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Chapter 15

The Soviet–Russian Space-Suits: A Historical Overview of the 1960s*

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Abstract

The development of protective suits for space use started with the *Vostok* suit SK-1, first used by Yuri Gagarin on 12 April 1961 and then used on all subsequent *Vostok* flights. The technical background for the design of these suits was the work on full pressure protective suits for military pilots and stratospheric flights in the 1930s through the 1950s.

The Soviet–Russian space program contains a large number of "firsts," and one of the most well known is the first Extra-Vehicular Activity (EVA) by Alexey Leonov in 1965. This event is also the starting point for a long series of space-suit developments for EVAs during the past 35 years.

The next step was the transfer in void space of crew members between the *Soyuz 4* and *5* spacecraft in 1969. As has later become known, this was an essential element in the planned Soviet lunar exploration program, which in itself required a new space-suit. After the termination of the lunar program in 1972,

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space-suit development concentrated on suits applicable to zero-gravity work around the human space stations *Salyut 6*, *Salyut 7*, and *Mir*. These have become known as the Orlan family of suits, and an advanced version of this suit (Orlan-M) will be used on the *International Space Station* with the U.S. Extravehicular Mobility Unit (EMU).

This article covers the space-suit development in the Soviet Union in the 1960s and the experience used from the pre-space era.

Introduction

At about the same time, in the early 1960s, the development of several different types of space-suits was started in the Soviet Union. The first cosmonauts for the *Vostok* flights were to be equipped with a protective suit against accidental decompression and for rescue purposes, and the planned lunar missions required one or more suits for on-orbit and lunar surface EVA.

Just as the spacecraft in the first decade of the human space race between the Soviet Union and the United States showed similarities and distinct differences, the same was the case for the to-be-developed space-suits. Major reasons for this are to be found in the technological heritage of the two nations and for all the capability of the Soviet Union to launch larger payloads into space.

On the other hand, both nations could gain from the experience of the pressure suits developed in the 1930s for the stratosphere ballooning in the Soviet Union, the United States, and other countries and the extensive experimentation of protection for the pilots of high altitude aircraft up until the end of World War II. After that, little information was published because of the cold war. Another common source of ideas was the theoretical analysis of the problems associated with working in void space and the proposed countermeasures by space pioneers, such as Konstantin Tsiolkovsky and Hermann Oberth.

With the space-suits to be developed by the Soviet Union, several spectacular firsts were to be achieved in the 1960s. In the 1980s and 1990s the Soviet–Russian space-suits were to become the real overalls for space work![1]

Background

Technically it should be distinguished between three different categories of space-suits:

- The space-suit for working on orbit in void space, generally referred to as the "space-suit" or the "EVA-suit"

- The space-suit for work on another celestial body, the "lunar/Moon space-suit"
- The protective/rescue suit for cosmonauts/astronauts, the "Intra-Vehicular Activity suit" or the "IVA-suit."

The basic construction principle of a space-suit can be soft, semi-rigid (with a hard upper torso), or rigid (a full hard suit). Dependent on the mission specific requirements, the soft suit has been used as the IVA and rescue type of suit from *Vostok* on until today's IVA-suit for the *Soyuz* missions to *Mir* (the Sokol suit). This suit provides comfort and protection when seated in a cramped spacecraft cabin.

The first EVA-suits were also of the soft type (*Voskhod* and *Soyuz*), as they served the dual purpose of pilot protection and rescue, in addition to being the EVA-suit for EVAs of shorter duration (less than a few hours).

Starting with the lunar application, the semi-rigid suit was to become the basic design for EVA suits in the Soviet Union, in particular for the *Salyut/Mir* EVA activities. Rigid suits have been frequently proposed and tested but never put into flight until today, because of high weight and restricted mobility.

An overview of the three different suit categories and the various suit concepts in the Soviet–Russian human space program is given in Figure 1.

The Heritage for Space-Suit Development in the Soviet Union

When the first steps were taken toward space-suit development in the Soviet Union around 1958–59, this could be done based on 25 years of experience with the design and development of partial- and full-pressure suits. The first known facts about development of high-altitude, full-pressure suits in the Soviet Union date from the early 1930s.

The first full-pressure suit, identified as Ch-1, was designed by engineer E. E. Chertovsky in 1931. It was a simple pressure-tight suit with a helmet, fitted with a small visor. The suit did not have joints. Thus, when the suit was under pressure, substantial forces were required to flex arms and legs. With positive pressure under the enclosure, any work for the person wearing the suit was impossible.

On 30 January 1934 the Osoaviakhim-1 stratosphere balloon suffered a catastrophe. The tragic event gave an impetus to engineers and inventors of various backgrounds to look for means of personal protection for pilots to save them in case of pressure-tight cabin decompression or to make use of unpressurized cabins. In the period 1931 to 1940, Chertovsky and his team developed a whole family of pressure suits, Ch-1 thru Ch-7 (Figure 2).

