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SATELLITE TRACKING FACILITIES

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FOREWORD

This analytical report, prepared in response to ATD Work Assignment No. 101, discusses the organization, station network, optical tracking capabilities, and current observation programs of Soviet-bloc, primarily USSR, satellite observation stations. Emphasis is on the optical and radio facilities employed in near-space rather than deep-space tracking. The difficulties encountered by the Soviet Union in developing advanced tracking instrumentation and the methods elected to overcome them are outlined.

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I. Administrative Structure

The understandable and necessary cross-use of civilian and military tracking facilities characterized in the United States [1] by the activities of NASA's Office of Tracking and Data Acquisition, intended primarily for tracking reported launchings, and the USAF's SPADATS (Space Detection and Tracking System), intended as a space surveillance system for the detection of unreported and possibly hostile launchings, also exists in the USSR. There, ultimate responsibility for all launchings and operations, as General Tolubko has stated [2], resides with the USSR Strategic Rocket Forces. All non-military scientific and technical personnel associated with the Soviet space program, though they may be affiliated with and administered by one or another civilian research organization, are in the final analysis subordinate to military requirements. In the case of USSR tracking facilities immediate responsibility for day-to-day operations has been assigned to the Astronomical Council of the USSR Academy of Sciences under the administrative direction of A. Masevich and operational control of D. Ye. Shchegolev. Control over the operations of the tracking facilities in the satellite states is exercised through the Commission on Multilateral Cooperation—Project-Optical Observations of Artificial Earth satellites. The Commission is also subordinate to the Astronomical Council. The results of all observations are sent by coded telegram to the "Moskva-Kosmos" Computer Center and the Institute of Theoretical Astronomy, Leningrad, where the orbital elements are analyzed on BESM computers [3, 4]. The codes used between the stations and the control centers are given in Appendix I and II.

II. Soviet Station Network and Equipment

a. Station Network

Preparations for the first satellite launching on 4 October 1957 included the establishment of an extensive network of visual and photographic observation stations—first, in the USSR proper, then in the other Soviet-bloc states, and, finally, in other cooperating non-Soviet countries. Special training courses, organized by the Astronomical Council, were held for observation station chiefs months before the actual launching in the summer of 1957 at the Ashkhabad Astrophysical Observatory of the Turkmen Academy of Sciences. An observation instruction manual had been prepared by the Council and

I. S. Astapovich of the Ashkhabad Observatory. As early as 1958, the USSR officially reported the operation of 88 visual observation stations [5]. Adequate, if not sophisticated, visual and radio-tracking facilities existed from the start of the program. Photographic, photometric, and radar facilities were added later and have been under constant development. By 1960 there were 74 stations engaged in visual observations and 26 in photographic observations. Station personnel included some 3,300 university students and instructors [6]. Amateurs and DOSAAF (All-Union Voluntary Society for Army, Navy, and Air Force Cooperation) clubs have aided in observations from the outset. Appendix III lists Soviet-bloc optical and radio-tracking stations as reported by COSPAR [7]. The list gives station coordinates, equipment, and reporting procedures.

b. Station Equipment

A well equipped Soviet satellite observation station in the early 1960's would contain the following equipment [8]:

20—30	AT-1 telescopes
2—4	TZK telescopes
2—5	B7 x 50 binoculars
1	Riga-10 radio receiver
1	PRV radio receiver
1	pulse attachment for receiver
1	MKh-6 contact chronometer
2	printing chronographs (1 quartz)
10—20	stop watches
30	telegraph keys
1	audio frequency oscillating generator
1	MAG-8 m magnetophone
1	optical quadrant
6	Becvar sky atlases
20	Mikhaylov atlases
10	Wulff grids
1	astronomical yearbook
2—24	compasses

The principal characteristics of these and other instruments used at Soviet and other Eastern European stations for optical observations of artificial earth satellites are as follows [9]:

AT-1	- wide-angle telescope d = 50 mm magnification, 6 x diameter of field of sight, ∿11°
TZK (TPZ)	- binocular on a theodolite mounting magnification, 10 x diameter of field of sight, ∿7°
TZK - 1 photo	- TZK telescope with a camera for photographing the circles
Maksutov meniscus telescope with a plane-parallel glass plate	- d = 500 mm f = 1200 mm
KPP	- camera with a moving film without an "Uran-12" shutter objective d = 200 mm f = 500 mm
Astrograph	- d = 400 mm f = 1600 mm field of sight, 10° x 10°
Double-camera	- two aerosphotocameras with an "Industar - 17" objective d = 100 mm f = 500 mm
Camera with an oscillating plate-holder	- "Uran-16" objective d = 210 mm f = 750 mm diameter of field of sight, ∿31.5°
Three-axis automatic photo-camera	- "Uran-16" objective d = 210 mm f = 750 mm diameter of field of sight, ∿31.5°

c. Night Aerial Camera (NAFA) 3c/25

In 1957 the Astronomical Council assigned the Pulkovo Observatory tne responsibility of developing a suitable camera for satellite observations from existing night aerial cameras (NAFA) equipped with special high-speed shutters and an accessory for the precise recording of exposure times. D. Ye. Shchegolev, B. A. Firago, G. V. Banova and others modified the camera to the point that it could record the position of satellites brighter than the 4th magnitude with an accuracy of ±4" and the time with an accuracy of ±0.004^{s}. The NAFA 3c/25, consisting of a Uran-9 lens (F = 25 cm, D = 10 cm, field of view 32 x 52°), eventually proved most suitable for photographing bright satellites and became the standard camera at photographic stations [10]. A further improved version of this camera, the NAFA 3c/50, has now been introduced and is considered superior to its predecessor in synchronous satellite observations [11].

