regions of near Earth space," and presumably was intended to go out as far as the Moon's orbit. By not going directly to the Moon, its return path would not be affected by lunar gravity. Considering the significance of a new program of such magnitude and portent, the failure of the Soviets to give any further report on the flight suggests that it was not successful; there is no evidence in the public domain on which to base a definitive judgment regarding the mission's success.

ZOND 5

Zond 5 was launched on September 14, 1968 in a similar fashion to Zond 4, but this time was directed toward the Moon. On September 17, a mid-course correction maneuver was made to place the spacecraft on a correct trajectory for swinging around the Moon at a distance of 1,950 km and returning to Earth. Another trajectory correction was made enroute to the Moon to place it on a correct trans-Earth route.

The ship was described as having two compartments, one a recoverable cabin with a heat regulating system, power supply, parachute packs, scientific instruments, and radio communications equipment; the other a service module with large solar panels, a radio telemetry system, control equipment, orientation and stabilization systems, batteries, and heat regulation systems. Optical sensors and radio antennas were mounted externally.

Zond 5 returned to Earth after 7 days in space. This was the first time that the Soviets returned a spacecraft from a deep space mission, and their first water recovery. The ship was slowed aerodynamically from 10,900 meters per second (m/s) to 200 m/s, after which a parachute was deployed at 7 km altitude. The approach to Earth was over the South Pole and it landed in the Indian Ocean at 32°38′ S., 75°33′ E., as it headed north. The capsule was exposed to heat levels of 13,000 °C during reentry.

Not only was this the first time that the Soviets recovered a spacecraft in the water, but it was a night landing, complicating matters further since the recovery team had to search for it in the darkened waters. Recovery was directed by the Academy of Sciences' rescue service and the tracking ship *Borovichiy*. An oceanography ship, the *Vasiliy Golovnin*, transported the spacecraft to Bombay where it was transferred to a Soviet AN-12 cargo plane and flown to the Soviet Union.

Although the mission was primarily an engineering test, it also carried cameras and a biological payload. The cameras returned the first high quality photographs (as opposed to radio facsimile pictures). The biological payload consisted of turtles, wine flies, meal worms, a spiderwort plant with buds, wheat, pine, and barley seeds, chlorella in various nutrients, and various types of lysogenetic bacteria. After they were recovered, the turtles had lost about 10 percent of their body weight and had excessive glycogen and iron in their livers compared to Earth controls. As far as the plants were concerned, the Soviets revealed that changes were noted only in the barley and pine seeds, as had been expected because of their sensitivity to radiation.

ZOND 6

Zond 6 was launched on November 10, 1968 and was essentially a repeat of Zond 5. Three trajectory corrections were made, the first on November 12 and the other two after the spacecraft had passed the Moon at a distance of 2,250 km on November 14. The Soviets announced that equipment was carried to study the effects of radiation on living creatures, although no other details of the biological payload were provided. A photoemulsion chamber to record the paths of cosmic rays was carried, together with a micrometeorite detector.

More lunar photographs were taken with a standard aerial camera which had a focal length of 400 mm, frame size 13×18 cm, and a resolution of 50 lines per mm. Each photograph had 134 million data bits, compared with 1.2 million data bits with each Zond 3 facsimile picture Some of the photographs provided stereo views of both the near and far sides.

Zond 6 returned to Earth on November 17 in much the same manner as Zond 5, but with one important difference—a skip-return trajectory. The spacecraft approached Earth at 11 km per second, and using aerodynamic braking, slowed to 7.6 km per second. Then an onboard control mechanism was used to orient the craft so that it developed lift and skipped outside the atmosphere, followed by a second reentry and a controlled landing in the Soviet Union in the "preset district."

The Soviets explained that the South Pole approach was the only one practical for returning Zond payloads to the Soviet Union because a direct ballistic approach would cause a G force overload for a human crew. Academician Petrov noted, however, that the prolonged reentry increased the effect of heat flow, and added a considerable strain to the structure of the heat protection system.[196] He also stated that the G-load for Zond 5 reached 10-16 G's, and implied that for Zond 6 it was closer to that encountered with a manned Soyuz mission (3–4 G's).[197]

Following this flight, the Soviets formally announced that Zonds 4, 5 and 6 were aimed at perfecting a manned spaceship to go around the Moon. Although all indications were that Zond 6 performed well, Academician Blagonravov stated that further unmanned tests would be required before men could be sent.[198]

ZOND 7

The launch of Zond 7 occurred on August 7, 1969, with the announced purpose of further engineering tests and more photographs of the Moon's surface. The spacecraft circled the Moon at a distance of 2,000 km on August 11. The craft returned to Earth in the same manner as Zond 6 on August 14.

The only notable difference in this mission was that it took color as well as black and white photographs in an attempt to show differences in the microstructure of lunar material and to discern new features on the Earth. Picture taking sessions were held on

[196] Izvestiya, Moscow, Nov 19, 1968, p. 2.
[197] Moscow Rural Life, Nov. 24, 1968, p. 4.
[198] Moscow Radio. Dec. 10, 1968, 1200 GMT.

August 8 for Earth and on August 11 for the Moon (twice) and the Earth as it set beneath the Moon's horizon.

ZOND 8

The last spacecraft in the series was launched on October 20, 1970. The next day it transmitted the first television images of Earth from a distance of 65,000 km, and these continued for the next 2 days. The ship passed within 1,100 km of the Moon, and both color and black and white pictures were taken of the surface.

The mission used a significantly different approach to Earth for reentry, coming in over the North Pole instead of the South. The advantage was that Soviet ground stations could control the flight during most of the reentry. This also was the second Soviet water recovery, with the craft splashing down 725 km southeast of the Chagos Archipelago in the Indian Ocean, probably in a ballistic reentry. This time, recovery ships were sufficiently well positioned to see the actual reentry, and although it was night, as in the case of Zond 5, the capsule was quickly recovered by the *Taman*. Zond 8 was then transferred to the *Semyon Chelyushkin* for the trip to Bombay and subsequent airplane flight to the Soviet Union.

KOSMOS 379, 382, 398, AND 434

Four Kosmos flights in the 1970–71 time period were the subject of various interpretations for many years as to their purpose. The mission of one of these, Kosmos 382, still remains somewhat in doubt, but is included here as part of tests for the manned lunar landing program, since it seems most likely to have been related to that program.

The other three, Kosmos 379, 398 and 434 had orbital parameters and maneuvers very similar to each other and are summarized in table 13. As can be seen, Kosmos 379, 398 and 434 were launched into initial orbits with apogee in the 250 to 285 km range and perigee around 200 km, similar to a Soyuz mission. The signal formats and frequencies used also resembled Soyuz, and it is therefore concluded that an A-2 vehicle was utilized. However, Soyuz has been described as having a maximum altitude range of 1,300 km, and using orbital platforms, the apogees of each of these spacecraft were raised to as much as 14,035 km. Since these altitudes are out of the range of the A-2 vehicle, this was apparently the first use of the A-2-m vehicle, a much more maneuverable version of the A-2. Using data from Kosmos 159, which he classifies as a Soyuz propulsion test, David Woods has calculated the amount of propellant that can be carried on Soyuz and its derivatives, and therefore that could have been used for the Kosmos 379 maneuvers. He concluded that the initial maneuvers of all three A-2 missions were accomplished by an add-on propulsion unit.[199]

Geoffrey E. Perry of the Kettering Group calculated the delta V's required for the maneuvers of Kosmos 379 and found a close correlation with what might be expected for lunar orbit insertion and for trans-Earth injection.[200]

[199] W ds, D. R., Lunar Mission Cosmos Satellites. Spaceflight, Nov. 1977, p. 383.
[200] Pe , G E., Flight International, London, Dec. 10, 1970, p. 923.

By a fortuitous set of circumstances, the Soviets were led to publicly reveal the nature of Kosmos 434 in 1981. On August 25, a bright light was seen over Western Australia and initial reports stated that it was the reentry of Kosmos 434. Public concern over possible radioactive hazards associated with reentering Soviet spacecraft following the 1978 reentry of Kosmos 954 (which carried a nuclear reactor, see part 3 chapter 5), prompted the Soviet Foreign Ministry to issue an official statement on the subject wherein they stated that the object could not have been Kosmos 434 for it had reentered on August 22.[201] An analysis by Perry concluded that the Soviet account was probably correct. The interesting point, however, was that the Soviets identified Kosmos 434 as having been a test of lunar cabin. This confirmed the long-standing speculation that it had been part of the manned lunar program, and, by inference, that Kosmos 379 and 398 were as well. Whether it was a module which could have landed cosmonauts on the surface of the Moon, or just a circumlunar capability is still hotly debated in the West.

According to Woods' analysis, Kosmos 379 had the heaviest initial weight (7,495 kg) and lowest initial orbit, with the largest propellant supply used for the second manuever; Kosmos 398 (7,255 kg) had the shortest first manuever burn; and Kosmos 434 had the lightest initial weight (7,495 kg) and highest initial orbit. He concluded that Kosmos 379 was a test conducted with a full propellant load, while the other two carried a propellant load comparable to that needed for trans-Earth injection.[202]

Kosmos 382 is obviously different from the other three, not only because perigee was raised instead of apogee, but a very substantial plane change was made in the final maneuver. If the payload was similar to the other three, then only a D class vehicle could have been used to accomplish such maneuvers, and apparently was a D-1-m. Perry has concluded that all four Kosmos flights were tests of the Soviet equivalent of the American SPS engine used for the Apollo command module on lunar flights. Woods has gone further to conclude that Kosmos 382 was in fact a test of a heavier payload than the other flights (hence the use of the D-1-m instead of A-2-m) and was, in fact, a manned lunar orbiter plus a lander.[203]

While it is tempting to conclude definitively that Kosmos 382 was truly part of the same series as Kosmos 379, 398 and 424, the fact that the mission profile was different than the others requires that this judgment still be made on a tentative basis.

Possible Lunar Landing Mission Profiles

Woods has considered the various mission scenarios that the Soviets might have had in mind for accomplishing a manned lunar landing.[204] He speculates that the mission would start with the

[201] Quoted in: Gillette, Robert. Soviets Hint "Experimental" Fallen Satellite Lost Its Way to the Moon. Washington Post, Aug. 30, 1981: A25.
[202] Woods, op. cit.
[203] Woods, op. cit.
[204] Ibid.

launch of all the unmanned hardware on a G-1 booster (described in Part 1, chapter 1). The crew would follow in a heavy Zond launched by an A-2, and rendezvous and dock with the 135 tonne G-1 payload in Earth orbit. The two spacecraft would remain docked until trans-Earth injection (TEI) utilizing propulsion modules in the G-1 payload for both trans-lunar injection (TLI) and lunar orbit insertion (LOI). According to Woods, simulating TLI-LOI would require subjecting the Heavy Zond to a force of 1 G in a direction opposite to the normal thrust vector, which therefore could be accomplished only by a separate propulsion module mounted where the orbital module would be on a conventional Soyuz. He further proposes that the proplusion system used by Luna 4-14 could have served such a role. Once in lunar orbit, Woods suggests that two members of the three-man crew would have gone to the surface and back.

While the Woods scenario of a combined Earth orbit rendezvous/lunar orbit rendezvous method for landing cosmonauts on the Moon is well argued, some questions necessarily remain.

There were many available options for sending crews to the Moon and back, and in the United States, the debate over whether a direct ascent, Earth orbit rendezvous, or lunar orbit rendezvous method should be used was highly acrimonious. The ultimate decision to use the lunar orbit rendezvous approach was bitterly opposed by the President's Science Adviser, Jerome Weisner.[205] Surely a similar debate would have raged within the Soviet space hierarchy and Woods' scenario is, in one sense, the worst of both worlds, requiring rendezvous operations in both Earth and lunar orbit. If the G-1 booster was, in fact, designed as the equivalent of Saturn V, the need for both rendezvous operations seems questionable, since the Saturn V was able to launch both the manned and unmanned components of Apollo. If they had been willing and able to perform Earth and lunar orbit redezvous, then the question remains as to why they did not do so using the D venicle.

Phillip S. Clark has also proposed a Soviet manned lunar mission scenario which does not involve landing.[206] According to Clark, the Soviets might have decided to gain experience in lunar orbit using a Zond/Salyut combination. The Zond, with a three-man crew, would be launched by an A-2 into Earth orbit. A day later, a G booster would be launched carrying a Salyut whereupon the two vehicles would dock and be sent into a trans-lunar trajectory. Upon arrival in lunar orbit, the Zond/Salyut could enter a 110 km lunar orbit and remain for as long as a month, after which the Zond could return to Earth leaving the Salyut in lunar orbit.

FUTURE PLANS FOR MANNED LUNAR MISSIONS

Like the United States, the Soviets have not launched any missions, manned or unmanned, to explore the Moon for many years.

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[205] NASA Firm on Lunar Orbit Choice, Missiles and Rockets, Oct. 22, 1962: 13. For a detailed accounting of the decisions involved in the Apollo program, see: Smith, Marcia, Manned Space Flight Through 1975. *In* U.S. Congress. House. Committee on Science and Technology. United States Civilian Space Programs 1958–78: Volume I. Committee print. Washington, U.S. Goverment Printing Office 1981, pp. 379–428.

[206] Clark, Phillip S. A review of the Soviet Union's Manned Lunar Programme, privately published, 1977, pp. 16–29.

The last Luna spacecraft was launched in 1976. This may not indicate a lack of interest in the Moon, but simply a lowering of its status on the long list of priorities for space exploration.

If Western analysis is correct that the Soviets did not win the Moon race because they did not have the hardware (particularly the launch vehicle) to accomplish the task, then it may stand to reason that once such hardware is available, new attempts at landing cosmonauts on the Moon may be made. This would certainly be in concert with the long range, broad goals expressed by the Soviets for their space program, including manned missions to the planets. Such flights could more easily be launched from the Moon since it has only one-sixth Earth's gravity.

FUTURE PLANS

The following section examines what the Soviets revealed about their plans for the future during the period 1976–80. There have been significant developments since 1980 both in the area of permanent, modular space stations, and in Soviet development of a reusable space vehicle. These recent achievements are discussed in the 1981–83 supplement which appears as chapter 2 of this volume.

PERMANENT EARTH ORBITING SPACE STATIONS

With the advent of Salyut 6 and its two docking ports, the Soviets had created the opportunity to permanently occupy orbiting space stations. For whatever reasons, they have never exercised this option, even though they have publicly stated that this is a goal of their manned program. Part of the reason could be the small size of Salyut, which leads to the discussion of larger Soviet space stations.

STATIONS WITH MULTIPLE DOCKING UNITS

Even before Salyut 6 was orbited, Soviet space officials were talking confidently of larger space stations. Some of the discussion was focussed on docking two Salyuts together,[207] but most of the talk has been of a core with multiple docking ports. In September 1978, Cosmonaut Konstantin Feoktistov explained that it would be "expedient" to have an orbiting Salyut laboratory with a "minimum of seven or eight docking units."[208] Modules for carrying out "specialized research—technological, astronomical and geophysical—could dock with the station," he added.

This theme has been echoed ever since. In December 1980, for example, Valdimir Shatalov, head of cosmonaut training, repeated the fact that space designers were working on orbital stations of the future with Salyut as a base to which modules would be linked for performing various scientific functions such as meteorology, geology, and astronomy.[209]

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[207] See, for example, summary of "Outlines of the Future in Space" by V. P. Denisov, V. I. Alimov, AAA. Zhurenko and V.A. Misharin in Aerospace Daily, Nov. 1, 1976, p. 5. Also: Radio Sophia, 16 Jan. 1979, 1942 GMT reported that "a large space installation with a capacity for 8 persons aboard will be created on the basis of two stations of the Salyut type."

[208] Tass, 0533 GMT, 16 Sept. 78.

[209] Tass, 1132 GMT, 11 Dec. 80.

KOSMOS 929

The first step toward building modular space stations occurred on July 17, 1977, with the launch of an unusual spacecraft, Kosmos 929. Once in orbit, the spacecraft conducted extensive orbital maneuvers, and on August 16, 1977, a portion of the spacecraft reentered. The main part of the spacecraft reentered on February 2, 1978 after 200 days in orbit.

The purpose of this spacecraft remained obscure until the 1981 flight of Kosmos 1267, which followed a similar mission profile, and the 1983 Kosmos 1443 mission during which the Soviets identified Kosmos 929 as having been the first of the series. The 1981 and 1983 missions are described in chapter 2. This series of flights involves development of a combination space tug, cargo craft, and space station module which could be outfitted for particular tasks, such as materials processing, and either remain attached to a space station, or fly independently. The separation of a section of the spacecraft is useful for returning the results of scientific experiments to Earth, as was finally accomplished with Kosmos 1443.

MAN V. MACHINE—THE SOVIET VIEWPOINT

The Soviets are attempting to determine the relative roles of man versus machine in space, just as other countries are. In April 1978, cosmonaut Feoktistov conceded that the topic was very controversial, with some specialists believing that space is "above all a sphere for the operation of machines," and others pointing out that "it is still people who have to elaborate the methods for this research and correlate the degree to which the information obtained by machine corresponds with the real picture." [210]

As detailed in the earlier sections of this chapter, the Soviets have developed considerable experience with crews as repairmen in orbit. Discussing the design of future space stations, engineer Oleg Tsygankov explained that this experience has led engineers to design stations so that crew members can have easy access to any particular component or system so that they can be replaced by new ones. He added that these repair methods will also be useful for flights to the planets.[211]

A REUSABLE SPACE VEHICLE

Speculation that the Soviets are developing a reusable space vehicle along the same lines as the U.S. space shuttle has been widespread for many years. By the end of 1980, it appeared that any plans the Soviets might have had in the 1970's had been put on hold for economic reasons, but as detailed in chapter 2, (p. 465), 3 years later there had been flight tests which may be associated with developing such a capability.

EARLY RUMORS: KOSMOLJOT/ALBATROS

In 1976, Maarten Houtman, a Dutchman interested in Soviet space activities, published an article in his magazine, *Spaceview*,

[210] Sotsialisticheskaya Industriya, 12 Apr 78, p. 3.
[211] Tass, 1406 GMT, 5 Dec 80.

called "Albatros, the Soviet Shuttle."[212] According to Houtman, the Soviets were pursuing development of a reusable space system called Kosmoljot. He called the orbiter associated with the system Albatros. According to Houtman, rumors associated with development of the system had first seeped into the West as early as 1964.

Houtman described two different reusable systems on which the Soviets were allegedly working at the time the article was published. The first was based on vertical takeoff, while the second would use a horizontal takeoff approach. This latter vehicle, Kosmoljot, was the focus of the research effort because it would be fully reusable, while the former would be only partially reusable, according to Houtman.

Houtman described the exterior appearance of the booster as similar to a Tu-144, with widened wings and without the tail section, thus looking like a triangle. The booster would be piloted by two to three people to an altitude of 30 kilometers, after which it would separate from the orbiter and return to Earth, landing like an airplane.

The orbiter, Albatros, would look like a mini-Tu-144 with thickened delta wings bent upward, resembling an arrowhead. Houtman stated that the orbiter would be approximately 25 meters in length, carry two to three persons, use ion engines, and be capable of multiple plane changes and other orbital maneuvers enabling a single crew to complete three or four separate tasks before returning. Among the missions Houtman envisioned for Albatros was deployment and retrieval of satellites, and retrieval of "space junk."

Houtman predicted that an orbital launch of Kosmoljot would take place by 1977. This did not occur.

KOSMOS PAIRS: 881/822, 997/998, 1100/1101

Although there were no flights that could be definitively associated with a space shuttle in the 1970's, there were three launches whose missions remain obscure but are often categorized in the West as possible reentry tests of a new manned space system.

In each case, two spacecraft were launched on one booster (a D-1) from Tyuratam into a 51.6° orbit, and both would reenter after less than one orbit. The first launch, of Kosmos 881 and 882, occurred on December 15, 1976. Kosmos 997 and 998 followed 15 months later on March 30, 197 , and Kosmos 1100 and 1101 on May 22, 1979, 14 months after the previous flight.

Kosmos 881/882 had an apogee of 248 km and perigee of 202 km, and a period of 88.8 minutes. Kosmos 997/998 had an apogee of 230 km and perigee of 200 km, with a period of 88.7 minutes. Kosmos 1100/1101 were in a 230×199 km orbit, with a period of 88.6 minutes.

U.S. Government sources were quoted at the time as saying that 881/882 were "definitely man-related",[213] although specifics were not forthcoming. Analysis by other observers suggested that the mission profile would fit with a maneuverable vehicle, possibly the long awaited reusable vehicle.[214]

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[212] Houtman, Maarten. Albatros, the Soviet Shuttle. Spaceview, May/June 1976m pp. 24-31.
[213] Aerospace Daily, Dec. 23, 1976, p. 262.
[214] See for example: Gregg, Rachan. Winged Spacecraft. Letter to Aviation Week and Space Technology. June 2, 1980.

1978 RADIO MOSCOW REPORT AND FURTHER RUMORS OF A "RAKETOPLAN"

By 1978, the rumors of the appearance of a Soviet reusable vehicle were still just that, rumors. In October 1978, however, in response to a question from a listener, Radio Moscow released details of a reusable plane under development. The announcer stated that the vehicle would resemble an airplane with delta wings, and would have three powerful rockets in the rear. Overall length of the vehicle would be 200 feet (including the launch vehicle) with a diameter of 26 feet (compared to the 78-foot wingspan of the U.S. shuttle).[215]

At the same time, the U.S. weekly *Aviation Week and Space Technology* reported that drop tests of a delta-winged reusable spacecraft (similar to those conducted with the U.S. space shuttle orbiter in 1977) had taken place from a Tu-95 Bear bomber for aerodynamic testing as early as 1975.[216] The magazine reported that the vehicle was very similar in appearance to the U.S. X-20 Dyna-Soar which had been planned for development in the early 1960's (the program was canceled before any flight models were built).

By this time, another designation for the Soviet shuttle effort had appeared: "raketoplan" or rocket plane, a term reportedly used as early as 1927 by Soviet rocket designed Sergei Korolev. At the same time, rumors began to appear that a runway for the new vehicle was under construction at Tyuratam.[217] Further information on the possible location of the shuttle runway at Tyuratam is discussed in chapter 1 of this study.

SUBSEQUENT STATEMENTS BY SOVIET OFFICIALS

Statements by Soviet officials at the 1979 International Astronautical Federation conference in Munich further added to expectations that a Soviet shuttle was in development, but left doubt as to when it might be introduced. Cosmonaut Georgiy Beregovoy called a Soviet shuttle a "logical next step" and his colleague Anatoliy Filipchenko added that "We are trying to build a vehicle that we don't have to throw away." [218] These statements were tempered, however, by reference to trying to accomplish manned space goals in an "economic" manner.[219]

In June 1980, cosmonaut Shatalov commented that "Soviet specialists have also investigated the possibility of producing spacecrafts [sic] which can be used more than once. In the given stage, however, they consider that the employment of these spacecrafts [sic] is not justified because the present tasks can be solved with the well-tested methods in an economic way." [220]

Thus, at the end of 1980, the status of the Soviet reusable space vehicle program was ambiguous at best. Evidence suggested that

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[215] Soviets confirm Shuttle Vehicle Effort. Aviation Week and Space Technology, Oct. 16, 1978: 25.

[216] Covault, Craig. Soviets Build Reusable Shuttle. Aviation Week and Space Technology, March 20, 1978: 14-15. Covault, Craig. Soviets Developing Fly-Back Launcher. Aviation Week and Space Technology, Nov. 6, 1978: 19-20.

[217] Shuttle Runway. Aviation Week and Space Technology, Jan. 8, 1979: 11.

[218] Quoted in: Spaceflight, v. 21, Dec. 1979: 481.

[219] Spaceflight, v. 22, March 1980: 136.

[220] Budapest MTI, 1100 GMT, 5 June 80.

some developmental work had occurred during the last part of the 1970's, but the program may have encountered budgetary difficulties similar to the U.S. space shuttle, or technical problems, thus delaying its appearance.

As discussed in chapter 2, the smaller reusable vehicle suggested by the 1978 Radio Moscow report and/or a larger vehicle similar to the U.S. shuttle, may be launched in the mid-1980's.

MANNED PLANETARY VOYAGES

The Soviet Union has always exhibited an interest in the very long term aspects of space flight, in fact, they speak more often of their far range plans than what might develop in the next 5 to 10 years.

This is the case with the possibility of sending people to other planets in the solar system, notably Mars. As early as 1976, cosmonaut Georgiy Beregovoy commented that some day there would be "bases and camps on the Moon. And in the more distant future there will be expeditions, first to Mars and then to other planets."[221]

In 1978, an interesting aspect of this long-range plan developed with the linking of Mars flights to the Salyut space station program. During a discussion of the 96 day flight to Salyut 6 (Soyuz 29/31), a Radio Moscow commentary stated that the need to extend manned stays in space was "dictated to a greater extent by the future tasks of space exploration than by the present ones . . . For example, a manned flight to our nearest neighbor, the planet Mars, will require 1.5 years in weightlessness, under the most favorable conditions."[222]

Thus the Soviets showed that they have more than a passing interest in such flights, and they are actually performing the requisite physiological and psychological research to make such a mission possible. Viewed together other developments, it would appear that the Soviets are paving the way for manned missions to the planets. For example, Soviet engineer Oleg Tsygankov commented in 1980 that the methods of repairing Salyut 6 "may also prove useful for long-distance flights."[223] Coupled with closed-cycle research onboard the Salyut space stations to make the stations self-sufficient in terms of food and water, and the development of more capable launch vehicles, such flights may be a reality in this century.

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221 Tass, 0835, GMT, 10 Apr 76.
222 Moscow Domestic Service, 0001 GMT, 19 Sep 78.
223 Tass, 1406 GMT, 5 Dec 80.

TABLE 14.—WORLD RECORD OF MANNED SPACE FLIGHTS

Name/call sign	Crew (number of flights)	Launch date	Termination	Duration (hr min)	Orbits	Launch site	Launch vehicle	Spacecraft weight (kg)	Remarks
Vostok 1/Kedr (Cedar)	Gagarin	Apr 12, 1961	Apr 12, 1961	1 48	1	TT	A-1	4,725	First manned flight.
Mercury Redstone 3/Freedom 7	Shepard	May 5, 1961	May 5, 1961	15		CC	Redstone	1,290	First U.S. flight, suborbital
Mercury Redstone 4/Liberty Bell 7	Grissom	July 21, 1961	July 21, 1961	16		CC	Redstone	1,286	Suborbital; capsule sank after landing
Vostok 2/Oryel (Eagle)	G. Titov	Aug 6, 1961	Aug 7, 1961	25 18	17	TT	A-1	4,731	First flight exceeding 24 hours
Mercury Atlas 6/Friendship 7	Glenn	Feb 20, 1962	Feb 20, 1962	4 55	3	CC	Atlas	1,355	First American to orbit.
Mercury Atlas 7/Aurora 7	Carpenter	May 24, 1962	May 24, 1962	4 56	3	CC	Atlas	1,349	Landed 402 km from target.
Vostok 3/Sokol (Falcon)	Nikolayev	Aug 11, 1962	Aug 15, 1962	94 22	64	TT	A-1	4,722	Target for Vostok 4.
Vostok 4/Berkut (Golden Eagle)	Popovich	Aug 12, 1962	Aug 15, 1962	70 57	48	TT	A-1	4,728	Passed Vostok 3 at 6.5 km.
Mercury Atlas 8/Sigma 7	Schirra	Oc[illegible]962	Oct. 3, 1962	9:13	6	CC	Atlas	1,373	Landed 8 km from target.
Mercury Atlas 9/Faith 7	Cooper	Ma[illegible]963	May 16, 1963	34:20	23	CC	Atlas	1,376	First U.S. flight exceeding 24 hours.
Vostok 5/Yastreb (Hawk)	Bykovsky	June [illegible]	June 19, 1963	119:06	81	TT	A 1	4,720	Target for Vostok 6.
Vostok 6/Chayka (Sea Gull)	Tereshkova	June 16, 1963	June 19, 1963	70:50	48	TT	A-1	4,713	First woman in orbit; passed Vostok 5 at 5 km.
Voskhod 1/Rubin (Ruby)	Komarov, Feoktistov, Yegorov	Oct. 12, 1964	Oct 13, 1964	24:17	16	TT	A-2	5,320	First three man crew; included designer and medical researcher.
Voskhod 2/Almaz (Diamond)	Belyayev, Leonov	Mar. 18, 1965	Mar. 19, 1965	26:02	17	TT	A-2	5,682	Leonov performed first extravehicular activity.
Gemini Titan 3/Molly Brown	Grissom (2), Young	Mar. 23, 1965	Mar. 23, 1965	4:53	3	CC	Titan II	3,225	First U.S. 2-man crew, first maneuvers.
Gemini Titan 4	McDivitt, White	June 3, 1965	June 7, 1965	97:56	66	CC	Titan II	3,574	White performed first U.S. extravehicular activity.
Gemini Titan 5	Cooper (2), Conrad	Aug 21, 1965	Aug. 29, 1965	190:55	128	CC	Titan II	3,605	Duration record; phantom rendezvous.
Gemini Titan 7	Borman, Lovell	Dec. 4, 1965	Dec. 18, 1965	330:35	220	CC	Titan II	3,663	Duration record; target for Gemini Titan 6.
Gemini Titan 6	Schirra (2), Stafford	Dec 15, 1965	Dec. 16, 1965	25:51	17	CC	Titan II	3,546	Rendezvous within 30 cm, sustained coorbit.
Gemini Titan 8	Armstrong, Scott	Mar 16, 1966	Mar. 17, 1966	10:41	7	CC	Titan II	3,788	First docking (Agena 8); high spin forced emergency landing near Okinawa.
Gemini Titan 9	Stafford (2), Cernan	June 3, 1966	June 6, 1966	72:21	47	CC	Titan II	3,750	Cernan EVA, 3 rendezvous but no docking because shroud problem on ATDA.
Gemini Titan 10	Young (2), Collins	July 18, 1966	July 21, 1966	70:47	46	CC	Titan II	3,741	Collins EVA; rendezvous with Agena 8 and Agena 10; docked with Agena 10.
Gemini Titan 11	Conrad (2), Gordon	Sept. 12, 1966	Sept. 15, 1966	71:17	47	CC	Titan II	3,860	Gordon EVA; initial orbit rendezvous, Agena 11, 2 ship rotation with tether; climb to 1,372 km.
Gemini Titan 12	Lovell (2), Aldrin	Nov. 11, 1966	Nov. 15, 1966	94:35	63	CC	Titan II	3,763	Aldrin EVA; 3 dockings with Agena 12.
Apollo 1/(AS 204)	Grissom (3), White (2), Chaffee.	Jan 27, 1967	Jan 27, 1967			CC	Saturn IB	20,412	Preliminary test on pad; fire killed all 3 astronauts, but launch vehicle later used for Apollo 5.

TABLE 14.—WORLD RECORD OF MANNED SPACE FLIGHTS—Continued

Name/call sign	Crew (number of flights)	Launch date	Termination	Duration (hr min)	Orbits	Launch site	Launch vehicle	Spacecraft weight (kg)	Remarks
Soyuz 1/Rubin (Ruby)	Komarov	Apr 23, 1967	Apr 24, 1967	26:48	18	TT	A 2	6,450	Parachutes tangled in landing, killing Komarov
Apollo 7	Schirra (3), Eisele, Cunningham	Oct 11, 1968	Oct 22, 1968	260:09	174	CC	Saturn IB	20,569	First U.S. 3-man crew, rendezvous with third stage.
Soyuz 3/Argon (Argon)	Beregovoy	Oct 26, 1968	Oct 30, 1968	94:51	64	TT	A 2	6,575	Rendezvous with Soyuz 2 but no docking.
Apollo 8	Borman (2), Lovell (3), Anders	Dec 21, 1968	Dec 27, 1968	147:01	2 Earth 10 Moon	CC	Saturn V	43,663	First manned orbits of Moon, first manned escape from Earth, first high speed reentry with men.
Soyuz 4/Amur (Amur)	Shatalov (Yeliseyev), (Khrunov)	Jan 14, 1969	Jan 17, 1969	71:21	48	TT	A-2	6,625	First docking with a manned ship, first crew transfer.
Soyuz 5/Baykal (Baikal)	Volynov, Yeliseyev, Khrunov	Jan 15, 1969	Jan. 18, 1969	72:54	49	TT	A-2	6,585	Target for rendezvous and docking. Two of crew transferred to Soyuz 4 by EVA.
Apollo 9/Gumdrop, Spider	McDivitt (2), Scott (2), Schweickart	Mar 3, 1969	Mar. 13, 1969	241:01	162	CC	Saturn V	43,136	Tested propulsion, rendezvous and docking of LM.
Apollo 10/Charlie Brown, Snoopy	Stafford (3), Young (3), Cernan (2)	May 18, 1969	May 26, 1969	192:03	2 Earth 31 Moon	CC	Saturn V	48,638	Tested propulsion, rendezvous and docking of LM in lunar orbit
Apollo 11/Columbia, Eagle	Armstrong (2), Collins (2), Aldrin (2)	July 16, 1969	July 24, 1969	195:19	2 Earth 30 Moon	CC	Saturn V	49,698	First landing of men on Moon July 20, returned safely.
Soyuz 6/Antey (Antaeus)	Shonin, Kubasov	Oct. 11, 1969	Oct. 16, 1969	118:43	80	TT	A-2	6,577	Coorbit with Soyuz 7, tested welding in space.
Soyuz 7/Buran (Snowstorm)	Filipchenko, Gorbatko, Volkov	Oct. 12, 1969	Oct. 17, 1969	118:40	80	TT	A-2	6,570	Rendezvous target for Soyuz 6 and 8.
Soyuz 8/Granit (Granite)	Shatalov (2), Yeliseyev (2)	Oct. 13, 1969	Oct. 18, 1969	118:51	80	TT	A-2	6,646	Coorbit with Soyuz 7, but did not dock.
Apollo 12/Yankee Clipper, Intrepid	Conrad (3), Gordon (2), Bean	Nov. 14, 1969	Nov. 24, 1969	244:36	2 Earth 45 Moon	CC	Saturn V	49,804	Landed on Moon Nov. 19, returned safely.
Apollo 13/Odyssey, Aquarius	Lovell (4), Swigert, Haise	Apr 11, 1970	Apr. 17, 1970	142:55	2 Earth 1 Moon	CC	Saturn V	49,990	Explosion in service module aborted lunar landing; returned on circumlunar path.
Soyuz 9/Sokol (Falcon)	Nikolayev (2), Sevastyanov	June 1, 1970	June 19, 1970	424:59	286	TT	A-2	6,500	Duration record of 18 days.
Apollo 14/Kitty Hawk, Antares	Shepard (2), Roosa, Mitchell	Jan. 31, 1971	Feb. 9, 1971	216:02	2 Earth 34 Moon	CC	Saturn V	46,346	Landed on Moon Feb. 5, returned safely.
Salyut 1		Apr 19, 1971	Oct. 11, 1971	4,200	2,817	TT	D-1	18,600	Launched unmanned; space station visited by Soyuz 10, 11.
Soyuz 10/Granit (Granite)	Shatalov (3), Yeliseyev (3), Rukavishnikov	Apr. 22, 1971	Apr. 24, 1971	47:46	32	TT	A-2	6,575	Docked with Salyut, but no entry into station.