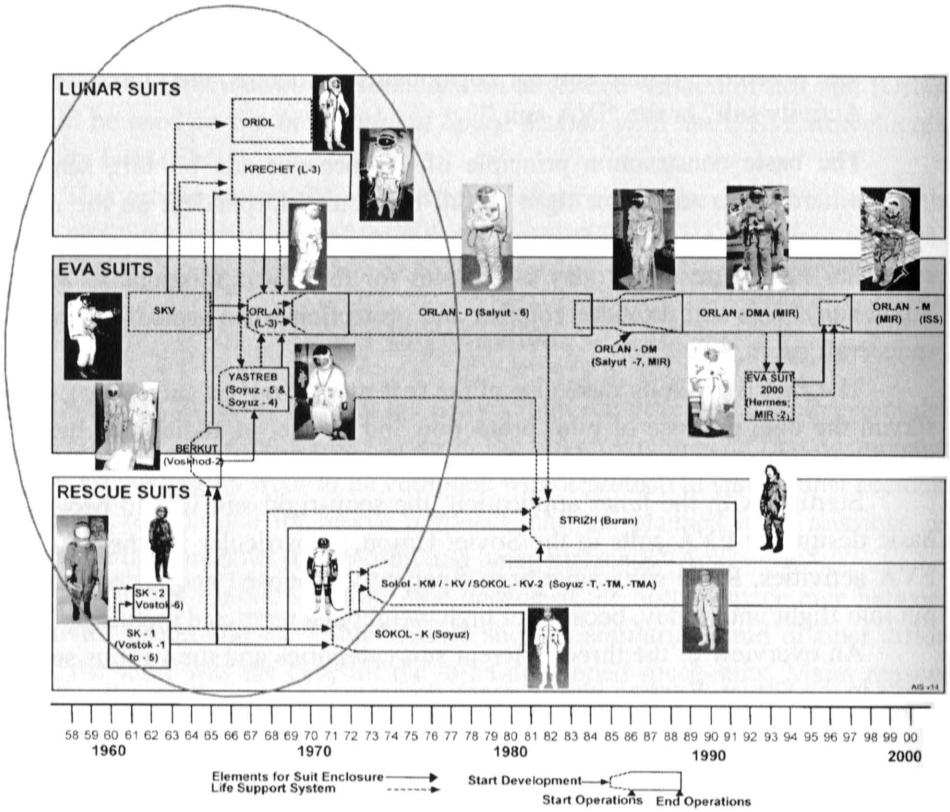
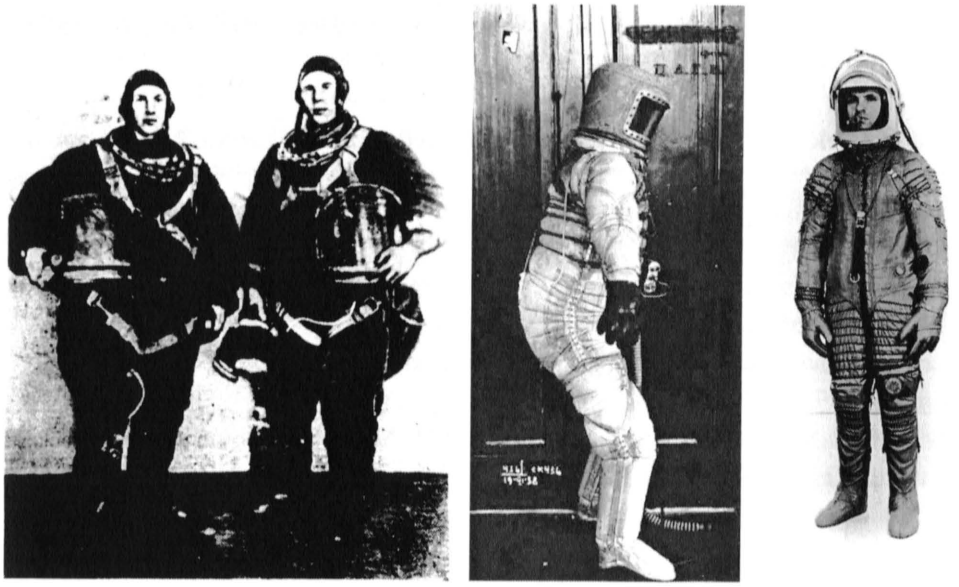


Figure 1: The Soviet/Russian Space-Suit Family Tree (*Archive Skoog*).

In 1936, the TsAGI (Central Institute of Aerohydrodynamics) began developing high-altitude, full-pressure suits to support increasing performance of aircraft (at that time without pressure cabins), in particular for the race to set new altitude records, in a team lead by A. I. Boiko and A. I. Khromooshkin. TsAGI put these activities on a sound scientific ground corresponding to the high technological level of the already world-renowned institute. The first TsAGI suit, SK-TsAGI-1, a full-pressure suit, was developed, manufactured, and tested in 1937. The suit consisted of two parts, an upper torso or a "shirt," and a lower part or "pants." The waist interface was made of metal. To follow were suits SK-TsAGI-2 thru SK-TsAGI-8 (Figure 3).

World War II terminated activities on the development of "stratospheric" full-pressure suits and the post-war period was a time of rapid development of jet aircraft equipped with pressure tight cockpits, ejection seats, and other technical innovations, which called for new approaches to the development of high-altitude protective gears for crew members.



Figures 2, 3 and 4: Left, Ch-3 suit of E. E. Chertovsky design, 1937. Center, TsAGI full pressure suit SK-TsAGI-4, 1938. Right, Zvezda suit Vorkut, 1959 (*Archive Zvezda*).

As indicated above, TsAGI and LII (Flight Test Institute), later Gromov LII, were the first Soviet scientific aviation organizations involved in the development and test of high-altitude, full-pressure suits. TsAGI developed the full-pressure suit technology for piloted flights in the period from 1936 to 1941 and LII was involved in similar activities from 1946 to 1952. A transfer of technology and personnel between these two institutes took place. To develop and test full-pressure suits, LII formed a department (high-altitude laboratory) that included a design team, a production shop, and a test laboratory equipped with a thermal vacuum chamber. Four models of experimental air crew full-pressure suits (VSS-01, VSS-02, VSS-03, and VSS-04) were developed during the six years of activities.

With the formation of Plant No. 918 in October 1952, all pressure suit activities were allocated to this enterprise and certain people of the LII high altitude department joined the new organization. Semion Mikhailovich Alekseyev, who also worked for LII as a manager of a design and manufacturing department, got the position of chief designer.

Plant No. 918, now Zvezda, got down to the development of high-altitude air crew full-pressure suits in line with existing rules for the development of aviation technology. It formed several design teams, a suit assembly shop, and a high-altitude test laboratory.

Table 1 lists air crew full-pressure suits developed at Plant No. 918 in the period from 1953 up to 1959.

Table 1: Pre-space Era Development Activities at Plant No. 918 /Zvezda

Year	Type (Identification) of Suit	Project Manager	Note	Legend
1953	VSS-04 VSS-05 VS-06	A.I. Boiko S.P. Umansky S.P. Umansky	Completion of the LII initiated project	VSS—high-altitude, rescue, full-pressure suit (vysotny spasatelny skafandre) VS—high-altitude, full-pressure suit (vysotny skafandre) VKS—high-altitude, combined full-pressure suit (full-pressure suit plus anti-G suit) (vysotny kombinirovanny skafandre) SI—fighter pilot full-pressure suit (skafandre istrebitelia) SB—bomber crew full-pressure suit (skafandre bombardirovschika) S—full-pressure suit (skafandre)
1954	VKS-1 (VSS-07) VSS-04A VSS-04M	A.L. Zelvinsky A.I. Boiko A.I. Boiko		
1955	SI-1 SB-2 SI-3	S.P. Umansky S.P. Umansky S.P. Umansky		
1956	SI-3M SB-4	S.P. Umansky S.P. Umansky		
1957	"Vorkuta" SB-4B SI-5	A.I. Boiko S.P. Umansky S.P. Umansky	Start of Vorkuta activities	
1958	SI-5 S-9	S.P. Umansky S.P. Umansky	Start of S-9 activities	
1959	"Vorkuta" S-9	A.I. Boiko S.P. Umansky	Development and tests	

In 1959, activities on full-pressure suits for human spaceflights started. However, activities on full-pressure suits for air crews continued. They included testing and final development of the S-9 and Vorkuta full-pressure suits (Figure 4).

The Vostok Era

As It Began

Less than a year after the launch of the first satellite in 1957, the Special Design Bureau (OKB-1) got down to initial studies aimed at development of a human "Earth Satellite." With the consent of Sergei Korolev, the first concept for

human spaceflight was prepared within OKB-1 by Michail Tikonoravov and Konstantin Feoktistov in August 1958.[2]

January 1959 saw a resolution of the Soviet government and a corresponding order of the Minister of Aviation Industry with the instruction to start activities on the preparation of a human mission onboard an Earth satellite. On 17 April 1959 the OKB-1 issued technical specifications (or statement of work) for the development and manufacture of a pressure suit with an emergency air conditioning system, and on 22 May 1959 the Soviet government issued a resolution, which specified main contractors and subcontractors. Those documents initiated the activities on the design and development of space-suits in the Soviet Union.