To photograph fainter satellites, L. A. Panaytov had earlier developed a camera capable of photographing satellites to the 7th magnitude. The film in this camera is fed at a rate close to that of the satellite image displacement in the focal plane of the camera. A Uran-9 lens is used in this camera as well [12].

Attempts have also been made at various USSR stations to use the FED, Leningrad, Kiev, Zorkiy, and Zenit-C small-aperture cameras for satellite photography, but with varying degrees of accuracy [13].

Essentially, the use of the NAFA 3c camera consists in obtaining a broken satellite track by means of a series of short exposures ($0^{s}.1$—$0^{s}.2$) on a single frame. The moments of shutter opening and closing are fixed by means of the printing chronograph. Star images are obtained on the same photograph. The coordinates of the satellite are determined from a star chart onto which the negative is projected. To obtain precise satellite positions, the negatives are measured on the KIM-3 coordinate-measurement machine or with the UIM-21 universal microscope. This method of reduction, developed by A. N. Deych and A. A. Kiselev, consists in the interpolation of the equatorial coordinates of two reference stars on opposite sides of the satellite track to the point where the straight line connecting the stars intersects the track [14].

An interesting experiment involving the use of the NAFA 3c/25 camera of the Zvenigorod Station to photograph a pulse source (IFK-2000 pulse lamp) mounted on an aircraft against the star background has been described by Lozinsky, et al. [15]. This experiment was undertaken preparatory to follow-up experimental photography and observation of satellites equipped with similar pulse light source.

Experiments have also been conducted in the USSR employing the use of a highly sensitive television installation for observing faint satellites. The transmitting camera of this installation, whose main component was a Gelios lens (D = 80 mm, F = 200 mm), was set on a paralactic mounting. The image size on the photocathode was 17'/mm, the field of view 9 x 9°, and the resolution, ~10 lines/mm. Using this installation, it was possible to observe and photograph satellites to the 8th and 9th magnitude [16].

d. Accuracy of Observations

Varying claims of accuracy have been published by Soviet investigators with respect to visual and photographic tracking in the USSR. In 1961 A. G. Masevich reported that good visual tracking was capable of accuracy to 0°.1 in position and $0^s.1$ in time, but that on the average, accuracies did not exceed $0^s.2$—$0^s.3$ in time and 0°.2—0°.3 in position. Standard cameras used in the USSR, she claimed, reached an accuracy of 6" in position and $0^s.002$ in time. The US Baker-Nunn cameras, she observed, excelled in time accuracy ($0^s.001$) [17]. In 1962 A. S. Sochilina claimed that visual observations made by means of the AT-1 telescopes had an accuracy of 0°.5 in position. Photographic observations made by means of small cameras had an accuracy of 0°.1. The NAFA-3 camera had an accuracy of 0'.1—0'.2 in position and $0^s.01$ in time [18]. According to G. V. Romanova, in 1967 estimates had been made on the accuracy of the determination of satellite coordinates by comparing satellite positions on photos obtained simultaneously by four NAFA-3c/25 cameras during synchronous observations of Echo satellites. The Turner method was used to reduce the photos on the Minsk-2 computer. Errors in α were found to be systematically greater than errors in δ because of inaccuracies in time recordings which reached 2—3 msec. On the average the mean quadratic error of $\sigma_\alpha = \pm 4''.4$, while that of $\sigma_\delta = \pm 3''.2$ [19].

By way of comparison, D. C. King-Hele lists the following position and time accuracies achieved in the West [20]:

Method of observation	Position accuracy, min. of arc	Time of passage accuracy, msec
12-m radar	5	1
Minitrack (radio)	1—2	1
Baker-Nunn camera (precise reduction of observations)	0.06	2
Hewitt camera	0.02	1
Baker-Nunn camera (preliminary reduction of observations)	1—2	2
Kinetheodolite (photographic observation)	0.5	5
Kinetheodolite (photovisual observation)	1	5
Theodolite (semiautomatic)	2	10—100
Visual method	1—2	100

III. Reduction of Observational Data and Compilation of Ephemerides

One of the first methods used in the USSR to reduce satellite observational data was proposed in 1959 by I. D. Zhongolovich, V. M. Amelin, and T. B. Sabanina. In this approximate method the satellite ephemerides and the conditions of satellite visibility were graphically found through the use of a map of the Earth in Mercator projection, the satellite path on tracing paper, and the zones illuminated by the Sun also on tracing paper. On the basis of the orbital elements and the solar ephemerides the successive positions of the tracing paper relative to the map were located and the conditions of visibility at a given point checked. If the required visibility conditions prevailed, the ephemeris was computed with the aid of other tables and graphs [21].

L. A. Sadovski later developed a method of computing n (satellite orbit number) after epoch T_0, when it can be observed at a given point φ, λ. It is assumed in this method that at epoch T_0 the satellite was over the horizon and could be observed at a reference point having the coordinates φ_m, λ_m. After the orbit number is found the satellite's topocentric coordinates are determined first according to the Zhongolovich method described above, and then at the moment the satellite has reached the highest point on the celestial sphere using formulas developed by Sadovski relating to the argument of the latitude $u = v + \omega$, orbital inclination i, the right ascension of the ascending node Ω, and the coordinates of the reference point φ_m, λ_m [22].