Soyuz 11/Yantar (Amb	Dobrovolskiy, Patsayev, Volkov (2)	June 6, 1971	June 29, 1971	570:22	383	TT	A-2	6,790	Docked with Salyut 1; crew set duration record of 24 days, but all killed during reentry
Apollo 15/Endeavor, Falcon	Scott (3), Worden, Irwin	July 26, 1971	Aug. 7, 1971	295:12	2 Earth 74 Moon	CC	Saturn V	52,759	Landed on Moon July 30, returned safely. Used lunar roving vehicle.
Apollo 16/Casper, Orion	Young (4), Mattingly, Duke	Apr. 16, 1972	Apr. 27, 1972	265:51	2 Earth 65 Moon	CC	Saturn V	51,571	Landed on Moon Apr. 20, returned safely. Used lunar roving vehicle.
Apollo 17/America, Challenger	Cernan (3), Evans, Schmitt	Dec. 7, 1972	Dec. 19, 1972	301:52	3 Earth 75 Moon	CC	Saturn V	51,808	Landed on Moon Dec. 11, returned safely. Used lunar roving vehicle.
Skylab 1		May 14, 1973	July 11, 1979	53,975		CC	Saturn V	89,439	Launched unmanned; space station visited by SL-2, 3, 4
Skylab 2	Conrad (4), Kerwin, Weitz	May 25, 1973	June 22, 1973	672:50	433	CC	Saturn IB	30,803	Docked with Skylab 1, crew repaired damaged station.
Skylab 3	Bean (2), Garriott, Lousma	July 28, 1973	Sept. 25, 1973	1,427:09	919	CC	Saturn IB	30,694	Docked with Skylab 1, crew made further repairs to station.
Soyuz 12/Ural (Ural)	Lazarev, Makarov	Sept. 27, 1973	Sept. 29, 1973	47:16	31	TT	A-2	6,575	Checkout of engineering fixes; first flight of ferry version of Soyuz.
Skylab 4	Carr, Gibson, Pogue	Nov. 16, 1973	Feb. 8, 1974	2,017:17	1,298	CC	Saturn IB	31,232	Docked with Skylab 1, crew set duration record of 84 days.
Soyuz 13/Kavkaz (Caucasus)	Klimuk, Lebedev	Dec. 18, 1973	Dec. 26, 1973	188:56	127	TT	A-2	6,575	Astrophysical, biological, Earth resources experiments.
Salyut 3		June 24, 1974	Jan. 24, 1975	5,136	3,424	TT	D-1	18,600	Launched unmanned, first military space station. Visited by Soyuz 14. Soyuz 15 could not dock.
Soyuz 14/Berkut (Golden Eagle)	Popovich (2), Artyukhin	July 3, 1974	July 19, 1974	377:30	252	TT	A-2	6,570	Docked with Salyut 3.
Soyuz 15/Dunay (Danube)	Sarafanov, Demin	Aug. 26, 1974	Aug. 28, 1974	48:12	32	TT	A-2	6,570	Did not achieve docking.
Soyuz 16/Buran (Snowstorm)	Filipchenko (2), Rukavishnikov (2)	Dec. 2, 1974	Dec. 8, 1974	142:24	96	TT	A-2	6,570	ASTP phantom docking test and other tests.
Salyut 4		Dec. 26, 1974	Feb. 2, 1977	18,745		TT	D-1	18,900	Launched unmanned, space station visited by Soyuz 17, 18, and 20 (which was unmanned).
Soyuz 17/Zenit (Zenith)	Gubarev, Grechko	Jan. 10, 1975	Feb. 9, 1975	709:20	466	TT	A-2	6,570	Docked with Salyut 4.
April 5 Anomaly/Ural (Ural)	Lazarev (2), Makarov (2)	Apr. 5, 1975	Apr. 5, 1975	:20		TT	A-2	6,570	Intended to dock with Salyut 4, but aborted in launch phase.
Soyuz 18/Kavkaz (Caucasus)	Klimuk (2), Sevastyanov (2)	May 24, 1975	July 26, 1975	1,511:20	993	TT	A-2	6,570	Docked with Salyut 4.
Soyuz 19/Soyuz (Union)	Leonov (2), Kubasov (2)	July 15, 1975	July 21, 1975	142:31	96	TT	A-2	6,800	Docking target for Apollo.
Apollo Soyuz Test Project	Stafford (4), Slayton, Brand	July 15, 1975	July 24, 1975	217:28	145	CC	Saturn IB	14,743	Docked with Soyuz 19.
Salyut 5		June 22, 1976	Aug. 8, 1977	9,888		TT	D-1	18,900	Space station visited by Soyuz 21 and 24. Soyuz 23 could not dock.

TABLE 14.—WORLD RECORD OF MANNED SPACE FLIGHTS—Continued

Name/call sign	Crew (number of flights)	Launch date	Termination	Duration (hr min)	Orbits	Launch site	Launch vehicle	Spacecraft weight (kg)	Remarks
Soyuz 21/Baykal (Baikal)	Volynov (2), Zholobov	July 6, 1976	Aug 24, 1976	1,182:23	790	TT	A-2	6,570	Docked with Salyut 5
Soyuz 22/Yastreb (Hawk)	Bykovskiy (2), Aksenov	Sept. 15, 1976	Sept 24, 1976	189:52	127	TT	A-2	6,570	Carried MKF-6 camera for Earth resources study
Soyuz 23/Radon (Radon)	Zudov, Rozhdestvenskiy	Oct. 14, 1976	Oct 16, 1976	48:07	32	TT	A-2	6,570	Intended to dock with Salyut 5, but failed.
Soyuz 24/Terek (Terek)	Gorbatko (2), Glazkov	Feb 7, 1977	Feb 25, 1977	425:26	285	TT	A-2	6,570	Docked with Salyut 5
Salyut 6		Sept 29, 1977				TT	D-1	18,900	Second generation space station. Visited by Soyuz 26-32, 34-40, Soyuz T-Soyuz T4
Soyuz 25/Foton (Photon)	Kovalenok, Ryumin	Oct. 9, 1977	Oct. 11, 1977	48:45	32	TT	A-2	6,570	Intended to dock with Salyut 6, but could not achieve hard dock.
Soyuz 26/Taymyr (Taimyr)	Romanenko, Grechko (2), (Dzhanibekov), (Makarov)	Dec. 10, 1977	Jan. 16, 1978	898:06	590	TT	A-2	6,570	Docked with Salyut 6, crew stayed 2,314:00 in orbit, returning in Soyuz 27. Set new duration record of 96 days.
Soyuz 27/Pamyr (Pamir)	Dzhanibekov, Makarov (3), (Romanenko), (Grechko)	Jan. 10, 1978	Mar 16, 1978	1,558:53	1,024	TT	A-2	6,570	Docked with Salyut 6, crew stayed 142:59 in orbit, returning in Soyuz 26.
Progress 1		Jan. 20, 1978	Feb. 8, 1978	450:14		TT	A-2	7,020	Unmanned supply ship. Docked with Salyut 6, crew unloaded supplies. First in-space fuel transfer.
Soyuz 28/Zenit (Zenith)	Gubarev (2), Remek	Mar. 2, 1978	Mar. 10, 1978	190:16	125	TT	A-2	6,570	Docked with Salyut 6, crew included first Czechoslovakian cosmonaut.
Soyuz 29/Foton (Photon)	Kovalenok (2), Ivanchenkov, (Bykovskiy), (Jahn)	June 15, 1978	Sept. 3, 1978	1,911:23	1,257	TT	A-2	6,570	Docked with Salyut 6, crew stayed 3,350:48 in orbit, returning in Soyuz 31. Set new duration record of 140 days.
Soyuz 30/Kavkaz (Caucasus)	Klimuk (3), Hermaszewski	June 27, 1978	July 5, 1978	190:03	125	TT	A-2	6,570	Docked with Salyut 6, crew included first Polish cosmonaut.
Progress 2		July 7, 1978	Aug. 4, 1978	662:06		TT	A-2	7,020	Unmanned supply ship. Docked with Salyut 6, crew unloaded supplies.
Progress 3		Aug. 7, 1978	Aug. 23, 1978	378:59		TT	A-2	7,020	Unmanned supply ship. Docked with Salyut 6, crew unloaded supplies.
Soyuz 31/Yastreb (Hawk)	Bykovskiy (3), Jahn, (Kovalenok), (Ivanchenkov)	Aug. 26, 1978	Nov. 2, 1978	1,628:14	1,070	TT	A-2	6,570	Docked with Salyut 6, crew stayed in orbit 188:49, returning in Soyuz 29. Crew included first cosmonaut of German Democratic Republic.
Progress 4		Oct. 3, 1978	Oct. 26, 1978	545:19		TT	A-2	7,020	Unmanned supply ship. Docked with Salyut 6, crew unloaded supplies.

Soyuz 32/Proton (Proton)	Lyakhov, Ryumin (2)	Feb 25, 1979	June 13, 1979	2,596:24	1,711	TT	A-2	6,570	Docked with Salyut 6, crew stayed 4,200:36 in orbit, returning in Soyuz 34. Set new record of 175 days
Progress 5		Mar 12, 1979	Apr 4, 1979	571:17		TT	A-2	7,020	Unmanned supply ship. Docked with Salyut 6, crew unloaded supplies
Soyuz 33/Saturn (Saturn)	Rukavishnikov (3), Ivanov	Apr 10, 1979	Apr 12, 1979	47:01	31	TT	A-2	6,570	Intended to dock with Salyut 6, but engine irregularity precluded docking; crew included Bulgarian cosmonaut.
Progress 6		May 13, 1979	June 9, 1979	662:34		TT	A-2	7,020	Unmanned resupply ship. Docked with Salyut 6, crew unloaded supplies
Soyuz 34/Proton (Proton)	(Lyakhov), (Ryumin)	June 6, 1979	Aug 19, 1979	1,770:17	1,153	TT	A-2	6,570	Docked with Salyut 6. Launched unmanned, but used for return of Soyuz 32 crew
Progress 7		June 30, 1979	July 20, 1979	570:32		TT	A-2	7,020	Unmanned resupply ship. Docked with Salyut 6, crew unloaded supplies.
Progress 8		Mar 27, 1980	Apr 26, 1980	708:01		TT	A-2	7,020	Unmanned resupply ship. Docked with Salyut 6, later arriving crew unloaded supplies.
Soyuz 35/Dnepr (Dnieper)	Popov, Ryumin (3), (Kubasov), (Farkas)	Apr 9, 1980	June 3, 1980	1,321:29	868	TT	A-2	6,570	Docked with Salyut 6, crew stayed 4,436:12 in orbit, returning in Soyuz 37. Stayed for 185 days, but no new record.
Progress 9		Apr 27, 1980	May 22, 1980	594:20		TT	A-2	7,020	Unmanned resupply ship. Docked with Salyut 6, crew unloaded supplies.
Soyuz 36/Orion (Orion)	Kubasov (3), Farkas, (Gorbatko), (Pham Tuan)	May 26, 1980	July 31, 1980	1,580:54	1,040	TT	A-2	6,570	Docked with Salyut 6, crew stayed 188:46 in orbit, returning in Soyuz 35. Crew included first Hungarian cosmonaut.
Soyuz T-2/Jupiter (Jupiter)	Malyshev, Aksenov (2)	June 5, 1980	June 9, 1980	94:19	62	TT	A-2	7,000	Docked with Salyut 6, first manned test of new vehicle.
Progress 10		June 29, 1980	July 19, 1980	477:06		TT	A-2	7,020	Unmanned resupply ship. Docked with Salyut 6, crew unloaded supplies.
Soyuz 37/Terek (Terek)	Gorbatko (3), Pham Tuan, (Popov), (Ryumin)	July 23, 1980	Oct 11, 1980	1,911:17	1,257	TT	A-2	6,570	Docked with Salyut 6, crew stayed 188:42 in orbit, returning in Soyuz 36. Crew included Vietnamese cosmonaut.
Soyuz 38/Taymyr (Taymyr)	Romanenko (2), Tamayo Mendez	Sept. 18, 1980	Sept. 26, 1980	188:43	124	TT	A-2	6,570	Docked with Salyut 6. Crew included first Cuban cosmonaut.
Progress 11		Sept. 28, 1980	Dec. 11, 1980	1,774:50		TT	A-2	7,020	Unmanned resupply ship. Docked with Salyut 6, crew unloaded supplies.
Soyuz T-3	Kizim, Makarov (4), Strekalov	Nov. 27, 1980	Dec. 10, 1980	307:08		TT	A-2	7,000	Docked with Salyut 6. First 3-man crew since 1971.

Notes: 1. This is a quick reference lists of all manned flights giving the abbreviated popular name and call sign, the astronauts or cosmonauts, the dates of launch and termination, the duration in hours and minutes, the number of orbits, the launch site (TT for Tyuratam and CC for Cape Canaveral and Merritt Island), the launch vehicle, the announced or estimated weight of the spacecraft in kilograms, and general remarks.
2. The best available information is that there have been no manned launch failures other than the few problems listed in the table.

3 There is some uncertainty regarding U.S. flight durations because different times are reported by the several NASA offices involved, and this goes beyo. d rounding out fractions of minutes. In the most extreme ca e, one lunar flight was delayed, but by orbit adjustment achieved its original time line, and some accounts credit as flight time the extra time it was held on the pad. For the Soviet missions, all durations are taken from the Russian book "Kosmos," published in Leningrad in 1982. The one exception is the April 5 Anomaly in 1975 which was not included in that book. The duration time for this flight was derived from the distance it flew.

4 In addition to the missions listed here, the total record includes a variety of unmanned precursor flights of similar spaceships. The Russians placed in orbit two other manned stations which were not occupied: Salyut 2, launched April 3, 1973, and Kosmos 557, launched May 11, 1973. There were two successful unmanned dockings to stations not included in this table because no crew was on board the stations at the time. These were Soyuz 20, launched November 17, 1975, which docked with Salyut 4 and was recovered on February 16, 1976, for a total flight time of 90.5 days, and Soyuz T 1, launched December 16, 1979, which docked with Salyut 6 and was recovered on March 25, 1980 for a total flight time of 100.29 days (2,409.17).

5 Termination times for Progress flights are to the point of retro-fire, not landing, as these ships typically burn in the atmosphere with any remaining debris falling in the Pacific Ocean away from traveled shipping lanes.

6 More details about Soviet manned and man-related flights and about the cosmonauts are shown in separate tables in the chapter.

Sources: Most data on Soviet flights are from TASS bulletins, with gaps filled in by estimates; U.S. data are from NASA press releases or internal NASA reports.

TABLE 15.—EVENT TIMES OF SOVIET MANNED AND SELECTED RELATED FLIGHTS

Flight	Launch date	Launch hour	Docking date	Docking hour	Undocking date	Undocking hour	Retro date	Retro hour	Landing date	Landing hour	Docked duration	Flight duration	
Vostok 1	Apr 12, 1961	0607					Apr 12, 1961	0725	Apr 12, 1961	0755		1:48	
Vostok 2	Aug 6, 1961	0600							Aug 7, 1961	0715		2⁴ ..	ship
										0718		25:18	cosmonaut
Vostok 3	Aug 11, 1962	0830							Aug 15, 1962	0652		94:22	ship
										0655		94:25	cosmonaut
Vostok 4	Aug 12, 1962	0802							Aug. 15, 1962	0659		70:57	ship
										0701		70:59	cosmonaut
Vostok 5	June 14, 1963	1200							June 19, 1963	1100		119:00	ship
										1106		119:06	cosmonaut
Vostok 6	June 16, 1963	0930					June 19, 1963	0755	June 19, 1963	0816		70:46	ship
										0820		70:50	cosmonaut
Voskhod 1	Oct 12, 1964	0730							Oct. 13, 1964	0747		24:17	
Voskhod 2	Mar 18, 1965	0700							Mar. 19, 1965	0902		26:02	
Soyuz 1	Apr 23, 1967	0035							Apr. 24, 1967	0323		26:48	
Soyuz 2	Oct 25, 1968	0900					Oct. 28, 1968	0725	Oct. 28, 1968	0800		71:00	
Soyuz 3	Oct. 26, 1968	0834							Oct. 30, 1968	0725		94:51	
Soyuz 4	Jan 14, 1969	0730	Jan 16, 1969	0820	Jan. 16, 1969	1255			Jan. 17, 1969	0651	4:35	71:21	ship
Soyuz 5	Jan 15, 1969	0704	Jan 16, 1969	0820	Jan. 16, 1969	1255			Jan. 18, 1969	0758	4:35	72:54	ship
									Jan. [illegible], 1969	0653		47:49	2 cosmonauts
Soyuz 6	Oct 11, 1969	1110							Oct 16, 1969	0953		118:43	
Soyuz 7	Oct. 12, 1969	1045							Oct. 17, 1969	0925		118:40	
Soyuz 8	Oct 13, 1969	1020							Oct. 18, 1969	0911		118:51	
Soyuz 9	June 1, 1970	1900							June 19, 1970	1159		424:59	
Salyut 1	Apr 19, 1971	0140					Oct. 11, 1971					4200	
Soyuz 10	Apr 22, 1971	2354	Apr 24, 1971	0147	Apr. 24, 1971	0418	Apr. 24, 1971	2259	Apr. 24, 1971	2340	[1] 5:30	47:46	
			Apr 24, 1971	0547	Apr. 24, 1971	0717					[2] 4:01		

Soyuz 11	June 6 1971	0455	June 7 1971	0745	June 29, 1971	1828	June 29, 1971	2235	June 29, 1971	2317	538 43	570·22	
Salyut 2	Apr 3, 1973	0900					May 28, 1973		May 28, 1973	1146		1,322 46	
Kosmos 557	May 11, 1973	0120					May 22, 1973		May 22, 1973	0307		265 47	
Soyuz 12	Sept 27 1973	1218							Sept 29, 1973	1134		47 16	
Soyuz 13	Dec 18 1973	1155							Dec. 26, 1973	0851		188 56	
Salyut 3	June 24, 1974	2238					Jan 2, 1974		Jan 24, 1974			5,136	
Soyuz 14	July 3, 1974	1851	July 4, 1974	2035	July 19, 1974	0903	July 19, 1974	1135	July 19, 1974	1221	348 28	377.30	
Soyuz 15	Apr 26, 1974	1958					Aug 28, 1974	1925	Aug. 28, 1974	2010		48 12	
Soyuz 16	Dec 2, 1974	0940							Dec. 8, 1974	0804		142 24	
Salyut 4	Dec 26, 1974	0415					Feb 2, 1974		Feb 2, 1974	2331		18,475.16	
Soyuz 17	Jan 10, 1975	2143	Jan 12, 1975	0125	Feb. 9, 1975	0608			Feb. 9, 1975	1103	676·43	709 20	
Anomaly	Apr 5 1975	1100							Apr. 5, 1975	1120		.20	
Soyuz 18	May 24, 1975	1458	May 26, 1975	1844	July 26, 1975	1056			July 26, 1975	1418	1,456:12	1,511·20	
Soyuz 19	July 15, 1975	1220	July 17, 1975	1609	July 19, 1975	1202			July 21, 1975	1051	[1] 47:23		
			July 19, 1975	1220	July 19, 1975	1532					[2] 47:05	142·31	
Soyuz 20	Nov 17, 1975	1437	Nov. 19, 1975	1920	Feb. 15, 1975	2304			Feb. 16, 1975	0224	2,115:44	2,171·47	
Salyut 5	June 22, 1976	1804					Aug. 8, 1976		Aug. 8, 1976			9,888	
Soyuz 21	July 6, 1976	1209	July 7, 1976	1340	Aug. 24, 1976	1512			Aug. 24, 1976	1834	1,153:32	1,182:23	
Soyuz 22	Sept 15, 1976	0948							Sept. 23, 1976	0740		189:52	
Soyuz 23	Oct 14, 1976	1740	(Oct. 15, 1976	1858)					Oct. 16, 1976	1747		48:07	
Soyuz 24	Feb 7, 1977	1612	Feb. 8, 1977	1738	Feb. 25, 1977	0621			Feb. 25, 1977	0938	396:43	425:26	
Salyut 6	Sept 29, 1977	0650											
Soyuz 25	Oct 9, 1977	0240	(Oct 10, 1977	0409)					Oct. 11, 1977	0325		48:45	
Soyuz 26	Dec 10, 1977	0119	Dec 11, 1977	0302	Jan. 16, 1977	0805			Jan. 16, 1977	1125	869:03	898:06	ship
					Mar 16, 1977	0800			Mar. 16 1977	1119	2,284:58	2,314:00	cosmonauts
Soyuz 27	Jan 10, 1978	1226	Jan 11, 1978	1406	Mar. 16, 1978	0800			Mar. 16, 1978	1119	1,529:54	1,558:53	ship
					Jan. 16, 1978	0805			Jan 16, 1978	1125	113:59	142:59	cosmonauts
Progress 1	Jan 20, 1978	0825	Jan 22, 1978	1012	Feb. 6, 1978	0553	Feb. 8, 1978	0239			355:41	450:14	
Soyuz 28	Mar 2, 1978	1528	Mar. 3, 1978	1710	Mar. 10, 1978	1024			Mar. 10, 1978	1344	161:14	190:16	
Soyuz 29	June 15, 1978	2017	June 16, 1978	2158	Sept. 3, 1978	0823			Sept. 3, 1978	1140	1,882:25	1,911:23	ship
					Nov. 2, 1978	0746			Nov. 2, 1978	1105	[1] 3321:48	3350:48	cosmonauts
											[2] 3320:18		
Soyuz 30	June 27, 1978	1527	June 28, 1978	1708	July 5, 1978	1015			July 5, 1978	1330	161:07	190:03	
Progress 2	July 7, 1978	1126	July 9, 1978	1259	Aug. 2, 1978	0457	Aug. 4, 1978	0132			567:58	662:06	

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TABLE 15 EVENT TIMES OF SOVIET MANNED AND SELECTED RELATED FLIGHTS—Continued

Flight	Launch date	Launch hour	Docking date	Docking hour	Undocking date	Undocking hour	Retro date	Retro hour	Landing date	Landing hour	Docked duration	Flight duration	
Progress 3	Aug 7 1978	2231	Aug 10 1978	0000	Aug 21 1978	1929	Aug 23, 1978	1730			279 29	378 59	
Soyuz 31	Aug 26 1978	1451	Aug 27 1978	1638	Sept 7 1978	1053			Nov 2, 1978	1105	[1] 1,599 08	1,628 14	ship
			Sept 7 1978	1203	Nov 2, 1978	0746					[2] 1,597 38		
					Sept 3, 1978	0873			Sept 3, 1978	1140	159 45	188 49	cosmonauts
Progress 4	Oct 3 1978	2309	Oct 6 1978	0100	Oct 24, 1978	1307	Oct 26 1978	1628			444 07	545 19	
Soyuz 32	Feb 25 1979	1154	Feb 26 1979	1330	June 13 1979	0951			June 13, 1979	1618	2,564 21	2,596 24	ship
					Aug 19, 1979	0907			Aug 19, 1979	1230	[1] 4,171 37	4,200 36	cosmonauts
											[2] 4,170 07		
Progress 5	Mar 12, 1979	0547	Mar 14, 1979	0720	Apr 3, 1979	1610	Apr 5 1979	0104			488 50	571 17	
Soyuz 33	Apr 10, 1979	1734	Apr 11, 1979	1854					Apr 12, 1979	1635		47 01	
Progress 6	May 13, 1979	0417	May 15, 1979	0619	June 8, 1979	0800	June 9, 1979	1851			577 41	622 34	
Soyuz 34	June 6 1979	1813	June 8, 1979	2002	June 14, 1979	1618			Aug 19, 1979	1230	[1] 1,717 05	1,770 17	
			June 14, 1979	1748	Aug 19, 1979	0907					[2] 1,715 35		
Progress 7	June 28 1979	0925	June 30, 1979	1118	July 18, 1979	0350	July 20, 1979	0157			424 32	520 32	
Soyuz T 1	Dec 16, 1979	1230	Dec 19, 1979	1405	Mar 23, 1979	2104			Mar 25, 1979	2147	2,286.59	2,409 17	
Progress 8	Mar 27, 1980	1853	Mar 29, 1980	2001	Apr 25, 1980	0804	Apr 26, 1980	8654			636 03	708 01	
Soyuz 35	Apr 9 1980	1338	Apr 10, 1980	1516	June 3, 1980	1147			June 3, 1980	1507	1,292 31	1,321 29	ship
					Oct 11, 1980	0630			Oct 11, 1980	0950	[1] 4,407 14	4,436 12	cosmonauts
											[2] 4,404 07		
Progress 9	Apr 27 1980	0624	Apr 29, 1980	0809	May 20, 1980	1851	May 22, 1980	0044			514 42	574 20	
Soyuz 36	May 26 1980	1821	May 27, 1980	1956	June 4, 1980	1639			July 31, 1980	1515	[1] 1,551.59	1,580 54	ship
			June 4, 1980	1809	July 31, 1980	1155					[2] 1,550 29		
					June 3, 1980	1147	June 3, 1980	1507			159 51	188 46	cosmonauts
Soyuz T 2	June 5 1980	1419	June 6, 1980	1558	June 9, 1980	0920			June 9, 1980	1240	65.22	94 21	
Progress 10	June 29 1980	0441	July 1, 1980	0553	July 17, 1980	2221	July 19, 1980	0147			400 28	477 06	
Soyuz 37	July 23, 1980	1833	July 24, 1980	2002	Aug. 1, 1980	1643			Oct. 11, 1980	0950	[1] 1,882 28	1,911 17	ship
			Aug 1, 1980	1820	Oct 11, 1980	0630					[2] 1,880 51		
					July 31, 1980	1155			July 31, 1980	1515	159 53	188 42	cosmonauts
Soyuz 38	Sept 18, 1980	1911	Sept 19, 1980	2049	Sept 26, 1980	1234			Sept. 26, 1980	1554	159 45	188 43	
Progress 11	Sept 28, 1980	1510	Sept 30, 1980	1703	Dec 9, 1980	1023	Dec 11, 1980	1400			1,673 20	1,774.50	
Soyuz T-3	Nov 27, 1980	1418	Nov 28, 1980	1554	Dec. 10, 1980	0610			Dec. 10, 1980	0926	278 16	307 08	

[1] Gross
[2] Net

Notes This table shows the time in GMT for certain key events in the operations of Soviet manned flights and associated unmanned flights. From these numbers other statistics on flight durations and cosmonaut times can be derived.

[1] Soviet source materials generally quote Moscow time which is 3 hours ahead of GMT, and on occasion this will shift even the apparent day of the event if it went early one day Moscow time which might be late the previous day GMT.

[3] For the most part TASS reports the launch hour and the docking hour (if appropriate) for all the listed flights. They are not quite complete in reporting undocking times and landing times. In the case of Progress flights, the time given at the end of the flight is for retro (braking) fire and the ships are not recovered but for the most part, like abandoned stations, burn up in the atmosphere over the Pacific Ocean well away from heavily traveled shipping lanes.

4 When times have been lacking, average numbers have been estimated by studying similar flight profiles.

5 One source of confusion in times is occasioned in flights Vostok 2 through 6 where the cosmonaut ejected from the capsule to complete the trip on a personal parachute, usually taking a few minutes longer to reach the ground than the capsule itself. Both times are shown in the table. Equally authoritative Soviet sources disagree as to whether in the case of Vostok 1, there was a separate landing for the cosmonaut.

6 In the case of Soyuz 4 and 5, two of the cosmonauts from Soyuz 5 transferred in orbit to Soyuz 4, so their personal times in flight were less, as shown.

7 In the case of several flights, the Soyuz craft were docked and redocked at some point in the flight, so that gross and net docked times are shown.

8 In the operations with Salyut 6, several crews traded Soyuz ferries as a way of extending the stay time in the station of the long duration crew. In such cases, the crew times are shown separately from the ship times.

9 Although TASS bulletins have been the primary source, other Soviet publications have permitted filling in some missing data well after the fact. It is gratifying that some of the later disclosures have matched to the minute the estimates which had been developed earlier based upon repetitive patterns and on Goddard two-line elements which include the right ascension of the ascending node for key orbits. In other cases, differences of plus or minus 1 minute have been noticed, and in one case (Soyuz 1), as much as 11 minutes. All landing and duration times shown have been adjusted to conform with the times in the book "Kosmos" published in 1982 in Leningrad.

10 TASS reports the time for undocking when a Soyuz moves from one docking port on Salyut to the opposite end, and gives the duration in each case as 90 minutes. In the case of Soyuz 37, the Kettering Group (G.E. Perry) heard the exclamation "Kas nye" after 97 minutes instead and that longer time has been used for that flight.

11 Soyuz T 3 presented particular problems in determining precisely when it undocked and when it landed, in the absence of the usual TASS announcements. Late on December 9, a NORAD bulletin reported an extra object separated from Salyut 6, which the United States assumed was part of Salyut, while the Royal Aircraft establishment assumed it was the orbital compartment portion of Soyuz T 3, known to separate before the retro fire of the ferry. Philip S. Clark, David Hawkins, and Robert Christy, through study over a period of weeks, make a good case for the extra object being Progress 11, rather than the orbital compartment of Soyuz T 3. Flight International reported the undocking took place on December 10 at 0610.

Sources: TASS bulletins, estimates by the Kettering Group, and three other Soviet publications: "Kosmos," Leningrad, 1982, giving flight durations for all Soviet manned flights (this is a children's book); Kravchenkov, et al. Pilotiruyemye Mezhdunarodnyye Polety Po Programme Interkosmos SSSR-SRV (Manned International Flights of the Interkosmos Program USSR-SRV) Izd. Novosti, Moscow, June 23, 1980, pp. 144-154, giving times and durations for Salyut 6 through Soyuz T 2 (found by Theo Pirard); also two pages from an unknown Soviet book giving data on flight durations from Vostok 1 through Soyuz 20 (found by James E. Oberg).

Chapter 4

The Soviet Space Life Sciences

INTRODUCTION

The Soviet Union was the first country to launch a live organism into an orbit around the Earth. This historical event, November 3, 1957, the flight of Sputnik 2 containing the dog, Layka, ushered in a new era of biomedical research related to manned spaceflight. For 1 week, the dog orbited around the Earth in a state of weightlessness and was exposed to the then relatively unknown hazards of space. After 1 week, an automatic device poisoned the dog and the experiment was terminated. This was the first hint that a higher vertebrate, fairly similar to man physiologically, could not only withstand the rigors of the rocket launch, but could also tolerate for at least 1 week a variety of spaceflight factors.

Other biological experiments were to follow (tables 3 and 4 of chapter 3) finally culminating in the historic flight of Vostok 1 on April 12, 1961, which contained the first human ever to orbit the Earth, Yuriy Alekseyevich Gagarin. As summarized in chapter three of this report, there has followed a rapid sequence of progressively larger, longer duration, and more complicated manned spaceflights (Vostok 2-6; Voskhod 1 and 2; Soyuz 1, and 3-T-3 and Salyut 1-7) and biological satellites of the Kosmos series. All of these events have been supported by a very large and comprehensive research effort in the space life sciences.

EARLY HISTORY

As emerging rocket technology in the 1950s made it possible for man to reach the edge of space, it was natural that Soviet specialists in areas such as altitude physiology and aviation medicine should turn to the design of space suits and the initial selection of space crews. This early activity took place primarily in the Military Medical Academy named after Kirov and the Scientific Research Institute of Aviation Medicine in Moscow.[1]

Before the historical flight of Sputnik 1, the field of bioastronautics in the Soviet Union was not considered to be quite respectable. There was an unrealistic, science-fiction aura about it in addition

[1] Mandrovsky, B. Soviet Bioastronautics and Manned Spaceflight Programs, Organizations, and Personalities. Library of Congress. Aerospace Technology Division. Mar. 18, 1965. 118 p.

to serious academic doubts as to whether vertebrate organisms, including man, could withstand the rigors of a weightless environment. Early Soviet experiments with animals in vertical rockets did little to command the serious attention of the Department of Biological Sciences of the U.S.S.R. Academy of Sciences. Consequently, all early research was conducted in various facilities of the Academy of Medical Sciences and the Institute of Aviation Medicine in Moscow. At the latter facility was Dr. Oleg Gazenko who pioneered early research in gravitational physiology and was later to become the leader of the entire Soviet space life sciences effort, a position he holds today. Later, the success of animal experiments in spacecraft in 1960 and early 1961 caused key individuals in the Academy of Sciences to take a second look at the new scientific discipline of bioastronautics. There followed a number of papers by Dr. N. M. Sisakyan of the Department of Biological Sciences on biological problems of spaceflight.[2 3 4 5]

It was quite evident in early phases of the Soviet space life sciences effort that there was considerable competition for leadership between the prestigious Academy of Sciences and the less prestigious Academy of Medical Sciences. Perhaps it was the scientific weight of the Academy of Sciences that convinced the Soviet political leadership of that day to include it in activities theretofore dominated by the Academy of Medical Sciences and the Institute of Aviation Medicine. In early international symposia addressing the space and aviation life sciences it was obvious that a bitter battle was being waged between the two academies. For example, at one such symposium, Basic Environmental Problems of Man in Space, held in Paris in October 1962, not a single leader from the Academy of Medical Sciences was permitted to appear. By that time it was fairly clear that N. M. Sisakyan and the Academy of Sciences had won the battle for overall leadership in the space life sciences.[6]

To commemorate and consolidate this victory, Sisakyan published the first two volumes of Problems of Space Biology and a monograph on the First Manned Space Flights. These publications were printed under the auspices of the Department of Biological Sciences of the U.S.S.R. Academy of Sciences. Gradually, through the remainder of the 1960s and 1970s, the Academy of Medical Sciences and Ministry of Health were to reassert their influence in the space life sciences. Ultimately, Dr. Oleg Gazenko, now a full academician in the Academy of Sciences was to head up the Institute of Biomedical Problems under the Ministry of Health.

Early Organization

In the early phases of the Soviet manned space effort (roughly 1956 64), the following facilities were identified as being involved in various facets of the space life sciences, primarily in ground-based research.[7]

[2] Sisakyan, N. M. Pravda, Nov 1, 1961, pp 7 16

[3] Ibid , AN SSSR Vestnik, Nov 6, 1961, pp 31 40

[4] Ibid , AN SSSR Izvestiya, Seriya biologisheskaya, Nov 5, 1961, p 657 663

[5] Ibid , Aviatsiya i Kosmonavtika, Nov 2, 1962, p 24

[6] Mandrovsky, B , op cit

[7] Ibid

ACADEMY OF SCIENCES, U.S.S.R.

Institute of Biochemistry named after Bakh, Moscow.
Institute of Atomic Energy named after Kurchatov, Moscow.
Institute of Biophysics, Moscow.
Institute of Cytology, Leningrad.
Institute of Evolutionary Physiology named after Sechenov, Leningrad.
Institute of Microbiology, Moscow.
Institute of Physiology named after Pavlov, Leningrad.
Institute of Plant Physiology named after Timiryazev, Moscow.

ACADEMY OF MEDICAL SCIENCES, U.S.S.R.

Laboratory for of Experimental Biology, Moscow.
Institute of Experimental Pathology and Therapy, Sukhumi.
Institute of Experimental Medicine, Leningrad.
Institute of Industrial Hygiene and Occupational Diseases, Moscow.
Laboratory for Experimental Physiology of Reanimation, Moscow.
Central Scientific Research Institute of Sanitation and Hygiene named after Erisman, Moscow.
Institute of Normal and Pathological Physiology, Moscow.

ACADEMY OF SCIENCES, SIBERIAN DIVISION

Institute of Cytology of Genetics, Novosibirsk. Institute of Experimental Biology and Medicine, Novosibirsk.

ACADEMY OF SCIENCES, UNION REPUBLICS

Institute of Physiology named after Bogomolets, Kiev (Ukrainian Academy of Sciences).
Institute of Physiology, Tbilisi (Georgian Academy of Sciences).
Pamir Botanical Garden (Tadzhik Academy of Sciences).
Botanical Institute (Uzbekistan Academy of Sciences).
Institute of Regional Experimental Medicine, Tashkent (Uzbekistan Academy of Sciences).

MINISTRY OF DEFENSE

Institute of Aviation Medicine, Moscow.
Military Medical Academy named after Kirov, Leningrad.