The meeting of the Keldysh-chaired special committee at the Presidium of the Academy of Sciences of the Soviet Union, held on 18 July 1959, had arrived at the decision to make Plant No. 918 the prime contractor for development of life support, means-and-rescue systems needed for human space missions. In 1959, Zvezda made a conceptual design and shop drawings of the first space-suit (it was identified as S-10) and manufactured two operating models for laboratory tests (Figure 5).

It is appropriate to indicate that Zvezda did not have a medical department then (it was organized in March 1960), and the main partner of Zvezda in physiological and hygienic tests was the State Scientific Research Institute of Aviation and Space Medicine (GNIIIA&KM). Zvezda provided the institute with an S-10 model for joint tests.

The suit design and the life-support system arrangement were developed to ensure safety of humans in emergency situations, such as cabin depressurization in orbit, disturbances in the cabin gas content, rescue in case of splash down, and rescue of an unconscious person.

The S-10 suit enclosure was developed on the basis of the design of the previous aviation pressure suits. The suit helmet had a new design and was equipped with a system for automatic closure of the visor. The system featured an integrated parachute suspension and seat restraining system, used as the suit reinforcement element, and a special integrated line interface unit.

The suit was meant to operate autonomously with a regeneration system. Purchase orders for the development of part of the onboard equipment of the system were given to the OKB-124 (known currently as the Nauka enterprise) and to SKB-KDA (for the oxygen loop).

The statement of work meant to provide ventilation of the suit with the cabin air under 1 bar pressure, with the flow rate from 50 to 150 liters/minute for up to 10 days, in case the open loop was used, and for up to 14 hours in case the closed loop emergency system was in operation. Special oxygen equipment sup-

plied the pilot with oxygen in the deorbiting phase both before the seat ejection and after the ejection. The KP-50 oxygen unit was developed to automatically purge the suit when the cabin pressure falls. Because the cabin temperature could reach the 40-degree level, the suit used a special ventilation system and a unique liquid cooling system by means of spraying water on the cosmonaut's torso in an emergency.

At the beginning of 1960, Zvezda continued activities on the development of the S-10 pressure suit. However, in February 1960, the OKB-1 issued a new statement of work to Zvezda for the development of a protective suit (instead of the pressure suit). There were several reasons for such a decision. The main ones were the weight deficit of the spacecraft and a negative attitude of OKB-1 design engineers, led by Feoktistov, to the necessity of a full-pressure suit. Their rationale proceeded from the idea that the probability of cabin depressurization is considerably lower than the occurrence of other emergency situations, which may cause catastrophic consequences.

The protective suit (it was identified as "the V-3 suit")[3] was under development up to the end of August 1960. The main purpose of the V-3 suit was to protect the cosmonaut after landing under cold conditions or when splashing down, especially in cold water (Figure 6).

Figures 5 and 6: Left, general view of S-10 space-suit breadboard in 1959. Right, Testing of the V-3 protective suit under winter conditions (*Archive Zvezda*).

A waterproof enclosure worn on a special thermal protection garment used elements of an immersion pilot suit. The garment was fitted with a ventilation system fed with cabin air during the flight from a self-contained ventilation unit. The garment torso was made of quilted foam rubber. Woolen jersey was used for the garment legs and sleeves. Zvezda made a conceptual design of the protective suit and shop drawings and then manufactured eight suits.

Several suits were delivered to the GNIIIA&KM to support physiological tests and several suits were delivered to the Flight Research Institute for parachute jumping tests. Zvezda performed 12-hour, cold-water immersion tests in a pool and two-day, open-air exposure tests in winter conditions.

The S-10 pressure suit and later the V-3 suit projects were managed by A. M. Gershkovich. Enclosures were developed by the team led by A. Y. Stoklitsky, and the team led by I. P. Abramov developed life-support systems (jointly with subcontractors, mainly OKB-124 and SKB-KDA).

Discussions on the full-pressure suit did not stop when activities on the protective suit were under way. The most persistent advocates of the full pressure suit were Air Force representatives (namely V. A. Smirnov, chief of an Air Force Department Office, and S. G. Frolov, a Department Chief of the State Scientific Research Institute of Air Force). They were supported by physicians and Zvezda specialists.

Hot discussions had culminated by the summer of 1960. A full-pressure suit with the life-support system of a closed-loop type was proposed again. Design engineers of the OKB-1 stated that there was no weight margin for that. Then S. P. Korolev personally interfered with the discussion.

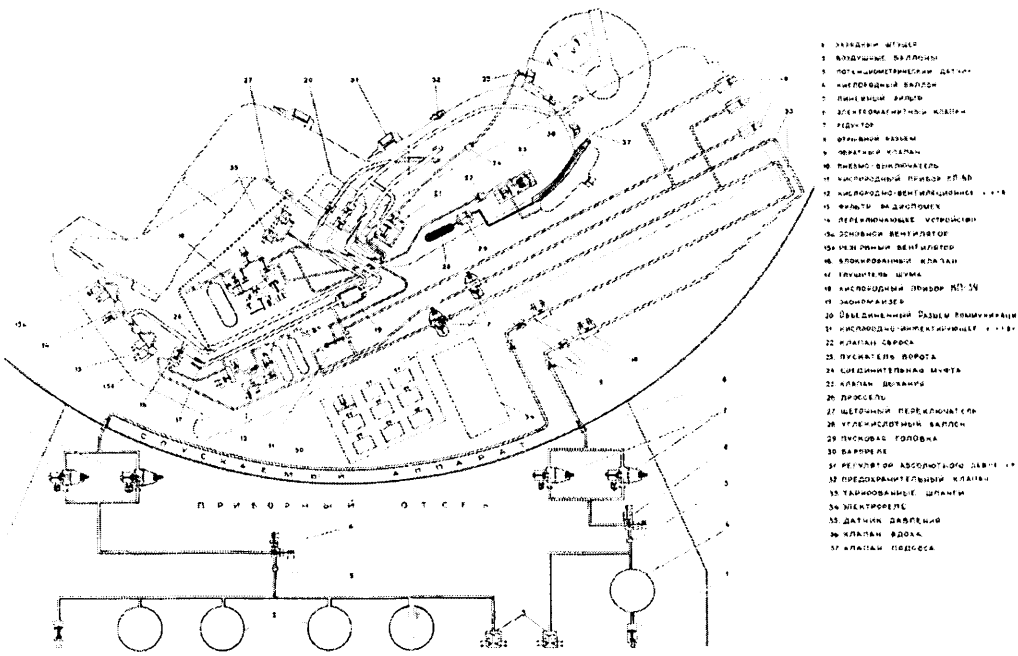
A meeting was held at Zvezda at the end of August 1960 with the participation of all parties involved, that is S. P. Korolev, K. P. Feoktistov, G. I. Voronin, V. A. Smirnov, A. M. Genin, L. G. Golovkin, and Zvezda specialists led by S. M. Alekseyev. Taking into account the time available until the planned date of the first human spaceflight, the meeting had reviewed various full-pressure suit versions, including that with the system connected to the cabin regeneration system.