The standard tables and nomograms for the reduction of satellite observations, compiled by I. D. Zhongolovich and V. M. Amelin, were published by the Institute of Theoretical Astronomy in 1960. The tables can be used for satellite orbital inclinations from 0 to 90°, eccentricities from 0 to 0.76, and period up to 1728 minutes, while the nomograms can be used for satellites up to heights of 6400 km. Using the tables it is possible 1) to calculate the period of revolution and semi-axis from the satellite's mean diurnal motion; 2) to calculate for an elliptical orbit the values of v - M, i.e., the difference between the true and the mean anomaly, and the values of r/a, i.e., the ratio of the radius vector and the semi-major axis from two arguments: the mean anomaly M and the eccentricity e; 3) to calculate the geocentric equatorial and local geocentric coordinates; and 4) to determine the approximate values of secular perturbations of the satellite caused by the oblateness of the Earth. Using the nomograms, it is possible to determine the topocentric altitude and distance of the satellite [23].

In 1965 L. A. Sadovski published tables, complementing those of Zhongolovich and Amelin, for the reduction of observations of satellites with almost circular orbits. Using these tables, the satellite radius vector and its true anomaly from arguments for the mean anomaly and the eccentricity can be determined [24].

a. Space Triangulation

Two methods are used in the USSR to determine satellite position on the basis of synchronous or almost synchronous observations: 1) the method proposed by K. Popovici, which permits the use of observations which need not be strictly synchronous, and 2) the method of "closing directions," developed by B. M. Klenitskiy and G. A. Ustinov, which is more widely used and which has been adopted by the Astronomical Council [25].

In the Popovici method [26] the geocentric coordinates of the satellite are derived mathematically from the topocentric positions as determined at several different stations. It is only necessary to know the precise time of observation at the main station. It is sufficient at the second station to know only the topocentric trajectory of the satellite on the celestial sphere during the time period involved in the moments of observation at the main station. In studies made to determine the relative accuracy of the two methods, S. K. Tatevyan [27, 28] found that the discrepancy in the satellite geocentric rectangular coordinates does not exceed 30 m in the two methods if the angle formed by the intersection of the simultaneity circle with the satellite trajectory is about 90°, but can reach several hundreds of meters if it is smaller. The advantage of the Popovici method is that it can be used to reduce nonsynchronous and almost synchronous observations and that it may be used when stations unequipped with precise time recording devices have to be included in the triangulation network. A program has been established in the Astronomical Council to determine station coordinates by means of a simultaneity circle and the use of a Stela computer.

More recently, K. M. Kaverznev has described [29] a method for determining the coordinates of a space vehicle from measured distances between three widely separated points and the vehicle. A ranging device is used to measure distances between the three points, A, B and C, and the vehicle. The centroid of triangle ABC is found and, after correction is made for propagation distortion, the value of R is found, i.e., the slant range from the centroid of triangle ABC to the space vehicle. The rms error probability of H, the component of R perpendicular to the plane of triangle ABC, is a function of the rms error in the range measurement, the area of a triangle formed by paths between two adjacent measuring stations and the vehicle and the included side of triangle ABC, and the three distances between the centroid of triangle ABC and its apexes. The technique gives a fast and accurate solution of the range of a space object, irrespective of the geometry involved.

b. Nomograms to Predict Satellite Passage

Various nomograms have been devised by Soviet and East-bloc scientists to predict satellite passage. Prime Soviet effort seems to have been directed toward the development of a nomogram to predict the passage of satellites in circular orbit. This may reflect a special Soviet interest in those satellites whose missions are best carried out in circular or near circular orbits—possibly photography or docking operations. Such satellites are often returned to Earth after completion of their mission. Thus, V. A. Vorotnikov and P. M. Pershin have reported [30] the construction of a graph to predict the passage of a satellite in a circular orbit for a specific latitude. Knowing one passage, it is possible with the graph to predict satellite time and coordinates at the orbital point closest to the point of observation for all future passages up to a month in advance. This graph has been used successfully at the Yeniseysk station since 1962. Pershin [31] has also devised an azimuthal grid which, when used in conjunction with companion stereographic grid and table, makes it possible to precompute all past and future passages of satellites on circular orbits having a daily period. The computation of approximate ephemerides for a given satellite on all passages has also been examined.

In the GDR Professor Penzel and his colleague F. Berth of the Rodewisch station have designed a satellite ephemeris chart, which they call the Rodewisch Ephemeris, that can be used to determine the time and celestial location of the passage of a satellite through the zenith azimuth on any day and from any observation station. The data which must be fed into the chart, which is designed in the manner of a rotating celestial chart, are the orbital period and orbital inclination, the heights of perigee and apogee, the geographic coordinates of the launching site, and the time of launching. The opposite procedure, that is, the identification of observed satellites is also possible with the Rodewisch Ephemeris within approximate limits [32].