MINISTRY OF HEALTH

Institute of Biomedical Problems, Puschino (established in the late 1960s).
Moscow Scientific Research Institute of Experimental Surgical Equipment and Instruments, Moscow.
Central Scientific Research Institute of Health Resorts and Physical Therapy, Moscow.
Central Institute of Hematology and Blood Transfusion, Moscow.
Central Scientific Research Institute of Medical Radiology, Moscow.
All-Union Scientific Research Chemical and Pharmaceutical Institute, Moscow.

RSFSR MINISTRY OF HEALTH

Leningrad Institute of Industrial Hygiene and Occupational Diseases, Leningrad.
Leningrad Medical Institute of Sanitation and Hygiene, Leningrad.
Leningrad Scientific Research Institute for Radiation Hygiene, Leningrad.

STATE UNIVERSITIES

Moscow State University named after Lomonosov, Moscow.
Leningrad State University named after Zhdanov, Leningrad.
Ural State University named after Gorkiy, Sverdlovsk.

MUNICIPAL MEDICAL INSTITUTES

First (order of Lenin) Moscow Medical Institute, Moscow.
First Leningrad Medical Institute named after Pavlov, Leningrad.
Chelyabinsk Medical Institute, Chelyabinsk.
Kalinin Medical Institute, Kalinin.
Kubyshev Medical Institute, Kubyshev.
Turkmen Medical Institute, Ashkhabad.
Yerevan Medical Institute, Yerevan.

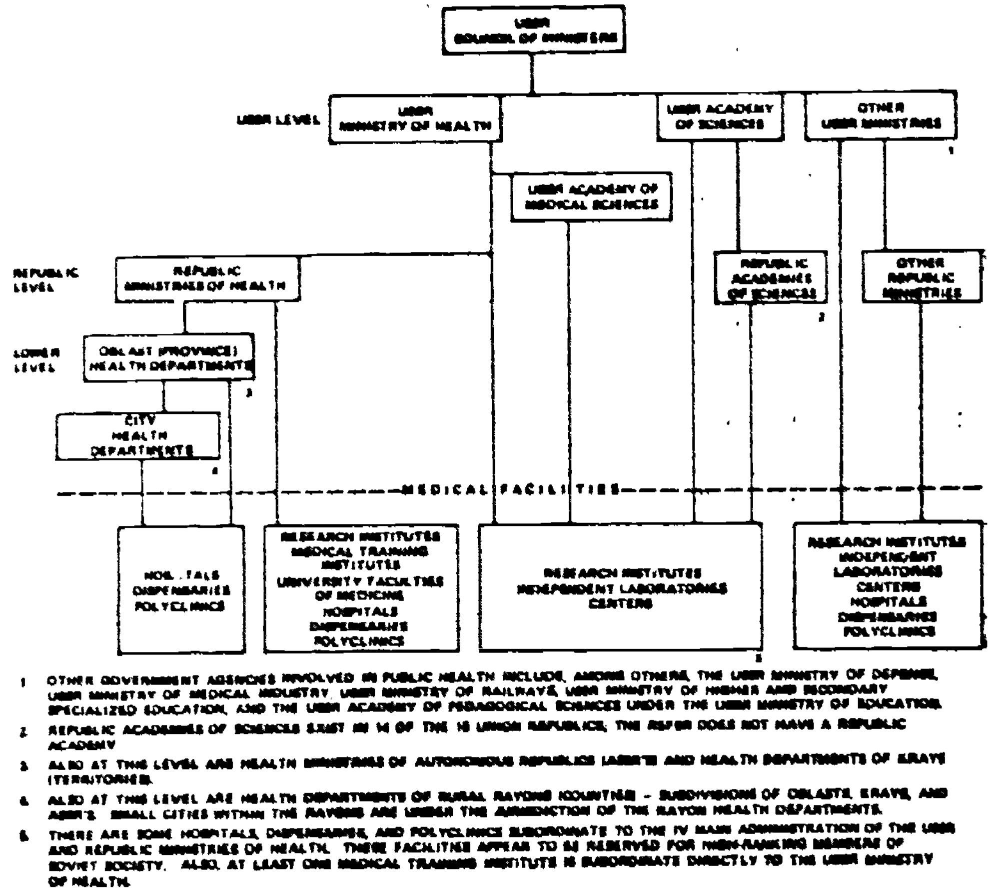
MISCELLANEOUS

All Union Scientific Research Institute of Antibiotics, Moscow.
All Union Scientific Research Institute of Medical Instruments and Equipment, Moscow.
All Union Scientific Research Institute of Railway Hygiene, Ministry of Transportation.
Central Institute for the Advanced Training of Physicians, Moscow.
Institute of Hygiene, Moscow.
Scientific Research Institute of Neurosurgery, Leningrad.
State Institute of Physical Culture, Moscow.
Scientific Research Institute of Occupational Physiology, Donetsk.
Ukrainian Institute of Industrial Hygiene and Occupational Diseases, Kharkov Georgian Institute of Physical Culture, Tbilisi.

From the foregoing, it can be observed that even in the early phases of the Soviet space life sciences effort, more than 50 major facilities across the U.S.S.R. had some involvement in that effort. Presumably, the same and additional facilities have continued that involvement to date.

PRESENT ORGANIZATION

The present organization of Soviet biomedical facilities, including those involved in the space life sciences effort, is summarized in figure 45.



Source: Biotechnology, Inc., 1975.

FIGURE 45.—Organization of Soviet Biomedical Institutions.

Today, the facility with overall and centralized responsibility for the space life sciences is the Institute of Biomedical Problems in Moscow under the direction of Dr. Oleg Gazenko. This facility was constructed in the late 1960s. Many of the articles published in the Soviet journal, Space Biology and Aerospace Medicine, largely reflect the research being conducted and supported by this facility.

As in the U.S. space life sciences program, a definitive prioritization of problem areas has been developed in the Soviet program as will be reviewed in subsequent sections of this chapter. These current problem areas have been identified on the basis of experience gained from 20 years of spaceflight and include:

—motion sickness in space;
—cardiovascular and body muscle deconditioning;
—hematological (blood) changes;
—bone mineral loss;
—psychology and human factors in prolonged flights; and

--space cabin toxicology in prolonged flights.[8]

Additional problem areas of continuing concern involving prolonged flights, including flights to the planets, include:

—selection of space personnel;
—medical training of flight crews;
—medical care during prolonged flights;
—extravehicular activity;
—artificial gravity; and
—man/man and man/machine interfaces and design.[9]

A more detailed breakdown of these problem areas follows:

Acceleration and Deceleration Effects: Impact Accelerations, Coriolis Accelerations (vestibular effects).

Acoustic Energy Effects.

Altered and Normal Gas Atmospheres: Oxygen (hypoxia, hyperoxia). Carbon dioxide (hypercapnia, acapnia), Noxious Gases (carbon monoxide, pyrolysis by-products, etc.). Odors (food, body, chemical, etc.).

Biological Rhythms: Circadian Rhythms, Work-Rest Cycles.

Decompression Effects: Hypoxia, Dysbarism (decompression sickness), Explosive Decompression

Diseases and Injury: Cause and Prevention, Treatment and Drug Therapy, Personal Hygiene

Nutrition: Vitamins, Minerals, Natural and Synthetic Foods, Food Packaging

Radiation: Relative Biological Effectiveness, Dose and Dose Rate, Somatic and Genetic Effects, Protective Measures (drugs, shielding, force fields, etc.).

Temperature and Humidity: Hyperthermia, Hypothermia.

Weightlessness: Motor Kinetics, Motion Sickness, Hypodynamia and Hypokinesia, Preventive and Prophylactic Measures.

Work Capacity: Fatigue, Muscle Tone

Physical Training and Exercise

Subjects being investigated in the psychological and behavioral sciences include:

Boredom and Confinement.

Disorientation

Mental Fatigue

Motivation and Vigilance

Neuroses and Psychoses: Anxiety, Compulsion, Depression, Phobia

Personality Dynamics: Group Interaction.

Space Crew Problems: Requirements, Selection and Screening, Training, Task Analysis, Work Schedule and Performance

Weightlessness Effects: Orientation, Work Rest Cycles (sleep etc.).

Human engineering subjects include:

Air Conditioning: Spacecraft Temperature and Humidity Control, Atmosphere Control, Oxygen and Diluent Gas Management, Carbon Dioxide Removal, Photosynthesis of Lower and High Plants, Odor Management, Toxic Gas Management.

Fire Hazard Management

General Life Support Management: Food Storage, Preservation, and Refrigeration, Personal Hygiene Equipment.

Insulation (acoustic and thermal)

Leisure, Exercise, and Recreation Equipment

Instrumentation: Biomedical Monitoring, Biotelemetry, Communications Equipment (radar, T.V., radio, etc.)

Radiation Protection (U.V., I.R., Ionizing, etc.): Individual Shielding, Electrostatic, Magnetic, or Electromagnetic Force Fields.

Safety and Survival Equipment: Space Suits, Emergency Rescue Equipment, Emergency Pressure and Atmosphere Control, Repair and Maintenance Equipment.

Sanitation Facilities: Waste Management, Disposal, and Storage

[8] Nicogossian, A. and J. F. Parker. Space Physiology and Medicine. National Aeronautics and Space Administration, 1982. 324 pp. (NASA SP-447)

[9] Ibid

Space Vehicle Controls and Equipment: Manual and Automatic Controls, Cabin Atmosphere Controls
Vision: Lighting and Color Scheme, Instrument and Other Displays, Optical Controls (Periscope).
Washing and Hygiene Equipment.
Water Recycling and Purification: Respiration, Urine, and Perspiration Management

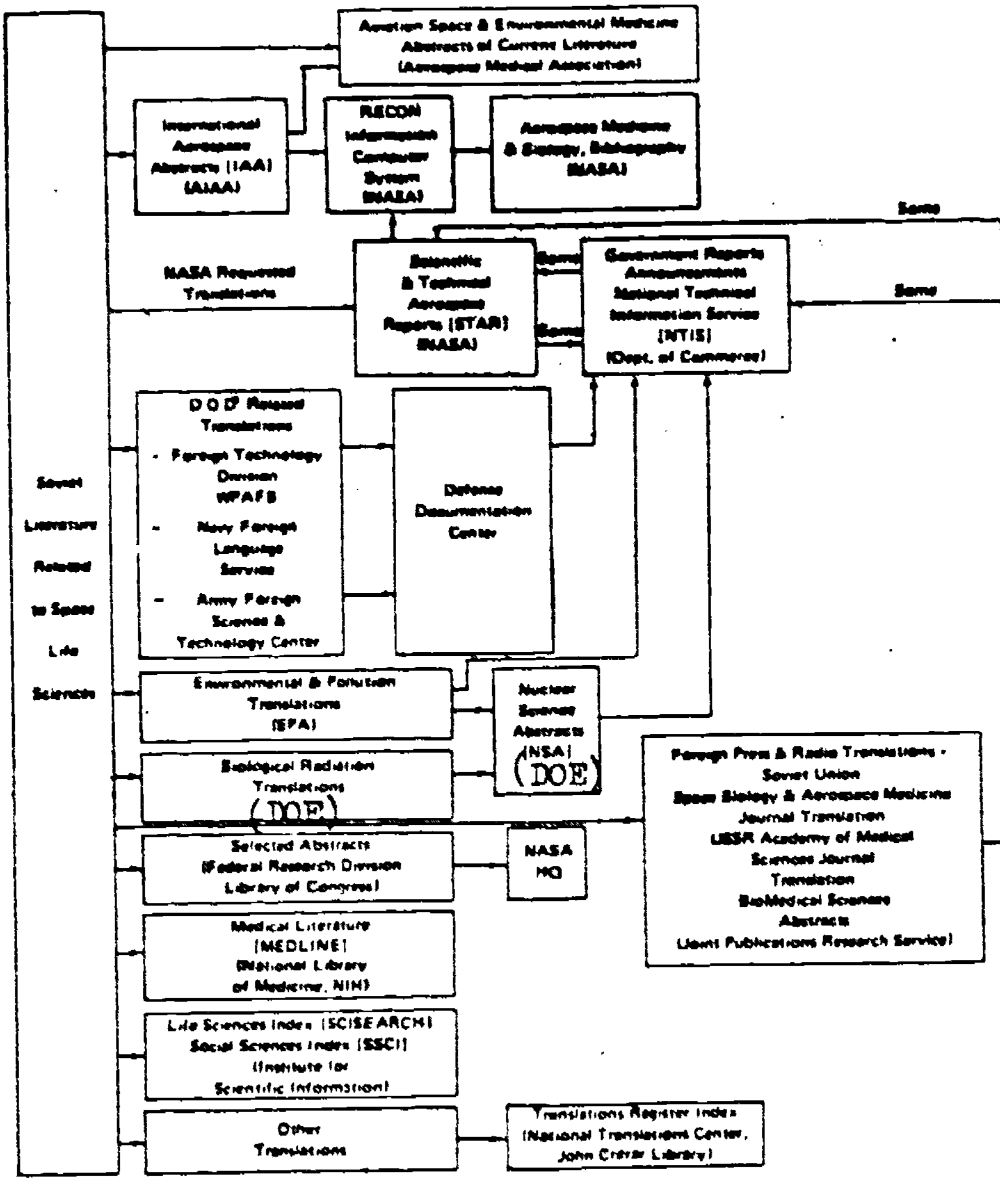
Problems of particular concern in the continuing Soviet space life sciences effort include:

Concentrated Ground Laboratory Studies—
Effect of Hypokinesia (reduced movement): Simulation of Prolonged Weightlessness (improvement in techniques).
Energy Loss Studies: Gravitational Effects, Space-suit Limitations, Oxygen Deficiency Effects
Acceleration Effects: Hyperoxia (high oxygen or air pressures), Metabolic Studies, Pharmaco-dynamics, Biochemistry and Cell Physiology.
Mechanism of Adaptation to Space Factors: Role of Neural and Neuro-humoral Mechanisms, Regeneration Processes (emphasis on blood cell replacement), Central Nervous System Conditioning, Inhibition of Cerebellar Functions, Vestibular Analyzer Conditioning, Eye Effects (vision generally).

INFORMATION RESOURCES

In the early phases of the Soviet spaceflight program (roughly 1960-67), it was difficult to obtain timely and detailed information about the program from the open-source literature, including scientific journals, monographs, and popular media such as newspapers. First, few people in the United States had a command of the Russian language. Second, it was quite difficult to obtain source material. Therefore, a concerted effort was made in this country to overcome this information gap. Private foundations, academic institutions, and the Federal Government, including military and intelligence concerns, pooled and organized personnel with the proper linguistic and scientific background in order to screen systematically the Russian and East European scientific and technical literature. Some early efforts toward this end were quite successful. One such organization, the Aerospace Technology Division of the Library of Congress, provided the Federal Government and other interested concerns with timely compilations of bibliographic materials, abstracts of the Soviet and East European literature, and comprehensive reports synthesized from these materials. As new and more automated methods of processing foreign literature came into vogue, manual operations were phased out. Thus, the Aerospace Technology Division was terminated in 1969.

Since that time, a number of Federal Government and private concerns continue to provide translated and abstracted materials relating to the Soviet spaceflight effort. It is worthy to note that there is at present no significant, centralized effort in the United States to systematically locate, translate or abstract, and disseminate the Soviet life sciences literature to the space life sciences community. Major organizations which provide published translations and abstracts of the Soviet and East European literature include NASA, the Joint Publications Research Service (JPRS), and a variety of non-Government translation agencies. Most translated and abstracted materials may be obtained from the National Technical Information Service (Springfield, Va. 22151). The various Federal sources of information related to the Soviet spaceflight effort in general and to the Soviet space life sciences effort in particular are provided in figure 46.



Source: Biotechnology, Inc., 1975.

FIGURE 46.—Soviet Literature Agencies and Interrelationships.

The task of collecting, translating, or abstracting, let alone disseminating the voluminous Soviet literature dealing with the space and space-related life sciences, continues to be quite complicated. Sources of information and data are varied and often difficult to identify and obtain. From 1972 through 1981, the U.S./U.S.S.R. Working Group on Space Biology and Medicine, sponsored by

NASA and the U.S.S.R. Academy of Sciences, was a source of information that has appeared in various conference proceedings and other publications in one form or another. There have been no formal Working Group publications

From 1979 through 1980, the Soviet space life sciences literature was summarized on an annual basis by the Life Sciences Division of NASA. Inputs to those summaries were provided by the NASA Unit of the Federal Research Division, Library of Congress and by a private firm, Biotechnology Incorporated of Falls Church, Virginia.[10 11]

The raw material for the U.S.S.R. Space Life Sciences Digest was obtained from a variety of sources listed below:

—Abstracts in Soviet space biology and medicine provided by the Library of Congress, Federal Research Division—NASA Unit 11-G.

—Aerospace Medicine and Biology—A continuing bibliography (NASA SP-7011).

—Scientific and Technical Aerospace Reports—A bibliography produced by the Scientific and Technical Information Office, NASA.

—Foreign Broadcast Information Service, Volume III, Soviet Union—NTIS. Abbreviated FBIS.

—Daily Soviet News Abstracts Publication—Translated abstracts of news items from the Soviet press. Published by Foreign Technology Division, Battelle Columbus Laboratories. Abbreviated Daily SNAP.

—Space Biology and Aerospace Medicine—A complete translation of the Russian language monthly journal Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina, published in the United States by Joint Publications Research Service.

—U.S.S.R. Report, Biomedical and Behavioral Science—Translated articles and abstracts in biochemistry, radiobiology, aerospace biology, and medicine, from a variety of Russian language sources. Published in the United States by Joint Publications Research Service.

—U.S.S.R. Report, Space—Translated articles and abstracts of formal scientific reports and news items on the Soviet space program, from a variety of foreign language sources. Published in the United States by Joint Publications Research Service.

—U.S.S.R. Report, Life Sciences—Effects of Nonionizing Electromagnetic Radiation—Translated articles, abstracts and news items from U.S.S.R. scientific and technical journals on the effects of nonionizing electromagnetic radiation on organisms and biological tissues. Published in the United States by Joint Publications Research Service.

—Aviation Week & Space Technology—Weekly periodical published by McGraw-Hill, Inc. Abbreviated AW&ST.

—Astronautics and Aeronautics—Monthly periodical published by the American Institute of Aeronautics and Astronautics, Inc.

[10] NASA Life Sciences Division. U.S.S.R. Space Life Sciences Digest. Annual Summary. 1979. 71 p.

[11] Ibid., Annual Summary. 1980. 67 p.

—Aviation, Space and Environmental Medicine—Monthly periodical published by the Aerospace Medical Association.

—Spaceflight—Monthly periodical published by the British Interplanetary Society.

Until 1982, the trend toward a more open exchange of information in the space life sciences was enhanced by the aforementioned U.S./U.S.S.R. Working Group on Space Biology and Medicine and today it continues through a series of annual international and national conferences in which Soviet space life scientists participate on a regular basis. Summaries of these exchanges may be found in a series of monographs entitled "Foundations of Space Biology and Medicine" which contain contributions of Soviet and United States Researchers. Published in 1975, these monographs contain a wealth of information on the Soviet space life sciences and remain useful references to this day.[12] [13] [14] [15]

The contents of these monographs follow:

FOUNDATIONS OF SPACE BIOLOGY AND MEDICINE

VOLUME I

OUTER SPACE AS A HABITAT

VOLUME II

ECOLOGICAL AND PHYSIOLOGICAL FOUNDATIONS OF SPACE BIOLOGY AND MEDICINE

BOOK ONE

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[12] Calvin, M. and O. G. Gazenko (eds.). Foundations of Space Biology and Medicine, v. 1. Outer Space as a Habitat. NASA, 1975. 442 p.

[13] Ibid., v. II, Book 1. Ecological and Physiological Bases of Space Biology and Medicine.

[14] Ibid., v. II., Book 2.

[15] Ibid., v. III. Space Medicine and Biotechnology.

Chapter 5. Effect of Prolonged Linear and Radial Accelerations on the Organism. P. V. Vasil 'yov, A. R. Kotovskaya.
Chapter 6. Impact Accelerations. James W. Brinkley and Henning E. von Gierke.
Chapter 7. Angular Velocities, Angular Acceleration, and Coriolis Accelerations. Ashton Graybiel.
Chapter 8. Weightlessness. Siegfried J. Gerathewohl and I. D. Pestov.
Chapter 9. Vibration and Noise. Charles W. Nixon, John Guighard, Henning E. von Gierke.

BOOK TWO

Part III. Effect of Radiant Energy from Cosmic Space on the Organism:
Chapter 10. Radiofrequencies and Microwaves, Magnetic and Electrical Fields, Sol M. Michaelson.
Chapter 11. Ultraviolet, Visible, and Infrared Rays. John H. Taylor and A. A. Letavet.
Chapter 12. Ionizing Radiation. Yu. G. Grigor'yev and Cornelius A. Tobias.
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THE CONGRESSIONAL RESEARCH SERVICE

At the request of the former Committee on Aeronautical and Space Sciences and more recently the Senate Committee on Commerce, Science, and Transportation, the Science Policy Research Division of the Congressional Research Service has reviewed in 5 year segments since 1962, the Soviet space life sciences program.[16 17 18]

A review of the U.S. space life sciences program through 1978 prepared by the Science Policy Research Division appeared in a report for the House Committee on Science and Technology in 1981.[19]

The present chapter of this volume reviews the Soviet life sciences program between 1976 and 1980. Chapter two of this volume contains a brief summary of that program through 1982.

COSMONAUT SELECTION AND TRAINING

SELECTION PROCESS

THE FIRST STAGE

The selection of space crew candidates is still one of the most critical elements in the manned space program of both the Soviet Union as well as the United States. Though many modifications and advances in hardware technology have taken place since the inception of both space programs, the one factor that has not changed and is becoming an even increasing integral component of the space station effort of the U.S.S.R. is man.[20]

As the complexity of scientific experimentation has increased during manned space flights, selection, based primarily on previous flights experience as in the military or civilian sector, is no longer practical. Candidate cosmonauts are currently selected from groups of volunteers having extensive flying experience, as well as from a variety of other appropriate backgrounds. This includes individuals with advanced degrees in medicine, biology, engineering, and physics.[21] The ages of these individuals range from 25 to 45 years and include both sexes. The selection and use of women for space missions will probably continue.[22] Reports have it that the Soviets are

[16] U.S. Congress. Senate. Committee on Aeronautical and Space Sciences. Soviet Space Programs, 1962-65 (Ch. III (V) Soviet Man in Space Programs: Bioastronautics). Staff Report. 98th Cong., 2nd Sess. Dec. 30, 1966. Washington, D.C., U.S. Government Printing Office. 1966, p. 296-320

[17] Ibid., Soviet Space Programs, 1966-70 (Ch. Seven. Soviet Bioastronautics: Biological, Behavioral, and Medical Problems) Staff Report. 92nd Cong., 1st Sess., Dec. 9, 1971. Washington, D.C., U.S. Government Printing Office, 1981, p. 265-296

[18] Ibid., Soviet Space Programs, 1971-75 (Ch. Four. The Soviet Space Life Sciences). Staff Report. 94th Cong., 2nd Sess., Aug. 30, 1976. Washington, D.C., U.S. Government Printing Office, 1976, p. 257-344

[19] U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space Science and Applications. United States Civilian Space Programs, 1958-78 (Ch. Eight, Space Life Sciences) Report. 97th Cong., 1st Sess. Washington, D.C., U.S. Government Printing Office, 1981, p. 641-714

[20] Yeliseyev, A. Soviet Cosmonautics in the Eighties. Soviet Life, Apr. 1981, p. 62-63.

[21] Link, M. M., et al. Selection of Astronauts and Cosmonauts. In Foundations of Space Biology and Medicine 3, 1975, p. 419-437

[22] Sanoy, P. The Journey Out and In. Psychiatry and Space Exploration. American Journal of Psychiatry 140, 1983, p. 519-527

training cosmonauts and future scientists from even younger age groups. These teenage individuals begin their training in cosmonautic space clubs.[23]

Rigid medical evaluation is the primary criteria for the preselection of candidates. Based on general medical practices, Soviet cosmonauts undergo a multiteam medical selection process.

The Soviet Union has also emphasized extensive psychological testing, which has taken on even greater importance due to the recent Soviets multicrew, long-duration space observations.

The medical selection of cosmonaut candidates is conducted in three stages. Preliminary screening is performed on an outpatient basis by a battery of medical sub-specialists, representing internal medicine, neurology, ophthalmology, ear-nose-throat, endocrinology, and other medical specialties. As in any in depth physical examination, a medical history of the individual is compiled. Based on the clinical and historical data, an evaluation board consisting of the aforementioned sub-specialists then recommend whether the candidate is suitable and should continue in the selection process.[24]

The second stage of the medical selection process requires the individual to undergo extensive clinical evaluations. During this time, an in depth medical history reevaluation takes place in an attempt to exclude hereditary disorder trends, as well as recurring pathological conditions, particularly of such organ systems as the circulatory, respiratory, urinary, intestinal tract and skeletal system.[25]

The physical examination employs the usual hands-on evaluation as well as the most up-to-date technological processes including both roentgenography and endoscopy, when indicated, as well as various forms of electrocardiography. Laboratory tests are very extensive ranging from complete blood cell counts to other hematological evaluations. Detailed blood chemistry is performed, encompassing most recognized medical significant enzyme and immune parameters. An extensive neurological evaluation includes motor coordination, sensory and reflex functions of the nervous system, as well as skull roentgenography and electroencephalography.[26]

Complete psychological testing includes many of the recognized analyses and recently developed tests.[27] The Soviets' experiences in orbital station operations has mandated the need for significant psychological testing.[28] New trends in space psychology such as psychological support during the flight and selection of compatible crews has gained great favor. During the training process, emphasis is continually placed on psychological evaluation and selection in order to find individuals particularly suited for professional work with specific space equipment. A more detailed discussion of this process will be covered later, see p. 681.

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[23] Bednyakova, O. The Cosmodrome in the Heart of Moscow. Soviet Life, Apr. 1981, p. 18-21.

[24] Link, M. M., et al. Selection of Astronauts and Cosmonauts, op. cit.

[25] Ibid

[26] Link, M. M., et al. Selection of Astronauts and Cosmonauts, op. cit.

[27] Gazenko, O. G. Psychological Compatibility on Earth and in Outer Space, Aviation Space, and Environmental Medicine. June 1980, p. 622-623

[28] Lomov, Boris, U S S R. Social Science. Psychological Aspects of Space Flights, 11, No. 2, 1980. p. 96-103.

An otolaryngological examination includes exo and endoscopy, roentgenography of the nasal sinuses, as well as auditory and vestibular function. In view of the early recognition by the Soviets of the balance and orientation difficulties encountered during the early stages of a space flight, they have placed great emphasis on evaluating the candidates' vestibular system. (See p. 686 for a more detailed discussion). A more functional examination includes physiological effects of moderate degrees of hypoxia concurrent with recordings of EKG and arterial pressure. This is followed by a "dive" test to evaluate adequate acclimation of the ears and nasal sinuses to changes in barometric pressure. Tests of cardiac function include various parameters of cardiac rhythm during orthostatics (erect posture) and antiorthostatic tests. Physical load studies on the candidates are performed by means of bicycle ergometry. During this interval of testing, pulmonary function as well as cystolic and diastolic blood pressure recovery are evaluated. This is followed by numerous electroencephalograms and other instrumentational evaluations of the nervous, circulatory and cardiac system, as well as numerous vestibular stability tests. The ability to withstand centrifugal forces both in the direction of "head-toe" as well as "chest-back" are evaluated. The Soviets continue to stress load testing in the selection of cosmonaut trainees.[29]

Based on medical and stress testing, the evaluation board either selects the individual for cosmonaut training; postpones selection until certain physiological abnormalities can be treated; or rejects the candidate based on unsatisfactory responses that are not rectifiable over a short time frame.

THE SECOND STAGE

The final stage of the selection process is conducted at the Yu A. Gagarin Center for Cosmonaut Training.[30] A senior medical evaluation commission bases its decision both on physical and psychological results. Selection is then confirmed by the Chief Medical Commission of the U.S.S.R., comprised of the leading specialists in clinical and space medicine. All serious psychological illnesses are grounds for rejection. In individual cases, if the candidate possesses certain technical (research) attributes that are required for the mission, efforts are made to treat certain psychological abnormalities. Selection for cosmonaut training may be made following at least 1 year of complete recovery. Such a selection process, on an individual basis, may also be done in cases when the individual cosmonaut-researchers are judged cured of an infectious or noninfectious disease.

In general individuals are judged unsuitable for cosmonaut training if disorders are found in psychic, nervous, anatomic, or infectious parameters, including venereal, cardiac, ear-nose-throat, ophthalmologic, and skin disorders.[31]

[29] Bluth, B. J. Space Science. Soviet Space Stress. No. 2. Sept. 1981. p. 30-35.
[30] Link, M. M., et al. Selection of Astronauts and Cosmonauts. op. cit.
[31] Ibid.

TRAINING PROCESS

BASIC CONCEPTS AND FACILITIES

Since the early 1960s, the majority of cosmonaut training is carried out at Star City (Zvezdny Gorodok, 19 miles from Moscow). The Soviet cosmonauts at this facility include cosmonauts preparing for future space missions as well as cosmonauts from previous missions serving in management, and instructor roles. Gen. G. Beregovoy is the commander of this training facility. The Soviets claim that the cosmonaut contingent is represented by equal numbers of military and civilian trainees.[32]

The international cosmonaut program, under the direction of U.S.S.R.'s Interkosmos Council includes the integrated collaborative flight programs of the Soviet bloc countries. More recently this collaboration has been enlarged to include joint space missions of non-soviet bloc countries such as France and India.[33]

The training facilities at Star City include Salyut flight simulators, two Soyuz simulators (the basic Soyuz manned transport vehicle and a newly modified Soyuz T). The training of foreign cosmonauts for joint space flights includes rigorous 1.5 to 2 year training at Star City and other facilities within the Soviet Union. These latter facilities provide specialized high altitude, underwater and stress physiology training. One significant difference, according to Western sources, in approach to the training practices of the Soviet Union and the United States, is that the former's training does not involve the distribution of basic documentation such as systems manuals. Rather the cosmonauts develop their own notes and refer back to them during the mission.[34] The U.S.S.R. also places great emphasis in its training program on repetition in the form of lectures by specialists on a particular subject matter, which is repeated at various times throughout the program.[35]

The Soviets still adhere to the concept that the cosmonaut must be able to function at several levels; namely to fly the spacecraft, to provide onboard servicing of the various critical systems, and to participate in some aspects of the specific mission. However, as advancements in mission requirements have progressed, one sees the strengthening of the involvement of pilot and crew concept, with the latter responsible for carrying out of detailed technical experimentation.[36]

The various training protocols for Soviet cosmonauts still demand rigorous physiological and psychological stress training, in those areas of space flight considered critical for the successful accomplishment of the mission. In particular, based on actual experience gained in prior manned space flights, training emphasis is placed in areas considered to be the most troublesome to the cosmonaut. The overriding problem influencing all training efforts is to moderate, if possible, the effects of weightlessness on physiologi-

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[32] Lenorovitz, J. M. Soviet Cosmonaut Training at Star City. Aviation Week and Space Technology, Aug. 9, 1982, p. 44-46.

[33] Ibid.

[34] Ibid.

[35] Ibid.

[36] Rukavishnikov, N. N., et al. The Cosmonaut as a Researcher. Moscow, "Inaniye" Press 1973, p. 64 (NASA TT F-15, 196)

cal well being.[37] Since the inception of manned space flight a rather specific series of problem areas have been defined. These are all related in some degree or other to the weightless state and consist of motion sickness, circulatory deconditioning, red blood cell mass loss and bone demineralization. In addition, isolation may be a serious psychological problem.[38]

An issue still under active debate is whether and to what degree the cosmonaut should be physically conditioned. Is maximum physical conditioning a benefit or a disadvantage in tolerating the variety of physiological stresses posed by weightlessness and subsequent return to Earth?[39][40] Can the cosmonaut readapt more readily to Earth's gravity if he is less physically trained, because he does not decondition as significantly during space flights?

PHYSIOLOGICAL AND PSYCHOLOGICAL TRAINING

In order to prepare the cosmonaut, as much as possible, for the rigors of space flight, a variety of conditioning programs are practiced. These include vestibular, visual, acceleration, weightlessness, survival and psychological training.

A major problem encountered by both Soviet cosmonauts and U.S. astronauts has been vestibular disorders or space motion sickness (SMS) (space adaptation syndrome in U.S. terminology). The etiology of this disorder is still not fully understood. However, the Soviets encountered this difficulty in 1961 aboard the Vostok 2 flight.[41] At that time cosmonaut Titov reported periods of disorientation and nausea. In view of this initial observation, the Soviets have devoted extensive pre-flight training time and have utilized exposure to preflight vestibular stress in selecting cosmonauts less prone to motion sickness. Pre-flight training is directed at utilizing both passive and active exposure to increase vestibular tolerance and is tailored to the individual cosmonaut. Active conditioning is a process where the individual cosmonaut participates in specific strenuous physical exercises as well as using gymnastic equipment. Passive conditioning includes the cosmonaut only in the sense that he is strapped into or is otherwise an integral component of a piece of equipment that is mechanically activated and either rotates about several axes or in some manner stresses the vestibular and optical system.[42] The Soviets report that this conditioning reduces gastrointestinal SMS.[43] In Soviet spaceflights involving the Salyut 6 space station, active vestibular ground stress training has been supplemented by active prophylactic intervention.[44][45][46] A detailed discussion on the motion sickness countermeasures employed will be presented later, see p. 724, dealing with gravitational influences on manned space missions.

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[37] Bluth, B. J. Soviet Space Stress, op. cit.

[38] Gazenko, O. G., A. M. Genin, and A. D. Egorov. Summary of Medical Investigations in the U.S.S.R. Manned Space Missions. ACTA Astronautica 8, 1981, p. 907-917.

[39] Beregovoy, J. T. Soviet Cosmonaut Training Center Reviewed. Zemlya i Vselennaya No. 5, 1980, pp. 15-19.

[40] Bodde, T. The Body's Answer to Zero Gravity. Bioscience 32, 1982. pp. 249-252.

[41] Soviet Space Programs (Ch. Four The Soviet Space Life Sciences), op. cit.

[42] Ibid.

[43] Shatalov, V. Motion Sickness View. Aviation Week and Space Technology, Dec. 20, 1982, p. 22.

[44] Link, M. M. and N. N. Gurovskiu. Training of Cosmonauts and Astronauts. Journal of Space Biology and Medicine, 1975. pp. 438-450.

[45] Molina-Negro, P., et al. The Role of the Vestibular System in Relation to Muscle Tone and Postural Reflex in Man. Acta Otolaryngol. 1980, 89, 524-538.

[46] Nicogossian, A. E., et al. Space Physiology and Medicine. NASA SP-447, 1982.

All aspects of the training program are directed at adapting the individual cosmonaut, as much as possible, to subsequent space stress condition by repeated exposure, with gradual increased intensity, to a variety of these external stimuli. In all instances, individual physical, psychological, and physiological profiles are taken into consideration in order to arrive at exposure and optimal load conditions appropriated for each cosmonaut.[47]

In order to provide the individual cosmonaut with the capacity to adapt to transverse acceleration during space flight, particularly during initial liftoff or other phases of rapid acceleration, extensive familiarization runs are made in human centrifuges. During such an exposure, individual tolerance levels are significantly increased to transverse acceleration stress, as is the capacity of the cosmonaut to develop the ability to respond to such a stress and thereby reduce its adverse impact. This is augmented by means of cosmonaut leg muscle tensing, and abdominal and thoracic breathing. Centrifugal forces are increased gradually over periodic exposures during a 2-month interval. The Soviet cosmonauts have been exposed to transverse G forces up to 10G.[48] Soviet scientists have demonstrated that gradual increasing G force exposure is effective in enhancing tolerance levels. They also suggest that the best responses have been attained when G forces are gradually increased, concomitant with gradual greater time intervals between G force exposure.[49]

Although weightlessness for any length of time is not readily reproduced on Earth, it can be replicated for short intervals by aircraft flights along Keplerian (parabolic) trajectories. The use of such flights for conditioning purposes have been used since the late 1950s both by the United States and the Soviet Union.[50] These studies have proven that human response is individualistic, but that repeated exposure of individuals does permit a degree of adaptation even for individuals who initially have a low tolerance.