When G. I. Voronin stated that the onboard system for the regenerative pressure suit with closed-loop system for gas regeneration would be ready not earlier than the end of 1961, S. P. Korolev said that he would agree to make 500 kilograms available for the suit system people, provided that the suit with the appropriate system would be ready by the end of 1960.

Because the delivery schedule was tough, the meeting had arrived at a compromise settlement to accept for development a simplified version of a self-contained pressure-suit system with the maximum utilization of the already de-

veloped elements of the S-10 full-pressure suit and V-3 protective suit and with the use of the experience gained during activities on high-altitude, full-pressure suits.

In September 1960, a statement of work for a full-pressure suit (identified as SK-1) was finally signed. The SK-1 suit was required to operate as an open loop system only for five hours in a depressurized cabin using onboard compressed oxygen and air. Components of the suit's self-contained ventilation and oxygen supply system were located partially on the Zvezda-developed ejection seat, and partially in the descent vehicle and spacecraft instrument module (Figure 7). It is appropriate to indicate that the concept of an IVA-suit, self-contained system is currently used for the *Soyuz* vehicles.



(1) charging connection; (2) air bottles; (3) 35-pressure sensors; (4) oxygen bottle; (5) filter; (6) electromagnetic valve; (7) reducer; (8) umbilical connector; (9) check valve; (10) pneumatic switch; (11) oxygen set; (12) oxygen and ventilation unit; (13) radio interference filter; (14) switching device; (15a) primary fan; (15b) redundant fan; (16) shut-off valve; (17) noise suppressor; (18) parachute oxygen device; (19) additional reservoir or bag; (20) combined service connector; (21) oxygen injector; (22) relief valve; (23) collar inflation actuator; (24) connector; (25) breathing valve; (26) gas flow rate control valve; (27) switch; (28) CO_2 bottle; (29) starting head; (30) barometric relay; (31) absolute pressure regulator; (32) relief valve; (33) connecting hoses; (34) electric converter; (36) inhalation valve; (37) air inflow valve.

Figure 7: Overall life support system for space-suit, spacecraft and ejection seat (*Archive Zvezda*).

First Space-Suits for the Vostok Spacecraft

The world's first human spaceflight was performed on 12 April 1961 by Yuri A. Gagarin onboard the *Vostok* spacecraft. Gagarin wore a Zvezda-developed full-pressure suit identified as the SK-1 suit (Figure 8). The SK-1 suit was also used by cosmonauts G. S. Titov, A. G. Nickolayev, P. R. Popovich, and V. F. Bykovsky in their space missions. V. N. Tereshkova wore the female version SK-2.

Figures 8a and 8b: Left, SK-1 full pressure suit used by Yuri A. Gagarin. Here with test person Yuri Orekhov; Right, SK-1 space-suit without the protective overall. Here with test person Victor Yefimov (*Archive Zvezda*).

In combination with the life-support system, the SK-1 suit ensured the fulfillment of the following main requirements:

1. Normal hygienic conditions for the cosmonaut in the pressurized cabin for 12 days.
2. Safe occupation by the cosmonaut of a depressurized cabin for five hours in the orbit and safe occupation of the descent module for 25 minutes.
3. Protection of the cosmonaut in case of ejection at altitudes up to 8 kilometers with velocity head up to 2,800 kilogram/centimeter squared.
4. Oxygen supply for breathing during parachute descent from an altitude up to 10 kilometers.
5. Survival of the cosmonaut in cold water (after splashing down) for 12 hours (outside a rescue boat), and for three days under the temperature of –15° C after landing or in a rescue boat.

In case of cabin decompression, the suit operating pressure was maintained between 270 and 300 hectopascal (hPa), which corresponds to the altitude of 10 kilometers. The SK-1 suit set included a nominal ventilation system and an emergency ventilation and oxygen supply system developed in cooperation with the Nauka (Science) and SKB-KDA enterprises.

The suit system included the following components and units:

- Enclosure (two-layer with separate load bearing and pressure tight enclosures)
- Helmet with a dual visor and a device for automatic closure of the visor
- Removable gloves and cuffs
- Internal thermal protection suit with a ventilation system
- Protective coverall
- Boots adapted for parachute landing
- Rescue float support collar with a CO_2 inflation system
- Group suit inlet interface unit
- Headset
- Emergency radio set
- Survival kit needed to survive in wilderness (a pistol, a knife, a mirror, and an anti-shark substance, fluorestine).

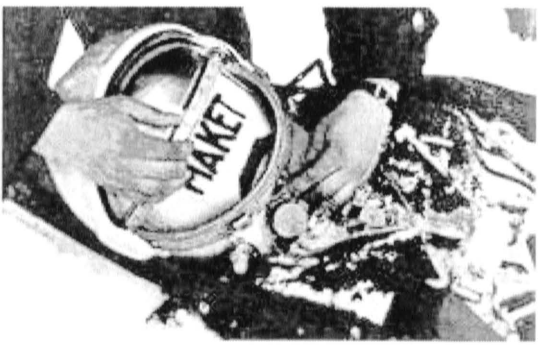
The suit mass amounted to about 23 kilograms. The SK-1 suit was designed, manufactured, tested, and prepared for nominal operation within an extremely short time, practically within six months. The SK-1 space-suit used the thermal protection suit and ventilation system developed for the V-3 full-pressure suit. The SK-1 suit helmet was an improved version of the S-10 suit helmet fitted with a device for automatic closing. The enclosure, a principal component of the suit, was similar to that of the Vorkuta air crew full-pressure suit (Figure 4).

In November 1960, Korolev's OKB-1 got down to comprehensive tests of the suit life-support system jointly with *Vostok* spacecraft systems. However, only the laboratory tests of hardware had been performed by that time, and the suit final tests were in the initial phase.

The test program included strength tests (verification of static strength margin), dynamic tests with simulation of explosive decompression from the 1013 hPa level to the 41 hPa level, exposure to mechanical loads on a shaker and a centrifuge, tests in a vacuum chamber jointly with oxygen equipment, flight jump tests with landing and splash down, thermal tests (including 11-day tests in the spacecraft cabin and exposure to cold water in a pool), operating life tests, and full-scale sea tests under storm conditions. Tests were performed at Zvezda, Gromov LII, Institute of Aviation and Space Medicine, Feodosia Air Force Base,

TsAGI, and other organizations. By December 1960, Zvezda had manufactured eight SK-1 suits for in-house tests, for tests at the State Scientific Research Institute of Aviation and Space Medicine, and for delivery to the OKB-1.