J. Vondrak [33] has designed a nomogram now used at the Pecny Geodetic Observatory, one of two stations for photographic satellite observations in Czechoslovakia, to determine the horizontal coordinates and time moments for specific points on the satellite flight path. This nomogram, compiled on the basis of Ephemeris 7, published by the Smithsonian Astrophysical Observatory, consists of a fixed and rotating part. On the basic fixed part appear a geographic coordinate net and curves of equal spherical distances and azimuths, while on the movable part are the satellite orbital elements which are viewed as constants. The nomogram reportedly can be used at any geographic latitude to precompute satellite passage.

c. Human and Instrument Error in Tracking Celestial Bodies

The problem of complications arising in the observation of celestial bodies (including satellites, meteors, high-altitude aircraft, etc.) due to the human or instrumental factor has been discussed in several papers. The Czech investigator J. Kabelac [34], for example, has discussed the problem of the refraction angle of rays passing through the atmosphere from an object in space to a ground observer for the cases where 1) the object is within the atmosphere (high-altitude target), 2) the object is beyond the atmosphere in near space (satellite, meteor), and 3) the object is at infinity (star). Theoretically this investigation is based on work performed by L. Oterma [Astr. opt. Inst. Univer. d. Turku, Informo No. 20 Turku 1960] and A. A. Baldini [GIMRADA, Res. Note No. 8, Fort Belvoir, Va. 1963]. Data for the construction of the atmospheric models are taken from COSPAR [COSPAR International Reference Atmosphere 1961]. A distinction is made in the various cases of the problem between astronomical refraction R_∞ and parallactic refraction $\bar{R}_H$. Kabelac has found that astronomical refraction R_∞ is not dependent on the momentary state of the atmosphere, while the expressions $\Delta R_{\Delta H}$ and ΔR_H, characterizing ray deviation when passing through a specific layer ΔH or to a specific height H, are very dependent on the existing state of the atmosphere, and therefore on time. The dependence is of the order of 1" for a zenithal distance of 45°. The influence is indirectly proportional to the height of the target above the place of observation and directly dependent on the air density. An analogous dependency obtains in the case of parallactic refraction, if the object is inside the atmosphere.

With respect to the human factor, Z. Kviz, another Czech investigator [35], on the basis of ten-year observations of some 21,488 meteors, has examined the question of the probability of a group of observers perceiving a meteor by means of the independent counting method. The empirical formula $p = [1 + e^{-k(\mu_0 - \mu)}]^{-1}$, valid for $p < 0.5$, is introduced to express the probability (p) dependence on the brightness of the meteor (μ). In this case, $\ln [p/(1 - p)]$ depends linearly on μ. The calculated probability value depends on the number of observers in the group, since such observations do not satisfy the ideal conditions under which the probability formulas would be entirely valid. The probability of meteor perception depends primarily on the brightness and apparent path length of the meteor in the field of view and only slightly, if at all, on other parameters. It is determined that an eight-member observation group would be most effective. Computation of the probability values was performed on the URAL-2 computers of the Czech Technical University and the Computer Center of the Czech Academy of Sciences as well as on the ZUSE Z 23 of the National Research Institute of Heat Engineering.

The Czechs, incidentally, have established a nationwide station network to photograph meteors, and have entered into an international agreement with the GDR for the same purpose [36].

Researchers at the Novosibirsk Institute of Geodesy Engineers, Aerial Photography, and Cartography have developed an instrument, employing a point light source which can be shifted directionally, to determine the differences which arise in observations attributable to the human factor. Its operating principle consists in the comparison of an observer's recorded moments of observation with those of the point light source as determined by means of a contact device [37].

The practical application of such studies is eventually reflected in tracking camera design and improvement. V. S. Plotnikov [38], for example, has shown how the selection of camera parameters depends on the nature of the object to be photographed and the environmental conditions. The main selection criterion, according to Plotnikov, is the choice of an exposure value expressed in lux seconds equal to the product of image illumination by the exposure. The dependence on the form of the object (point or elongated) is taken into account. Analysis of photographic records of rapidly moving and weak-brightness point objects obtained by a fixed or tracking camera has shown that the angular velocity plays an essential role in the determination of the necessary exposure. The entrance pupil of the objective must be enlarged and the focal length and scattering circle in the image plane must be made smaller. A maximal entrance pupil creating a relative aperture of 1:1 is considered most favorable. Using the deviation of the angular velocity and the illumination on the entrance pupil of the objective, Plotnikov found the optimal camera parameters and object brightness expressed in stellar magnitude.

IV. Soviet-Bloc Station Network and Equipment

In order to extend the satellite observation network beyond the borders of the Soviet Union, the Astronomical Council—acting through the Soviet International Geophysical Year Committee and the Presidium of the USSR Academy of Sciences—made arrangement in April 1957 to enlist the cooperation of the other Soviet-bloc nations, including China, the GDR, Czechoslovakia, Poland, Hungary, Rumania, and Bulgaria in tracking operations. Some 500 AT-1 telescopes were shipped to these countries in November—December 1957 for this purpose [39]. To further control and coordinate the operations of the satellite stations, the USSR Astronomical Council, acting in cooperation with the

Tashkent Astronomical Observatory, established an international school in Tashkent to train satellite observers. The project was enacted under the auspices of the Commission on Multilateral Cooperation. The school opened in September 1965 and was attended by 40 specialists from Bulgaria, Hungary, the GDR, Mongolia, Czechoslovakia, Poland, and the USSR. Lectures and practical exercises were conducted by scientists of the Astronomical Council, the Institute of Theoretical Astronomy, the Main Astronomical Observatory at Pulkovo, and the Tashkent Observatory of the Uzbek Academy of Sciences [40].