Soviet investigators have demonstrated that individuals who are experienced flight personnel in general are more tolerant to short term weightless exposure and adapt more readily during repeated exposure than do nonflight personnel.[51] These types of studies, as well as experience in space flight over the past 20 years, have led some Soviet and space scientists to conclude that short term exposure of space flight personnel to parabolic flight trajectories are beneficial both for training purposes as well as to determining predisposition to vestibular disorders.[52]

An integral component of acceleration and vestibular training is visual perception training. The eye is thought to be a contributing sensory factor associated with SMS.[53 54]

Physical conditioning demands have been lowered and the age of acceptable candidates raised. In particular, such requirements as

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[47] Bluth, B J, Soviet Space Stress, op cit

[48] Link, M M and N N Gurovskiu Training of Cosmonauts and Astronauts.

[49] Ibid

[50] Ibid

[51] Kolosov, I A Human, Statokinetic Reactions during Brief Weightlessness Izv Acad Nauk SSSR Biol, 1969 p 736 741.

[52] Yuganov, Ye M and A I Gorshkov Characteristics of the Functional State of the Otolithic Apparatus under Conditions of Altered Gravity NASA TT-F 616, 1970.

[53] Crosby, T N, and R S Kennedy Postural Disequilibrium and Simulator Sickness Following Flights in a P3 C Operational Flight Trainer Aeronautical Medical Association Meeting, 1982, p 147 148

[54] Nikolayev A Space Road Without End Moscow "Molodaya Gyardiya" Press, 1974, p 42 46

spatial orientation and visual perception training was lowered for science crewmembers, since the latter would not have a primary requirement to pilot the spacecraft. However, tolerance to G forces, and vestibular stability are still a major requirement for all crewmembers.[55]

Training protocols aid the cosmonaut in learning how to operate the spacecraft prior to actually going into space. This assures that a variety of experiences and sensations are simulated and recognized during the training phase of the program, thereby allowing the cosmonaut to respond in emergency situations in a similar manner to that while undergoing training. Weightlessness was first simulated by using a swimming pool. Currently a special hydraulic laboratory has been developed. This facility monitored visually via television and other electronic means during the time the cosmonauts are submerged in a pool in their Salyut and/or Soyuz simulator 12 meters below the surface. In addition, the cosmonaut training center now utilizes a IL-76 aircraft which permits the trainee brief exposure to zero gravity.[56]

Additionally newer facilities are available to acquaint the cosmonauts with expected flight conditions. These include a space planetarium to familiarize them with celestial bodies used for space navigation.[57] This facility also permits them to become familiar with the use of celestial bodies that will be studied as part of the scientific programs. Since the amount of research carried out in space increases continually and since the same individuals may be required to perform a multitude of such studies, it is absolutely necessary that they be adequately trained on Earth. The Soviets also seem to incorporate into cosmonaut training an understanding and appreciation of the Marxist-Leninist principles, which provide not only the technical rationale for the mission, but also social and political reasons.[58]

As space missions have increased in duration and interplanetary flights seem more feasible, the process of selection and training of cosmonauts has evolved into both training of the body and mind. The crew of a spacecraft should consist of individuals who are compatible.

Despite the selection and training process, psychological tensions between crewmembers do develop.[59] Therefore, appreciable training time is devoted to the behavioral areas, including response to emergency conditions potentially encountered in space. Since individuals are confined for long intervals in limited quarters under conditions requiring special safety and life support systems a detailed psychoanalysis of the individuals who would be most compatible in such environments is necessary. To accomplish this type of psychological selection and training, individuals are frequently subjected to multiple and sequential stresses such as heat, humidity, cold, and isolation.

[55] Saiki, H., et al. Effect Physical Fitness and Training on Physiological Response to Hypogravity. ACTA Astro 8, 1981, p. 959-965.

[56] Beregovoy, G. T., Soviet Cosmonaut Training Center Reviewed, op. cit.

[57] Ibid.

[58] Ibid.

[59] Ducrocq, A. The Terrible Return. Air et Cosmos 52-63, Paris, Dec. 18, 1982.

Factors that determine group psychology and compatibility are analyzed. These include intellectual abilities, and likes and dislikes. It is very important that members of a group have a positive attitude toward each other and are willing to cooperate and conform in order to accomplish their mission.[60]

Newer methods of evaluating stress responses are being investigated. These include brain scans, voice stress tests, and changes in circulatory endocrine levels. As techniques for quantifying physiological and psychological stress responses improve, the selection, and training of cosmonauts, as well as modification of the space capsule environment, may become more of a quantitative science.[61]

It has become apparent from prior space flights of multiple crews on Salyut-6 that psychological support for the crew during space flights of long duration is highly effective in maintaining motivation and emotional stability. The psychological support program is based on a series of informational exchanges and conversations between the cosmonauts and ground control, family members, scientific and technical specialists, as well as entertainers and politicians.[62] All of these support activities are, of course, also utilized during psychological stress training practiced on the ground which attempt to emotionally prepare the cosmonaut for the unexpected.

Soviet training programs prepare the individual for stresses other than crisis, such as isolation, boredom and confinement. The Soviet philosophy in this area of training is based on the supposition that equipment reliability is not limitless. The ultimate success of a mission may very well depend on the psychological fine tuning of the cosmonaut.[63] Therefore, they incorporate the various forms of stress training such as underwater tank diving, centrifugation, altitude chamber rides, isolation, parachuting, and survival training in their overall emotional and physical conditioning programs. The cosmonauts' parachute training involves at least 100 jumps of increasing difficulty. Trainees initially must count to 20 seconds prior to opening their parachutes. This is followed by requiring them to go through a check list during free fall. Later, they must await ground control approval prior to opening their prachutes. Survival tests include depositing of the cosmonauts and their space capsule trainer in remote, environmentally hostile areas where they are left to their own devices to survive and return to safer terrain. This training has reaped benefits.[64] For example, during the 175-day Salyut 6 flight, a radio-telescope antenna jammed during the jettison or deployment procedure, so that it blocked one of the station's two ports. The two cosmonauts, Ryumin and Lyakhov, suggested that they manually jettison the antenna. After much reluctance on the part of ground control personnel, the cosmonauts finally prevailed, and completed an unscheduled extravehicular procedure which saved the space station for subsequent missions.[65] The Soviets, as previously mentioned,

[60] Mel'nikov, L. N. Psychological Relief Rooms. Mashinostroitel No. 1, 1978.

[61] Ibid.

[62] Myasnikov, V. I. and O. P. Kozerenko. Prevention of Psychoemotional Disturbances During Long Term Space Flights by Means of Psychological Support. Kosmicheskaya Biologiya I Aviakosmicheskaa Meditsina No. 2, 1981. p. 25-29.

[63] Ibid.

[64] Bluth, B. J., Space Science, op. cit.

[65] Ibid.

load on the heart.[70] A more detailed discussion of the influence of weightlessness on the cosmonauts' circulatory system while in space and on subsequent return to Earth will be presented in section V.

By means of a mass meter, an instrument for determining the weight of a cosmonaut in zero gravity, muscle atrophy from lack of usage in space, as well as changes in body weight have been observed.[71] These observations have permitted ground support personnel to devise remedial measures for counteracting such occurrences. Countermeasures have included variations in diets, and increase in physical conditioning and activity in space.

The application of remote electronic medical monitoring has been extensively utilized both by the United States and the Soviet Union in manned space programs, as well as in a variety of biological experiments studied by both countries. Both nations have found that, by monitoring the various physiological parameters during space flight, significant information on the health status of mammals during various stages of space flight has been gained. As a result of these observations, remote sensing equipment has evolved which permits the delineation of physiological conditions encountered in space both prior to and during the time of a major biological crisis, such as motion sickness, cardiovascular impairment, bone demineralization and loss in both red cell mass and number.

As the duration of space flight increases, it is critical to determine whether the various abnormal physiological conditions observed were truly transitory and reversible or permanent and possibly life threatening.

Physical Activity

Exercise Programs

During the past 10 years, the duration of individual space mission has increased from days to months. In particular, the Soviet Union has had a concerted effort underway to extend the duration that cosmonauts can effectively function on a space platform. This increased tenure in space has placed additional stress on the cosmonauts. It therefore has become imperative that all conceivable effective countermeasures be employed to reduce the adverse effects of zero gravity on human physiology.

Several prominent and potentially serious problems encountered while in space have developed. Some of these are transitory and others are permanent. In some instances, the host has been able to adapt, after a few days, as in the case for motion sickness. In other instances such as the pooling of fluids in the upper portion of the body, the condition is of longer duration, and presents discomfort for several weeks and months. In the latter instance, the circulatory system eventually seems to compensate, but at the expense of

[70] Ibid.

[71] Sarychev, V. A., V. V. Sazonov, A. A. Zlatorunskiy, I. A. Samorukov, V. R. Freydel, S. F. Khlopina, A. D. Yegorov, and V. I. Somov. Body Mass Measurement Under Weightlessness Conditions. Moscow Kosmicheskiye Issledovaniya in Russian. 18, No. 4, 1980, p. 536-549.

stressing the cardiovascular system.[72] Experience gained over the course of extended space missions has provided the Soviets with data suggesting that adaptation in many instances is an individual phenomenon and that certain countermeasures may be prophylactic.

The Soviets claim that rigorous physical training prescribed for the cosmonaut while in terrestrial training and followed during the actual space flight, may reduce the physiolcgical abnormalities encountered in space. By establishing a prescribed physical training format, they have also noted that readaptation to gravity occurs more rapidly after returning to Earth.[73] In fact, the Soviet process of readjusting to Earth gravity takes the form of both physical exercise, physiotherapy, and psychotherapy (see fig. 47). In regard to specific exercise in their more recent space flights lasting over 6 months, the Soviets have required the crew to perform exercises three times daily. These exercises utilize an exercise bicycle which is rated for increasing physical loads and tailored to the individual cosmonaut. In general, the cosmonaut performed exercises consisting of 3,750 kg-m within 5 minutes and a speed of 60 revolutions per minute.[74] The treadmill exercises were performed under load conditions by utilizing tension straps (bungee cords) of approximately 50 kg along the longitudinal axis of the body. The cosmonauts were monitored telemetrically not only for the load being utilized and distance covered (3.9–4.3 km) on the treadmill, but also for their vital signs during their exercise periods.[75] The 3 day exercise cycles are followed by a day of rest when exercise is optional. This protocol is followed throughout the space mission. Even though there have been variations in the frequency and duration of the exercise regime,[76] dictated by the details of the mission and the desires of the cosmonaut, the overall concept of strenuous physical training during space flight has proven beneficial in helping the cosmonauts to maintain good physical conditioning and to reduce the difficulties in readaptation after return to Earth.

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[72] Georgiyevskiy, V. S., N. A. Lapshina, L. Ya. Andriyako, L. V. Umnova, V. G. Doroshev, I. V. Alferova, V. N. Ragozin and Ye. A. Kobzev. Circulation in Exercising Crew Members of the First Main Expedition Aboard Salyut 6. Moscow, Kosmicheskaya Biologiya I Aviakosmicheskaya Meditsina (in Russian), No. 3, 1980, p. 15–18.

[73] Krupina, T. N., A. V. Beregovkin, V. M. Bogolyubov, B. M. Fedorov, A. D. Yegorov, A. Ya. Tizul, V. V. Bogomolov, V. V. Kalinichenko, A. P. Ragulin and V. A. Stepin (Moscow). Combined Rehabilitation and Therapeutic Measures in Space Medicine. Moscow Sovietskaya Meditsina (in Russian), No. 12, December 1981, (manuscript received May 25, 1981), p. 3-8.

[74] Georgiyevskiy, V. S., N. A. Lapshine, L. Ya. Andriyako, I. V. Umnova, V. G. Doroshev, I. V. Alferova, V. N. Ragozin and Ye. A. Kobzev, submitted Dec. 26, 1978. Circulation in Exercising Crew Members of the First Main Expedition Aboard Salyut 6, op. cit.

[75] Gazenko, O. G. and A. D. Yegorov. The 175-Day Space Flight. Moscow, Vestnik Akademii Nauk SSSR No. 9, 1980, p. 49–58.

[76] Ibid.

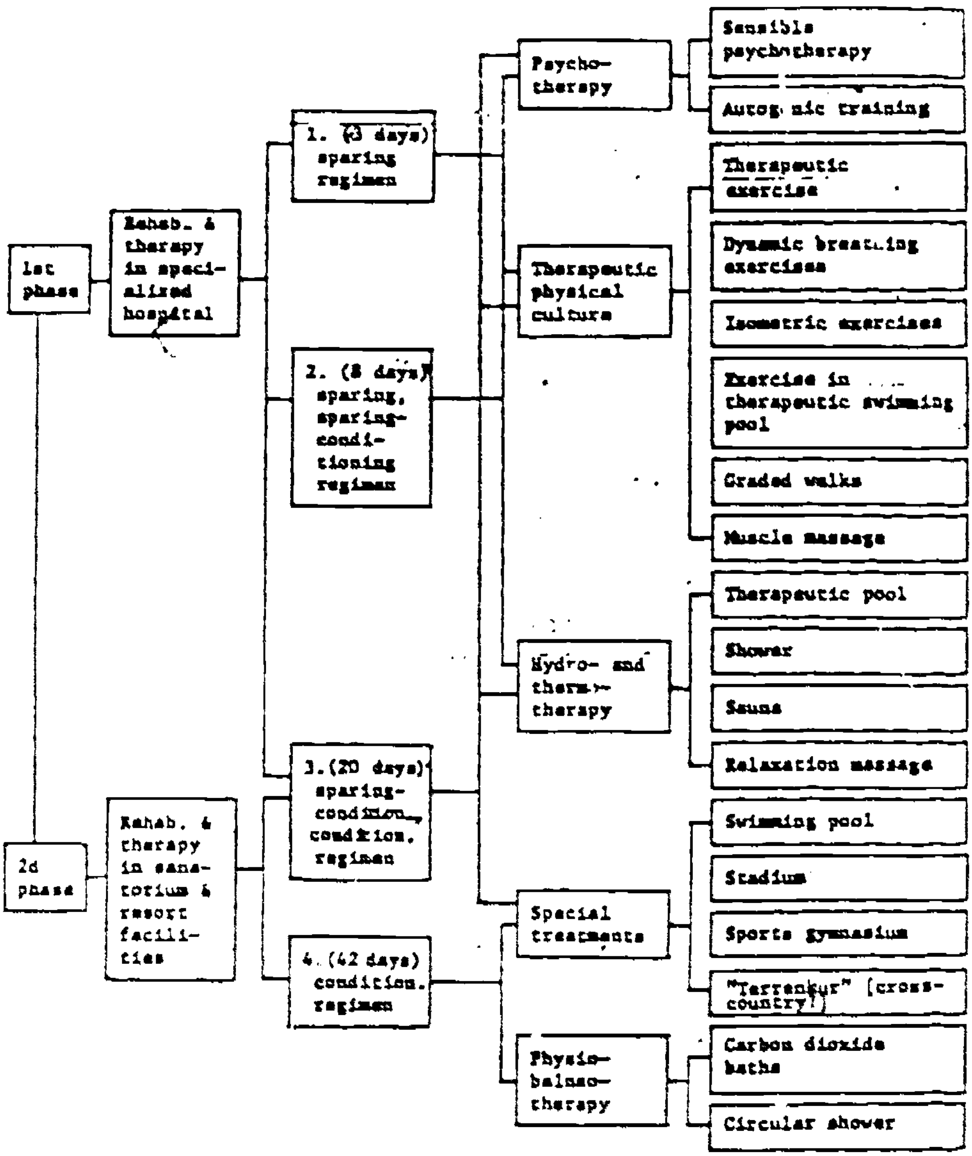

FIGURE 47.—Chart and Names of Main Rehabilitation and Therapeutic Measure Used at Different Phases and States of the Readaptation Period.[77]

GRAVITY SIMULATION

In addition to the aforementioned methods of maintaining a good physiological profile, the Soviets utilize a special elastic suit (penguin suit). This is attached by elastic bands from the waist and shoulders to the floor of the space station in order to provide artificial gravitational pull on the skeletal musculature, thus hopefully reducing the problems of bone demineralization.[78] Data available

[77] Krupina, T. N and V. M. Beregovkin, et al. Combined Rehabilitation and Therapeutic Measures in Space Medicine. Sovietskaya Meditsina 12, 1981. p. 3–8.
[78] Yegorov, A. D. Results of Medical Research During the 175-day Flight of the Third Prime Crew on the Salyut 6 Orbital Complex (NASA TM-76450), Washington, D.C. 1981.

32 985 O--84----17

to date does not indicate that this practice has reduced demineralization.

Three weeks prior to the termination of the long term space flights (over 6 months), the cosmonauts begin to use a lower body negative pressure suit (chibis vacuum suit).[79] The negative pressure to the lower half of the body causes a redistribution of body fluids from the upper part of the body downward. This redistribution permits the reestablishment of vascular tone for subsequent post flight orthostatic stability. The application of negative pressure is performed every fourth day for a 20 minute interval at negative pressures ranging from −10 to −45 mm of mercury. During the last 2 days of a flight, the negative pressure exposure is extended to a total of 50 minutes at a negative pressure ranging from 25–40 mm of mercury. During this phase of pre-readaptation exercises, the cosmonauts drink 300 ml of saline water (3 gm of sodium chloride to 400 ml of water) prior to donning their antigravity suits. This suit is worn prior to descent, in order to create additional pressure to the lower part of the body. This prevents the pooling of blood in that area immediately after landing and permits more rapid othostatic compensation.[80]

Therefore, during the evolution of both the Soviet and American space program, it has become clear that certain countermeasures can be instituted to counteract some of the deconditioning processes that set in due to zero gravity. The Soviets have found these exercises and associated protocols successful. Many of the physiological parameters, such as body mass, heart rate, arterial pressure and leg volume, remain relatively constant when compared to preflight values.

A variety of exercises and conditioning equipment has found its place aboard Soviet crafts. These are briefly described in table 16.

TABLE 16 - *Physical conditioning equipment on Soviet Space Stations* [1]

Equipment	*Application*
Bicycle ergometer	Arms and legs conditioning.
Treadmill	Respiratory and lower limb conditioning.
"Penguin" suit	Skeletal muscular synthetic gravitational load
Lower body negative pressure suit ("Chibis")	Cardiovascular conditioning and partial restoration of orthostatic tolerance
Antigravity suit	Reduces blood pooling during reentry.

[1] Nicogossian, A. E. and J. F. Parker. Space Physiology and Medicine. NASA SP 447, 1982

EMERGENCY AND PROPHYLACTIC DRUGS

PROPHYLACTIC DRUGS

Even though, prior to space flight, the cosmonaut is in optimum physical and mental condition, medical emergencies cannot be dis-

[79] Gazenko, O. G., and A. D. Yegorov, The 175 Day Space Flight. Results of the Medical Research, op. cit.
[80] Ibid.

counted. In order to permit the adequate management of such episodes, both Soviet and American spacecraft are equipped with emergency medical kits. These kits consist of medication used to counteract motion sickness, fatigue, nasal congestion, bacterial infection, pain, diarrhea, as well as minor lacerations.[81]

During the more recent long term space flights, the Soviets have utilized prophylactic medication during various stages of their space flight. For example, on two separate occasions during the flight, cardiac muscle prophylaxis was practiced aboard the 175-day Salyut-6 by providing the crew with Inozia-F and Panagin at midpoint and at the end of the mission. Once more, during the last 2 weeks of the flight, the cosmonauts also utilized supplementary Deka vitamins, methionine and glutamic acid. The Soviets claim that these supplements intensify the metabolic process, enhance catacholamine synthesis, normalize the intestinal flora and lipid metabolisms.[82 83]

The Soviets have not published data about space crew injuries or other medical emergencies;[84] however, they have most likely encountered similiar types of illnesses and injuries to those reported by the United States up through the Apollo Soyuz program. The space missions have encountered mostly minor injuries and inflight medical problems, a list of which are shown on table 17. This table does not include the reported motion sickness difficulties encountered.[85]

TABLE 17. *Illness/injury occurrence in U.S. space crews*[1]

	Number
Inflight illnesses/Injuries:	
Dysbarism	2
Eye/skin irritation (fiberglass)	3
Skin infection	2
Contact dermatitis	2
Urinary tract infection	2
Arrhythmias	2
Serious otitis	1
Eye and finger injury	1
Sty	1
Boil	1
Rash	1
Illness/Injury During Recovery and Landing:	
Trauma (scalp laceration from detached cornera)	1
Toxic pneumonia (inadvertent atmosphere contamination by N_2O_4)	3
Injury Discovered Postflight: Back strain (due to lifting of heavy object)	1

[1] Furukawa, S. and A. Nicogossian, P. Buchanan, P. Pool, S. Medical Support and Technology for Long Duration Space Missions. 33rd Int. Astro. Fed. Sept. 22, 1982.

Both the Soviet Union and the United States have considered procedures that might be utilized in the event of more serious injuries. In the case of the United States, procedures are under consideration for the transfer of an injured crew member via a rescue system to a rescue vehicle.[86] The United States also has considered

[81] Nicogossian, A. E., et al., op. cit.
[82] Shaskov, V. S. and B. B. Iegorov. Problems of Pharmacology in Space Medicine. Farmakologiya i Toksikologiya 42 (4), p. 325-339.
[83] Gazenko, O. G. and A. D. Yegorov. The 175 Day Space Flight. Some Results of the Medical Research, op. cit.
[84] Vorog'Ev, Ye. I. Preliminary Results of Medical Studies Conducted During Manned Flights of the Salyut-6 Program. Moscow. Isvestiya Akademii Nauk SSSR. Seriya Biolog., No. 1, 1981 p. 520.
[85] Nicogossian, A. E., op. cit.
[86] Nicogossian, A. E., et al., Space Physiology and Medicine, op. cit.

means of restraining a crewmember in the event of spinal injury or for other medical episodes requiring immobilization.[87]

EMERGENCY DRUGS

The Soviets, in view of their flight duration, have given serious consideration to protocols and equipment necessary in the event of medical emergencies that might require surgery and/or resuscitation.[88] They have come to the conclusion that the traditional methods of dealing with medical emergencies are not applicable in space flight. In particular, difficulties would be encountered in an emergency that could require surgical intervention. In that case, the conventional means of anesthesiology would not be possible due to changes in pulmonary physiology that occur during space flights and because it would not be practical to utilize inhalation anesthetics due to the limited space aboard the space vehicle. The close proximity of other crewmembers must be considered since they could also be influenced by the anesthetic being administered. Due to zero gravity the use of intravenously administered anesthetics also would not work well, because there is reduced blood circulation throughout the body. They therefore conclude that the most practical anesthetics would be those that could be given to the local area requiring the surgical procedure. In fact, they propose the possibility of utilizing auriculoacupuncture combined with electroanalgesic particularly for extracavital surgical intervension. In those instances requiring regional anesthesia, this technique seems to be satisfactory. They indicate that surgery should be employed only as a last resort and recommend local hypothermia as a conservative approach until the individual can be brought back to Earth.[89]

However, proceeding on the premise that they may, at one point, have no alternative to surgical intervention in space, the Soviets are developing lightweight surgical equipment, and means of sterilizing this equipment. Methods are also being developed for localized sterile containment of those areas of the body undergoing surgery.[90] In the latter instances, they suggest the use of isolation chambers constructed of transparent plastics having sleeve ports so that the surgery could be performed under more sterile conditions. The surgical procedures and patient isolation presumably would be similar to the techniques currently employed on Earth, where certain medical conditions require the isolation of the patient from his surroundings due to increased risk of infection.[91]

The Soviets are also considering means of removing toxic substances from body fluids that may accumulate during certain medical conditions occurring on space flights.[92] For this procedure they are studying the feasibility of using various sorbents through which the fluids would be passed and then reintroduced into the body. Because of the potential of medical emergencies in space, ad-

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[87] Ibid.
[88] Stazhadze, L. L., et al., Anesthesia, Surgical Aid and Resuscitation in Manned Space Missions. ACTA Astronautica 8, 1981, p. 1109-1131.
[89] Stazhadze, L. L., et al., Anesthesia, Surgical Aid and Resuscitation in Manned Space Missions, op. cit.
[90] Ibid.
[91] Pennington, J. Infectious Complications of Malignancy. In Clinical Cancer Medicine Treatment Tactics. J. J. Lokich, ed. G. K. Hall Publ., 1980, p. 303.

ditional research needs to be performed in these areas in order to come up with practical solutions that could be applied.[93] The need for the resolution of these problem areas is becoming even more apparent as the duration of space flight is extended.

BIORHYTHM PROBLEMS

A human being on Earth maintains a 24-hour cycle. This rhythm may be altered as the individual crosses time zones, in that the work-rest cycle as well as the day-night cycle may be modified by extending or contracting these intervals during the time of crossing such time zones. Even relatively moderate changes in the normal 24-hour cycle upsets the normal physiological, emotional and/or psychological health of an individual. This daily rhythm is linked to the well recognized light-dark cycle of Earth, which regulates the animal's biorhythm. Usually an eight-hour sleep cycle is followed by a 16-hour work cycle. When such a routine rhythm is even moderately interrupted the well-recognized "jet lag" develops. This is characterized by fatigue, lack of attention span and other manifestations of physiological and psychological changes. In some people the change in rhythm is demonstrated by an enhanced susceptibility to infection, intestinal upset and general malaise.[94]

Such vital functions as pulse and heart rate, brain activity, body temperature, renal function, metabolism, as well as changes in endocrine activity are altered at times of light-darkness cycle changes.[95]

The response to the consumption of drugs and alcohol is very dependent on when they are administered during our normal biorhythm. Similarly, emotional disorders are more readily manifested during alteration in the usual biorhythm. In view of the dramatic effects observed on Earth during moderate alteration to biorhythm, the question of how an individual responds to the much more severe changes in the biorhythm in space needs to be studied. Under that situation, the individual may undergo day-night changes every 1½ hours; therefore the 24-hour rhythm normally encountered on Earth is severely modified and can bring about appreciable stress response. Therefore, both the Soviets and the United States have had a keen interest in studying the influence of such drastic changes on the biorhythm and developing means for ameliorating these effects. The Soviets, particularly during their longer missions (Soyuz/Salyut) have attempted to maintain a 24-hour cycle for their cosmonauts. They have assumed that the biorhythm is a conditioned reflex and therefore on Salyut 6 they maintain the crews on a 24-hour day, 5-day work week synchronized to Moscow time.[96] Based on their studies, the Soviets also believe that biorhythm is somewhat individualistic and therefore select cosmonauts with specific biorhythms suited for particular space missions.[97] They are also looking at the feasibility of select-

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[92] Stazhadze, L. L., et al., Anesthesia, Surgical Aid and Resuscitation in Manned Space Missions, op. cit.
[93] Ibid.
[94] Gurovskiy, N. N., Designing the Living and Working Conditions of Cosmonauts. Moscow, Mashinostroyeiya Publishing Co., 1980, p. 1–163.
[95] Ibid.
[96] Stepanova, . I. Aktuaz Nyye Problem Kosmicheskoy Bioutmologi. Moscow, Nauka, 1977.
[97] Ibid.

ing cosmonauts based on their consistency of biorhythm with the assumption that individuals with more constant rhythms adapt more readily to changes and are able to endure desynchrony more readily.[98]

In general, individuals with similar biorhythms seem to function better in a restricted environment. This certainly is the case for the cosmonauts, considering that a fairly rigid schedule, in a confined space, is adhered to by Soviet cosmonauts. Therefore, since individual biorhythms vary as to optimum individual efficiency during different times of day, crew members should be persons with similar biorhythms. This permits the coordination of various activities aboard the space station so that the crew is at optimum efficiency during the time work is required and are all then able to rest during prescribed rest periods.[99]

People can be divided into three types according to their maximum efficiency during a day. There are the "larks," those that have maximum efficiency during the morning, the "owls" whose peak efficiency is at night and others whose peak efficiency is during the middle of the day.[100] The rather frequent day-night cycles during space flight obviously superimposes additional difficulties on biorhythmic synchrony.

A disruption of the observed individuality of biorhythm both by internal and external stimuli can lead to pathological conditions. Persons working on split-shifts, for example, have greater susceptibility to gastric and neurological disorders.[101]

Cosmonauts' conditions differ appreciably from the normal work-rest cycle of most other professions. The cosmonaut in reality cannot as readily separate himself from his work during leisure time, including the time when he sleeps. Since the cosmonauts are totally removed from physical contact with persons on Earth, and entirely dependent on the integrity and reliability of their space capsule, they cannot readily, at any time while in space, separate themselves from the mission. The link between the spacecraft and cosmonaut is vital, with his welfare totally dependent on the perfect functioning of the systems aboard the craft. He, therefore, is continually aware of potential danger signals. All stimuli that one cosmonaut senses will be obvious to the others regardless of whether they are on duty at that particular time.

Based on the biorhythm, the Soviets suggests that a programmed schedule for the day significantly reduce the influence of many of the negative factors encountered in space during long term flights.[102] In order to facilitate the organization of such a schedule, the Soviets suggest that the spacecraft must provide specific areas reserved for recreation, sleep, rest and privacy, as well as areas where joint work is performed.[103] The proper selection of cosmo-

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[98] Alyakrinskiy, B S Scheduling Work and Rest Periods during Long-term Space Flights. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina 1, 1980. p. 3-9.

[99] Ibid

[100] Stepanova, S I Biorhythmological Status as One of the Criteria for Cosmonaut Screening. Kosmicheskaya Biologiya i Aviakosmichskaya Meditsina #5, 1980. p 20-24

[101] Stepanova, S I Pressing Problems of Space Biorhythmology. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina No 5, 1979 p 88-90

[102] Gurovskiy, N P, F P Kosmolinskiy and L N Nel'nikov, Designing the Training and Working Conditions of Cosmonauts, op cit

[103] Ibid

nauts based on their biorhythm is therefore essential. This permits them to adapt to the radical changes encountered in space. In order to maintain a synchronous existence in space, certain acquired stimuli that contribute to this stability like the daily dynamics of light, temperature, and humidity present on Earth are very important and should also be maintained in space, if at all possible.[104]

Biomedical Findings

Cardiovascular Changes

During the course of both the Soviet and American space effort, certain biomedical difficulties have come to the forefront. Most seem to be related to the lack of gravity in space.

Acute changes have been noted in the cardiovascular system. This condition has not lead to any permanent irreversible damage, but it is a constant concern of physicians monitoring people in space.[105] Similarly, due to the absence of gravity, one notes muscle atrophy, with legs and the waistline appreciably decreasing in size both due to the minimal requirement for muscular activity as well as due to a shift of body fluids and internal organs toward the head.

The lack of gravity also leads to a significant and continual calcium loss. This process of bone demineralization, with a loss of potassium, magnesium, and calcium has been observed in both Soviet cosmonauts and American astronauts. Another problem is that over 50 percent of astronauts and cosmonauts have experienced motion sickness.[106]

Though all these conditions, except for demineralization, seem to be self-limiting once the body adapts to space or can be reversed after a readaption process on Earth, they do pose a potential problem and, according to some U.S. observers, may negate interplanetary manned space missions at least until there are major technical breakthroughs.[107 108] There is no indication at this time, however, that the Soviets plan to discontinue their progress toward longer and longer flights.

Another problem area that has come to the forefront in the past few years, largely due to the observation made by the Soviets during their long term space mission, is the psychological problem associated with isolation, limited human contact and limited living space. The Soviets have countered some of these problems by developing psychological support systems in space.[109 110]

A more detailed discussion of these biomedical difficulties seem appropriate since many have been observed virtually from the beginning of space exploration and have so far proved not readily soluble.

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[104] Ibid

[105] Levy M. N. et al Research Opportunities in Cardiovascular Deconditioning NASW-3616, 1983

[106] Gazenko, O. G., et al Summary of medical investigations in the U.S.S.R. Manned Space Missions Acta Astronautica 8, 1981 p. 907-917

[107] Ibid

[108] Engler, N. and D. Cheshire-Engler. Omni. May 1983 p. 108-133

[109] Vorob'ev, Ye I., O. G. Gazenko, N. N. Gurovskiy, A. D. Yegorov, A. V. Beregovkin, V. A. Degtyarev, V. V. Kalinichenko and I. I. Kas'yan. Preliminary Results of Medical Studies Conducted During Manned Flights of the Salyut-6 Program. Moscow, Izvestiya Akademii Nauk SSSR Seriya Biologicheskaya (in Russian), no 1, Jan.-Feb. 1981. p. 5-20

[110] Gazenko, O. G. and A. Yegorov, The 175-Day Space Flight: Some Results of the Medical Research, op. cit

Soon after going into space, a variety of cardiac functions of the crew begin to deviate from normal values. There is an initial shift of blood and body fluids from the lower half of the body to the upper torso. A substantial increase in jugular vein pressure becomes apparent. The dynamics of blood propulsion from the left ventricle through the systemic artery changes with a shortening in the heart's contractile phase and associated with a less consistent blood ejection time. The amount of blood reaching the lower extremities decreases by as much as 10 percent and veinous pressure increases throughout the flight. There has, however, been no observed significant change in the biolectrical potential of the myocardium as measured by electrocardiography.[111] When cosmonauts were subjected to stress tests during space flights, the frequency of cardiac contraction increased. This was attributed by the Soviets to a deconditioning in the functional capacity of the cardiovascular system.[112]

Regardless of the duration of a flight, all cosmonauts have demonstrated some degree of cardiovascular deconditioning. This has been manifested on return to Earth by altered heart rates and blood pressure changes. In addition, fatigue has been observed, together with signs pointing towards the potential for fainting, reduced tolerance to performing exercise, as well as a reduced capacity to move about. These manifestations of altered and impaired cardiac functions, have persisted post flight for as little as a few days to as long as 1 month. Echographic studies show that there is at least a 25 percent decrease in the left venticular volume, however, this does normalize, thereby suggesting that there is, most likely, no actual or permanent loss of cardiac muscle.[113 114]

One notes when evaluating the influence of weightlessness on the cardiovascular system, that other physiological abnormalities are manifested. These include electrolytic imbalance, altered metabolism of minerals and nutrients and modification of certain endocrine functions. Since these deviations from normal may impinge on the normal function of the cardiovascular system, one is looking at a multitude of complex interactions among diverse organ systems and functions all apparently influenced by weightlessness.[115 116]

Table 18 lists those effects of weightlessness on the cardiovascular system observed and reported by the Soviets.

TABLE 18 Influence of long term Soviet space flights on the cardiovascular system

During Flight
1. Moderate increase in heart rate
2. Transient increase in observed ejection time
3. Increase during first 2 to 3 weeks of stroke volume and cardiac output.
4. Increased cerebral blood flow during first 3 to 4 months; prior to stabilization

[111] Levy, M. N., et al., Research Opportunities in Cardiovascular Deconditioning, op. cit.
[112] Gazenko, O. G., et al., The 175 Day Space Flight, op. cit.
[113] Sandler, H. Cardiovascular Deconditioning. NASA Research and Technology Objectives and Planning. Ames Research Center, Moffett Field, Calif., 1982.
[114] Levy, N. M., et al., Research Opportunities in Cardiovascular Deconditioning, op. cit.
[115] Pestov, I. D., S. J. Geratewohl. Weightlessness. In Calvin, M. Gazenko, O. G. (general eds.) Foundations of Space Biology and Medicine. 2. Wash., D.C., NASA, 1975. p. 305-354.
[116] Levy, N. M., et al. Research Opportunities in Cardiovascular Deconditioning, op. cit.