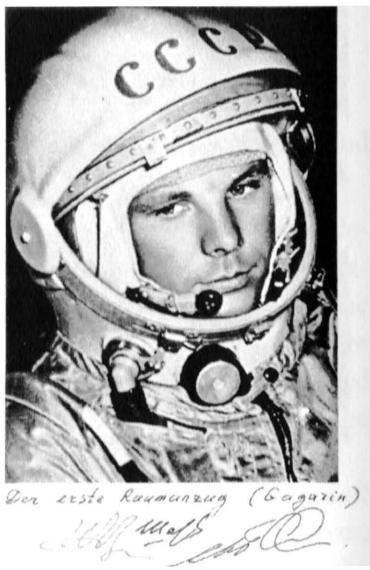
In the first quarter of 1961, before the first human spaceflight, two flights with a dummy ("Ivan Ivanovitch") were performed. For these flights, the suit and its onboard systems were prepared to operate in the human mode in case of cabin decompression. The final phase of the flight, which included ejection and parachute descent, ran in the nominal mode to finally demonstrate the proper operation of all systems (Figure 9). To avoid any misunderstandings the dummy (or mannequin) was given a cloth carrying the word mockup ("maket") over its face (Figure 10). The mannequin was mass and a center-of-gravity representative of separate parts of the human body. Inside the mannequin there were instruments recording accelerations during its return to Earth.



Figures 9 and 10: Left, Ivan Ivanovitch flew on 9 and 25 March 1961 to test the complete system spacecraft, suit, and ejection seat. Ivan Ivanovich is today in the Zvezda Museum (*Archive Zvezda & Skoog*). Right, the sign "Maket" (Puppet or mockup) used by Ivan Ivanovitch.

A crew of Zvezda specialists led by F. A. Vostokov (Figure 11) was sent to the space launch center Baikonur to verify and prepare Zvezda-delivered hardware for the Gagarin flight. The crew consisted of several support groups, including a group for preparation of the suit and life-support system led by I. P. Abramov. Vitaly Svertshek, the main member of the first group, assisted and instructed Yuri A. Gagarin (Figure 12) and subsequently G. S. Titov in the donning process and performed suit leakage tests at the launch pad when the cosmonaut was onboard the spacecraft (now Vitaly Svertshek is the First Deputy General Director and General Designer of Zvezda).

Figure 11: The team, which prepared the space-suits and other Zvezda equipment for Gagarin's flight in Baikonur (*Archive Zvezda*).



Figures 12 and 13: Left, Vitaly I. Svertshek assists Yuri A. Gagarin in space-suit donning prior to the mission on 12 April 1961. Right, official photo of Yuri A. Gagarin taken after the flight (*Archive Zvezda & Skoog*).

It is appropriate to indicate that the cosmonaut's performance capabilities in a space mission were inadequately studied in the period preceding the first human space mission. Therefore, the space-suit was equipped with many automatic devices used to close the helmet visor, open a breathing valve after landing, inflate floatation means, and perform other functions.

Nevertheless, the many specialists involved in the support of the mission were concerned about the final results. This subject was under discussion even during the last days and hours before the flight. The discussions resulted in a proposal to fit to the parachute suspension harness a plate bearing a sketch that explained how to open the suit helmet if a cosmonaut would fail to do so.

Moreover, to identify the nation the pilot belonged to, the decision was made to paint "CCCP" (the USSR) on the helmet. This last-minute decision was materialized after Gagarin had already donned the space-suit (Figure 13). A Zvezda test engineer, Victor Davidyantz, painted "CCCP" on Gagarin's helmet at the cosmodrome.[4]

Because of the tight schedule, a considerable part of the test program was performed with simultaneously run test phases and called for a considerable number of test models. The SK-1 suit manufacturing program included 8 suits produced in 1960, 23 suits in 1961, and 9 suits in 1962. This quantity included training suits and flight models worn by Yuri A. Gagarin and Titov in 1961, A. G. Nikolayev and P. R. Popovich in 1962, and V. F. Bykovsky in 1963.

After G. Titov's flight onboard the *Vostok 2* spacecraft, certain changes were introduced in the SK-1 suit design to improve its reliability and operation. The changes concerned primarily the suit life-support system.

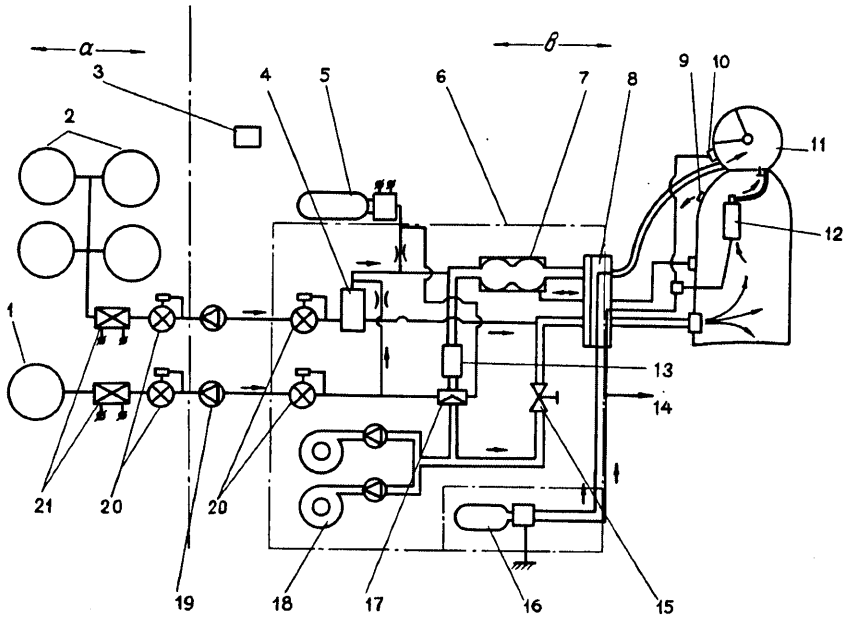
To support vital functions of the cosmonaut wearing a full-pressure suit, the *Vostok* spacecraft was equipped with a system that ensured the needed physiological hygienic conditions under the suit enclosure. Main components of the system were built into the ejection seat and arranged on the suit. Compressed air and oxygen bottles to maintain gas pressure in the suit and supply oxygen in case of emergency decompression of the cabin were installed outside the spacecraft in the instrument module (Figure 14).

A decision was made to extend, starting from *Vostok 3*, the duration of the independent life support of the cosmonaut in a sealed suit for as long as it was needed for the cosmonaut to release the parachute canopy, get rid of the suspension system, and get in the emergency kit boat. Only when these operations were completed, it was time for the respiratory valve to be automatically open (Figure 15).

