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On Creating the World's First Strategic Long-Range Missile R-7 and Its Control System

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The development of the R-7 (8K71) rocket was made according to the Government Resolution dated May 20, 1954.

The chief manufacture OKB-1 (special research bureau) at NII-88 (chief designer S.P. Korolev) and co-manufactures: OKB-456 (engine, chief designer V.P. Glushko), NII-885 (control system, chief designers M.S. Ryazansky and N.A. Pilyugin), NII-10 (giroinstruments, chief designer V.I. Kuznetsov), GSKB "Spetcmash" (Barmin's Spetcmash bereau) (ground-based equipment, chief designer V.P. Barmin) were assigned according to the Resolution.

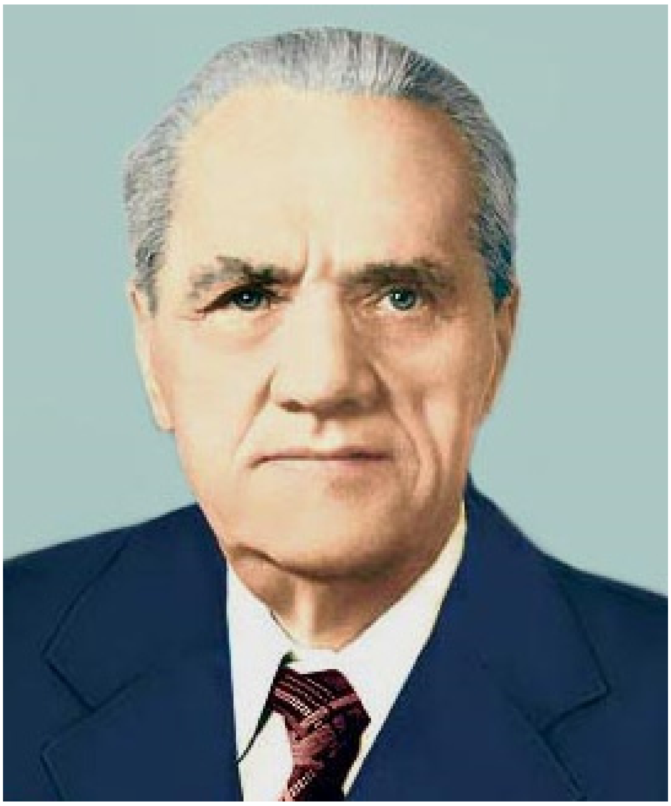
The preliminary design on the R-7 rocket complex was completed in July 1954.

The commission of experts headed by M.V. Keldysh, the president of the USSR Academy of Sciences, was formed for consideration of the preliminary design. The commission included prominent scientists and representatives of the customer. The commission of experts concluded that the materials of the preliminary design proved correctness of the choice of the schematic diagram for the rocket, its propulsion systems, and flight control system with the ground-based equipment and could be the basis for further efforts.

On November 20, 1954, the preliminary design of the R-7 rocket was approved by the Council of Ministers of the USSR.

Ryazansky Mikhail Sergeyevich

Deputy Director General for Science at NII-885 during 1955-1985, Chief Designer of the R-7 radio control system



Pilyugin Nikolay Alekseyevich

Chief Designer of the R-7 autonomous control system during 1955-1963

The R-7 was a two-stage vehicle built according to the cluster configuration. Its first stage consisted of four side units symmetrized around the central unit, which, in its turn, was the second stage (Fig. 1).

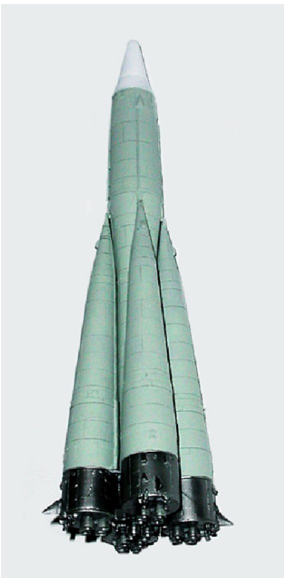


Fig. 1. The R-7 general appearance

The central stage included an instrument section, oxidizer tanks (cooled oxygen), fuel (kerosene) tanks, and propulsion.