TABLE 18.—Influence of long term Soviet space flights on the cardiovascular system—Continued

5. Increase in jugular vein pressure.
6. A decrease in leg volume.
7. A decrease in venous blood pressure in legs.
8. A decrease in systolic arterial pressure.

Post Flight (transient, days to weeks in duration):
1. Fatigue
2. Faintness.
3. Perception of increased body weight.
4. Tachycardia
5. Decrease in stroke volume and ejection time.
6. Orthostatic intolerance.
7. Reduced capacity to move and coordinate.
8. Reduced capacity to endure physical stress.

Source: Gazenko, O. G., A. M. Genin, A. D. Egorov. Major Medical Results of the Salyut-6/Soyuz 185-day Space Flight, v. 2. 32nd Cong. of Int. Astro. Fed., Sept. 6, 1981.

BODY CHANGES

In addition to the cardiovascular manifestations, both during adaption to zero gravity and on readaption to Earth, the lack of gravity appreciably affects motor functions. This is manifested by a decrease in leg and trunk muscle tonicity, and decreasing muscle strength, frequently leading to muscle atrophy. One also observes changes in the normal posture of the body.[117] These manifestations are to some degree controlled by strenuous physical exercise while in space.

BONE CHANGES

A major hazard associated with long-term space flight is the progressive loss of bone mass and strength. To date, the progressive nature of this demineralization does not seem to plateau, at least up to the most recently available data reported on the Salyut 6 mission lasting for 175 days.[118] In the absence of being able to stop and reverse the process of osteoporesis during space flights, a situation could arise where the cosmonaut might become susceptible to bone fracture both in space and even more so upon return to Earth and in the event of abrupt deceleration. In the event that the process of demineralization is irreversible then space flights of long duration might bring about a significant increase in bone fracture risk, in later life of the cosmonaut.[119]

DECONDITIONING COUNTERMEASURES

Attempts to reduce and control the effects of weightlessness on cardiovascular changes, muscular deconditioning and bone demineralization have involved inflight, reentry, and post flight measures. These interventions have included inflight exercise, lower body negative pressure, venous blockage, fluid and electrolyte sup-

[117] Kozlovskaya, I. B. Kreidich, Yu. V., V. S. Oganov, and O. P. Koserenko. Pathophysiology of Motor Functions in Prolonged Manned Space Flights. Acta Astronautica 8, 1981. p. 1059-1076.
[118] Gazenko, O. G., A. M. Genin, and A. D. Egorov. Summary of Medical Investigations in the U.S.S.R. Manned Space Mission. Acta Astronautica 8, 1981, p. 907-917.
[119] Parfitt, A. M. Bone Effects of Space Flight: Analysis of Quantum Concept of Bone Remodelling. Acta Astronautica 8, 1981. p. 1083-1090.

plementation and the use of anti-G suits. Additionally, nutritional supplements, and the administration of drugs on an experimental basis have been attempted.[120]

The Soviets feel that these countermeasures have appreciable benefits.[121] However, there is no unanimity in the U.S. space science community that these are effective practices. Some researchers regard such countermeasures as only marginally effective or perhaps noneffective.[122] In the case of maintaining muscle tone and body mass, exercise does seem to have beneficial effects and warrants further investigation.[123]

BLOOD CHANGES

Blood chemistry analysis performed on cosmonauts after long-term space flights showed no significant changes. However, there is a continuous elevated level of 17-hydroxycorticoids. This is a normal manifestation found in mammals during stress. However, in addition to these observations, and perhaps as a consequence of elevated steroid levels, a decreased immune cellular capacity has been observed.[124] [125] [126] After returning to Earth, within several days, there is a reversal of this deficiency. However, it should be kept in mind that there may be a time during space flight that a fully competent immune system may be needed. The Soviets have reported observing significant changes in composition of the microbiological flora of the respiratory tract with intestinal organisms populating it.[127] This could present difficulties in long-term flights where rectal-oral contamination could lead to serious disease potentials.

PSYCHOLOGICAL PROBLEMS

The close confinement imposed by space limitation of the spacecraft, monotony and reduced social contacts all contribute to both physiological as well as potential psychological difficulties. The proximity of a limited number of people, away from familiar surroundings, over a long time span, under constant stress, may in the long run be the limiting factor of interplanetary travel.[128]

Even the selection of compatible individuals, as currently practiced by the Soviet space program, leads to both conflicts as well as euphoric states during a space flight.[129] An understanding of the

[120] Gazenko, O. G., et al. The 175-Day Space Flight: Some Results of Medical Research. Vestnik Akademii Nauk SSSR No. 9, 1980, p. 49-58.

[121] Ibid.

[122] Sandler, H. Effects of Bedrest and Weightlessness on the Heart. In Bourne, G. H., ed. Hearts and Heart-like organs. 2 Physiology. N.Y., Academic Press, 1980.

[123] Ibid.

[124] Kesnyak, A. I. and R. Yu. Tashpulatov. Effects of Space Flights on Lymphocyte Blast Transformation in Cosmonauts' Peripheral Blood. Kosmicheslaya Biologiya i Aviakosmicheskaya Meditsina 15 (1), 1981, p. 32-34.

[125] Taylor, G. R. and J. R. Dardano. Response of Shuttle Crew Lymphocytes to In Vitro Mitogenic Challenge. Abstract, Aerospace Medical Meeting, Houston, Tex., 1983.

[126] Hellman, A., et al. Potential Biohazards Associated with Depressed Cellular and Humoral Immunity. In Neubaum, R. E., ed. Naturally Occurring Immunosuppressive Factors and Their Relationships to Disease. CRC, 1977, p. 257-271.

[127] Zaloguyev, S. N., A. N. Viktorov and N. D. Startseva. Sanitary Micro-Biological and Epidemiological Aspects of Habitability. In Problems of Space Biology. Yu. G. Nefedov, ed. Moscow, Nanka Press, 1980, p. 75-137.

[128] Gurovskiy, N. N., F. P. Kosmalinskiy, and L. N. Mel'nikov. Designing the Living and Working Conditions of Cosmonauts, op. cit.

[129] Ibid.

functions of the mind is still very rudimentary. Extensive research will be required prior to coming to grips with these problem areas.

MOTION SICKNESS

Another medical problem, usually of a transitory nature, is space motion sickness. This is the only adverse effect, thus far noted, that has significantly impaired crew effectiveness during the first few days of a flight. Usually from 30 percent to 50 percent of a crew succumb to this condition. Although pharmacological measures have been attempted, they have met with only limited success. The cause of space motion sickness is not well defined. The sequences leading to its manifestation are not understood due to a lack of information as to sequence of biological stimuli that initiates the phenomena. Motion sickness over extended flights does not seem to be of serious consequence; however, if crew alertness is required during early stages of a flight (1-5 days), it could impair the success of that type of mission.[130]

The myriad of acute biological problems thus far encountered in space flight, for missions of less than one year, seem to be manageable. The success of missions beyond such a time frame at this stage of our knowledge is unknown.[131 132 133 134] Due to the infancy of space exploration, potential chronic or long term pathological consequences have as yet not been addressed or noted.

NUTRITION

DIET SELECTION

Both in the U.S. and U.S.S.R. programs, the quality and variety of food substances available during the earlier space missions have been improved substantially over the years. It became evident early in the space age that food and food selection is not only a requirement in order to maintain the space traveler's nutrient, fluid, and mineral balance, but that nutrition also contributes significantly to the psychological well-being of the space crew. The availability of rehydrated foods has made a major impact on the diversity of foods available to the crew. Beginning with Soyuz 9 (1970) the Soviets had both hot and cold water available aboard the spacecraft. Water is currently partially reconstituted from water condensed aboard the space station and the rest is brought from Earth.[135] This water is used for a variety of things, including the rehydration of foods. In view of the shortage of water, earlier flights were limited both as to types and quality of food available. However, the crews of the Salyut-6 had foods packaged in tubes, canned and dehydrated.[136]

At this time, the menu for the cosmonauts is designed so that individual taste is taken into consideration. A menu is prepared so that there is no repetition of a particular dish for at least 6

[130] Talbot, J. M. Research Opportunities in Space Motion Sickness. NASA 3616, 1983

[131] Levy, M. N., Research Opportunities in Cardiovascular Deconditioning, op. cit

[132] CERMA-CNES-CNRS Documents, 1983

[133] Bodde, T., The Body's Answer to Zero Gravity, op. cit

[134] Bones in Space. British Medicine Journal, May 31, 1980

[135] Salyut 4 Water Regeneration System. Pravda (U.S.S.R.), May 31, 1975, p. 3 (FRD 2445)

[136] Popov, I., Food and Nutrition for Long Missions in Space. Aviatsiya i Kosmonavtika No. 1 January 1981, p. 42-43

days.[137] It has been observed in several Salyut 6 flights that due to the stresses, there is a change in taste perception.[138] In order to improve the cosmonauts' acceptance of a balanced and relatively high caloric diet (3200 kcal), it has become necessary to add different spices suited to individual taste.[139] The diet must meet certain requirements so that adequate caloric and nutritional values are provided commensurate with the energy expended by the cosmonaut. Criteria have been established which dictate that the food should remain stable at 20–25 degrees C, and retain its quality of taste as well as being conveniently packaged and sized for easy manipulation.[140]

With the development of the Salyut orbital station, it became imperative that nutrition, as well as general living conditions be improved. This space station is equipped with a dining table, food heater, and hot and cold water and means of cleaning and sanitizing utensils and disposing of leftover.[141] To provide sufficient nutrients to compensate for the additional exercise requirement performed by the cosmonauts to counteract some of the physiological effect of weightlessness, the caloric consumption of cosmonauts aboard the Salyut station has been raised to 3200 kcal.[142]

The incorporation of newer dehydrated foods also permitted a reduction in space and weight requirements taken up by foods. Better than 20 percent of foods utilized in the Salyut station are dehydrated. However, Progress cargo craft, as well as Soyuz and Soyuz T transport ships, resupplied the Salyut 6 space station with dehydrated and canned food supplies as well as with fresh vegetables, milk and fruits.[143, 144] It has been observed that both a proper schedule of feeding as well as acceptable foods are very important for the maintenance by the cosmonauts of an optimum work capacity. The four meals that the crew partakes in per day are spaced 3 to 5 hours apart. Intervals of 15 to 20 minutes are provided, between exercise and the intake of food, and 1 to 1.5 hours between food intake and initiation of exercises.[145]

As seen in table 19, Soviet crews on long-term Salyut space missions (75 to 185 days) have, maintained a relative stable body weight distribution. During the fourth mission (185 days) the cosmonauts gained weight, a tribute, they claim, to the meticulous adherence to preventive measures including prescribed exercise, intake of vitamins twice daily, body rehydration prior to landing and the use of appetite stimulators such as onions, garlic and other sharp seasonings. Weight gain obviously indicates that the intake of food exceeded the energy expenditure. These data also suggest that strict regulations of nutritional intake during space flight is essential. These observations have convinced the Soviets to increase the use of a variety of dehydrated foods. The typical foods available to the cosmonaut during an average day in space is given in table 20.[146]

[137] Bychkov, V. P., et al. Diet of Crews of Three Main Expeditions Aboard Salyut 6 Orbital Station. Kosmicheskaya Biologiya i Aviakosmicheskama Meditsina, 15, 1980, p. 17–20.

[138] Ibid.

[139] Popov, I. Food and Nutrition for Long Missions in Space, op. cit.

[140] Ibid.

[141] Ibid.

[142] Ibid.

[143] Bychkov, V. P., A. S. Ushakov, S. Kalandarov, M. V. Markaryan, Ye. A. Sedova, A. K. Savuk and O. S. Khokhlova. Diet and Crew in Salyut 6 Orbital Station, op. cit.

[144] Nicogossian, A. E., et al., Space Physiology and Medicine op. cit.

[145] Ibid.

TABLE 19 DYNAMICS OF WEIGHT OF CREWS OF MAIN MISSIONS ABOARD SALYUT-6 STATION

Mission and crew member	Body mass			Change in body mass	
	Recommended	Pre flight	After landing	kg	Percent
First					
CDR	67 3	74 4	71.2	- 3 2	4 3
FLE	75 5	82 0	77 6	4 4	5.3
Second					
CDR	71 3	84 5	82 4	2 1	2 5
FLE	76 4	75 0	68 6	6 4	8 5
Third					
CDR	65 9	81 7	76 2	- 5 5	6 7
FLE	92 3	84 0	84 2	+ 2	.2
Fourth					
CDR	69 1	70 2	70 8	+ 6	9
FLE	82 3	86 5	90 0	+ 3.5	4 0
Fifth					
CDR	71 3	83 0	81 2	1 8	2 1
FLE	74 1	73 2	70 1	3 1	4 2

TABLE 20.- *Typical menu during average day in space*

Breakfast:	
pork with sweet pepper	40 gm
Russian cheese	100 gm
honey cake	45 gm
prunes	50 gm
coffee with sugar	24 gm
multivitamins lozenge	1 gm
Lunch:	
jellied beef tongue	100 gm
praline candies	50 gm
cherry juice	40 gm
Dinner:	
ham	100 gm
borsche with smoked foods	165 gm
tallin beef with mashed potatoes	52.5 gm
cookies with cheese	25 gm
apple juice	30 gm
multivitamins lozenge	1 gm
Supper:	
cottage cheese with nuts	50 gm
assorted meats	100 gm
wheat bread	30 gm
plum and cherry dessert	50 gm
tea and sugar	23 gm

Laboratory studies performed on blood serum, urine, and fecal disgestive enzyme levels, indicate that the stress of space flight does alter the levels of enzymes such as amylase, lipase, pancreatic enzymes and pepsinogen. Soviet studies suggest that variations observed in these enzyme levels as well as other parameters of digestive function can be well controlled during long term space flights by proper dietary combinations as well as by the physical conditioning.[147]

The Soviets consider nutrition as part and parcel of the overall preparation, execution and subsequent rehabilitation of the cosmonaut. The maintenance of an optimum metabolic and energy level

[146] Ibid

[147] Smirnov, K. V., G. D. Syrykh, V. I. Legen'kov, L. G. Goland-Ruvinova, I. L. Medkova, and L. I. Voronin. State of Digestive System Following Long-term Space Flights. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina, 16, No. 2, Mar.-Apr. 1982, p. 19-22.

prepares the cosmonaut both physiologically and psychologically. This also maintains the cosmonaut at a high work capacity even in the face of adverse flight conditions and appreciable stress.[148]

The Soviets, also control the pre-flight diet. This refers to all food intake within 24 hours of lift off. Cosmonauts are prohibited from eating any food not prepared in the flight kitchen. The meals are composed of food that is easily digested and not too large in quantity. The food provided has a low capacity for developing intestinal gas, and is composed of nutrients that do not have excessive bulk and lipid content.[149] The composition of the diet while in space has already been discussed. However, the Soviets also place great emphasis on diet after the cosmonauts return to Earth. In order to accelerate rehabilitation to gravity, the cosmonaut is provided with food and fluids consisting of fruits, berry juices, fresh vegetables, stewed and dried apricots, as well as meat such as liver, kidneys, dairy products and eggs The caloric value of the diet during the first 3 days after returning to Earth is increased gradually to preflight levels (approximately 3300 kcal).[150]

ONGOING RESEARCH

In summary, the Soviets consider nutrition as a significant part of a space mission. They feel, however, that many questions on this subject require additional investigation.[151] These include:

(1) Data to determine energy requirements of cosmonauts under space condition. Information will be provided by establishing an experimental laboratory in their oribtal station;

(2) Nutrition requirements during different phases of the space mission;

(3) Consideration of the cosmonauts individual metabolic rate at various stages of the mission;

(4) Modification of catabolic activity due to the space environment and concurrent stress by employing dietary and pharmaceutical supplements;

(5) Improvement in diets to improve long-term storage and acceptability;

(6) Further understanding of nutritional requirements both in preflight and post flight adaption; and

(7) The use of dietary substances for counteracting detrimental space conditions such as radiation, weightlessness, demineralization, and other encountered physiological difficulties.

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[148] Ibid

[149] Popov, I. G. Preflight Diet for Flight Personnel. Kosmicheskeya Meditsina 16, No 5, Sept-Oct 1982 p 1 and 7

[150] Bychkov V. P., S. Kalandarov, M. V. Markaryan, N. D. Radchenko, K. A. Stepchkov, and M. L. Frumkin. Diet of Crews of a Three Man Expedition Aboard Salyut-6 Orbital Station. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina 15, No 5 Sept-Oct 1981 p 17-20

[151] Bychkov V. P. Principles of Creating Food Links in the Life Support Systems for Crews of Spacecraft. Ed. Yu. G. Nefedov. Moscow, Navka Press, 1980 p 214-263. In Problems of Space Biology 42

LIFE SUPPORT

Basic Metabolic Requirements in Space

Space beyond the Earth environment is harsh, characterized by a fluctuation of severe temperatures and the absence of a significant atmosphere required to sustain human life. To enable man to survive this environment, a space capsule is necessary which contains the necessities of life. This capsule must provide the proper amount of oxygen required for normal respiration as well as a moderate temperature, between 64 degrees to 81 degrees C, the necessary foods and fluids and the capacity to dispose or recycle human generated waste products such as carbon dioxide, urine, feces, and body perspiration.

Soviet studies have ascertained that the average adult daily requires approximately 800 grams of oxygen, 700 grams of solid food with a total caloric value of 3000–3300 kilo calories, and 2500 grams of drinking water. If the subsequent bodily excretions are not recycled for the production of oxygen, food and water, a three-man crew on a 1-year mission would require 1.5 tons of food, 3.3 tons of bound oxygen, and 5.9 tons of water. This is equivalent to almost one-half the total weight of a space station such as Salyut 6.[152 153] In order to support life in outer space, the capsule environment and support systems must function properly 24-hours per day for the duration of the mission. The capsule environment must also be sufficiently comfortable to provide the psychological support systems necessary to maintain the mental well-being of the space crew for the duration of the mission.

Since this support system is the only link with Earth, it must contain all those human necessities available on Earth. These include protective equipment to prevent harm to the station from such factors as meteorites and radiation. The capsule must have facilities to serve both recreational as well as exercise functions. For long term space missions it must also provide a means for the regeneration of oxygen, drinking and housekeeping water and food. By the end of 1980, several missions approaching 185 days in space had been completed by the Soviet Union. In those instances, the maintenance of adequate environmental and nutritional supplies has been achieved by resupplying the Salyut space stations with these necessities using primarily "Progress" cargo ships. These efforts as well as the on-board systems have proven very functional. However, as longer and perhaps interstellar space missions are undertaken it will become necessary to develop systems that will be totally self-contained and capable of regenerating oxygen, water and food.[154]

Air Regeneration and Space Cabin Environment

An inherent problem in a sealed environment such as a space capsule is that the human contaminates the spacecraft by micromixtures of exhaled air, urine, intestinal gases, and perspiration. The magnitude of this contamination is, of course, all dependent on

[152] Bychkov, V. P., et al., Diet and Crew in Salyut-6 Orbital Station, op. cit.
[153] Popov, I. Food and Nutrition for Long Mission in Space, op. cit.
[154] Adamovich, B. A. Life Support in Space. Moscow, Zemlya I Vselennaya, No. 6, 1980, p. 20-25.

the temperature, humidity, concentration of c bon dioxide, mobility of the occupants and the character and types of foods consumed.

The waste products of people reaching the external environment via the intestinal tract, kidneys, skin and lungs are composed of more than 400 different chemicals.[155] The emission of volatile components of these waste products may contaminate the space capsule even in the presence of adequate storage areas. The major volatile mixtures generated by the crew from exhaled air, perspiration, urine and intestinal gases consists of the following: ammonia, methylamine, diethylamine, formaldehyde, acetone, methylethylketone, propinic aldehyde, carbon dioxide, formic, propionic, valeric, isovaleric, butyeric and lactic acide, methyl, isopropyl, and propyl alcohol, methane, ethane, propane, hexane as well as trace amounts of other organic compounds.[156] Without effective removal of these substances from the air of a sealed cabin, they could accumulate to toxic levels and thereby reduce the human capacity to work in that environment.

The Soviets employ a series of filtering media for the removal of waste gases and microparticulates. These include activated charcoal filters, high efficiency fiberglass filters and catalytic chemical absorbents.

They are also reported to be experimenting with a variety of techniques for maintaining a purified space cabin environment. Techniques under consideration for removal of carbon dioxide include molecular sieves, synthetic zeolites, as well as freezing of carbon dioxide out of the gas mixtures. A more detailed schematic depicting carbon dioxide removal techniques is shown in figure 48.[157]

[155] Veber, T. B. Man Under Water and in Space. Moscow, Voyenizdat Printed 1967.
[156] Ibid.
[157] Calvin, M. and O. G. Gazenko, eds. Foundations of Space Biology and Medicine, chapter 3 NASA Scientific Information Office Washington, D.C., 1975

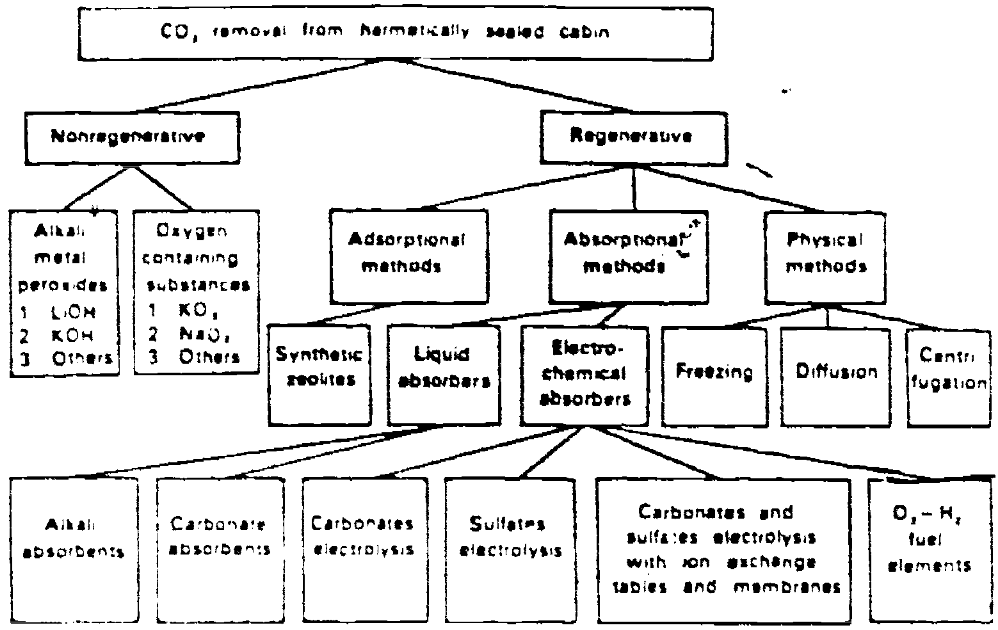

FIGURE 48.—Removal of Carbon Dioxide from Air of Closed System.

The microenvironment aboard the Soviet space station is maintained at values virtually identical to those encountered on Earth. Oxygen is generated by utilizing oxides and superoxides of alkali metals. The generated air in the working and living compartments is usually of a two-gases mixture, nitrogen and oxygen. The air's oxygen and carbon dioxide content is routinely monitored and regulated by means of a gas analyzer. On the Salyut 6 space station the microclimate was as follows: [158]

Total pressure, 700–830 mm Hg; oxygen partial pressure, 154–195 mm Hg; carbon pressure, 1.34–6.64 mm Hg; air temperature, 14.6–24.3 °C; and water vapor partial pressure, 5.37–17.1 mm Hg.

This contrasts appreciably both in the mode of generating oxygen and in the partial pressure of the gaseous environment employed in the Skylab space station.[159] The latter maintained a partial pressure of 5.0 psi of oxygen (70 percent oxygen, 30 percent nitrogen) supplied from liquid oxygen reservoirs. A regenerated molecular sieve was used to scrub out the carbon dioxide. The space cabin temperature was maintained between 21.2 degrees C and 26.8 degrees C with a relative humidity between 40 and 70 percent. During the more recent U.S. shuttle missions, respiratory gases were supplied at 14.7 psi, a partial pressure, identical to that found on Earth. The gas composition was 20 percent oxygen and 80 percent nitrogen. The carbon dioxide was removed by lithium hydroxide absorption.[160]

There are advantages to the chemical generation of oxygen. These include a reduced weight requirement to that necessary for carrying liquid oxygen. In addition, the Soviet system is much less

[158] Gurovskiy, N. N., et al. Designing the Living and Working Conditions of Cosmonauts. Moscow: Mashinostroyeniye, 1980, p. 1–168.
[159] Nicogossian, A. E., et al., Space Physiology and Medicine, op. cit.
[160] Ibid.

complicated and therefore less prone to malfunction and the influence by external factors, and provides for a less flammable environment. The disadvantage is that it lacks flexibility in altering the gaseous environment for experimental purposes and in emergencies. A schematic depicting the Soviet life support system is shown in figure 49.

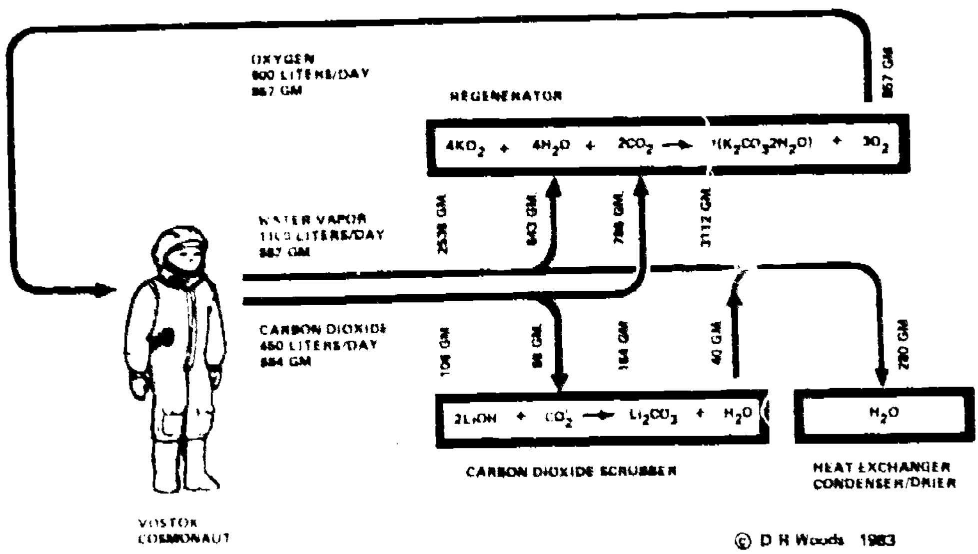

FIGURE 49 Cosmonaut Metabolic Balance. Soviet manned spacecraft rely on cartridges of potassium super oxide for an oxygen source, and lithium hydroxide to remove carbon dioxide. A heat exchanger condenses out excess moisture. This figure shows the metabolic balance for a Vostok cosmonaut for 1 day. Approximately 2.5 kg of regenerator yields about 600 liters of oxygen per day.

There is increasing evidence that under weightless conditions, a modification of proportions of gaseous mixtures differing from those found on Earth might be advantageous.[161 162 163] It has been observed that in a space capsule environment, due to weightlessness and hypokinesis, there is a decrease in oxygen uptake and carbon dioxide output. In addition, such other physiological parameters as basal metabolism, blood pressure, and heart stroke as well as the minute volume of the heart, nitrogen balance, muscle mass, plasma and erythrocyte volume are all decreased. Soviet studies have pointed toward the use of altered gas atmospheres to prevent or diminish the effect of deconditioning brought about by hypokinesis and zero gravity.

Additionally, Soviets suggest that the ability to regulate the gaseous atmosphere of a closed environment may effectively be utilized to maintain a high work efficiency with optimum energy expenditure. To these ends it is critical that the space cabin environment be optimum by eliminating toxic substances as well as by regulating on demand the gaseous environment in the capsule.[164]

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[161] Agadzhanyan, N. A. Optimum Atmosphere in Pressurized Cabins and Future Use Thereof. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina. Mar. Apr. 1981. p. 37-43.
[162] Ibid., Kosmisheskaya Biologiya. Nov. 5, 1969. p. 3-14.
[163] Genin, A. M. Problems of Space Biology. Nov. 3, 1964. p. 59-68.
[164] Ibid.

Water and Food Management

Metabolic activity of man requires the consumption of such necessities as water, oxygen and solid food. In turn, via bodily functions, he eliminates waste products in the form of urine, feces, carbon dioxide and other gaseous products. He also produces by perspiration and exhalation, organic waste and water vapor. These waste products must either be stored aboard the space capsule, jettisoned into space or recycled for subsequent consumption. The earlier Soviet spacecrafts, being in space for a short duration, primarily brought their water supply from Earth, and stored the waste products and brought them back to Earth. In view of the increased time spent in space and looking forward to even longer missions, it is becoming imperative that these waste products be recycled as efficiently as possible.

Currently, the U.S.S.R. recycles water vapor by condensing it on cooling coils. The condensate as well as water previously used for bathing is passed through ion exchange columns and then through activated charcoal filters, prior to being sterilized by heating. Minerals such as calcium, magnesium, bicarbonate, chloride and sulfate are added to this recycled water. The latter is then stored in water batching units for future use.[165] The water that is brought aboard the spacecraft from Earth is sterilized by a very old technique, ionic silver. This process is bacteriocidal, thereby being an effective sterilant. However, long term storage of water does alter its taste, therefore influencing its acceptability to the cosmonauts.

The Soviets reclaim oxygen from recycled water by electrolysis. Byproducts, such as methane gas, are jettisoned into space. Urine is collected in storage tanks, as is solid waste. When these tanks are filled, they are jettisoned into space.[166]

In summary, the problems associated with water storage for long term space flights prohibit sufficient quantities from being brought aboard the spacecraft at the time of launch. This therefore mandates the need for a system that can efficiently extract, purify, upgrade, and store water generated by respiration, perspiration and body waste.

Weight penalties and storage difficulties would be too great to use significant quantities of fresh foods, although the Soviets in their Salyut program do provide limited space for refrigeration.

Obviously, the use of dehydrated food requires an adequate water supply. The long term goal of the Soviet space program is the development of methods for growing a portion or all of their food supply aboard the space station. This presumably would also provide a means of carbon dioxide removal from the space cabin and the generation of a portion of the required oxygen.[167]

Waste Management and Personal Hygiene

Extended manned space flights impose special requirements on the general areas of waste management and particularly on per-

[165] Adamovich, B. A., Life Support in Space. Zemlya I Vselennaya, 6, Nov.-Dec. 1980. p. 20-25.
[166] Agadzhanyan, N. A., Optimum Atmosphere in Pressurized Cabins and Future Use Thereof, op. cit.
[167] Adamavoich, B. A., Life Support in Space, op. cit.

sonal hygiene. An adult male, as a byproduct of metabolism, produces 1.2 liters of liquid waste and 200 grams of solid waste per day. The earlier Soviet space missions of relative short duration (5 to 18 days) did not require any complex means of either recycling or otherwise disposing of waste. However, as space missions have increased in duration it has become necessary to either dispose of or recycle waste products. Regeneration systems processing fluid waste into potable water as well as recovering of oxygen from such byproducts are now practical and necessary.[168]

The use of solid waste for the production of food and water in closed ecological systems is under intensive investigation.[169] The Soviet publications suggest that waste products in general are still collected and ejected through air locks into space or placed aboard expendable Progress transports that on reentry into the upper atmosphere of Earth are incinerated.[170]

The communal hygiene of the spacecraft inhabitants must be given serious attention in view of the rather confined living quarters aboard a spacecraft. This is necessary not only to provide comfortable living conditions, but also to reduce the risk of transmission of pathogenic microorganisms amongst the inhabitants of the cabin. A high level of personal hygiene also is conducive towards establishing and maintaining a high degree of personal motivation. In order to establish acceptable levels of hygiene, recent Soviet Salyut 6 orbital stations have a shower aboard (see fig. 50).[171] This consists of an elastic cylinder with two capped ends, containing a mechanism for mixing and spraying hot water and hot air and for removing the expanded water vapors. During the earlier Salyut 6 missions, the cosmonauts showered about once a month and supplemented this by using washcloths impregnated with germicidal lotions as well as a deodorant.[172] In the more recent Salyut 6 missions, cosmonauts shower once every 10 days. This latter schedule obviously requires additional water supply.[173] In studies performed both aboard the Soviet orbital station as well as in sealed capsules maintained on Earth, the Soviets observed that there is a marked increase in microbial discharge by the occupants of microorganisms into the space capsule. It has been noted that under normal terrestrial conditions man expells approximately 110 microorganisms per hour from the upper respiratory tract. This discharge accumulates in an airtight space and the concentration becomes 10 times higher when one is confined in a closed environment. Similarly, the microbial flora of the skin is increased by 10 fold in an airtight environment, under reduced personal hygiene, restricted by a limited energy and water supply, as well as by the weight and dimensions restrictions posed by the space capsule.[174]

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[168] Ibid.
[169] Vasil'yev, G. In Order to Fly Infinitely Long. Aviatsiya i Kosmonavtika 10, 1979, p. 38-39.
[170] Adamovich, Life Support in Space, op. cit.
[171] Ibid
[172] Yu. G. Nefedov, and S. N. Zaloguyev, Current Status and Prospects of Hygienic Support of Manned Space Flights. Kosmicheskaya Biologiya i Aviakosmichoshaya Meditsina, Mar.-Apr. 1981, p. 30-37.
[173] Ibid
[174] Zaloguyev, S. N., V. V. Borshchenko, A. N. Viktorov, A. G. Prishchep, and G. A. Shumilina. Some of the Principles Involved in Sanitary and Housekeeping Arrangements in Spacecraft. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina 6, 1979 p. 14-17

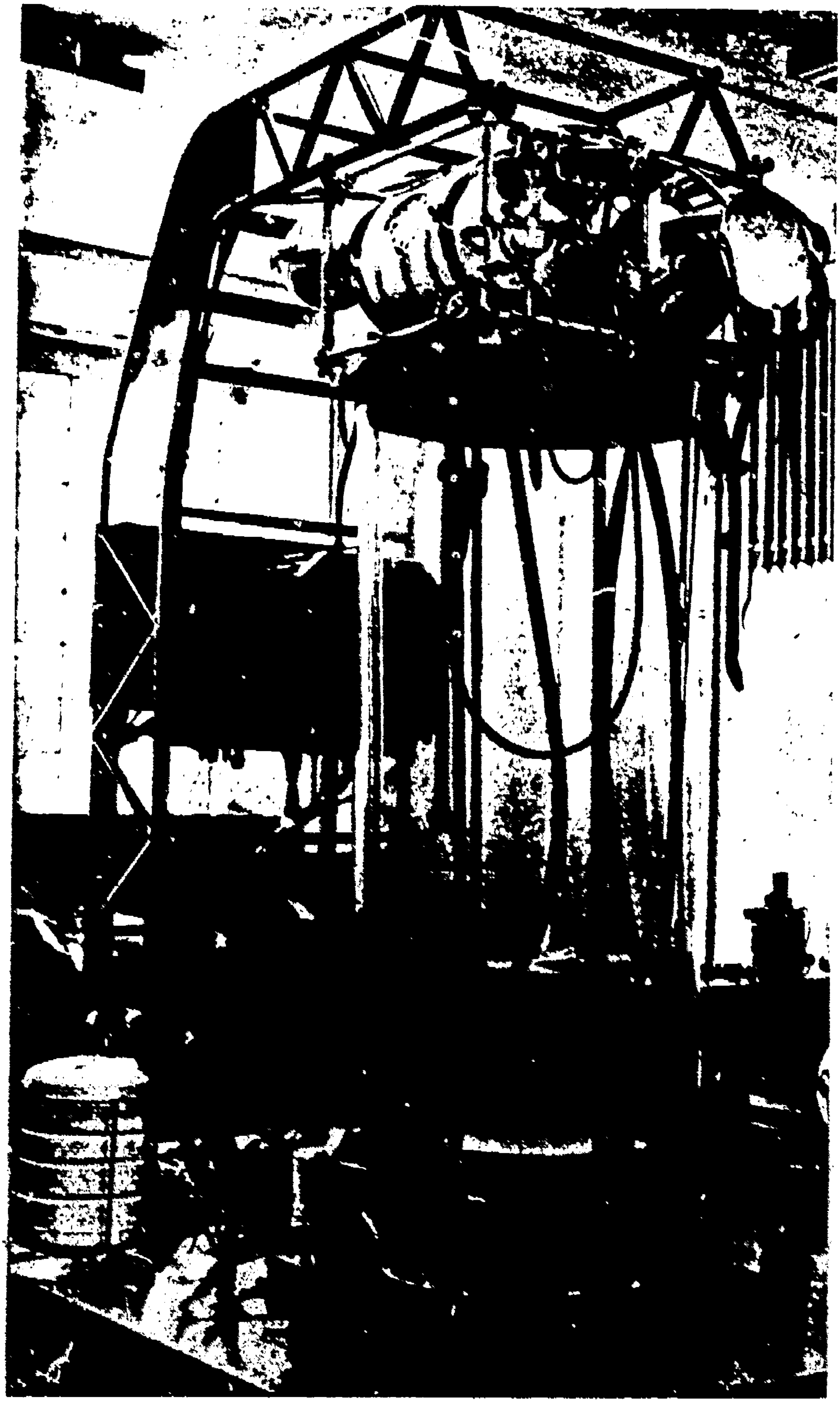

FIGURE 50 —Shower unit in the Salyut 6 station.