a. Soviet-Bloc Cooperative Tracking Programs

The USSR Astronomical Council acting through the Commission on Multilateral Cooperation currently has two major cooperative tracking programs in operation involving stations in the USSR, Poland, Bulgaria, Czechoslovakia, Hungary, and the GDR. These are: 1) INTEROBS—the simultaneous visual tracking of low satellites to determine short-period variations of perigee distance primarily for geophysical purposes, and 2) the synchronous photographic tracking of Echo I for geodetic purposes. The INTEROBS program, described detail in *Foreign Science Bulletin, no. 2, 1968*, was conceived by Dr. Ill in 1963 and initiated by GDR and Hungarian satellite observation stations. The program has been most successful in determining sudden upper-air density changes on the basis of simultaneous observations of the orbital elements of satellites. For some time now, INTEROBS has been broken down into two independent station networks—one international with the USSR participating and the other exclusively Soviet. INTEROBS I includes the Bautzen and Rodewisch stations of the GDR, the Brno and Skalnate-Pleso stations of Czechoslovakia, the Cracow and Olsztyn stations of Poland, the Cluj station of Rumania, the Stara-Zagora station of Bulgaria, the Baja and Budapest stations of Hungary, and the Riga, Kiev, Krasnodar, Dnepropetrovsk, and Chernovtsy stations of the USSR. INTEROBS II consists of the Riga, Arkhangel, Vclogda, and Ryazan' stations. Thus, the Riga station serves as the link between the two networks [41].

The Riga Satellite Observation Station of the Latvian SSR is important not only because it is the link station between INTEROBS I and II but also because of the contributions of M. Abele and K. Lapushkin to tracking technology. One of Abele's earliest cameras, designed especially for tracking faint satellites, combined the three-axis system of the Baker-Nunn camera with the Uran-16 lens system of Soviet manufacture. The camera (f' = 75 cm, D/f = 1:3.5) was capable of photographing celestial objects up to the 10.4th magnitude with a positional accuracy of ±0.5—1" [42]. Improvements have continued to be made.

The synchronous photographic tracking of Echo I, primarily to solve problems in geodesy, has been carried out by participating stations with the NAFA 3c/25 camera and a special timing device with an accuracy to 2 msec. The Czech OMA time system, described below, regulates observations. It may be noted that the USSR and USA chose the tracking of Echo II as their first reported joint space experiment.

In accordance with the recommendations of the First Conference of Representatives of the Commission on Multilateral Cooperation between the Academies of Science of the Socialist States on the Question of Optical Observations of Satellites (Leningrad, 1962), satellite observations have been tied to the OMA time signals. The coordinates of the radio stations of this system, the call signs, carrier frequency, stability ($1 \cdot 10^{-9}$), transmitter power (1—10 kw), transmission interruption times, and the transmission schedule are given.

The first regular transmissions of the Czechoslovak time signals began in 1955. At present the following transmissions are sent: 1. Round-the-clock transmission of second signals on a standard frequency of 50 kc, intended primarily for the automatic synchronization of the quartz clock generators within a radius of not less than 5000 km. 2. Round-the-clock transmission on the standard frequency of 2500 kc, intended for time and frequency measurement. 3. Round-the-clock transmission of second signals (OLB 5) on a frequency of 3170 kc. 4. Special transmission (OLD 2) on a frequency of 18,985 kc, intended to study time variations in signal propagation along the Prague-Tokyo path; the transmission is directed sharply to the Far East. The OMA radio station is located in Podebrady [43].

In addition to the two major Soviet-bloc cooperative tracking programs, viz., INTEROBS and synchronous satellite photography, the Astronomical Council through the Commission on Multilateral Cooperation has recently authorized participation in other programs. In May 1967 A. Masevich authorized satellite participation in Program SPIN, a research program proposed by Dr. Grigor'yevskiy, director of the Kishinev Satellite Observation Station. Program SPIN involves the tracking of objects in space, primarily final rocket stages, which exhibit variations in brightness due to tumbling and change in the period of rotation. The fourth program in which the satellite states may now participate is in observations to determine the draconic period of a satellite. This research project was originally proposed by Dr. Lozinskiy, director of the Zvenigorod Satellite Observation Station. Both project SPIN and the program to determine the draconic period have been developed for the purpose of establishing the relationship between events on the Sun and physical changes in the upper atmosphere. The findings will be used to develop a reliable means of predicting solar activity [44].

b. Satellite Observation Program of the German Democratic Republic

Owing to its relatively high level of scientific and technological accomplishment, wisely sustained by the USSR in critical areas (e.g., Carl Zeiss Works) in the post-war period, the GDR has played an important role in the Soviet space program. Though forbidden to develop an independent rocket or even aviation capability, GDR scientific and technological energies have been recruited under COMECON arrangements to support the Soviet effort. Organizationally, GDR space activities are administered by the [East] German Astronautical Society whose current officers are: President—Professor Johannes Hoppe, Director of the Heinrich Hertz Institute for the Study of Solar-Terrestrial Relationships; Vice President—Professor Hans Reichardt, Director of the Mathematical Institute of Humboldt University; Vice President—Dr. Eberhard Hollax, Institute of Nuclear Research; Vice President—Heinz Mielke, writer; and Scientific Secretary—Herbert Pfaffe. The international scientific activities of the tracking stations are coordinated by the GDR COSPAR Commission and the Working Group for International Geophysical and Geodetic Cooperation of the GDR Academy of Sciences in Berlin [45].