The SK-2 Suit

The SK-2 suit is the model specially developed for the flight of Valentina Tereshkova, the first female cosmonaut. The SK-2 suit differed from the SK-1 suit mainly in the enclosure cutout that took into account specific features of a female body. The enclosure featured a decreased shoulder breadth, an increased

hip girth and a decreased opening in the neck partition. In accordance with the decreased shoulder breadth, the load bearing system of shoulder joints was modified to retain arm mobility. To support the test, training, and flight programs of V. Tereshkova, eight SK-2 suits were manufactured in 1962.

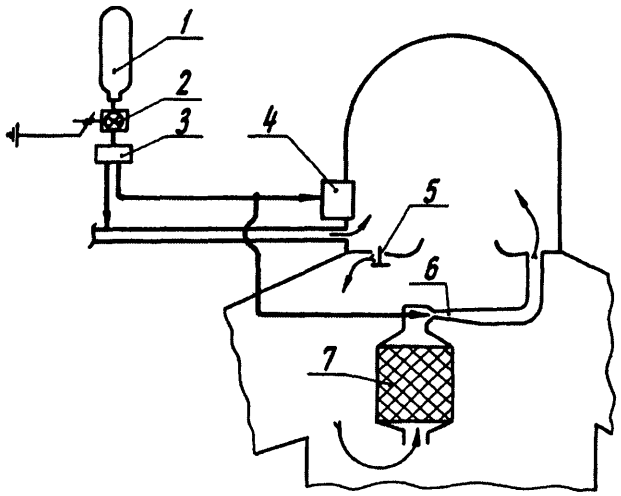


Flow diagram of the self-contained life support system in the *Vostok* space-suit: (a) detachable module; (в) re-entry capsule; (1) primary oxygen bottle; (2) air bottles; (3) barometric relay; (4) oxygen regulator; (5) oxygen and ventilation unit; (6) ejection seat; (7) additional reservoir or bag; (8) interface; (9) SS pressure regulator; (10) breathing valve; (11) space-suit; (12) life support unit (provides for breathing during and after splash-down); (13) silencer; (14) to floating means; (15) ventilation control valve; (16) oxygen parachute device; (17) pneumatic shut-off valve; (18) fan; (19) check valve; (20) reducer; (21) electropneumatic valve.

Figure 14: Flow diagram of the *Vostok* cosmonaut wearing the SK-1 suit (sketch from 1975 for MAI) (*Archive Zvezda*).

The First EVA by Alexei Leonov

Flights of the *Vostok* program were still under way when conceptual studies for future missions (*Soyuz*, orbital stations, and a Moon program) were initiated. In line with these programs the activities on full-pressure suits for space crews were initiated. There were two definite directions of activities, specified by the designation of the space-suits: rescue of the space crew in case of spacecraft cabin decompression or an onboard life support system failure (IVA-suits); and support of EVA periods in free space or on the Moon surface (EVA-suits).



(1) oxygen bottle; (2) starter; (3) mechanism for switching over oxygen flow from the helmet ventilation line to the injector at altitudes below 4 km; (4) valve automatically open after depletion of bottled oxygen to let ambient air in for breathing; (5) exhalation valve on the neck partition; (6) injector; (7) cartridge with CO_2 absorber.

Figure 15: Flow diagram of the *Vostok* cosmonaut life support system after the separation from the ejection seat (*Archive Zvezda*).

Sergei Korolev believed that in the initial stage of space development the crucial part would belong to habitable orbiting stations, where much attention would have to be paid to cosmonaut extravehicular activities. Thus early experiences of EVA activities were of great importance, to find out the influence on and the behavior of the human body in a full-pressure suit in void space. The initiation of the first EVA mission started in 1964 and was scheduled to take place with *Voskhod 2* in early 1965.

By June 1964, when activities on the first EVA suit for the *Voskhod 2* program were initiated, the experience of developing space-suits was rather limited. Therefore, specific parameters and design concepts of the suit and LSS were selected, in many respects, on the basis of experience gained in the process of development of air crew life support technology and full-pressure suits (SK-1) for the *Vostok* program.

In the *Voskhod 2* program the Berkut (Figure 16) full-pressure suit had the dual purpose of protecting the crew in case of cabin decompression (IVA) and supporting EVA periods. In the IVA mode, the system for ventilation and emergency pressurization of the suit in the cabin was similar to that of the *Vostok* spacecraft but designed for simultaneous activities of two crew members. For the EVA mode, an additional life support pack was designed.

The Berkut full-pressure suit, in contrast with the SK-1 suit, featured a removable helmet with a two-layer sliding visor and a light filter. Overalls with a multi-layer shield vacuum insulation were worn above the suit. The suit featured a dual bladder and two operating pressure modes (400 and 270 hPa).

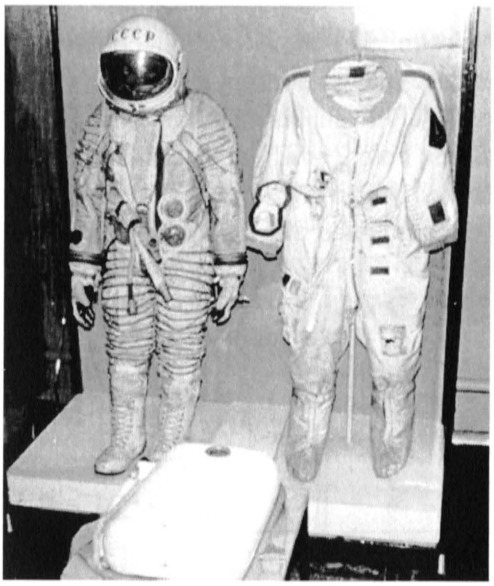
Because tasks of the world's first EVA were rather limited, the cosmonaut vital functions were supported by the most simple and reliable open loop, ventilation type system assembled in a backpack and designed for 45 minutes of operation. The system had a backup oxygen supply from bottles located in the airlock and an emergency umbilical (7 meters) from the airlock.

Zvezda developed the necessary equipment for this flight, the space-suit Berkut, the life support pack, and the inflatable airlock (Figure 18), in fewer than nine months. Despite the fact that the non-human precursor mission *Cosmos 57* on 22 February 1965 failed, Sergei Korolev decided to go on with the human launch as planned. This was justified by the fact that all data concerning the in-orbit operation of the airlock showed normal functions. *Cosmos 57* was blown up in orbit due to an erroneous telemetry signal and was not connected to the airlock modification. The stable descent of the *Voskhod* vehicle with the airlock attachment ring was proven on *Cosmos 59* on 15 March 1965.

On 18 March 1965 Pavel I. Belyayev and Alexei A. Leonov were launched on board *Voskhod 2*. After the inflation of the airlock, Leonov performed the first EVA of 12 minutes outside the *Voskhod 2* (Figure 17). The total time under pressure in the suit (EVA plus airlock operations) was 22 minutes. Both cosmonauts wore a soft space-suit, whereas Leonov was equipped with the additional life support pack. The EVA was successful, but when reentering the airlock Leonov had some problems due to a ballooning of the suit, and had to be supported by Belyayev.