Current personal hygiene practices aboard the Salyut orbital stations include daily sponging with a moist washcloth of the hands, face and mouth. Underwear consisting of a knitted absorbent material is changed once per week. This is preceded by rubbing the skin with moistened and dry towels. The cosmonauts also use a damp washcloth to clean their hands prior to eating and after using toilet facilities. The area of the skin where electrodes had been applied for monitoring of vital functions are also cleansed in this manner. In all instances, a lotion containing antimicrobials is used to dampen the washcloths.[175] Soviets indicate that there occur an average accumulation on the face and hands of 99 mg of chlorides, 105 mg of ammonia and 0.7 mg of nitrites. It is reported that utilizing germicidal lotion did not adversely affect the crew's skin.[176]

Ground based studies by the Soviets have indicated that for long term missions, more novel techniques for cleansing the skin, particularly areas covered with hair, are necessary. The use of showers certainly enhances personal hygiene. However, products must be developed that have sufficient detergent properties to remove lipid accumulation on the skin. These must have selective bacteriocidal properties to maintain relatively normal skin function and microbial flora. Once more, because of the requirement to recycle expended water for subsequent topical and internal consumption, it is mandatory that the detergent and antimicrobial agents be readily removed by the recycling process.[177]

Other components of a comprehensive personal hygiene program consist of the use of tooth brushes with low foaming toothpaste, as well as the use of chewing gum after meals. Shaving as well as hair grooming are accomplished by conventional means, except that hair and shed cornified epidermal cells are removed by a vacuum system.[178]

Communal hygiene aboard the space station must provide conditions that are comfortable and safe in regards to the microclimate, the respiratory gas composition, illumination, vibration levels as well as the microparticulate composition within the space capsule. The microparticulate composition is the summation of the individual's metabolic process as well as the caloric composition of the consumed food. Penetration of microparticulates into the respiratory tract and particularly of potential pathogenic microorganisms may prove to be significantly different under the influence of zero gravity. This factor must be kept in mind when considering the space cabin environment and crew contamination.[179]

The requirement for a comprehensive and effective hygienic program in space is also critical from an aesthetic point of view. The space travellers are confined in a rather small space, thereby being in close proximity to each other, usually over extended time periods. More significantly, from a risk point of view, individuals do shed microorganisms both from their orifices as well as their skin.

175 Ibid.
176 Yu. G. Nefedov, ed. Problems of Space Biology. Sanitary, Hygienic and Physiological Aspects of Habitable Spacecraft. Moscow, Nauka Press, 1980.
177 Yu. G. Nefedov. Current Status and Prospects of Hygienic Support of Manned Space Flights. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina. p. 30-37, Mar. 1981.
178 Ibid.
179 Ibid.

As Soviet studies have indicated, there is a transfer of microorganisms from one individual to another, particularly in confined space. Some of the organisms have even shown a modification of their antibiotic sensitivity.[180] In the absence of adequate hygienic protocols, potentials for cross infections are enhanced.

Space Suits and Clothing

During the past 18 years, both Soviet cosmonauts and American astronauts have performed space walks [extravehicular activity (EVA)]. In order to survive the adverse environment of space, the space suits (EVA suit) must supply the life support found in the spaceship. The current EVA suits are designed so that they are capable of supporting EVA for up to 5 hours.[181] See figure 51.

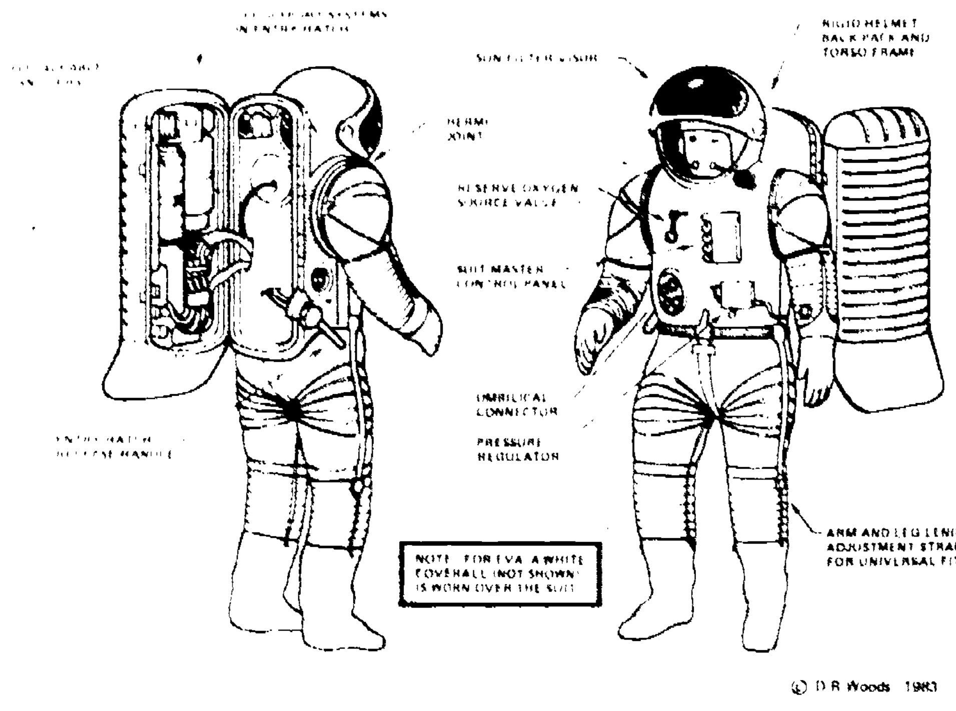

FIGURE 51. Soviet EVA Semi-Rigid Space Suit. Soviet cosmonauts use a rather unique space suit for EVA missions on the Salyut space station. The torso and helmet are a single, rigid unit. The back is an entry hatch, fitted with removable canisters, for the oxygen source. Adjustment straps on the arms and legs make it possible to fit the suit to any crew member.

The Soviet EVA suit has evolved over the years to its present configuration. It consists of a metal helmet and plastic visor with sleeves and trouser legs made of a flexible material, suitable for quick donning. The EVA suit contains all life support systems, in duplicated form for greater safety and dependability. These newer suits are twice as light as the earlier one worn by Leonov. The Soviets claim that the gloves permit sufficient finger dexterity for

[180] Yu. G. Nefedov, ed., Problems of Space Biology, op. cit.
[181] Feoktistov, K. P. Moscow Novoye v zhizni, Nauke Teknilse, Seriya, Kosmonavtika, Astronomiya (doctoral thesis). 1980. p. 1-63.

winding a watch or picking up a needle.[182] The space suit has a recycling system for absorbing carbon dioxide. The cosmonauts have a high degree of confidence in their EVA equipment, as exemplified in 1979, when a radio telescope antenna jammed during the jettison procedure and was corrected by employing EVA.[183] Current information suggests that one size EVA suit fits all sizes of cosmonauts.[184] The arms and legs are made of flexible material, specifically designed to be adjusted to meet individual needs. The gloves are screwed into the space suit to meet individual fit and to permit the exacting use of the hands and fingers. As part of the space suit, the cosmonauts wear a harness which has incorporated medical monitoring equipment capable of telemetering back to Earth EKG data as well as pulse and respiratory rate. Under the EVA suit, the cosmonaut wears coveralls that carry water lines, permitting individual temperature regulation of the EVA suit. Power may be supplied to the EVA suit from the spaceship via an electrical line, however, it can also operate autonomously from the spaceship. The cosmonaut is connected to the surface of the spaceship by a safety line.[185 186]

During routine space platform operations, the cosmonauts wear conventional flight garments. In earlier missions, the cosmonauts, for hygienic reasons, changed their undergarments at regular intervals and discarded the soiled clothing. Because of longer space missions, this practice is no longer practrical, therefore, undergarments are cleaned and reused.

Still other garments are worn as countermeasures to weightlessness. These include the Penguin suit, a special garment which produces passive resistance to the musculature. To counteract the risk of muscle atrophy, the suit is worn during the entire working day in space. The Penguin suit partially compensates for the absence of gravity by offering a constant artificial gravitational load to the musculature of the legs and torso.[187]

During various phases of the Salyut mission, and as a prophylactic measure to the deconditioning of the cardiovascular system, the Soviets also utilize a lower body negative pressure suit (LBNP).

As experimental results dictate, a variety of other apparel, that may enhance man's survivability and comfort in space, will become integral components of the garments worn during space flights.[188]

Response to Emergency Situations

An emergency in space may be categorized as an equipment emergency or a medical emergency. Obviously an equipment emergency may rapidly evolve into a medical emergency.

The majority of systems found in the spaceship that permit man to survive in space have emergency backup systems (redundancy). Associated with and separate from these life support systems in the EVA suit, which contains its own oxygen, temperature, and pres-

[182] Paris Air and Cosmos, June 28, 1980, p. 44
[183] Ibid., p. 44
[184] Pokrovskiy, A. Comments on Salvut-7 Cosmonauts EVA. Pravda, July 31, 1982
[185] Ibid.
[186] Paris air and Cosmos. June 28, 1980, p. 44
[187] Yegorov, A. D. Results of Medical Research During the 175-Day Flight of the Third Prime Crew on the Salyut 6-Soyuz Orbital Complex (NASA TM 76450), Jan. 1981.
[188] Paris Air Cosmos, 1980, op. cit.

sure system. This permits, in an emergency, the EVA suit to maintain a microspace cabin environment for up to 5 hours. In the event of equipment failure, this is sufficient time for the crew to return to Earth. In addition, the Soyuz descent module can separate from its work module. The descent module then serves as an emergency vehicle in the event of power failure occurring during the early launch phase. The module contains a variety of emergency equipment, including food, water, clothing and other survival gear for either land or water ditching. The Soviets have described an emergency reentry capsule for their Salyut space station.[189] When constructed, it will have the capability of returning safely three people and maintaining a closed life support system for up to 24 hours. It will be capable of surviving either land or water touchdowns. Whether such an emergency vehicle has in fact been developed and deployed is not certain at this time.

In addition to the redundancy built into the spaceship system, much of the equipment can be repaired by the cosmonauts. Some of the equipment is functional even at less than optimum capacity, so that if malfunctions occur in a support system, it can still provide the environmental controls to effectively sustain life. The spaceship or station is equipped with sensing devices that detect potential emergency situations in order to give the cosmonauts time for remedial action. Such actions may include the repair of the malfunction, modification of the system, as well as the donning of garments and equipment to protect the cosmonaut from potential hazardous environments. Unfortunately these sensing devices did not prevent disaster in the Soyuz 11 return to Earth.

The personnel transport ships (Soyuz and Soyuz T) which are utilized by the Soviets to at times resupply the Salyut stations as well as to change crews can act as an emergency vehicle in the event of space station emergencies. They contain food, water, and clothing supplies, as well as medical and electronic equipment to broadcast their location to rescue personnel. Survival equipment such as fishing gear, [illegible]es and other equipment necessary for emergency survival is aboard. However, a critical point worth mentioning is the physical condition of the cosmonaut upon returning to Earth. The cosmonauts are required to readapt to terrestrial conditions after long space missions. Therefore, much of the emergency equipment found aboard the Soyuz may be of little use due to the inability of the cosmonauts to maintain orthostatic stability and the frequently observed muscle atrophy. Even during routine landings, recovery teams are necessary to assist the crew out of the space capsule. It is therefore imperative that emergency rescue vehicles and personnel be rapidly deployed to extricate returning cosmonauts from returning vehicles.

Medical emergencies in space can be of two types, those that are treatable aboard the spaceship and those that require expeditious return to Earth. Those that can be handled aboard the spaceship consist primarily of minor emergencies, as, for example, lacerations, pain and minor infections. Cosmonauts are trained to handle

[189] Belonogov Ye. K., S. A. Ivarovskiy, V. K. Grigorovich, A. Yu. Zatsepin, V. V. Ignat'Yev, V. A. Sokolov, V. N. Tarasov, and V. Ye. Minenko. System for Emergency Rescue of Cosmonauts from Orbital Stations. Moscow, 1978. p. 101-108.

these situations. Adequate medication is aboard the spaceship to handle such conditions.

Serious medical complications may require on-board action. A discussion of this can be found under "Medication and Emergency Drugs." In the event treatment aboard is not feasible, the individual would have to be brought back to Earth. Both Soviet and United States investigators are actively studying and developing equipment and protocols for the handling of complicated space medical emergencies.

Any emergency situation aboard a spacecraft has profound psychological effects on the crew. Consequently, scenarios have been developed and countermeasure practiced prior to going into space. It is important that cosmonauts can respond with rapidity and confidence to all emergencies.[190]

FUTURE SYSTEMS AND TRENDS

Space missions for up to 1 year in duration should contain a life support system that has the capacity to regenerate water from atmospheric moisture and human liquid waste.[191] Missions for up to 2 years also require that the life support system has the capacity to generate oxygen from carbon dioxide and waste water.[192] However, if flights are planned to last over 2 years, a closed controlled ecological life support system is a virtual requirement, particularly if the mission's task is to explore other planets.[193]

The goal of the Soviet Union is to develop a closed ecological system which could sustain life in space for an indefinite period.[194] This system would most likely utilize some form of plant life that could efficiently utilize human waste as nutrients to replicate itself and in the process produce a balanced diet for man. Oxygen would be the by-product of plant photosynthesis. In the process of photosynthesis, carbon dioxide would be utilized by the plant, thereby removing this product of human metabolism from the space capsule environment. Another by-product of such synthesis would be the production of potable water. A schematic of the Soviet concept of such a system is shown in figure 52.[195]

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[190] Fefelov, N. Contingency Situations Aboard a Spacecraft. Aviatsiya i Kosmonavtika, 5, 1976, p. 10-11.

[191] Jones, W. L. Life-Support Systems for Interplanetary Spacecraft and Space Station for Long Term Use. In Found of Space Biology and Medicine Ch. 9, 1975, p. 247-273.

[192] Ibid.

[193] Ibid.

[194] Adamovich, B. A., Life Support in Space, op. cit.

[195] Ibid.

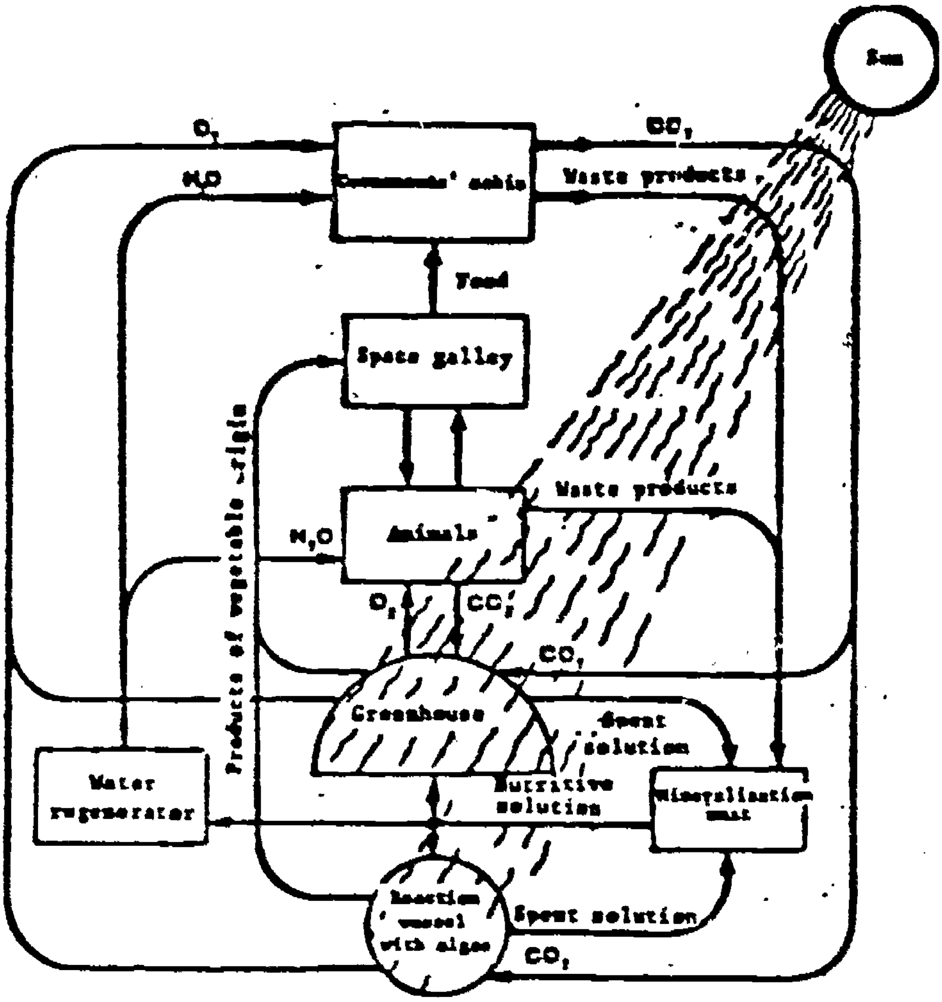

FIGURE 52.—Schematic diagram of closed, ecological life support system.

Ideally, a closed ecological system would be of minimal size and weight. Since the substrate utilized by planets would most likely be composed of human waste, great care will be necessary to control the various contaminants introduced in such a system. Previous studies on Earth both in the United States and the Soviet Union have employed algae as the organism to grow on the waste substrates. In this process the organism replicates and produces oxygen as well as consuming carbon dioxide. Unfortunately, numerous difficulties have been encountered. In order to produce food products more acceptable for human consumption, the Soviets have more recently attempted to select plants that could effectively grow on human waste and still be acceptable for subsequent human consumption.[196]

A multitude of problems can be envisioned in the development of a closed environmental system. First, one must consider the sub-

[196] Shepelev Ye. Ya. Biological Life-Support Systems. In Foundation of Space Biology op. cit.

strate used for propagation of the organism to be used for food, carbon dioxide conversion and oxygen synthesis. Since the substrate primarily will consist of human waste in the form of feces and urine, methods will have to be developed for the degradation of the substrate into a suitable composition. This will require that it be solubilized, decontaminated, and toxic substances removed. Techniques will be required that will prevent subsequent microbiological contamination. Conditions must be such that no mutations occur to the organism being grown for food. The substrate must be of a stable composition so that the organism can efficiently produce the by-products, i.e., oxygen and edible food substances. In addition, even when these conditions are met, it will be necessary that the products are acceptable, edible and nutritious. It is also critical that the ecological system functions optimally in removing toxic substances such as carbon dioxide and that sufficient oxygen is produced to sustain life aboard the spacecraft.

Even though the Soviets have been successful in sustaining human life in closed ecological systems operating on Earth,[197] the required volume and weight to accomplish this feat would most likely negate its use in space. In addition, with the more recent findings of psychological stress of long term space flights, the superimposition of food products that do not offer much variety and leave much to be desired as to taste, makes this a long term and difficult problem to resolve. However, with the development of genetic engineering technology, it is within scientific probability that biological systems can be constructed that have the desirable characteristics needed for functioning in a closed ecological system.

Space greenhouses have been developed and sent into space in order to develop a partial life-support system. The Soviets have devoted significant research efforts to accomplish this task. A more detailed discussion on this subject will follow in the section dealing with the Kosmos biosatellite program.

NEGATIVE AND POSITIVE GRAVITATIONAL FORCES

Basic Concepts

From a physiological point of view, it is now well recognized that weightlessness is not merely the reduction or removal of weight on the body. Rather, zero gravity brings about a number of physiological responses to which man must adapt. The various symptoms that become evident after initial exposure to weightlessness have been discussed in some detail previously. Briefly they consist of body fluid, particularly blood redistribution to the upper part of the body, i.e., head and chest, accompanied by nasal congestion, facial puffiness and headaches. At times it is also associated with disorientation, space motion sickness, and loss of appetite. On the opposite scale, the cosmonaut is also subjected to gravitational forces substantially higher than those normally experienced on Earth. These times of elevated G forces occur primarily during lift-off and reentry.

[197] Gitelson, I. I. Life Support Systems. Internal Control Based on Photosynthesis of High and Unicellular Plants. 24th IAF Congress, Krasnoyarsk, U.S.S.R., 1973, p. 34

The superimposition and possible synergistic effects of gravitational stress during reentry on the consequences of deconditioning of the cardiovascular, skeletal, muscular, hematological and immunological systems require additional investigation. Unfortunately, the conditions responsible for these physiological phenomena occurring in space are difficult to reproduce and evaluate on Earth.

Simulation of Positive and Negative Gravity

In order to study the influence of the various gravitional gradiations that a cosmonaut encounters from the time of lift-off to his return to Earth, a variety of experimental protocols and equipment have been developed. These permit the reproduction of some of the physiological responses observed during positive and negative gravitational stress experienced during spaceflights. Bed rest, among other means, has been used to simulate zero gravity and the associated hypokinetic effects. Since it became evident that zero gravity causes such physiological phenomena as cardiovascular deconditioning, bone demineralization, muscle atrophy and shifts in fluid and electrolyte balance, both the United States and the Soviet Union have devoted considerable monies and expertise in duplicating these effects on Earth. Simulation of zero gravity on Earth can, in part, be accomplished by inducing both hypokinesis and hypodynamic conditions. Therefore, researchers have devoted significant time on mammals in evaluating the effect of immobilizing, restraining, denervating as well as other means of decreasing mobility and motor functions. These studies all have been done in order to simulate certain conditions encountered in space, due to zero gravity. Even though it is well recognized that these simulations do not parallel zero gravity, hypokinetic studies do produce physiological conditions somewhat similar to those encountered under actual weightlessness. A recent compendium of over 700 pages developed by NASA covers the literature encompassing these studies through 1980. This reference is included both to demonstrate the extraordinary amount of effort that has been devoted to this problem and to provide the reader with the opportunity to review and evaluate this major research area.[198]

As has been mentioned in the section dealing with selection and training of cosmonauts, water immersion, utilizing a simulator Salyut space station submerged in a large pool of water, is a routine Soviet training procedure. This technique, as well as bed rest, particularly with a head down tilt at between 4 and 12 degrees, is used by the Soviets to simulate weightlessness.[199]

Significant differences between these experimental ground based simulations and true weightlessness do exist. In particular the distribution of pulmonary blood, body fluids, gas volume and flow are still subject to gravitational influences during both bed rest and water immersion. One must also take into consideration some of the organ systems that are influenced by zero gravity. For exam-

[198] Pleasant, L. G., P. F. Axelrod. A Compendium of Hypokinetic and Hypodynamic Animal Studies. NASA 3365, 1980. p. 370.

[199] Kakurin, L. I., V. I. Lobachik, M. Mikharlov, Y. A. Senkevich. Antiorthostatic Hypokinesis as a Method of Weightlessness Simulation. Aviat. Space Environ. Medicine 47, 1976. p. 1085-1086.

ple, the lung has very little supportive structure and the pulmonary vascular bed is very responsive to pressure differences. Therefore, they react to both the experimental condition on Earth as well as the gravity encountered in ground based experiments. Additionally, the differences in density of respiratory gases and blood make these highly susceptible both to direction and magnitude of flow.

Short intervals of a true weightless state can be achieved by flying an aircraft through a parabolic trajectory. Unfortunately, only certain sensory effects can be experienced during this maneuver, because the weightless state is obtained for rather short intervals (30 to 40 seconds). This therefore does not provide the time necessary to experience the myriad of physiological changes encountered during exposure to longer spans of zero gravity.

Simulation of Reentry Gravity

Even though both the Soviet Union and the United States have expended considerable research efforts in simulating zero gravity on Earth, none of these studies can replicate the conditions and body responses encountered at zero gravity. On the other hand, in the areas of positive gravitational forces, experimental conditions and protocols have significantly contributed to an understanding of the physiological responses obtained. By utilizing both high performance aircraft, human centrifuges and rapid deceleration equipment, massive amounts of data have accumulated on the response of man to gravitational forces greater than those normally experienced on Earth.[200] This information has led to the development of effective countermeasures. In addition, the development and application of such hardware as antigravity suits, harnesses and restraining devices all have been very helpful in preventing serious adverse physiological effects. This equipment has also considerably extended man's capacity to withstand high gravitational forces. Information gained from this research pointed toward means of positioning the body in reference to the gravitational force, so that it can tolerate even higher forces. It has been observed that the body can withstand transverse (front to back) gravitational forces much more readily than longitudinal forces (head to toe).[201]

Thus far, no adverse effects have been noted from the positive G forces encountered on reentry after long space missions.[202] Nevertheless, there is the potential for adverse effects to the cardiovascular and the skeletal system. In the case of the skeletal system, this is because of the continued problems posed by bone demineralization. This process is not well understood, and up to this time no demineralization plateau has been reached. Demineralization seems to progress for the duration of the space flight. Potentially the skeletal system could become sufficiently weakened to suffer fractures when subjected to positive gravitational forces during reentry or when stressed immediately at touchdown. Similarly, the magnitude of deconditioning of the cardiovascular systems could

[200] Nicogossian, A. E., et al., Space Physiology and Medicine, op. cit.
[201] Ibid.
[202] Ducrocq, A. The Terrible Return. Air et Cosmos, Dec. 18, 1982, p. 52-53.

pose a problem when this system is subjected to the stresses of excessive gravitational forces on reentry.[203]

The problems encountered by the human body when placed under a weightless state has spurred the interest of scientists in both the Soviet Union and the United States. Significant information has accumulated with regard to the effects of zero gravity on the well being of man in space. The Soviet Union has conducted extensive biological experimentation in its Kosmos series as well as its manned orbital studies on these problems and the countermeasures necessary during the various transitional and adaptive states of weightlessness.

Biochemical and Immune Responses

In addition to the physiological responses already discussed, there are other responses during space flights that warrant mentioning. Among these are the observed reduction in red blood cells numbers and mass as well as reduction in hemoglobin.[204, 205] Reductions of up to 21 percent in red blood cell (R.B.C.) mass, 26 to 50 percent in red blood cell number from 12 to 33 percent of hemoglobin and a 4 to 16 percent in plasma volume have been noted. R.B.C. and hemoglobin mass were restored to normal preflight levels within 45 to 67 days after return to Earth. Changes in these parameters were not significantly different after long or short duration space flights. The changes in R.B.C. and hemoglobin are most likely due to the increased oxygen tension and/or the decrease in oxygen requirement due to decreased muscular activity brought on by zero gravity. On returning to Earth, there is a rapid return to normal and even above normal (40 to 50 percent) R.B.C. In spite of the dramatic fluctuations observed in R.B.C. number during the course of the Soviet 175 day mission, R.B.C.'s synthesized while the cosmonauts were in space (R.B.C. turnover is approximately 120 days) functioned normally.[206]

The Soviets have also reported on changes in the cosmonauts immune system brought about by zero gravity, including a reduced lysozyme level.[207] Lysozyme is found in saliva and plasma and is thought to have bacteriocidal properties. The Soviets have reported an appreciable increase in both complement and immunglobulins. This suggests that some immunological reactions are occurring in space. The increase in globulin levels has been attributed to an elevation in autoantibody production against degradation products of skeletal muscle, due to atrophy of the latter. These observations could lead to serious consequences at a later time. Once the body recognizes its own tissue and produces antibodies against it, there is the possibility of a reoccurrence. Antibodies being produced could react against normal body tissue and lead to pathological conditions. An example of this is found in Lupus erythematosis, a

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[203] Levy, M. N., et al., Research Opportunities in Cardiovascular Deconditioning, op. cit.

[204] Kimzey, S.L. and C.P. Johnson, Hematological and Immunological Studies. In: Apollo-Soyuz Test Project, Medical Report, NASA SP 411, 1977, p. 101-115.

[205] Balkhovskiy, I.S., R.K. Kiselev, M.A. Kaplan and M.G. Sereda. Changes in Total Body Potassium, Hemoglobin and Bromine in the Crew of Soyuz 14. Space Biology Aerospace Medicine 12 (3), 1978, p. 11-16.

[206] Yegorov, A.D., Results of Medical Studies During Long-term Manned Salyut-6 and Soyuz Complex, op. cit.

[207] Gazenko, O.G., N.N. Gurovskii, et al. Preliminary Medical Results of Salyut 6 Manned Missions. XXX I.A.F. Congress, Sept. 1979, p. 16-22.

disease of unknown etiology, but due to autoantibody production.[208 209 210]

The number of circulating leucocytes has been reported to be depressed during some missions and not changed during others. However, as previously mentioned under the section of biomedical findings, lymphocyte function has routinely been observed to be significantly depressed.[211] Even though the abnormalities observed all seem to return to normal preflight levels, the possible consequence to the cosmonauts and astronauts in later years are yet to be determined.

BASIC HUMAN'S ANIMAL PHYSIOLOGY

A summary of the various human and animal physiological responses experienced at zero gravity is presented in table 21.[212]

Even though this table was compiled in 1975, the major difficulties detailed at that time still plague space crews today.

[208] Guseva, Ye. V. and R. Yu. Tashpulatov. Effect of Flight Differing in Duration of Protein Composition of Cosmonaut Blood. Space Biol. Aerospace Medicine 14, 1980, p. 15-20.

[209] Decker, J.L., et al. Systemic Lupus Erythematosis: Evolving Concepts. Am. Int. Med. 91, 1979, p. 587-604.

[210] Roffler, D., et al. Systemic Lupus Erythematosis: Prototype of Immune Complex Nephritis in Man. J. Exp. Med., 1971, 174, p. 169.

[211] Yegorov, A. D. Results of Medical Studies during Long-term Manned Salyut-6 and Soyuz Complex. NASA TM 76104, 1979, p. 173-195.

[212] Berry (1973) as cited by Pestov, I. D. Weightlessness. In Foundations of Space Biology and Medicine 2, 1975, p. 305-354.

1979, p. 587-604.

TABLE 21. Reactions of man and animals to effects of weightlessness.

Reactions	Conditions and objects of observations [1]	Notes
1	2	
Sensations of an unsupported position, floating, falling, spinning, turning, flow of blood to head, deterioration of orientation in space, predominance of visual information role in evaluating position of body in space	Man (TW, KP, SF)...	Emotional coloring of sensations (fear, joy, etc.) depends on experience and training of subjects, in orbital flight-adaptation
Displacement of successive visual image during G-forces—downward (oculogravic illusion) and upward during weightlessness (oculoagravic illusion); illusions are characteristic of initial periods in weightlessness	Man (KP, SF)........	Actual position of visual targets during G-forces—above the successive image and below it during weightlessness; with gaze fixed on a target, the successive image coincides with it
Slowing down of speed and accuracy of movements; errors in trying to hit center of target (deviation of hits upward)	Man (KP, SF)........	Only in initial phase of SF, then adaptation
Deterioration of ability to carry out measured muscular efforts and evaluate differences in mass of subjects not fastened down	Man (KP)........	
Pulse frequency: slowing of normalization following action of G-forces; subsequent tendency toward slowing, increase in variability (possible arrhythmias of the [illegible] type); in final stage of long SF, slight increase	Man, animals (SF)...	With PBR following initial decrease in frequency of pulse, increase in frequency (lack of training)
Arterial pressure: moderate decrease, followed by stabilization, tendency toward decrease in pulse pressure	Man (SF)........	In PBR, initial decrease followed by increase (sympathetic effect)
Heart: decrease in size (according to data from x-ray studies); symptoms of decrease in the contractile ability (according to electrocardiographic and [illegible] data and results of phase analysis of cardiac cycle)	Man (SF, R)........	Descriptions of cases of increased mechanical activity of heart during flight
Bone tissue: demineralization (according to the data from x-ray photometry) due to loss of Ca	Man, animals (R)....	No changes observed when using method of photon absorption
Muscles: decrease in volume and strength........	Man, animals (SF, R).	Primarily atrophy of antigravitational musculature
Dehydration (decrease in plasma volume, followed by loss of intracellular fluid)	Man, animals (R)....	Decrease in plasma volume develops on 1st or 2nd (Henry-Gauer reflex), recovery possible later
Decrease in weight (mass) of the body by 2–5% of original value	Man, animals (R)....	Stay on moon in individual cases decreased body weight loss; following flight, weight rapidly returned to normal (exception, 18-d flight of Soyuz-9)
Protein metabolism: increase in blood urea content, increased excretion of creatinine with urine, negative nitrogen balance	Man, animals (SF, R).	Similar changes in PBR
Lipid metabolism: increase in the cholesterol, lecithin, and unesterified fatty acid content of blood	Man, animals (SF, R).	Changes not constant, depending also on nature of diet
Decrease in excretion of Na-, Cl-, K- electrolytes with urine	Man, animals (R)....	Related to previous losses of electrolytes during weightlessness
Reduced excretion of 17 oxycorticosteroids in flight; increase in excretion following flight	Man (SF, R)........	Similar relationship in experiments with simulation of weightlessness
Increase in concentration of antidiuretic hormone, aldosterone and renin	Man (R)........	Increase in aldosterone also noticed in SF
Blood: neutrophilic leukocytosis, lymphopenia or lymphocytosis, eosinopenia, increase in [illegible]; changes in coagulatory and anticoagulatory systems of blood; thrombocytes—decrease or absence of changes	Man, animals (SF, R).	Similar changes in experiments with PBR
Delay in excretion of water from organism in test with waterload	Man (R)........	Not noticed after 18-d flight of Soyuz-9
Deterioration of tolerance to transverse G-forces during launch	Man (SF)........	Not on all flights
Sensation of heaviness of body, rapid fatigue, difficulty in walking, muscular pains	Man (R)........	Primarily after long-duration flights without preventive measures
Changes in postural, oculomotor reflexes and behavior	Animals (TW, KP)...	Changes less in delabyrinthized animals than in normals
Decrease in oculomotor activity, asymmetry of nystagmoid movements	Man (SF)........	
Development of pain during movement or individual symptoms of [illegible] (dizziness, discomfort in stomach, nausea, vomiting)	Man (KP, SF)......	Participation of both vestibular and extralabyrinthic mechanisms suggested, as well as change in interaction of afferent systems
Frequency of respiration and pulmonary ventilation: increase during flight along the KP; various changes in SF; increase in post-flight period	Man (KP, SF, R).....	Changes in flight depend on previous action of G-forces or nature of the work
Gas exchange: increase during flight along a KP; decrease (according to data from analysis of regenerative substance) during the SF; increase during post-flight period	Man (KP, SF, R)....	Based on an analysis of samples of expired air, collected during the SF, both a decrease and an increase were noted; decrease in the PBR
Decrease in food consumption........	MAN (SF)........	Not observed on all flights; characteristic of PBR
Orthostatic instability........	Man (R)........	Develops also under conditions of terrestrial experiments involving simulation of weightlessness
Decrease in physical working capacity........	Man (R)........	Consequence of hypodynamia
Decreased immunity........	Man, animals (R)...	Increased danger of infectious diseases during and after flight
Increase in recovery period on long compared with short flights	Man (R)........	Improved living conditions and preventive measures shorten recovery period

[1] TW—tower of weightlessness, KP—Keplerian parabola, SF—space flight, R—readaptation period, PBR—prolonged bed rest.