The following GDR Institutes and personalities are engaged in supporting research: The Lohrmann Institute for Geodetic Astronomy of Dresden Technical University, whose prime responsibilities are 1) to improve the techniques of precision time and position determinations, 2) to perfect passage instruments, 3) to make latitude determinations, and 4) to investigate the atmosphere in the vicinity of astronomical instruments [46]; the Jena Institute for Magnetohydrodynamics, under the direction of Professor M. Steenbeck whose research includes the development of experimental x-ray flash tubes which find application in the photography of projectiles in flight, bomb model detonations, shock wave propagation, and other high-speed processes [47]; the Kuehlungsborn Observatory for Ionospheric Research, which receives and processes weather satellite data with equipment developed by Dr. K. H. Schmelovsky; the Computer Center of the Potsdam-Babelsberg Observatory, which serves the ephemeris service; the Ilmenau Higher Technical School and Institute for Precision Mechanics; and most important, the Carl Zeiss Optical Works, Jena.

c. Tracking Equipment of the German Democratic Republic.

The most active GDR satellite observation stations have from the beginning been the Potsdam Astrophysical Observatory and the Rodewisch station. In 1961 A. Masevich referred [48] to the work of Professor Guenzel-Lingner of the Potsdam Observatory in photographing faint satellites, like Explorer VII, with the long-focus double astrograph of the Observatory (f = 13.5 m; field of view 25 min of arc) as masterful. To a great extent, observations were made with improvised existing equipment. The rapid-action camera used in the Potsdam Observatory to determine the astronomical coordinates of satellites has a 4-lens Taksar objective (D = 175 mm, F = 262.5 mm). The camera uses 25/10 Agfa-Press, Wolfen film which is capable of recording stars of the 8th magnitude in a one-second exposure. Shutter action is regulated by an electric pulse sent from the chronograph [49].

By 1965 the nearby Potsdam Geodetic Institute had developed a transportable photographic camera-reflector (F = 1000 mm, 1:5.6) on a parallactic mounting especially for satellite observations. The camera consists of a Zeiss 5.6/1000-mm mirror objective with a plate-change cassette, a Zeiss 110/750-mm observation telescope, and an AT-1 finder telescope. Plate size was 6.5 x 9 cm. Depending on the rate of motion of the satellite, the objective ranges from $1^m.7$—$4^m.0$. The accuracy of position determination is ∿1", while that of time is $0^s.002$. Satellites up to 3^m having a rate of motion of 0.5/s may be recorded. The high lens quality makes possible photometric investigations of satellite brightness. A synchronous motor controls the rotating sector in front of the lens to increase the accuracy of observation and to synchronize the time of observation at different stations. A contact device attached to the sector records the moments of interruption of satellite tracking on the printing chronograph. The technical specifications of the mirror objective are: aperture diameter, 200 mm; F = 1000 mm; coefficient of distortion, 2.6 x 10^{-16}; field, 3.5 x 4°.7 [50].

The Zeiss 420/500/760 telescope, which was first put into operation in the Helmert Tower of the Potsdam Geodetic Institute in 1965 and which entered serial production in 1966, represents one of the most advanced instruments used in the Soviet-bloc for the precise determination of satellite coordinates against a fixed star background. The technical specifications of the instrument are: F = 760 mm; diameter of the correction plate, 425 mm; relative aperture, 1:1.8; diameter of the main mirror, 500 mm; diameter of the effective field, 2.85; plate size, 90 x 120 mm^2. The guide telescope has a magnification of 21.3^x, field of view of 3°, and an effective entrance aperture of 75 mm. The height of the instrument is 1950—3800 mm, the weight is ∿2.5 t, and the length of the telescope, ∿2000 mm. The instrument can photograph a satellite of ∿12^m. The instrument operates on a four-axis mounting. Among the new models of this instrument now under development are: 1) a dual axis design intended for use as an astrograph with a polar altitude range of from 0 to 90°; 2) a version with a 500-mm focal length and aperture ratio of 1:1 for image orthicon; 3) a ballistic camera with a four-lens system of 300- to 400-mm aperture and 1500- to 2000-mm focal length for plate sizes up to 300 x 200 mm; 4) a laser rangefinder for tracking satellites and similar flying bodies; and 5) a photometer telescope for satellite observations [51, 52].

Another improved satellite observation camera, designed by Dr. M. Steinbach and built at the Ilmenau Higher Technical School and the Institute for Precision Mechanics, permits the photography of satellites up to 10^m with an accuracy of not less than 2" in position and 1 msec in time. This camera also has an optical system developed by Carl Zeiss, Jena. It is equipped with a finder telescope that permits automatic tracking, a photochronograph, and a photographic plate magazine. When using ORWO-NP27 (9 x 12 cm) plates, the field of view is 7 x 9. In addition to the establishment of a new satellite observation station in Ilmenau, an astronomical station, intended to test instrumentation used in satellite observations, has now been built built near Ilmenau [53, 54, 55].

With regard to deep space tracking, it may be noted that the outstanding 2-m mirror telescopes built by Zeiss, one of which is in the Tautenburg Observatory, GDR, another in the

Shemakha Observatory near Baku, USSR, and a third in the Ondrejov Observatory, Czechoslovakia, have now been outfitted for deep space tracking, primarily of probes to other planets [56].