The Yastreb Suit for the *Soyuz 4* and *5* Missions

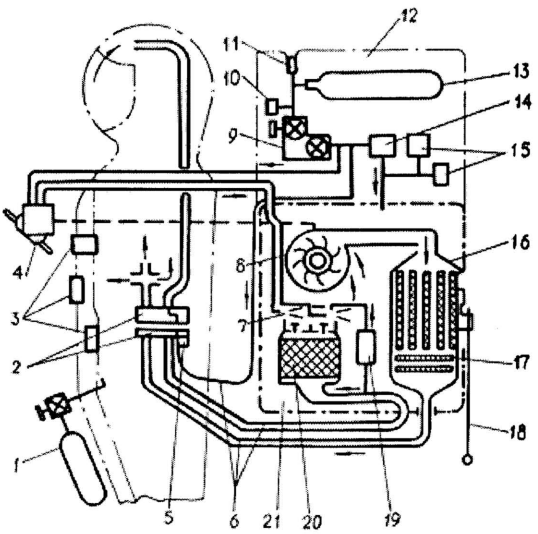
An integral part of each EVA is the operations, which have today already become routine: airlock operations, passing through hatches, and transfer along the outer surface of the space stations. For initial development of these operations, there was planned a two-cosmonaut transfer from one *Soyuz* spacecraft to another through open space. Originally a flight test was planned for the *Soyuz 1* and *2* mission in April 1967, but because of the mission abort of *Soyuz 1* and the sudden death of Vladimir M. Komarov during landing, the test flight was not performed until 14–18 January 1969, when Yevgeny V. Khrunov and Alexei S. Yeliseyev on 16 January transferred from *Soyuz 5* to *Soyuz 4* in a 37-minute EVA (one hour total in pressurized suit) using the new Yastreb suit.



Figures 16 and 17: Left, the Berkut space-suit with Life Support Pack (*Archive Zvezda & Skoog*). Right, A. A. Leonov during first EVA ever on 18 March 1965 (*Archive Zvezda*).

Figure 18: *Voskhod 2* with Airlock (at RKK Energya Museum) (*Archive Skoog*).

The Yastreb soft suit (Figure 19) is similar to the Berkut one, but had been modified taking into account the experience gained during Leonov's EVA. Furthermore, the Yastreb suit was designed solely to support EVA and thus was improved to ensure unassisted donning in orbit before an EVA (one should take into account that the use of IVA-suits for the first *Soyuz* flights was not foreseen). The helmet design was changed (sun visor was mounted outside the helmet) in addition to supply lines design and arrangement.



Figures 19 and 20: Left, the Yastreb space-suit for *Soyuz 4* and *5* (*Archive Zvezda & Skoog*). Right, Yastreb LSS (*Archive Zvezda*).

The life support pack (Figure 20) was strapped to the legs of the cosmonaut to reduce the overall size passing through the narrow (0.66 meters) hatches. Originally the Zvezda design envisaged the use of a backpack, but tests in July 1966 showed that a hatch diameter of at least 0.70 meters was required. On 4 August 1966 the final design of a LSS pack strapped to the legs was agreed on, because of the fact that the *Soyuz* vehicle could not be modified in time for the first flight in early 1967. The life-support system was of the closed-loop type providing air cooling and CO_2 removal, with an oxygen supply for 2.5 hours at 400 hPa. The life-support pack was pressurized by oxygen to reduce mass and increase heat removal capacity for electrical equipment, but also required a stringent design and testing for safety. This concept was proven safe during the *Soyuz 4* and *5* mission, and a life-support system contained in the oxygen suit atmos-

phere has been used on all later space-suit designs by the Soviet–Russian experts. The operation of a regenerative suit system for the first time became the start in the development of future, novel, more sophisticated, life-support systems of the closed type.

It is appropriate to indicate that the activities on the development of the *Soyuz* suit LSS ran in parallel with development of similar components for a suit LSS within the Moon program. Therefore, certain problems were under investigation in two programs simultaneously.

The Space-Suit for the Soviet Lunar Program

The Lunar Surface Suit

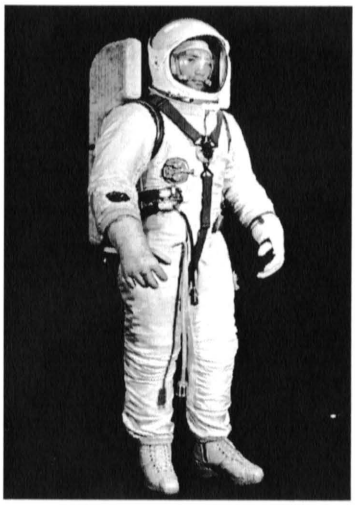
In the early 1960s Zvezda worked on space-suits for the Soviet lunar expedition, the L-3 project. The project envisaged the availability of two EVA space-suits onboard the lunar spacecraft. One of the space-suits was intended for a cosmonaut who was to land on the lunar surface and make a lunar EVA ("Moon-walk"), and the other one was for the mission commander, staying in a lunar orbit, to allow the commander a spacewalk if necessary.

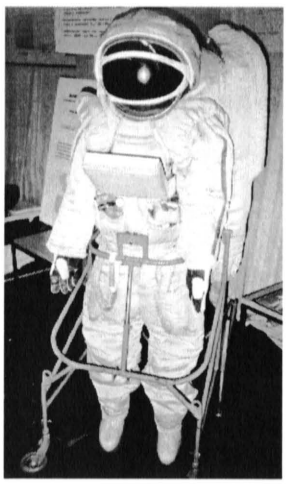
At that time two EVA space-suit design concepts competed with each other, both in the Soviet Union and the United States. The design concepts were the above-mentioned "classic" concept (a soft enclosure plus a removable back-pack), successfully used by *Voskhod 2* and *Soyuz 4* and *5*, and a space-suit concept with a hard upper torso and a built-in life support system.

By 1966 Zvezda had developed lunar surface space-suit mock-ups of both design concepts: the soft Oriol (Figure 21) and the semi-rigid Krechet (Figure 22). In the course of numerous tests and keen discussions, the second, semi-rigid, design concept (Krechet) became the preferred one. The principal design features of a semi-rigid space-suit are a hard upper torso integrated with a helmet and a backpack and soft arms and lower torso. The selected Soviet–Russian approach used a large hatch at the back of the torso to provide unassisted, easy, and fast donning/doffing. The backpack is an integral part of the hatch door concept and accommodates a major part of the life support equipment in a pressurized environment. The same design concept was also used for the semi-rigid Orlan EVA space-suit to be used in the orbiting spacecraft.