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Motion Sickness Theory and Research

The environment of outer space and the absence of gravity have caused numerous adverse biomedical effects. It is important to point out, though, that none of the biological encountered abnormalities have required aborting any space mission.

Nevertheless, space motion sickness (SMS) has been and still is one of the adverse effects that seems to be both transitory and highly arbitrary in whom it affects. It has significantly impaired the effectiveness of some cosmonauts, principally during the early portion of a space flight. Approximately 50 percent of the cosmonauts and astronauts succumb to SMS to one degree or another. These manifestations have ranged from mild nausea to severe nausea and vomiting.[213] The Soviets were the first to report vestibular disturbances in the flight of Vostok 2. Subsequent to this, both American astronauts and Soviet cosmonauts have reported various degrees of SMS, accompanied by gastric discomfort, spatial illusions, yawning, drowsiness and a general indifference toward accomplishing physical or mental tasks.

The genesis of terrestrial motion sickness and its space counterpart are not well understood. The sequence of events leading to the severe symptoms of motion sickness are most likely initiated by a series of physiological and perhaps psychological signals.[214 215] The lack of a precise understanding of motion sickness precludes a means of preselecting more tolerant individuals.[216] For the same reason, the use of antimotion sickness drugs has not been totally satisfactory both due to erratic results obtained and also because of the side effects that are at times produced by these drugs.

After 2 to 5 days in space, most individuals become resistant to further episodes of SMS. However, during some Salyut 6 missions the Soviets have reported that some members of the crew experienced symptoms of SMS during head and torso movements, for up to 130 days.[217] In fact upon return to Earth, some cosmonauts experience recurrent symptoms during head and body movements as well as when going from a horizontal to a vertical position.[218] The fact that SMS seems to be manifested during the first few days of a mission could be a particular problem during early stages of brief space missions.

As has been mentioned previously, the cause of SMS is not well understood; however, it is recognized that certain types of motion can precipitate it. At times it can even be brought about by eye perception of a particular motion. In space, though, sickness is brought about by rather gentle movements of the head and body, those that would not initiate the symptoms on Earth.

Based on these observations, one can deduce that SMS may be partially associated with zero gravity. However, studies conducted

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213 Yakovleva, I. Ya., L.N. Kornilova, G.D. Syrykh, I.K. Tarasov, and V.N. Alekseyev. Results of Studies of Vestibular Function and Special Perception in the Crews of the First and Second Expeditions Aboard Salyut 6 Station. Kosm. Biol. Aviakosm., Med 15, 1981. p. 19-23

214 Money, K.E. Motion Sickness, Physiol Rev 50, 1970. p. 1-39

215 Collins, W.E., et al. Some Psychological Correlates of Motion Sickness Susceptibility. Aviat. Space Env. Med 7, 1977, p. 587-594

216 Hornick, J.L. Space Motion Sickness. Acta Astronautica 6, 1979. p. 1259-1272

217 Yakovleva, I. Ya., et al. Results of Studies of Vestibular Function and Perception in the Crews of the First and Second Expeditions Aboard Salyut-6 Station., op. cit.

218 Ibid.

both by Soviet and American scientists suggest that head and/or body movement is a required associated factor.[219 220]

Several theories exist as to causative and associated SMS factors. Individuals that are deaf do not get motion sickness on Earth. This suggests that the existence of a functional vestibular apparatus is necessary. This functional organ may then also be stimulated by other sensory inpu' cluding changes in partial pressures and effects of zero gravit me experts have concluded that there may be confusion in sensory signal inputs or overstimulation, resulting in multiple messages from the center of equilibrium to centers that generate feelings of motion sickness.[221] However, other theories still persist including the idea that there is a mismatch between information being received and that which is stored from prior experience.[222] It has also been suggested that there may be an overstimulation of the vestibular organ due to exposure to vigorous motion.[223] Another hypothesis suggests that labryinthine fluid imbalance could be due to fluid sh toward the head as a consequence of zero gravity.[224] Other experts believe that SMS results from an amnestic response to previous life-threatening situations which effect the vestibular organ.[225] The Soviets, a number of years ago, developed the Voyachek-Khilov Tossing Theory.[226] This theory encompasses eight basic principles.

The first principle states that motion sickness can develop in any person under numerous situations. Second, motion sickness is a reflex of numerous body sensors, including the vestibular, visual and tissue sensors, all playing their part. The third principle states that the essential role in motion sickness is played by conditional reactions. The fourth states that the tossing sensation develops as a result of the summation of normal adjustment reactions coming from sensors that are analyzing the situation. The fifth principle is related to the fact that the feeling of tossing about arises when the body changes vertical location in space. The sixth principle suggests that one must be aware of the status of the nervous system. The seventh principle delineates those conditions in the environment that favor the development of motion sickness, as for example high temperatures and certain odors. The eighth principle states that man can adapt to mechanical as well as other factors that lead to motion sickness. This theory has led the Soviets to firmly believe that effective training of the individual cosmonaut can reduce or prevent SMS.[227] They believe that the basic reasons for SMS are due to the action of mechanical forces acting upon the body and repeatedly communicating small but multidirectional ac-

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219 Ibid

220 Benson, A J Possible Mechanisms of Motion and Space Sickness Proc of European Symposium Life Sciences Research in Space May 24, 1977 ESA-SP 130. p. 101-108

221 Money, K E Motion Sickness. Phys Rev 50, 1970, p 1 39.

222 Reason, J J Motion Sickness Adaption A Neural Mismatch Model J. Royal Soc Med 77, 1978 p 819 829

223 Steel, J E Motion Sickness and Spatial Perception —A Theoretical Study. In: Symposium on motion sickness with special reference to weightlessness. Report AMRL-TDR 63-25 W-P AFB, Ohio, 1963, p 43

224 Tonndorf, J Vestibular Symptoms in Meniere's Disorder. Mechanical Considerations 5th Winter Meeting of Assoc of Research Otolaryngology, 1982 p 64

225 Treisman, M Motion Sickness An Evolutionary Hypothesis Science 197, 1977 p 493 497.

226 Voyachek, V I Zhurn Ushnykh, nosovyk i gorlovykh bolezney 4, 1927, p 121-282

227 Link, M M, Training of Cosmonauts and Astronauts, op cit

celerating forces. This results in the body simultaneously moving through space in multiple directions.[228]

Associated with the primary causes are situations that aggravate the condition such as optokinetic stimuli on visual analyzers, and multiple barometric pressure changes similar to those experienced in transition to zero gravity.[229] Contributing to this are such factors as high temperatures, lower partial oxyen pressure, gas fumes, and noxious chemical fumes. Psychological factors stemming from overwork, chronic fatigue, emotional stress and boredom all contribute to the development of SMS.[230]

A factor that may eventually increase the SMS problems is the reported desire by the Soviets to produce artificial gravity in their space station.[231] In order to accomplish this, particularly for long term space platform operations, the Soviets are considering the application of centrifugal forces (rotation). Not only would gravitational forces differ at different radiae from the center of the platform, thereby requiring continual physiological adaption, but continued rotation may exacerbate SMS.

PREVENTIVE APPROACHES

Both the Soviet Union and the United States have conducted Earthbound and in orbit studies to determine the efficacy of both pharmacological as well as body conditioning protocols to control SMS. Even though ground-based studies have suggested that individuals can develop a tolerance to conditions that lead to motion sickness, adaptive training, according to U.S. specialists thus far has not worked well in actual space flight.[232]

Among the approaches that have been considered to prevent or reduce SMS are the use of prophylactic and/or therapeutic medication. This medication consists primarily of central anticholinergic acting drugs that augment central sympathetic activity.[233] In addition to training and medication, consideration has also been given for the preselection of resistant individuals as well as providing biofeedback training and physically restricting head and body movement.[234 235]

The application of physical devices such as pneumatic thigh cuffs, lower body negative pressure as well as special headgear to restrict head movement have all been reported by the Soviets to be beneficial. The headgear, in particular, reportedly reduced space motion sickness.[236]

NOISE AND VIBRATION

Physical as well as biological consequences have been reported from exposure of man as well as animals to noise and vibration. In

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228 Zabutyy, M B Problems of Medical Certification in Motion Sickness Doctor's Dissertation, Moscow, 1970

229 Kompaniets, V S Barosummation Syndrome as a Component in Air Sickness Doctoral Dissertation, Moscow, 1968.

230 Komendantov, G L., et al Motion Sickness NASA TM76326, 1980

231 Soviet Space Programs 1971 1975 (Chapter four, the Soviet Space Life Sciences), op. cit., p 315

232 Nicogossian, A E., et al., Space Physiology and Medicine, op cit

233 Ibid.

234 Link, M M., Training of Cosmonauts and Astronauts, op. cit

235 Nicogossian, A E., Space Physiology and Medicine, op. cit

236 NASA Workshop Johnson Space Center "Technical Content on an Accelerated Research Program in Space Motion Sickness, 1982

the presence of high-frequency noise levels (74 to 76 dB), for extended time periods, man feels poorly. However, the absence of any noise is just as psychologically and physiologically detrimental.[237]

Aboard a spacecraft the primary sources of noise are the electrical motors and equipment, ventilators and equipment that provide orientation. During liftoff, the space traveller is subjected to intensive, painful exposures of noise levels up to 145 dB.[238]

It has been suggested that noise levels need to be modulated by using low-noise motors, electrical commutators and sound absorbency material. Soviet scientists have concluded that work and rest areas should have noise levels that are not the same and that the rest area must have a noise level not to exceed 40 dB. Moreover, it has been determined that a background noise level in general of from 60 to 65 dB is not detrimental to the cosmonaut.[239]

Technical data suggests that high intensity noise can not only cause an alteration in nerve cells that perceive sound, but also can influence the functional and psychological state of the central nervous system. This can lead to a reduction to the capacity to perceive constantly changing conditions of the external environment and bring about such manifestations as irritability and fatigue. This may, in extreme conditions, lead to death.[240] In the opinion of some researchers, noise may bring about premature aging.[241] Infrasound (sound not captured by the human ear), such as certain frequencies caused by ventilators, compressors, and diesel and jet engines, nevertheless can be very stressful causing depression, decreased reaction capacity, and nausea.[242]

SYNERGISTIC EFFECTS

The synergistic imposition of noise, isolation, hypodynamia, biorhythm changes and the general consequences of weightlessness, all impinge on sensory mechanisms. In order to modify such adverse environmental factors encountered during space flight, the Soviets have been experimenting with the concept of noise modification using selected music, particularly during rest periods. They have also adapted the music to the taste and habits of the individual crew. The use of music not only modulates noise levels aboard the spacecraft but it also has been recognized that music may have exceptionally strong influence on man's emotional state. By using music abroad the spaceship they are attempting to enhance the cosmonauts capacity of work.[243] To stimulate the capability to work effectively, music is selected to bring about the appropriate mood. Certain music may stimulate certain activities while other renditions may distract attention from performing certain tasks.[244]

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[237] Gurovskiy, N. N. Designing the Living and Working Conditions of Cosmonauts. Moscow, Mashinstroyeniye, 1980, p. 1-168.

[238] Isakov, P. K., I. Ivanov, I. G. Popov, N. M. Rudnyz, P. P. Saksonov, and Ye. M. Yuoganov Theory and Practice of Aviation Medicine. Meditsina, 1971

[239] Krylov, Yu. V. Characteristics of the Reaction of the Auditory Analysor of Man Under the Influence of Some Factors of Space Flight. Kosm. Biomedical. 5: 1967. p. 84-89.

[240] Denisov, V. G. The Cosmonaut and the Spacecraft, op. cit.

[241] Ibid

[242] Ibid

[243] Go'dvarg, I. Music in Production. Permskoye Knizhnoye izdatel'stvo, 1971.

[244] Ibid

As certain activities increase in complexity, music may in fact become bothersome. During the performance of certain very complex tasks, the operator may be so absorbed in his work, he may stop paying attention both to the music and to the background noise. Therefore, the selection of music during the cosmonaut's work period requires consideration of the type of work being performed, the psychlogical state of the cosmonaut, and the individual responsiveness and perception of the music in question. The Soviets are also experimenting with music and color changes to regulate mood.[245]

As the duration of space missions increase, noise modification and mood enhancement may become even more significant factors in the development of a compatible space cabin environment.

Although vibration particularly during liftoff and reentry are of some concern, it does not seem to be a significant problem.

PROBLEMS OF RADIATION IN SPACE

Ionizing Space Radiation

The amount of radiation encountered while on a space mission is dependent on numerous factors, including the length of the mission and the trajectory of the flight. When evaluating radiation hazards to the crew, consideration also needs to be given to the composition of its members, including their age and sex. Protection needs to be provided against both permanent and nonpermanent sources of radiation. The former consists of galactic cosmic radiation and the Van Allen radiation belts surrounding the Earth. The Van Allen belts consist of geomagnetically trapped radiation, while galactic cosmic radiation is composed of extremely high energy and variable charged composition particles.[246] The nonpermanent sources of radiation eminate primarily from solar radiation. Solar radiation comes from eruptions occuring on the surface of the Sun. The intensity of these episodes go through 11-year cycles and can pose serious radiation hazards to man if he is beyond the altitude of 200 to 800 km.[247]

To date, the radiation exposure of both the Soviet cosmonauts and U.S. astronauts have been very low because the flights have been of relatively short duration, the trajectories have been carefully planned and the missions have not encountered serious unscheduled solar activity. As the space flights increase in duration and in distance from Earth, the risk of higher exposure levels is appreciably enhanced. Therefore, it becomes important to develop means of protecting the crew against hazardous radiation exposure.

Prevention of Radiation Sickness

Various methods of providing such protection have been suggested and explored. These include:

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[245] Ibid.

[246] Dorman, L. I. Variations of Cosmic Rays and Space Explorations. Akad. Nauk. SSSR. Moscow-Leningrad, 1963.

[247] Calvin, M. and O. G. Gazenko. Found of Space Biological and Medical 2, 1975. p. 536.

1. The use of physical barriers, by either increasing the thickness of spacecraft covering or by crew compartment shielding;

2. Physical protection of the most radiation sensitive body organs;

3. Pharmocological protection; and

4. Active protection by means of magnetic or electrical deflection or capture.[248]

Most of these methods of protection are fraught with difficulties. The use of additional shielding has two major shortcomings. As the thickness of the shield is increased to specific limits, space radiation itself causes secondary radiation emission from the shield. In addition, the added weight reduces the effective payload capacity of the spacecraft. Protection of the most radiation sensitive organs such as the hematopoietic system, gastrointestinal tract, gonads and the eye lenses have some merit. However, it is technically difficult to protect all these organs in the absence of developing a protective suit, but anything less would not deal with low-level exposure and the unknown consequences of long-term delayed radiation effects.

Pharmacologic protection has been under extensive investigation for many years. Even though radiation protective compounds have been developed and tested on experimental animals and man, none are without side effects, including potential additive adverse effects due to the space environment and possible long-term adverse harm posed by such drugs. The most promising protection may be that provided by active protection with an electrical field surrounding the spaceship. Active protections consist of creating and maintaining a strong electrical field around the spacecraft resulting in a deflection of radiation particles away from the space cabin.[249] These techniques are in their infancy.

Though experts have developed recommended maximum permissible exposure levels for different lengths of space flights, there is no unanimity in the scientific community either as to the maximum nor minimum levels of radiation exposure that are safe. When considering long-term, low-level adverse effects, such data have been difficult to develop. Current U.S. career exposure limits for astronauts are set at 400 rems. This level is calculated to increase the cancer risk by 2.3 percent. This is equivalent to doubling the cancer mortality rate of the 35 to 55 year age group.[250] However, in experimental animals there does not seem to be a level below which some form of damage, primarily genetic, is not observed.

Biomedical Effects of Ionizing Space Radiation

The primary objective of radiobiological research in space is the development of data which will permit an accurate definition of safety. It is doubtful, however, that research conducted and data obtained in space will significantly differ from data that can be

[248] Grigor'yev, Yu. G. Radiation Safety of Space Flights. NASA TT F-16, 853, 1976

[249] Gurovskiy, N. N., F. P. Kosmolinskiy, L. N. Mel'nikov. Designing the Living and Working Conditions of Cosmonauts. Mashinstreyenije, Moscow, 1980.

[250] Fry, R. S. M. and Nachtwey. MPS Newsletter, June 1983.

[251] Russell, W. Personal communication, 1983.

generated on Earth. The biological effects of space radiation with the possible exception of heavy particles such as argon and iron and some other cosmic particles does not differ from the effects that are observed on Earth. Nevertheless, the Soviet Union supports a significant amount of space radiation research. An obvious concern is the possible interaction, either additive or synergistic, of the various interacting factors encountered in the space environment. Recent synergistic effects of ionizing radiation and heat have been reported, as have antagonistic effects of hypoxia and radiation. The former observation in particular is receiving close scrutiny as a possible regime for cancer treatment.[252]

Appreciable information has accumulated over the years on the clinical consequences of whole-body, acute radiation effects. This data is summarized in table 22.[253]

TABLE 22 *Expected short term effects from acute, whole-body radiation*

Dose in Rads	Probable effect
10 to 50	No obvious effect, except, probably, minor blood changes
50 to 100	Vomiting and nausea for about 1 day in 5%-10% of exposed personnel. Fatigue, but no serious disability. Transient reduction in lymphocytes and neutrophils.
100 to 200	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 25%-50% of personnel. No deaths anticipated. A reduction of approximately 50% in lymphocytes and neutrophils will occur.
200 to 350	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness, e.g., loss of appetite, diarrhea, minor hemorrhage. About 20% deaths within 2-6 weeks after exposure; survivors convalescent for about 8 months, although many have second wave of symptoms at about 8 weeks. Up to 75% reduction in all circulating blood elements.
350 to 550	Vomiting and nausea in most personnel on first day, followed by other symptoms of radiation sickness, e.g., fever, hemorrhage, diarrhea, emaciation. About 50% deaths within 1 month; survivors convalescent for about 6 months.
550 to 750	Vomiting and nausea, or at least nausea, in all personnel within 4 hours from exposure, followed by severe symptoms of radiation sickness, as above. Up to 100% deaths; few survivors convalescent for about 6 months.
1000	Vomiting and nausea in all personnel within 1-2 hours. All dead within days.
5000	Incapacitation almost immediately (minutes to hours). All personnel will be fatalities within 1 week.

Source: (Langham, 1967) as cited in The Bioastronautics Data Book, 1973

Unfortunately, low-level radiation effects below 10 rads, as well as delayed effects of low-level radiation, are still not well understood, but are under active study. Data thus far obtained, using the mouse as a model, and compared with data derived from human studies, has demonstrated a close correlation in biological response between man and mouse.[254]

Observations by the U.S. Apollo 11 astronauts of flashes of light in their darkened cabin, accelerated studies by both the United

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[252] Dobrovol'skiy, L. A. The Combined Effects of Ionizing Radiation and Other Environmental Factors. Vrach. Delo 12, 1981 p. 11-16

[253] Ibid

[254] Russell, W., Personal communication, op. cit

States and the Soviets, on this form of radiation. The initial observations by the Apollo crew were apparently due to the penetration of the space cabin and the eyes of the crew of high energy and heavy cosmic rays. These rays impart their energy on the retina of the eye, accounting for the observed illumination.

The galactic cosmic radiation HZE particles [HZE—(H=high; Z=atomic number greater than 2; E=energetic)] have energies sufficiently high to be able to penetrate at least 1mm of spacecraft or spacesuit shielding.[255] Earlier studies had suggested possible biological damage due to HZE, when black mice that were exposed to space radiation showed localized graying of their fur.[256]

Subsequent dosimetry studies performed during the Apollo-Soyuz Test Project [257] as well as on Apollo 16 and 17, demonstrated that serious biological damage can be caused by the interaction of the HZE particles with biological matter. These studies demonstrated neurological damage to the brain of pocket mice [258] and tissue damage to several biological specimens (shrimp, maize, B. subtilis spores).[259] Analysis of these results indicated that the damage directly correlated with the area on the tissue through which the HZE particles passed. Similar results have been obtained by the application of heavy ions generated from accelerator experiments on Earth.[260] [261]

The potential hazard posed by the HZE to humans in space is still an open question. However, it is known that man is much more sensitive to radiation damage than the biological materials that have been studied thus far.[262] Of major concern is the damage that may be caused to nonregenerating tissue, such as the central nervous system and the eye lens. Additionally, sublethal damage to cells could manifest itself in several delayed, pathological events, such as leukemia, solid tumors, cataracts and decreased fertility. Once more, the possible synergistic interaction of radiological processes with other space flight factors needs to be more fully explored.

NONIONIZING RADIATION

The Soviet Union and several Eastern European countries have devoted extensive research efforts toward the demonstration of biological effects produced by nonionizing radiation. In particular, electomagnetic radiation at energy levels encountered in house current are being studied. Both epidemiological and experimental data generated by the Soviet Union and the United States, as well as other countries, point to possible adverse biological effects due to these types of radiation.

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[254] Osborne, W. Z., L. S. Pinsky, and J. V. Bailey. Apollo Light Flash Investigations. In: Biomedical Results of Apollo. NASA SP-368, 1975, pp. 355–366.

[256] Grahn, D. HZE Particles in Manned Space Flight. Natl. Acad Sci. USA, 1973.

[257] Chase, H B and J S Post Damage and Repair in Mammalian Tissues Exposed to Cosmic Ray Heavy Nuclei Aviation Med. 27, 1956, p. 533-540.

[258] Bucker, H. et al., Apollo-Soyuz Test Project. NASA SP-412, 1977.

[259] Haymaker, W., E. V. Benton and R. C. Simmonds. The Apollo 17 Pocket Mouse Experiment In Biomedical Results of Apollo. NASA SP-368, 1975, 381–403.

[260] Bucker, H. A Study of Biological Effects of HZE Galatic Cosmic Radiation. In: Biomedical Results of Apollo. NASA SP-368, 1975. p. 343–354.

[261] Facius, R., H. Bucker, G. Reitz, and M. Schafer. Radial Dependence of Biological Response of Spores of B. Subtilis Around Tracks of Heavy Ions. In: Proc-6th Symp. of Microdosimetry, 1978 Harwood Acad. Publ., London, p. 977-986

[262] Fry, R. S., et al., MPS Newsletter, op. cit.

In addition to the previously mentioned Soviet Union's interest in developing fields (electrostatic and magnetic) to protect space crews from solar radiation, they are also very interested in studying the effects of electromagnetic radiation on a variety of biological systems.[263 264]

It should be pointed out that space travel by its very pioneering nature entails some degree of risk. Apparently, this risk is willingly accepted by those individuals who volunteer for space missions. In light of this acceptance, the minimal additional acute risks posed by radiation, particularly nonionizing radiation, may not be a significant deterent factor, particularly when considering the more apparent physiological risks undertaken by space travelers.

BIOLOGICAL RESEARCH IN SPACE

THE KOSMOS BIOSATELLITES

From 1975 to 1980, the Soviets flew three major biological missions. These flights, aboard specifically modified Vostok spacecrafts, were designated Kosmos 782, 936, and 1129.

It is apparent from the number of biosatellites that the Soviets have flown since the programs were initiated in 1966, and the fact that virtually everyone of their manned space flights have had biological experimentation aboard, that they are very interested in this area of research. It is also apparent that the U.S.S.R. has a coordinated program of manned and complimentary unmanned biological research. The unmanned programs complement and in some cases supplement studies not readily performed on man.

RESEARCH CONTRIBUTIONS (EAST AND WEST)

Over the course of the past 5 years the experiments aboard the unmanned Kosmos flights were devised by scientists of many of the Eastern bloc countries, but also included major contributions by France and the United States. An example of the participation of U.S. scientists is seen in tables 23 and 24[265] where one sees the types of experiments and the scientists that participated as part of the United States' contribution on Kosmos 782 and 936.[266]

TABLE 23. -U.S. EXPERIMENTS FLOWN ON KOSMOS 782

Study	Investigators	Affiliation
Plants:		
1. Responses of carrot crown gall tumors to spaceflight	R. Baker et al.	Colorado State University.
2. The morphogenetic responses of cultured totipotent cells of the carrot (Daucus carota) at zero gravity	F. C. Steward, A. D. Krikorian	State University of New York at Stony Brook.

[263] Tomashevskaya, L. A. Changes in the Metabolism of Experimental Animals as One of the Indices of the Biological Action of a 50 HZ Electromagnetic Field. Vrach. Delo. 7. 1982. p. 98-100.

[264] Belokrinitskii, V. S. Ultracytochemical Changes in the Brain and Liver Following Exposure to Low-Intensity Nonionizing Microwave Radiation. Buill. Eksp. Biol. Med. 93, 1982. p. 112-115.

[265] Souza, K. A. The Joint U.S.-U.S.S.R. Biological Satellite Program. Bio Science 29, 1979. p. 160-166.

[266] Ibid.

TABLE 23.—U.S. EXPERIMENTS FLOWN ON KOSMOS 782—Continued

Study	Investigators	Affiliation
Fruit fly		
3 Effects of weightlessness on the embryonic development and aging of Drosophila melanogaster	J. Miquel, D. E. Philpott	Ames Research Center.
Fish		
4 Fundulus heteroctitus embryogenesis	H. W. Scheld et al	Lyndon B. Johnson Space Center
Rat		
5a Bone-quantitative analysis of selected bone parameters	E. Holton, D. J. Baylink	Ames Research Center, Veterans Administration Hospital (Seattle, WA)
b Histological studies on tibial bones, jaws, teeth	C.W. Asling, I. Asling	University of California at San Francisco.
6a Immune system: effect of spaceflight on cell-mediated immunity	A.D. Mandel, E. Balish	Ames Research Center, University of Wisconsin
b Histological examination of inguinal lymph nodes	L. Kraft	Ames Research Center
7 Effect of spaceflight on ulceration	J. Vernikos Danellis, P. A. Brown	Ames Research Center
8 Effect of spaceflight on random hemolysis and mean lifespan of red blood cells	H. A. Leon, S. A. Landaw	Ames Research Center, Veterans Administration Hospital (Syracuse, NY).
9 Effects of spaceflight on the hormonal content of the pituitary gland	S. Ellis, R. E. Grindeland, L. Keil	Ames Research Center
10 Histological and ultrastructural examination of cosmos and control rat eyes	D. E. Philpott, G. Harrison	Ames Research Center
Radiation dosimetry		
11 HZE particle dosimetry	E. V. Benton, D. D. Peterson, M. Tran	University of San Francisco

TABLE 24.—U.S. EXPERIMENTS FLOWN ON KOSMOS 936

Study	Investigators	Application
Fruit fly		
1 Effects of weightlessness on the development and aging of Drosophila melanogaster	J. Miquel D. E. Philpott	Ames Research Center
Rat		
2 Effects of weightlessness and centrifugation (1 x G) on erythrocyte survival in rats subjected to prolonged spaceflight	H. A. Leon, S. A. Landau	Ames Research Center, Veterans Administration Hospital (Syracuse, NY).
3 Effects . spaceflight on some liver enzymes concerned with carbohydrate and lipid metabolism in the rat	S. Abraham, H. P. Klein	Bruce Lyon Memorial Research Laboratory (Childern's Hospital Oakland, CA). Ames Research Center.
4. Quantative analysis of selected bone parameters	E. Holton, D. J. Baylink	Ames Research Center, Veterans Administration Hospital (American Lake, WA).
5 Cosmic ray effects on the eyes of stationary and rats flown on Cosmos 936	D. E. Philpott	Ames Research Center
6. Spaceflights effects on muscle fibers	K. R. Castleman, L. A. Chui, J. P. Van Der Mauden.	Jet Propulsion Laboratory, University of Southern California School of Medicine.
Radiation dosimetry		
7 Space radiation dosimetry on board Cosmos 936	E. V. Barton et al	University of San Francisco.

RESULTS OF BIOSATELLITE EXPERIMENTS

Details of the Kosmos 782 biosatellite, which was launched November 25, 1975, were discussed in the previous issue of this staff report. Briefly, the major findings of the Kosmos 782 mission, which lasted for 19.5 days, were that the application of artifical gravity, by rotating the experimental material along an axis, may be a feasible countermeasure to zero gravity. During both Kosmos 782 and 936 Wistar rats, 50 days old, were subjected to centrifugation. This simulated Earth's gravity. Histological examination of rats at zero gravity showed almost complete cessation of bone formation on the surface membrane of the tibia. Rats that were centrifuged and thereby subjected to artificial gravity had not quite as great a decrease in bone formation. The bone growth in the zero gravity group recovered 25 days after readapting to Earth's gravity. In the centrifuged animal group, bone growth recovery was more rapid and increased resistance to experimental induced fractions of the femur were observed.[267]

The musculoskeletal system of the rats was also studied aboard Kosmos 782 and 936. It was noted that muscle atrophy of the hind limbs occurred in the animals subjected to zero gravity. This phenomenon was appreciably decreased in the rats exposed to artifical gravity. In addition, the zero gravity rats developed osteoporosis and had a 30-percent decrease in mechanical bone bending strength, this in contrast to the experimental animals maintained under artifical gravity. Observations of thyroid function indicated that zero gravity caused a decrease in calcitonin secreting cells, an observation that was absent in the animals maintained under artifical gravity. A reduction in calcitonin synthesis, due most likely to reduce physical activity, in turn brought about an increase in calcium released from bone tissue.[268]

Metabolic studies on rats were done on Kosmos 782, 936 and Kosmos 1129 (launched Sept. 25, 1979). An analysis of liver enzymes showed that a shift in enzyme levels occurred under spaceflight conditions, probably due to an increase in gluconogenesis and the subsequent storage of the glucose in the form of glycogen. This enzymatic shift returned to normal after 26 days of readaption to Earth's gravity.[269]

The effect of zero gravity on the hypothalamic—hypophyseal—adrenal system and the lymph organs of rats flown on Kosmos 782 and 936 showed an increase in neurosecretory activity of the hypothalamus. There also was a decrease in size of the lymphatic organs with an appreciable breakdown in lymphocytes. These observations were most likely due to stress induced by the spaceflight.[270] These observations of rats could also explain the decreased cellular immune capacity observed in cosmonauts and astronauts returning from space flights. Histological analysis of rat

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[267] Morey, E. R. and D. J. Baylink. Inhibition of Bone Formation During Space Flight. Science 201, 1978. p. 1138-1141.

[268] Gazenko, O. G., Il'in, Ye. A., et al. Principle Results of Physiological Experiments with Mammals Aboard the Kosmos—936 Biosatellite. Space Biol. and Aerospace Med. 1980, 14, 26–29.

[269] Mikho, I. Sh., N. Nemet, et al. Activity of Some Source Hepatic Enzymes and Lipogenic Processes in Rat Adipose Tissue after Spaceflight. Space Biol. and Aerospace Med. 14, 1980 p. 26-29.

[270] Gazenko, O. M., A. M. Genin, et al. Adaptation to Weightlessness and Its Physiological Mechanisms. Izv. Acad. Nauk. SSSR, Ser Biol. 1: 1980 p. 5–18.

kidneys subjected to zero gravity and those exposed to artificial gravity showed that the former had increased sodium and potassium excretion, probably due to dehydration.[271] In general, rats exposed to spaceflight conditions and subjected to artificial gravity did not exhibit the disturbances in gas exchange, electrolyte metabolism, postural equilibrium, muscular atrophy, bone degeneration and decreased myocardial myosin ATPase activity as seen in the animals subjected to zero gravity.

Neurophysiological studies performed on the rats flown aboard Kosmos 782 and 936 suggested that animals subjected to zero gravity for approximately 19 days had an impaired capacity to procure food due to the inability to coordinate their body movements. It has been suggested that this was due to a prolonged reduction in sensory impulses during the flight.[272] Those animals that were maintained in an artificial gravity aboard the biosatellite had prolonged difficulty in controlling eyeball movement. This suggested that a decreased sensitivity of the semicircular canal to angular acceleration develops, brought on by the centrifugal rotation which provides the artificial gravity.[273]

Certain conclusions can be drawn from these types of animal studies, particularly if they are correlated with results obtained from manned flights. Current opinion is that it is reasonably safe to conclude that the musculoskeletal system will not be permanently damaged from space flights lasting for 8 to 10 months. However, musculoskeletal functions might be irreversibly damaged in crews participating in space flights of extreme duration.[274]

In addition to animal experiments performed aboard the Kosmos flights, the Soviets also have studied a variety of plant and microbiological systems aboard both the unmanned biosatellite and the manned Salyut/Soyuz spacecrafts. Though this part of their biomedical research program does not receive much publicity, the Soviets have been very active in studying plant germination and growth as well as microbial cell metabolism and replication. Their goal is to use these systems to generate oxygen, grow fresh vegetation for food, and provide psychological support. Ultimately they hope with plant systems to develop a closed life support capability.[275] Seeds have been taken aboard spacecrafts in order to determine effects of the space environment on seed germination and subsequent growth on Earth. These data have given confusing results. This is primarily due to technical difficulties that have been encountered in the plant growth hardware. For example, dill was exposed to the space environments and its growth characteristics studied on Earth. The Soviets reported that the male gamatophyte of the dill seed exposed to space flight grew more rapidly than com-

[271] Savina, Ye. A. and Ye. I. Alekseyev. Functional State of the Posterior Lobe of the Neurohypophysis of Rats Flown Aboard the Kosmos—936 Biosatellite. Arkev. Anatomii, Gistologev i Embrioloju, 1980, p. 62-76.

[272] Livshits, N. M., M. A. Kuznetsova, et al. Retention and Recovery of Food—Procuring Skill in a Maze for Rats After Spaceflight in Kosmos 782 Biosatellite. Zhurual, Vyrshey Nervnoy Deyatel'nosti. 30, 1980 p. 55-61.

[273] Shipov, A. A., et al. Semicircular Canal Function in Rats After Flight Aboard the Kosmos 936 Biosatellite. Space Biol. and Aerospace Med. 2, 1980. p. 38-44.

[274] Whedon, D. G. Changes in Weightlessness in Calcium Metabolism and the Musculoskeletal System. The Physiologist 25, 1982, 541-544.

[275] Vasil'yev, G. In Order to Fly Infinitely Long . . . Aviatsiya i. Kosmonavtika, 10, 1979, p. 38-39.

parable ground controls, but the dill plants showed a decreased germination rate. These data are subject to question particularly since other studies have demonstrated no substantial differences brought about by exposure to space.[276] On the Soyuz 21 flight they studied the influence of intermittant artificial gravity and concluded that only an occasional induction of artificial gravity was necessary to counteract any influence of zero gravity.[277]

EXPERIMENTS WITH PLANTS

Numerous plant experiments were conducted aboard the Salyut 6. These included the use of Chlorella, a species of algae that have numerous genera and are currently undergoing experimentation to determine the feasibility of their use as a source of oxygen and food and to remove carbon dioxide in closed ecological systems. Additionally, the Soviets have developed "Malakhit" apparatus which is designed to automatically provide water and sufficient light as well as taking time lapse photography of growing plants, such as wheat and peas. At times regenerated water was used for the irrigation of the plants in this "space garden."