The development of the design documentation for the missile system and its components began in 1953.

The first flight model of the rocket was sent to the newly-built research test site Tyuratam (Baikonur) at the end of 1956.

The creation of the test site was made according to the Resolution of Council of Ministers of the USSR of 12.02.1955, which was called "On the new research test site for the Ministry of Defence". The Resolution provided:

− creating in the period of 1955–1958 a research test site of the Ministry of Defence for flight development of the R-7 components and equipment, "Burya" and "Buran", with headquarters of the test site located in the Kyzylorda and Karaganda regions of the Kazakh Soviet Socialist Republic (KSSR) in the region between Kazalinsk and Zhosaly, an area of falling of the parts of products in the Kamchatka region of the Russian Soviet Federative Socialist Republic (RSFSR) at the cape Ozoyrny, an area of falling of the first stages of the R-7 in the territory of the Aktobe region of the KSSR near the Tangiz Lake;

− preparing in a three-months period the organization actions on construction of the specified research test site .

The choice of the place for the research test site was a very difficult task since the preliminary design of the R-7 involved obligatory existence of a radio control system. The system demanded a symmetric arrangement of the main and mirror points of a radio system on both sides from the launching pad at the distance of 250 km, which was defined by the need to ensure the accuracy of measurement of a side deviation of the rocket during a boost phase.

The location options for the research test site in Transcaucasia and in the Far East were rejected.

The launch-site data acquisition and measurements system consisted of the ground stations equipped with radio engineering and optical systems for trajectory parameters measurement was created as a part of the research test site on the extensive territory on the R-7 flight route and on the fields for head parts falling.

Building of launch and technical facilities, automobile and railroads, houses and social and cultural life institutions was developed to solve these tasks.

People who in severe climatic conditions had to perform tasks of the government in short terms were the main force.

On January 15, 1955, the first group of military builders under the command of the senior lieutenant I.N. Denezhkin arrived at the Tyuratam station. The first building of the inhabited area for test engineers, the Zarya settlement (the present city of Baikonur), was put already on May 15, 1955.

In December 1956, plane flights of all launch-site data acquisition and measurements system stations were carried out, and the special commission made the conclusion about their normal functioning and readiness for service.

The difficulties, which military builders and test engineers met during creation of the research test site and its measurement complex, were connected not only with severe climatic conditions, but also with extremely short deadlines of construction and lack of experience of building similar objects.

In March 1957, the first R-7 rocket for carrying out development flight tests (DFT) arrived to a technical position of the test site.

On April 10, 1957, the meeting of the State commission on carrying out the DFT took place. The state commission was approved by the Council of Ministers of the Soviet Union. V.M. Ryabikov from GU Glavspetsmontazh of the Ministry of Medium Machine-Building Industry of the USSR was appointed its chairman, and S.P. Korolev became its engineering manager.

On May 15, 1957, the State commission signed the act of acceptance of a launch pad and readiness of the test site for the first launch of the R-7.

The first missiles launches (on May 15, on June 11, and on July 12, 1957) were emergency, generally because of malfunctions of the propulsion system.

The fourth launch on August 21, 1957, was successful, and the rocket reached the targeted region for the first time.

A combined (radio- and autonomous) control system for the strategic ballistic missile R-7 providing the set deviations of a rocket head part was created in NII-885. At the same time, the integrator of the apparent velocity of the autonomous system was adjusted on the border of the area of possible switching off the engine corresponding to flight of the head part from the purpose on range.

Two new complexes were formed in NII-885 for solving this task: the Complex No. 1 for development of an autonomous control system headed by N.A. Pilyugin and the Complex No. 2 for creation of a radio control system headed by M.S. Ryazansky.