Both the Krechet and the Orlan suits were fully qualified and ready for flight by 1969, but were never put into operation because of the termination of the lunar L-3 project in 1973. The design features of the Krechet lunar suit (Figure 22) were governed by the requirement of mobility on the lunar surface (1/6

gravity) for up to 10 hours in an autonomous mode. The leg design contained soft thigh joints with two degrees of freedom to allow for walking on the lunar surface. Special boots with improved thermal insulation were developed. The suit enclosure had a thicker thermal protection than the Yastreb suits. The soft parts used a dual-bladder concept for increased safety. The helmet had double visor and two light filters (one for sun, another for shade).





Figures 21 and 22: Left, the soft lunar suit concept Oriol (*Archive Zvezda*). Center and Right, the Lunar Mission Krechet space-suit (*Archive Zvezda & Skoog*).

The life-support system used a dual-mode pressure control. The cooling system used water with a liquid cooling garment and a sublimator/heat exchanger provided the cosmonaut with a thermal comfort for practically any metabolic rate. All critical components were redundant. The only limitations for the EVA were the amount of stored consumables (oxygen, water, and CO_2 removal cartridge) and the physical tolerances of the cosmonaut. For the autonomous control of the suit, a hinged chest display and control unit was used. The suit was also equipped with electrical power supply and radio communications equipment.

The Lunar Mission Commander Space-Suit Orlan

The space-suit for the Lunar Mission Commander, the Orlan suit, was designed for on orbit use only, that is, to be used for emergencies and unscheduled support of the lunar cosmonaut on return to the command module.

The Orlan (Figure 23) suit design was similar to that of the Krechet suit but included the changes corresponding to its orbital purpose. Those changes were made to decrease the suit dimensions and mass. Unlike the Krechet suit, the Or-

lan thigh joint had one degree of freedom (flexion–extension), the helmet had only one sun filter, the chest panel had smaller dimensions fixed on the suit body, and the thermal protection had less layers. Power supply and radio communications were provided by means of an umbilical. The overall operational time for the Orlan suit was five hours, which reduced the overall size of the life support backpack. Other design features like the dual-pressure mode (nominal/emergency), dual bladders, rear entrance, and basic concept (not size) of the life-support system were kept the same as for the Krechet suit.

Figure 23: The Lunar Mission Commander space-suit Orlan (*Archive Zvezda*).

A common design approach of using a hard upper torso with soft limbs permitted the sizing for each cosmonaut to be done by the soft limbs only, and allowed for the use of one suit by different crew members. Arm and pant enclosures were fitted with a cord system, which made it possible to adjust the suit in accordance with the cosmonaut's height. Suit gloves were removable and tailored for each cosmonaut. This would turn out to be of great advantage for space station use, where the suit could be maintained in orbit for long-duration and multi-crew usage.

The Orlan space-suit from the Moon program was to become the origin of a family of space-suits for the *Salyut 6* and *7*, and later the *Mir* space station. For use on *Salyut 6* starting in 1977, the first Soviet EVAs since 1969, a modified version, the Orlan-D suit, was developed.

Summary

In the first decade of the Soviet human space program no less than five fully operational EVA/IVA space-suit systems were developed. In the *Vostok* project alone not less than 48 suits for testing, training, and flight were manufactured in less than three years.[5]

At an early stage all know-how and capabilities for space-suits (and aeronautical full pressure suits) were concentrated in one company, Plant No. 918, today's JSC RD&PE ZVEZDA, and most of the people involved in the development of the first suits for the *Vostok* project continued working with Zvezda to the present day.

Table 2: Soviet Space-Suits in the 1960s

Suit	Program	Operational	LSS Type	Time of Operation in Depressed Mode, Hrs	Suit Operating Pressure hPa	Mass kg	Performed EVAs EVA Time Suit Press. Time
SK-1	*Vostok 1* to *5*	1961	Open	5,0	270	25	(IVA)
SK-2	*Vostok 6*	1963	Open	5,0	270	25	(IVA)
Berkut	*Voskhod 2*	1965	Open, portable	4,0 (0.75 for EVA)	400/270	Suit: 20 LSS: 22	18 Mar 1965 12/22 min
Yastreb	*Soyuz 4–5*	1969	Closed, portable	2,5	400/270	Suit: 20 LSS: 31,5	16 Jan 1969 37 min /1 hr
Krechet	Lunar Project L-3	(1969)	Closed, with LCG, integrated backpack	10	400/270	106	—
Oriol	Lunar Project L-3	—	(Closed with LCG, separate backpack)	(4)	400/270	Suit: 20 LSS: 36	—
Orlan	Lunar Project L-3	(1969)	Closed, with LCG, integrated backpack	5	400/270	59	—

The early development of space-suits and the experience gained during the 1960s resulted in two distinct lines of suits: (1) *Vostok*, Berkut, and Yastreb until today's soft IVA suits for *Soyuz*: Sokol suits; and (2) *Vostok*, Berkut, Yastreb, Krechet/Orlan until today's semi-rigid EVA suits for *Mir* and *ISS*: Orlan suits.

The basic design features (Table 2) for these two-suit families are such that cosmonauts performed 25 years of "ferrying" to the *Salyut*, *Mir*, and *ISS* stations in *Soyuz* capsules and almost 1,000 hours of EVAs without any failure.

Despite the large development effort in the 1960s the only practical use of the space-suits, except for the *Vostok* flights, were the two flights with *Voskhod 2* and *Soyuz 4* and *5*. Both of these flights were, though historical, the first EVA by Leonov from *Voskhod 2* in March 1965 and the first EVA crew transfer by Khrounov and Yeliseyev between two space vehicles from *Soyuz 5* to *4* in January 1969.

The fully developed suits for the Soviet lunar program never entered into service because of the failure of the N-1 launch vehicle program. This semi-rigid technology with a rear entry and the life-support system components in an oxygen atmosphere though formed the basis for the Orlan suits used on all Soviet–Russian space stations from 1977 on.[6]

Reference Notes

[1] I. P. Abramov, G. I. Severin, A. Y. Stoklitsky, and Å. I. Skoog, "From Gagarin's Space Suit to Orbital Based Space Suits," International Space Forum 2001, 11–13 April 2001, Moscow.

[2] Boris V. Chertok, *Rockets and People,* volume II (Moscow: Maschinostroeinie, 1996). English translated version published as part of the *NASA History Series*, NASA SP-2006-4110, Asif A. Siddiqi, Editor, 2006.

[3] The space-suits were at this time given the same designation as the spacecraft. The first human version of the *Vostok*-type spacecraft was the *Vostok 3* (or V-3). V-1 and V-2 were robotic versions.

[4] The reason to paint "CCCP" on the helmet was because of the fact that the very first human spaceflight was not publicly known, and less than a year before Gary Powers landed in the Soviet Union after having been shot down in the famous U-2 incident. How should a farmer out in the steppe know that the pilot was a Soviet cosmonaut and not a U.S. spy pilot in case he would be unconscious?

[5] I. P. Abramov and Å. I. Skoog, *Russian Spacesuits* (Chichester: Praxis Springer, 2003).

[6] Abramov and Skoog, *Russian Spacesuits.*