During the 175-day Salyut 6 manned space mission, the crew planted an extensive garden, including onions, garlic, cucumbers, wheat, lettuce, peas, parsley, and dill. Unfortunately, only a few of the plants grew at all and these were not able to produce seeds for a second generation. Orchids were also carried aboard this mission, but they very rapidly lost their flowers, most likely as a result of space cabin pollution.[278] It has been suggested that the major difficulties that the Soviets have encountered in growing higher plants in space is not due to the fact that plants need gravity in order to grow, but because there is an altered physical environment. Specifically, in the absence of gravity, water will adhere, by surface tension, and not run to its lowest point, perhaps accounting for the numerous reports of plant "drowning".[279] Zero gravity appreciably reduces the exchange of heat, oxygen and carbon dioxide between the plant and its environment; all of these factors may impinge on proper metabolic gas exchanges as well as result in the possible accumulation of toxic substances in the immediate environment of the growing plants.[280 281]

Besides plants, another major component of any closed ecological system most likely will require microorganisms to recyle human waste.[282] *Proteus vulgaris* is an organism of choice to participate in such a recycling process. Unfortunately, the Soviets have had difficulty in propagating *P. vulgaris* in space.[283] However, more recent results suggest that this has been due to technical difficulties in

[276] Sidorenko, P. G. and A. L. Mashinskii. The Effect of Space Flight Conditions on Higher Plant Cells in In-Vitro Culture. Kosmicheskiye Issledovania NA Ukraine, 12, 1978, p. 36–42.
[277] Tairbekov, M. G., et al. Biological Research in Space. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina 2, 1981, p. 51–61.
[278] Ibid.
[279] Ibid.
[280] Yudin, I. Successful Techniques for Growing Plants in Space. Nauka I Tekhnika 8, 1981, p. 12–13.
[281] Milov, M. Greenhouse in Space. Aviatsiya i Kosmonavtika 3, 1980, p. 36–37.
[282] Sminov, V. A. Development of Microorganisms Under Conditions of Space Flight. Visnik, Akedmii Nauk Ukrains'koy SSSR 44, 1980 p. 97–99.
[283] Kordium, V. A. and Liv'Polivoda, et al. Results of Experiment "Microorganism Growth" on the Soyuz 22 Spacecraft. Kosmicheskie Issledovania NA Ukraine 12, 1978, p. 3–14.

that the media used to grow these organisms physically degradated during the variety of alternating spaceflight conditions.[284]

Many of the factors that will be required in a functioning and practical closed ecological system are still in the embryonic stages of development. However, if very long manned missions are planned, such a system will be a necessity.[285] Whether in fact the composition of such a system will include the currently envisioned microbial organisms is difficult to predict. However, with the evolution of recombinant DNA technology, it may become feasible to construct biological systems that will have the capacity to sustain life under a variety of adverse conditions, including that of space.

Future Biosatellite Research

Many significant biomedical questions still need to be answered prior to sending space crews to other planets and farther into the universe. Many of these problem areas deal with the biological limitations of man and the best way to technically compensate for them. The majority of the answers are likely to come from experimentation and remedial actions that will be developed at zero gravity, aboard a space station. To arrive at these answers, the Soviet Union is in a much better technical position than the United States because they have made a concerted effort in the development of space platforms which permit extended zero gravity experimentation. In order to study both sociological and technical areas, the Soviets can expand their current Salyut space platform into a multiple complex, a capability that will most likely require at least 7 to 10 years for the United States to accomplish.

Most of the major biological problems that require answers have been previously discussed. Some can be accomplished on Earth including the development of plants that may become integral links of a closed ecological system and the resolution of psychological difficulties associated with isolation.

Application of recombinant DNA technology (genetic engineering) might permit major breakthroughs in the construction of plant systems that will be capable of utilizing the space cabin environment (zero gravity and high carbon dioxide) to replicate and produce the food and environmental necessities such as oxygen and water, sources of energy and environmental detoxification. These types of studies most likely will be given high priority.

Mind control is another area that is currently being investigated. The ability to control the thought processes of space travelers would be highly advantageous, particularly in overcoming some of the currently well recognized isolation problems that have been experienced by some Soviet cosmonauts. Mind control could be accomplished by hypnosis, electrical stimulation and/or the use of drugs that influence the central nervous system.

The currently recognized biomedical problem areas associated with zero gravity include muscle atrophy, bone demineralization and cardiovascular deconditioning. To resolve these problems will

[284] Babskii, V. G., et al. The Effect of Space Flight Factors on the Characteristics of Nutrient Media for the Bacterium Proteus vulgaris. Kosmicheskie Issledovania NA Ukraine 12, 1978, p. 24–30.

[285] Jones, W. L. Life Support Systems for Interplanetary Spacecraft and Space Stations for Long Term Use. In Foundations of Space Biology and Medicine. M. Calvin and O. G. Gazenko (eds.) 1975. p. 247–273.

most likely require research to be done at zero gravity over relatively long time spans. Since the Soviets have demonstrated the capability to maintain man in space for more than 6 months, they have a distinct advantage in investigating these problem areas and arriving at countermeasures.

Additionally, the Soviets' significant biosatellite program can provide valuable information for application to manned experimentation. Many of the difficulties for the propagation of plants will most likely be resolved in this program.

FIGURE 53.—Primate physiological monitoring module.

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The Soviets are currently planning a biosatellite launch using nonhuman primates. Most of the equipment that will monitor and analyze the data has been developed by French scientists (see fig. 53).[286] Since nonhuman primates (Macaca mulatta) have a pattern of cardiovascular regulation similar to man,[287 288] the Soviet Union reasons that many of these problem areas may be effectively studied using this animal system. The French developed a restrain and physiological monitoring system, M.E.P.P. (Module D'Experimentation Physiologique sur Primates), which will be placed aboard the Kosmos biosatellite, planned to be launched in late 1983. In addition to restraining the animals and providing them with a suitable environment, the module is designed to monitor the following physiological parameters:

Arterial pressure	Urine collection
E.C.G.	Feces collection
Heart frequency	Blood sampling
Respiratory frequency	Conditioning test performance
Core and subcutaneous temperature	General activity monitoring
Evaluation of frequency and volume of food intake	E.E.G.
Evaluation of frequency and volume of water intake	E.M.G.
	Vascular flow
	Respiratory gases

This 1983 Kosmos mission will also include a joint U.S./U.S.S.R. effort. The members of the joint U.S./U.S.S.R. research team, their affiliations and research projects are given in table 25.

TABLE 25.—*Kosmos 83 U.S./U.S.S.R. research effort*

Investigator	*Project*
1. F. Sulzman, S.U.N.Y., Binghamton V. Klimovitsky, Institute of Biomedical Problems, Moscow	Synchronization of Primate Circadian Rhythms in Space.
2. C. Cann, U. California, San Francisco Yu. Kondratyev, Institute of Biomedical Problems, Moscow.	Calcium Metabolisms and Corrolated Endocrine Measurements (in Primates).
3. J. Keefe, Biospace Inc., Cleveland L. Serova, Institute of Biomedical Problems, Moscow.	Analysis of the Visual Vestibular and Alfactory Receptors and Central Nervous System Pathways in Fetal and Postnatal Rates.

Source: Summary of Results, XIIth Meeting of the US/USSR Joint Working Group on Space Biology and Medicine, Washington DC, Nov 9-22, 1981, attachment 3.

In addition, the United States will provide technical support and loan biomedical equipment to assist Soviet scientists in a primate cardiovascular study. The United States will also participate in data analysis activities following the flight and in ground-based control studies.

EXOBIOLOGY AND EXTRATERRESTRIAL INTELLIGENCE

Both the Soviet Union and the United States have an involvement in the search for extraterrestrial life. This not only is a quest to determine if the planet Earth is unique in the whole universe,

[286] Photograph courtesy of Centre D'Etudes Et De Recherches De' Medicine Aerospatiale, Paris, France.
[287] Golarz, M. N., G. W. deBourne, and H. M. McClure. The Rhesus Monkey (Macaca mulatta) as a Flight Candidate. In: Proc. Symp. on the Use of Nonhuman Primates in Space. NASA, Moffett Field, 1977. p. 245–246.
[288] Stone, H. Z. and H. Sandler. Cardiovascular Studies in the Rhesus Monkey. In: Proc. Symp. on the Use of Nonhuman Primates in Space. NASA, Moffett Field, 1977. p. 83–103.

but also to provide information on how life evolved on Earth. The search for extraterrestrial civilization not only stimulates the imagination of man, but it also enhances our scientific knowledge and ensures continued technological development. It therefore is reasoned that even if the search is unsuccessful, it will justify the financial outlays.

Exobiology

The search for the evolution of life in the universe, and particularly on this planet, has been undertaken by pursuing the following types of studies.

1. Origin of carbon components and their evolution in the universe;
2. Evolution of carbon components in the solar system;
3. Evolution of organic substances on Earth;
4. Models of nonbiological and biogenic synthesis of primitive life on Earth;
5. Models of various systems of compounds and energy as precursors of life;
6. Dynamics and evolutionary genetics of living systems;
7. The role of light, heat and other energies in the formation of biological molecules;
8. Methods of detection of extraterrestrial life; and
9. Automated detection systems for life on other planets and solar systems.[289]

The evolution of life is surrounded by controversy, both due to our lack of knowledge and because it has theological implications. It is, interesting to quote in part Father Theodore M. Hesburgh, President of the University of Notre Dame on this subject.

> I must now mention God--otherwise quite properly unmentioned in these scientific studies--and must go a step further and pose the question: Ca , a religious person, or even more, a theologian, possibly be legitimately involved in, even be excited by these discussions of the possibility of other intelligent and free creatures out there? Just last week, I was discussing the subject with a Russian lawyer who regarded me with some surprise and asked: "Surely you must abandon your theology when you consider these possibilities?" "Indeed, I don't," I replied. "It is precisely because I believe theologically that there is a being called God, and that He is infinite in intelligence, freedom and power, that I cannot take it upon myself to limit what He might have done." Once he created the Big Bang—and there had to be something, call it energy, hydrogen, or whatever, to go bang—He could have envisioned it going in billions of directions as it evolved, including billions of life forms and billions of kinds of intelligent beings. I will go even further. There conceivably can be billions of universes created with other Big Bangs or different arrangements. Why limit Infinite Power or Energy which is a name of God? We should get some hint from the almost, but not quite, infinite profusion of the Universe we still know only in part. Only one consideration is important here regarding creation. Since God is intelligent, whatever He creates—"Let there be light"—Bang—or otherwise, whatever He creates is a cosmos and not a chaos since all His creation has to reflect Him. What reflects Him most is intelligence and freedom, not matter. "We are made in His image," why suppose that He did not create the most of what reflects Him the best. He certainly made a lot of matter. Why not more intelligence, more free beings, who alone can seek and know Him?

Many years have elapsed since it was first suggested that life on Earth originated by the synthesis of organic molecules from inor-

[289] Oparin, A. I. Theoretical and Experimental Prerequisites for Exobiology In: Foundations of Space Biology and Medicine I, ch. 7, 1975.

ganic chemicals found on the evolving planet Earth. It is theorized that by means of high energy interaction, these chemicals formed organic compounds.[290] These organic compounds formed by a selection process, the basic components of life, namely nucleic acids, proteins and carbohydrates.[291] This theory of the origin of life on Earth has in part been experimentally reproduced.[292] [293]

SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

Thus far, there is no evidence that life exists in this solar system or the universe other than on Earth. However, both the United States in its Search for Extraterrestrial Intelligence (SETI) program and the Soviet Union in its Communication with Extraterrestrial Intelligence (CETI) program have ongoing efforts to detect the presence of extraterrestrial intelligence. In order to search for life the United States has sent out probes such as the Viking missions to Mars and other planets.

During the elapsed time between the first joint National Academy of Science Conference on Communication with Extraterrestrial Intelligence which was held at the Byurakan Astrophyics Observatory in Armenia in 1971 to the more recent Soviet meeting held in Kalyuga in 1980, pessimism has set in. Certain segments of both the Soviet and American astronomical community now doubt the presence of life, other than our own, in the universe. In 1976, the Soviet astrophysicist Shklovsky stated that it is highly likely that we are the only form of life possibily in the universe and likely in our galaxy.[294] This point of view is shared by other U.S. scientists. Scientists no doubt have arrived at these conclusions because they have been unable to detect any intelligent signals from the universe. Both the Soviet scientists from the Radiophysics Research Institute at Gorky and American astrophysicists at the Arecibo Observatory in Puerto Rico and other components of the U.S. National Astronomy and Ionosphere Center have surveyed over 600 stars closest to the Earth and have not detected any unnatural radio signals. Granted, Sagan has said that at least 1 million stars would have to be probed for even the slimmest chance of success.[295]

However, in addition to the silence of outer space, one U.S. scientist believes that the space surrounding the majority of stars is devoid of an atmosphere that could sustain life, with our Sun and its planets possibly being a rare exception.[296] Some Soviet, American and British scientists reason that if a technological advanced society really existed in our galaxy, there would be evidence of its activity. Even though the pessimists in the scientific community are still a small minority, they are gaining new disciples.[297]

A majority of the community still firmly believes that there is insufficient information to arrive at any conclusions at this time.

[290] Oparim, A. I. Evolution of Concepts on the Origin of Life. Izvestiya of the Acad. Sic. U.S.S.R. Biol. Series 1, 1975.
[291] Oparim, A. I. Theoretical and Experimental Prerequisites for Exobiology. In: Foundation of Space Biology and Medicine I, chapter 7, 1975.
[292] Oparim, A. I. Life, Its Nature, Origin and Development. N.Y., Academic Press, 1962.
[293] Calvin, M. Chemical Evolution. Oxford Univ. Press, N.Y. 1969.
[294] Shklovsky, J. The Uniqueness of Intelligent Life in the Universe as a Possibility. Vosprosy Philosophic, 1976.
[295] Sagan, C. The Cosmic Connection. Anchor Press, N.Y. 1973.
[296] Nishkin, L. Extraterrestrial Intelligence. Soviet Life. Apr. 1981.
[297] Shklovsky, J. The Uniqueness of Intelligent Life in the Universe as a Possiblity. Vosprov Philosophic, 1976.

In particular, it is argued that we will have difficulty intercepting and interpreting space noise from actual communication. Since most communication would be sent out in a highly directional mode to members of that civilization that are similar to each other.[298]

The Soviets have attempted to search for signals from extraterrestrial civilizations in the optical band, using a large mirror telescope. Seventeen suspicious objects have been detected. The significance of these observations are still in doubt. The majority of Soviet and U.S. scientists agree that the search for extraterrestrial life must be continued, utilizing the newest technologies.

The complexity of this problem can be better understood if one appreciates the major categories of research that are being pursued by the Soviets. These include:

The problem of extraterrestrial civilizations comprises an intricate complex of topics in philosophy and sociology as well as natural science. Within the domain of this broad interdisciplinary problem a narrower area is to be considered—the CETI problem. This represents a separate task confronting science and technology, including theoretical and experimental work on searching for extraterrestrial civilizations, as well as modeling the basic links in the CETI system. But a successful result will depend on resolving a number of fundamental questions that form the heart of the extraterrestrial civilization problem.

It is convenient to distinguish groups for planning the investigations.

Group A. Fundamental Problems of Extraterrestrial Civilizations Involving Communication

1. Astronomical matters—Cosmogany. Discovery of planets, planetlike bodies, and congealed stars. Sky surveys conducted in various parts of the electromagnetic spectrum. Examination of some peculiar sources. Investigation of organic compounds in cosmic objects.
2. Life—A more precise definition of the concept of "life." Possible existence of nonprotein life forms. Origin of life on the Earth; possible alternative origins of life on other cosmic bodies, and in interplanetary and interstellar space. Exobiology. Laws of biological evolution and their exobiological generalization.
3. Intelligence and intelligent systems—Refinement of the concept of "intelligence" or "reasoning." Models of an intelligent system. Theory of complex self-organizing systems. Information contacts in complex systems. Symbolic systems; language. Problems in the theories of knowledge and reflection; construction of models.
4. Mankind—Analysis of the laws governing the development of civilization on the Earth. Special characteristics of the rise and development of different civilizations worldwide. Forecasting. Development and mastery of the space environment.
5. Information transfer—Optimum methods of communicating information. These topics are being dealt with independently of the

[298] Ibid

CETI problem itself and therefore are not considered in the present program (except for the sky surveys).

Group B. Problems Pertaining Directly to CETI

1. Aspects of the theory of cosmic civilizations.
2. Contacts between cosmic civilizations: Possible types of contact and their consequences.
3. Modes of intercourse between cosmic civilizations—Linguistic media to be devised for establishing information contact between "intelligent" systems.
4. Procedures and scientific-technological basis for seeking signals from extraterrestrial civilizations—Development of signal search techniques. Influence of the cosmic medium on exchange of signals between civilizations. Choice of optimum electromagnetic wavelength range. Criteria for identifying signals from extraterrestrial civilizations. Characteristics of "call letters." Design of search instrumentation. Modeling of individual links in the CETI system. Computer modeling.
5. Searches for signals from extraterrestrial civilizations.
6. Deciphering of signals.
7. Searches for astroengineering activity of extraterrestrial civilizations—Although the main emphasis in this program is given to efforts to find signals in the radio range and to the development of suitable techniques and equipment, a more complete program should also include planning with regard to other aspects of the CETI problem.[299]

In conclusion, it is believed by some that man's curiosity will and should prevail, for the discovery of intelligent life in the universe, other than our own, would profoundly influence man's future.

SUMMARY AND CONCLUSIONS

Ongoing Trends

It is apparent from our analyses that the Soviet Union has a well-conceived and long-range program for the exploration of outer space. The U.S.S.R. utilizes this program both to enhance its worldwide prestige and to develop necessary biotechnology in a systematic manner.

Though the Soviet Union and the United States both have large manned space programs it is evident that the U.S.S.R.'s, particulary as it relates to biological space research, is far more extensive and all-encompassing. Long-term planning and stable funding is evident both for the Soviet manned and unmanned biomedical program. Undoubtedly, because they have a clearly defined program that seems to have continuous uninterrupted funding, their efforts appear to be both more efficient and productive.

At the governmental level, cooperation and official exchanges between the United States and the Soviet Union have diminished during the past 2 years, although cooperation is continuing in the less publicized scientific arena. In many aspects this cooperation is

[299] The CETI Program, Astronomy Journal (USSR), No. 5, 1974, p. 1125–1132 (Soviet Astronomy, 18(5), 1975; translated by the American Institute of Physics).

mutually benefical. The United States benefits by access to the more ambitious Soviet effort. This permits us to have experiments aboard their unmanned Kosmos flights and the Soviets benefit by having access to the data generated from our technical approaches. In particular, the application of our more sophisticated technology is a scientific benefit to the Soviet Union.

Data generated from Soviet manned spaceflights clearly point out that they have an appreciation of the biomedical problems that are encountered in space. The fact that the Soviets early on initiated and maintained a space station program, clearly gives them the capacity to effectively investigate long-term influence of zero gravity on man. Many of the observed biomedical deviations brought about by the space environment, in particular the absence of gravity, such as bone demineralization, cardiovascular irregularities, muscle atrophy, terrestrial readaptation and motion sickness, require experimentation under actual space flight conditions. A clearer definition of these problem areas and possible remedial action require extended space flights and spaceship facilities for experimentation. The fact that the United States did not develop a long-range space station program in the early years of space exploration places us at a distinct disadvantage in discovering, defining, and resolving these problems. In view of the difficulties thus far experienced by the Soviets during their extended space missions, it is critical that certain countermeasures be developed if manned space missions beyond 1 year are to become a reality. [300] [301] [302] [303]

Even though the Soviets have a larger and more complex biomedical space program, both in number of personnel and facilities involved, it is frequently very difficult to obtain verifiable technical information. This in part is due to the nature and organizational complexity of the Soviet scientific community. They have numerous science centers scattered throughout the Soviet Union. It is currently estimated that at least 200 science cities exist throughout the U.S.S.R.[304] These centers generated a vast amount of technical information, frequently in the open literature, but not widely circulated. It would be a distinct advantage to the United States and other Western countries if Soviet literature were more readily available. The establishment of a comprehensive science monitoring and translation service in the United States would be very helpful. Such a service would have knowledge of and access to the open literature emanating from the Soviet science cities. Benefits gained by such a literature service would most likely far outweigh the financial investment.

When viewing the Soviet and American space programs, it is clear that up to this time, the Soviets have and continue to pursue a long range goal of manned extraterrestrial exploration. On the other hand the United States has had a more modest unmanned extraterrestrial space program. Our program is limited both by the lack of space stations to house long-term biomedical experiments and our philosophy, which is based on the premise that solar exploration is readily carried out by unmanned flights. This difference

[300] Boddie, T. The Body's Answer to Zero Gravity. Bioscience 32. 1982, p. 249–251.

[301] Levy, M. N. and J. M. Talbot. Research Opportunities in Cardiovascular Deconditioning. FASEB Report. NASW 3619, 1983.

[302] The Human Organism in Space. CERMA-CNES-CNRS-ESA Document, 1983.

[303] Bones in Space. British Medical Journal. May 31, 1980, p. 1200.

[304] Personal communication. L. E. Kazarian, 1983.

in philosophy reflects, to some extent, the current state affairs vis-a-vis U.S., and U.S.S.R. space exploration. According to some U.S. authorities, however, unless the Soviets can resolve the many perplexing biomedical difficulties encountered in extended space missions, their manned program may have difficulties in achieving their ultimate goals. On the other hand, should the Soviets succeed, our hesitancy could place us at a distinct disadvantage.

THE FUTURE

From the foregoing sections of this chapter, two trends in the Soviet manned space and space life sciences program are revealed. First, the Soviet bioastronautics effort is large, comprehensive, stable, and forward-looking. Second, the effort is directed toward a permanent human presence in space in the short- and long-term future. These conclusions are further strengthened by many statements made publicly over the past 5 years by leading figures in the Soviet space program and political system. These statements have been chronicled in part I of this study, published in January 1983, which are recommended reading for those concerned with Soviet policy- and decisionmaking relative to the future of manned space programs. Some of the more notable statements made between 1976 and 1980 are provided below.[305]

General Georgiy Beregovoy, head of the Yuri Gagarin Cosmonaut Training Center was quoted by the Soviet Weekly News as saying:

> Making long term predictions is unwise; cosmonautics has developed so quickly that it surpassed the most optimistic forecasts. But one thing is clear—huge complexes that can stay in a near-earth orbit for several years will be created. Crews will shunt back and forth on shuttle craft. There will be bases and camps on the moon. And in the more distant future there will be expeditions, first to Mars and then to other planets. (Moscow, TASS, 0835 GMT, Apr. 10. 1976.)

In 1977, comments were made by former cosmonaut K. Feoktistov during an interview addressing the future of orbiting manned space stations and future industrial settlements in space:

> *Question.* How do you picture the development of cosmonautics in the immediate future?
>
> Answer. Above all, the development of research and work in the interests of the national economy. Cosmonautics is already gradually becoming a sector of the national economy. Communications satellites play an important role. The meteor weather satellites are having a tangible effect. Work is being developed on monitoring the Earth's surface from space. Surveys from satellites and orbiting stations in space, for example, help geologists in search of minerals, fishermen, agricultural workers, glaciologists, irrigators and specialists in many sectors of the national economy. . . . The direct return from cosmonautics can already be measured in tens and hundred of millions of rubles. And this contribution will increase.
>
> In addition we are studying the possibility of carrying out various technological operations in space—obtaining superpure substances, semiconductors, crystals. . . . Such orbiting production may prove very important to the national economy in the future.
>
> I feel it is quite possible that at some time, perhaps within our lifetime, the construction of plants with unique technology will begin in space. It may be possible to put environmentally harmful enterprises into space—for example, those enterprises which produce great quantities of heat (the problem of the Earth's energy balance is very serious). . . .
>
> Another direction in the development of cosmonautics is research into circumterrestrial and circumsolar space and the nearest planets. That is, man must get this

[305] U.S. Congress. Senate. Committee on Commerce, Science, and Transportation. Soviet Space Programs 1976-80 Part 1 (Appendix I. Chronology of Soviet Space Forecasts, 1975-80). 97th Cong., 2nd Sess. Washington, U.S. Government Printing Office, 1982. p. 343-390.

bearings in the environs of the home where he lives. This is chiefly a task for automatic machines

In my view, however, the most interesting results should be expected from investigating the universe. This is the third direction. This research will obviously be conducted both from onboard orbiting stations and in automatic astrophysical laboratories

To speak of design developments, there is the interesting task of creating large long-term orbiting complexes.

Interplanetary ships will undoubtedly be constructed in the future. Man no longer feels himself simply an inhabitant of Earth but also of the entire solar system. It would be interesting, for example, to go into orbit around Venus and set up a station there for an in-depth study of this planet. . . By that time, however, still more interesting ideas may have emerged.

Question. And how do you feel about space settlements—small cities with a population between a few thousand and tens of thousands of people?

Answer. Such settlements are possible in principle. There is no doubt about it. I believe they will appear in time. One of the possible reasons for their emergence will be if developing industry affects the biosphere on a menacing scale. . . . Who knows, perhaps an increase of a few more percent in the carbon dioxide in the atmosphere will prove too much for the biosphere. And then the launching of production into space will be inevitable, and settlements too. I repeat: Technically this is, on the whole, feasible, and we know how to go about it and what to do. . . .

Of course, such a project would be incredibly costly. However, scientific and technical progress is now so rapid that even this problem may be resolved more quickly than it is possible to suppose today. What seemed fantastic yesterday is a firm part of our lives today. Look: Quite recently computers were considered a miracle of technology. But now schoolchildren frequently use a pocket calculator behind the math teacher's back

It would be expedient to construct space settlements quite far from Earth—at distances of the order of tens of thousands of kilometers. The delivery of materials to them and the installation of structures—all this entails great difficulties . . . (Moscow, Trud (in Russian), Apr. 12, 1977, p. 3)

A similar question was asked of Shatalov, and though his answer was essentially the same, it had a slightly different emphasis.

Question. Vladimir Aleksandrovich, how do you see the immediate future of cosmonautics?

Answer. Clearly other planets will for the moment remain the province of automatic craft. Manned flights will be around the Earth and will increasingly be of specific practical benefit. The 25th CPSU Congress decisions directly show the way ". . . to continue the study and conquest of space, and to expand research for the employment of space means in studying Earth's natural resources, in meteorology, oceanology, navigation, communications, and for other needs of the national economy."

Manned ships and stations will work side by side with automatic satellites in resolving these tasks. The length of service of orbital stations will gradually begin to increase and their research potential will grow broader. Their work will be both automatic and manned. When cosmonauts are on board adjustment and repair work can be carried out on a broad scale, and the life of the station can be substantially prolonged

Unquestionably international cooperation in space research must be strengthened and the number of countries participating in it must increase. Life has convincingly shown that space can successfully serve the welfare of all peoples on our planet. (Moscow, Izvestiya (in Russian), Apr. 12, 1977, morning edition, p. 2)

In March 1978, the Soviet reporting service, Tass, announced that progress in the Salyut 6 space station program would lead to stays by humans in space of over 1 year in duration. An article in the Soviet journal, Trud, explained the importance of manned flights relative to future exploratory missions to the planet Mars:

Moscow, March 17, Tass.—"Man can live and work in outer space for over a year." This conclusion was made by Soviet scientists after summing up the preliminary results of the 36-day orbital flight made by flier Yuriy Romanenko and Flight Engineer Georgiy Grechko. Professor Anatoliy Yegorov who heads the medical group of the Flight Control Centre, singled out four factors that warranted such an optimistic conclusion "Throughout the flight," he said to Tass, "the cosmonauts retained high creative interest in scientific research and experimental work. They carried out over 50 major planned investigations and approximately as many at their own initiative."

The cosmonauts displayed an amazing spirit of creativity and capacity for work," he said.

As a second factor Professor Yegorov mentioned correct forecasting by specialist of the effects of weightlessness on the human body, and means of neutralizing them. A large dose of physical exercises and loads the crew got on the running track, veloergometer as well as the use of the load suit Penguin and the suit Chibis which coordinate blood flow in the body to bring it closer to that one has on Earth—are some of the measures which predetermined the good condition of Yuriy Romanenko and Georgiy Grechko. (Moscow, Tass (in English), 1321 GMT, Mar. 17, 1978)

A study of body adaptation to weightlessness is very important for specialists. For example, a flight to Mars can have a minimum duration of three years. In case of necessity the ship would not return to the Earth and would not land at any time. It is necessary to know precisely whether the human body could contend with such a flight, what preventive measures would be required and whether it is necessary to develop an appropriate biomedical strategy. . . . All this must be known in order to ensure effective operation of long-term orbital stations in circumterrestrial space. (Moscow, Trud (in Russian), Mar. 17, 1978, by V. Golobachev)

The Soviets continue to maintain a high level of interest in the concept of closed-circuit, biological life support systems utilizing the single-cell alga Chlorella. Experiments on this concept continue in Salyut 6 and will be carried out on Salyut 7.

Experiments aboard the space complex have already begun. The first of these is biological. It is being carried out with the well-known green alga Chlorella. This lower plant has already been in space more than once. The interest of scientists is understandable: Chlorella will be specially created for the greenhouses of future interplanetary ships and long-lived stations with a closed ecological system. Reference is to an autonomous biosphere in which the plants absorb carbon dioxide from the air and enrich it with oxygen and give man water, some food, everything necessary for life. Now space stations and ships have special absorbents and regenerators for maintaining the normal composition of the air, apparatus taking water from the air in the ship, and containers with food. It is impossible to store all this for a year or two for distant voyages into space. This means that it is necessary to create a closed biosphere with the complete cycling of matter in a relatively small volume of spaceships or stations. This problem is exceedingly complex. Chlorella is also interesting in that it very actively absorbs carbon dioxide and releases oxygen, simultaneously yielding water and food. It is rich in proteins and in chemical composition in a quite adequate nutritious product. Still another merit of this surprising alga is that it matures rapidly, which is very important for the space greenhouse.

Earlier space experiments with Chlorella gave scientists rich material. But, to be sure, by no means all problems have been solved. A further development of these investigations is the experiment carried out by the international crew aboard the "Salyut 6"-"Soyuz 27"-"Soyuz-28" complex. This time it is not Chlorella alone which is in use; other algae are also being employed. And the Chlorella itself is unusual; in addition to the normal algae there are special modified forms, so-called mutants, which have no chlorophyll.

Aleksey Gubarev and Vladimir Remek delivered to the Soyuz-28 four small containers with a nutrient medium and nine sealed ampules which contain algae. By means of special devices, the cosmonauts broke some of the ampules and the algae can now develop rapidly. Other containers are control ampules. After return of the containers to Earth the scientists will compare the algae. This will make it possible to learn how weightlessness acts on the cells of lower plants which are at rest and which are actively growing.

Three different types of algae are developing in one of the containers. Will there be a "competition" among them which will lead to a "struggle"? This is a question which is of interest to specialists. Similar investigations are being carried out simultaneously on Earth.

Unicellular algae have become part of the first experimental systems for regeneration of the atmosphere and water, successfully operating in terrestrial laboratories. New investigations aboard the space complex will make it possible to take still another step on the path of development of promising ecological systems.

Preparations for the "Chlorella" experiment were carried out jointly by the scientists of the Soviet Union and Czechoslovakia. A careful selection was made of the species and forms of algae and a method was developed for carrying out the experiment. The materials returned from space are sent for investigations to the laboratories and institutes of the USSR and CzSSR. (Moscow, Trud (in Russian), Mar. 8, 1978, p. 3. [Article by V. Golobachev: "Four in the Stellar House".])

Then President Leonid Brezhnev made it clear in 1979 that the Soviet manned space program was and would continue to receive high priority:

Of course, there is still a great deal to be done to improve working and living conditions in orbit. It is necessary, for instance, to pay special attention to improving conditions for sleep, the doctors say. The sport facilities in orbit, which were found to play a decisive part in preparing cosmonauts for return to Earth, need to be reorganized. In the long run it will be possible, perhaps, to turn the veloergometer into a real track bicycle so that cosmonauts could make circular runs inside a spacious cylinder. This will be possible to stimulate, if only insignificantly, a gravitation effect on the cosmonauts' organism, an effect that is badly needed by space travellers. (Moscow, Tass (in English), Aug. 23, 1979, Nikolay Zhelenov.)

[Speech by Leonid Ilich Brezhnev, general secretary of the CPSU Central Committee and chairman of the Supreme Soviet Presidium on September 7 at Kremlin ceremony awarding medals to Cosmonauts Vladimir Lyakhov and Valeriy Ryumin.]

Indeed, it is not for nothing that specialists in many countries are now talking about the presence of real conditions for a lengthy, perhaps even permanent activity by man in space, about how the basis is being created for future interstellar flights.

Dear Comrades Lyakhov and Ryumin: For successful fulfillment of the program of the longest space flight in history on board the Salyut-6-Soyuz orbital scientific research complex and the courage and heroism displayed during this you have been given the highest awards of the homeland. You have been awarded the titles of heroes of the Soviet Union with the presentation of orders of Lenin and gold star medals. Comrade Lyakhov has been awarded also the title of "Pilot Cosmonaut of the USSR." (Moscow, Pravda (in Russian), Sept. 8, 1979, p. 1.)

Finally, in a late 1979 interview, Director of the Space Research Institute, Academician R.Z. Sagdeyev, speculated on the future industrialization of space by man and future applications of permanent orbiting space stations.

In the past few years our country has taken a great step forward in the conquest of space. We have attained practically continuous manned operations in orbit; at the end of last year there was what I would call an explosion of new information on the chemistry of Venus; and there is an entire group of wonderful young scientists concentrating in the space sciences. Also among the most significant achievements is the sharp increase in the role of international cooperation in space research, which has been evident in the flights of the CEMA cosmonauts and in the cooperation with various other countries in the realization of scientific and technical programs in space, including the joint work with our French colleagues.

I am certain that in the next 5-10 years a vast amount of industrial activity will begin in orbit. Toward that end we must prepare not only technology but men as well. (Tallin, Sovetskaya Estoniya (in Russian), Dec. 7, 1979, p. 1. [ETA Report: "On Space Topics"])

There is still another important factor which forces us not to hurry with the creation of large stations. I have in mind the disproportion between the rate of collection of scientific information and the rate of its processing. This is a matter of great concern to scientists, designers and cosmonauts. Now when a crew works aboard an orbital station for one month we obtain so much scientific information about the earth, its environment and natural resources that years are required for its processing. And the problem here is by no means a matter of miscalculations. It is simply that former data processing methods do not correspond to the new situations.

An increase in the useful life of orbital stations is inseparably associated with an increase in the reliability of all its systems, instruments and assemblies. This is no simple problem. Even on the Earth not one machine operates continuously over the course of many months and years; it requires preventive maintenance and the replacement of parts. In space the situation is saved by the crew. It can be said with complete assurance that the prolonged operation of the "Salyut-6" station became possible only due to the cosmonauts. It has no equal with respect to the volume of preventive maintenance and repair-restoration work carried out aboard it.

But in order for such work to be carried out effectively, the possibilities for reconstruction must be incorporated in advance in the design of the station and its equipment. Otherwise even the most experienced crew can do nothing.

Long-term observations of the ocean from space made it possible to establish the possibility of directing ships of the fishing fleet into regions where fish were plentiful. The first experiments indicated great promise and great advantage. All this indicates that in the years immediately ahead there can be a considerable increase in the economic effectiveness of such investigations. This requires communication between the crews of orbital stations and ships at sea, a knowledge of their coordinates and the coordinates of the regions of fish concentration closest to them. (Moscow Vodnyy Transport (in Russian), Dec. 25, 1979, p. 3 [Article by M. Chernyshov: "They are studying the ocean from space"].)

Such frequent, public statements made by Soviet authorities about the future of man's activity in space leave the reader with little doubt that the Soviet Union has embarked upon an ambitious path of establishing a permanent human presence in near terrestrial space and of ultimately sending men to the Moon and planets.

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