The Complex No. 1 included four departments:

− for stabilization machine development (department head G.P. Glazkov);

− for design and theoretical efforts (department head M.S. Khitrik);

− for development of complex schemes, power supply system and onboard cable system (department head Ya.S. Zhukov);

− for creation of element means (department head M.S. Doynikov).

The Complex No. 2 included two departments:

− for development of low frequency equipment and a complex in general (department head Ye.Ya. Boguslovsky);

− for development of high frequency equipment and antenna systems (department head M.I. Borisenko).

Chief designers N.A. Pilyugin and M.S. Ryazansky were the outstanding scientists, both of them were included into the legendary Council of Chief designers created by S.P. Korolev in Germany.

The strategic R-7 rocket had considerable design differences in comparison with small range missiles. Due to this fact the autonomous control system was faced to solve a number of tasks of the accounting of the parameters, which influence the control accuracy in earlier developed control systems were not so considerable.

As a result, the autonomous control system besides traditional functions on stabilization of the rocket body in space, stabilization of the center of mass with respect to the planned trajectory and control function on flying range provided continuous velocity vector control of the rocket and regulation of process of fuel tank draining. It was implemented in the created systems of normal and side stabilization of the rocket center of mass, regulation system of phantom velocity (PVR), tank draining system (TDS), as well as in regulation system consumption and ratio of fuel's components. The autonomous system operated these processes during the flight of the first stage, cluster staging, and flight of the second stage. The radio system made correction of the rocket movement in the side direction and control in range by outputting the side commands and a command for of the engine switching off. Control engine chambers and air vanes were the executive bodies of the control system.