Zeiss has also produced a high-precision coordinatograph, the Ascorecord, which may be used to determine satellite coordinates from photographic plates. Ascorecord represents a further development of the Komess 3030 [57].

d. New Satellite Observation Stations in the German Democratic Republic.

In addition to the stations listed in Appendix III and those mentioned in the discussion above, the following developments merit note.

The Junge Welt Satellite Observation Station under the direction of Karl Heinz Neumann has been in operation four years and is the only GDR radio observation station to be listed in the COSPAR World List of Satellite Tracking Stations [See Appendix III, p. 54]. Since this entry, however, station equipment has been considerably increased. In order to improve Doppler-curve and field-strength recordings during satellite passages, a Praktina camera and 17-m film magazine as well as amplifier modifications have been introduced. Special preparations have been made at the station for optical observations of the decay of Echo-1 for the purpose of deriving data on upper air density changes. Experimental photographic observations of the brighter satellites using a Sonnar (1:2; f = 180 mm) optical system and film with a DIN 27 sensitivity rating have shown that satellites to the 6th magnitude can be successfully recorded to heights of 1000 km [58]. A general description of this station's activities and capabilities was given in the *Foreign Science Bulletin, no. 3, 1968.*

The new satellite observation station established in the Engineering School in Lichtenberg will become a central-collection and evaluation depot of all amateur radio stations in the GDR. The station is equipped with an Erfurt receiver capable of receiving signals up to 30 mc. The new station will cooperate with the ephemeris service in Potsdam-Babelsberg [59, 60].

The Beelitz Radio Station of the GDR Postal Service also monitors space flights and maintains a "space chronicle" in which taped recordings of manned flights are kept [61].

In addition, an astronomical and satellite observation station has been set up in Blankenhagen near Rostock. It will be the first such station operating in the northern GDR [62, 63].

The international scientific community has recognized the contributions of the GDR to progress in satellite geodesy and tracking technology in several ways. First, the Sonneberg Observatory in Berlin under the direction of Professor C. Hoffmeister has been given the international assignment of checking out dubious astronomical discoveries. This will be done with 18 cameras that take strip photographs of the entire sky on clear nights [64]. (See also *Sky and Telescope, April 1968.*) In addition, several international conferences on aspects of geodetic astronomy, for example, the Second International Symposium of October 1964, have been held in the GDR. More recently, in October 1966 an international conference on space geodesy was especially held in Jena and Potsdam to provide the participants with the opportunity of examining the new automatic camera for astrogeodesy (Zeiss 420/500/760) and other equipment.

e. Hungarian Satellite Observation Program.

Tracking activities in Hungary [65] are directed by the Astronomers' Committee of the Hungarian Academy of Sciences and by the Earth Satellite Tracking Subcommittee and are supported by the Soviet Academy of Sciences. Four satellite tracking stations operate in Hungary: Budapest; Szombathely; Baja; and Miskolc. These stations as well as those of the other satellites work in coordination with the following computer centers: COSMOS, Moscow; Computer Center of the Academy of Sciences of the German Democratic Republic, Potsdam; Computing Center of the Polish Academy of Sciences, Warsaw; Space Research Center Satellite Orbits Group, Slough (Great Britain); Smithsonian Astrophysical Observatory, Cambridge (USA); and the Independent Tracking Coordination Program, Washington.

All four stations employ the optical tracking method, but only Baja is equipped for photographic tracking. The expense and scarcity of measuring instruments are still problems. Many of the instruments used in Hungary had to be altered to meet qualifications. For timing accuracy Miskolc uses a continually running stop watch, the reading of which is photographed during measurements. With this method precision of 0.1—0.2 sec can be achieved. In Budapest and Baja an electromagnetic chronograph records time through synchronized contact with the photographic equipment used for position determination; the error is less than 0.05 sec. Baja also has a glow-discharge lamp chronograph with no moving parts. The chronograph registers time on film and permits measurements accurate to 0.1 msec. In Szombathely a frequency reference gage accurate to 10^{-8} and a digital time-interval meter accurate to 0.1 msec are used. All four stations use modified TZK-type telescopes for optical tracking.

At first Baja used a domestic camera having a speed of f = 1:5.6 and a 50-cm focal length for photographic tracking. In 1964 the Soviet Academy of Sciences gave Baja a NAFA-3c/25 type camera. Accurate timing is achieved by a Rohde Schwartz transistorized quartz watch with a chronograph. However, the NAFA camera has a relatively small magnitude (3—3.5). At present a photoelectric (nearly monochromatic) spectrophotometer is being built at Szombathely which will permit 2-channel photometry.

f. Chinese Satellite and Astronomical Observation Stations

In addition to the Chinese satellite observation stations listed in Appendix IV, the following institutes and observatories of the Chinese Academy of Sciences would be involved in tracking programs [66]:

1) the Artificial Satellite Research Laboratory
2) the Zikawei and So-se observatories in Shanghai
3) the Tzuchinshan (Purple Mountain Observatory) of Nanking, which has a 20-cm reflector, a 15-cm refractor, and other telescopes
4) the Tsingtao Observatory, which has a 15-cm refractor
5) the Tientsin Observatory, which has a Bamberg transit
6) the Kinming Observatory, which has a 15-cm refractor
7) the Peking Observatory, which has a 2-m reflector
8) the Hangchow Observatory
9) the Sheshan Observatory.