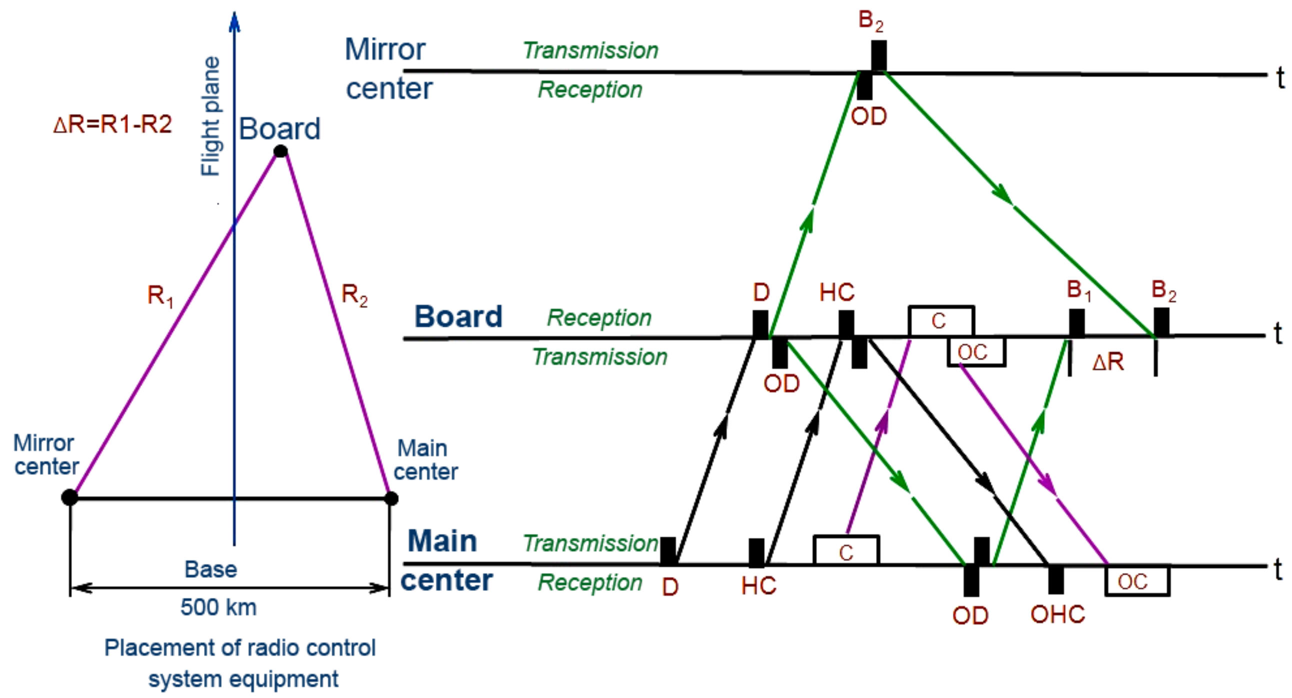


Fig. 2. Scheme of radio signal transmission in the radio control system of the R-7

A special modeling equipment with standard devices was installed at the Complex No. 1 stand for development tests of control processes and the choice of optimum interaction of the autonomous and radio control systems. An analog type computer was installed in the equipment to simulate dynamic characteristics of the rocket as a subject of control.

Subsequently, the simulating installation was used for carrying out functional control of standard devices before their delivery to the head enterprise.

The system of radio control was a pulsed and ranging system incorporating a ground and onboard equipment. The ground equipment was placed on the main and mirror points. The onboard receiving and transmitting equipment was placed in the instrument section of the rocket and was interfaced to the autonomous control system.

Radio control in range was made based on measurement of six movement parameters.

Measurement of movement parameters and command transmission of control in radio system was effected using a common pulsed multichannel radio communication line operating in the X-band of radio waves with coded signals.

Fig. 2 shows a scheme of radio signal transmission in the radio control system of the R-7.

Composition of the parameters being measured:

1. Radial velocity $\dot{R}$. Radial velocity measurement was carried out by discrimination of Doppler frequency increment of one of the spectrum harmonics of complex signals in the form of a narrow pulse packet sent from the main center and then retransmitted back.

2. Radial range R. Radial range measurement was effected by the method of active radiolocation.

3. Side deviation from the flight plane ΔR. The measurement was executed as difference of distances between the rocket and main and mirror centers.

4. Velocity change of side deviation $\Delta\dot{R}$. The measurement was a result of differentiation of the side deviation value being measured.

5. Elevation and speed of its change β and β. The measurement was carried out with a special radio direction finder built based on the method of amplitude-pulse modulation.

Side radio correction of the flight was carried out onboard the rocket by development of the signals corresponding to the measured side deviation and side velocity with respect to the flight plane with the amendment considering influence of the Earth rotation. To do this the results of measurements of a corner of the place β and the velocity of his change β made by a radio direction finder were used. These signals arrived in the amplifier-converter of the automatic machine of side stabilization of the autonomous system and were transformed into the commands sent to the mechanisms of turn of the rocket in the angle of yaw.

Originally, the system of radio control possessed an essential disadvantage: it did not allow one to carry out change of the flight direction of the rocket in the acceptable sector of angles.

Later, the equipment of the main point station involved a station of side control with a computer determining the size of side velocity, which needs to be reported to the rocket by the time of the engine switching off to compensate the accumulated disturbances at the end of an active lag of the flight to satisfy this requirement.

A calculation algorithm for problem solving of side velocity value included all six movement parameters being measured.

The station of side control formed the commands arriving aboard the rocket for giving it the corresponding angle of yaw.

The commands of side control had a discrete character and were designated as "Big left", "Small left", "Zero", "Big right", and "Small right".

The solution of a control algorithm in range was executed by the computing device located on the main station, which based on the current information on the movement coordinates of the rocket, gave a command for the engine switching off at the moment when a combined value of this information reached the set value. Switching off the engine for reduction of influence of dynamic disturbances occurred in two stages – on preliminary and main commands.

A ground equipment of the main station of the radio system was located in the settlement of Tartugay in the KSSR and placed at 13 stations having various functional purposes (receiving and transmitting stations, station of coder-decoders, station of timers, station of radial speed discrimination, station of computing devices, station of locational guidance of antennas, transmitting-receiving antennas, and radio direction finder).

The mirror station of the radio system was located in Sary Shagan settlement in the KSSR and served for retransmission of the radio signals radiated by the onboard equipment. The equipment of the mirror station was placed on 6 stations.

The onboard equipment of a radio control system incorporated the transferring and reception devices, onboard antennas (one was directed to the main station, another was directed to the mirror station), coder-decoder, device for antenna control and device of interface to the autonomous control system.

A preliminary flight development of the autonomous control system was made on the Р5РД rockets, and radio systems flight development occurred on the Р5Р rockets at their launch from the missile research test site Kapustin Yar.

The ideological foundation for creation of the radio control system was laid by the outstanding scientists of NII-20 who made the significant contribution to development of domestic telemechanics and radiolocation equipment, subsequently transferred to NII-885: B.M. Konoplev, M.S. Ryazansky, E.M. Manukyan, E.Ya. Boguslavsky. Considerable efforts were executed on the research of questions of radio wave propagation by the employees of NII-885 E.F. Dubovitskaya, K.I. Gringauz, Yu.S. Pavlov, M.I. Borisenko, and a number of the enterprises of the USSR Academy of Sciences.

Chief designers of radio control system at NII-885 were:

- E.Ya. Boguslavsky, M.I. Borisenko, F.I. Tokarev, G.A. Vilkov, A.M. Trakhtman, S.P. Peshnev, K.K. Zykov, R.A. Chigirev, E.A. Rozenman, G.Ya. Guskov, B.G. Sergeyev, V.A. Grishmanovsky (ground equipment);
- N.E. Ivanov, I.Ya. Sytin, E.P. Molotov, V.G. Buryak, V.F. Grushetsky, V.P. Kuzovkin, Yu.F. Makarov, T.D. Fatkina (onboard equipment).

With completion of the R-7 rocket development, including a rocket control system, following persons received high government awards: M.S. Ryazansky, N.A. Pilyugin, E.M. Manukyan, P.A. Tunik (laureates of the Lenin Prize); E.Ya. Boguslavsky, M.I. Borisenko, G.P. Glazkov and workers of the pilot-producing plant V.I. Ryabov, S.I. Mikhaylov (the Hero of Socialist Labour). In total, 304 employees of NII-885 were awarded with orders and medals.

Considering a great scientific, practical and social value of the efforts performed on creating a new technology, chief designers M.S. Ryazansky and N.A. Pilyugin became corresponding members of the USSR Academy of Sciences. Twelve employees of NII-885 were awarded a doctor of engineering science degree without defending a thesis.

During the R-7 and its control system creation a number of scientific and technical problems that laid a fundamental scientific and technical basis for further improvement of rocket and space developments was solved.

The R-7 and its control system became the basic for creating a number of modifications.

Thus, the two-stage R-7 rocket – carrier vehicle "Sputnik" (8К71ПС and 8А91) enabled three first Earth artificial satellites to be launched allowing one to start research of the near Earth space.

Three-stage launchers 8K72 with the E stage ("Vostok") and 11А511 with the I stage ("Soyuz") enabled one to start far space and Moon research, launch "Vostok" and "Voskhod" manned spacecraft and later "Soyuz" spacecraft. The four-stage rocket 8K78 with I and L stages ("Molniya") permitted far space and Moon research to be expanded, as well as to carry out the flights of automatic interplanetary probes to the Mars and Venus.

The R-7 rocket and its modifications enabled one to expand diversified space research and create conditions for the applied usage of rocket and space technology for benefit of science, defence and national economy. Later these missiles were used for launching spacecraft "Zenit", "Meteor", "Electron", "Progress", etc.

Nowadays research and experiments for scientific and national economy purposes are continued.

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Award of the Russian Federation Government in the Field of Science and Technology, Director of the History and Technology Museum

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