In a report of observations made of Soviet satellites in 1964 at the Purple Mountain Observatory, mention is made of the use of the AT-1 telescope and Becvar Atlas of the Heavens (1950.0). A position accuracy of $\pm 0^{\circ}.2$ and a time accuracy of $\pm 0^{s}.3$ is reported [67].

g. Satellite Tracking Vessels.

Soviet worldwide satellite tracking capabilities have been considerably extended through the introduction of ocean-going tracking vessels. This fleet, which now includes the *Vladimir Komarov*, the *Dolinsk*, the *Bezhitsa*, the *Ristna*, the *Aksay*, the *Morzhovets*, the *Nevely*, the *Kegostrov*, and the *Borovichi*, is being constantly enlarged [68]. With regard to worldwide tracking capability, note must also be taken of satellite observation stations built in Mali, Egypt, and Cuba with Soviet aid and participation.

Conclusions

Notwithstanding the prodigious amount of planning and foresight evidenced in the USSR satellite program, it has been from the beginning and continues to be handicapped by poor quality equipment. At a conference held on 15—18 May 1963 in Leningrad, the Plenum of the Committee on Theoretical Astronomy of the Astronomical Council noted [69] the following serious shortcomings in applied celestial mechanics: insufficiently accurate observations of major and minor planets and of natural and artificial satellites, a lack of necessary computer technology at the Institute of Theoretical Astronomy and the Department of Celestial Mechanics and Gravimetry of Moscow State University, and the difficulty of training personnel. These shortcomings and their proposed remedy were outlined again a year later when Academician M. V. Keldysh, head of the Soviet Academy of Sciences, told [70] Soviet astronomers complaining of the need for more and improved optical and radio telescopes and other equipment that they cannot expect to have the world's best equipment and that they had best resign themselves to greater dependence upon astronomers of other nations who may have better equipment. Keldysh stated: "In scientific development, it is necessary to base oneself on international scientific cooperation. I think that it is from this aspect that we must examine the problems of astronomy's development and in this area broadly utilize international cooperation. It is not obligatory to try to have in our country the world's largest telescopes, radio telescopes, telescopes on balloons, and on sputniks, etc." The Soviet Union has, therefore, from the start advocated international cooperation in those aspects of their space program where they are weakest. Months before the first sputnik was launched a group of Soviet scientists participating in a conference at the Smithsonian Astrophysical Observatory in Cambridge showed [71] considerable interest in the IGY program for optical tracking of satellites and suggested close cooperation between Moonwatch and a comparable group being organized in the USSR. This interest even extended to the possibility of direct communications between Cambridge and Moscow, in addition to the regular CSAGI world warning system. Professor I. Zhongolovich has proposed [72] that an internationally sponsored geodetic satellite be put into orbit and that a joint geodetic survey of the entire Earth be conducted. Professor S. Chaykin has advocated [73] the establishment of an international radio telescope, and so on. To a very considerable extent, the international scientific community has accommodated Soviet wishes. The USSR and the USA have engaged in joint tracking experiments of Echo satellites and have agreed to exchange information on space biology and medicine. A Washington-Moscow telephoto link to exchange cloud pictures from meteorological satellites has been established [74, 75]. Regular international conferences are held through the IGY, IAU, COSPAR and similar organizations on all aspects of space research at which NASA and USAF scientific workers exchange experience with their Soviet counterparts [76]. It would seem that the USSR has successfully parlayed its "surprise" first launching of October 1957 into a series of international scientific arrangements from which the USSR benefits most, because of her weaker technological base. The advantages and disadvantages of such arrangements are no doubt taken into account by both countries.

The second most important approach taken by the USSR to improve the quality of its optical observation equipment—as is evident in this report—has been to utilize to the full the resources and skills of the East European states, primarily the GDR, Czechoslovakia, and Hungary. In this regard the VEB Carl Zeiss, Jena, has been exceptionally important. In fact, in 1964 a decision was made by COMECON (Council of Economic Cooperation) [77] authorizing the GDR to manufacture and install observatories for the entire socialist camp. For this reason the activities and capabilities of the GDR in satellite tracking have been discussed in some detail.

In conclusion, it may be stated that, notwithstanding an initially very limited technological base, the USSR has achieved the best possible results in its satellite tracking program by virtue of 1) very good long-range planning and utilization of existing facilities and instrumentation, 2) the enlistment of the scientific and technical skills and resources of her East European satellites, and 3) the enthusiastic support and cooperation of the international scientific community.

Appendix I. Code for Compilation of Satellite Observational Data From Stations in the USSR

Code word: СПО

СП - from word "sputnik" (satellite)

О - from word "observation"

Symbolic code form: СПОКК НННДД ПЧЧММ СССИИ $Ч_1Ч_1М_1М_1М_1$ $ЗД_1Д_1Д_1Б$ surname, and if there are more observations, additional groups of the type ПЧЧММ СССИИ $Ч_1Ч_1М_1М_1М_1$ ЗДДДБ surname.

Key:

КК - control number equal to the sum of ciphers in 5-character groups following КК (if the total exceeds 99, then the number of hundreds is disregarded)

ННН - number of the observatory or station reporting its satellite observations

ДД - day for which data are reported in Universal Time

П - ordinal, based on launch time, satellite number (rocket carrier of first satellite is designated by cipher 0).

ЧЧ - hours, ММ - minutes, and ССС - seconds and tenths of seconds of moment of observation of satellite or rocket carrier with ordinal number П in UT

ИИ - stellar magnitude (without sign) of satellite with ordinal number П. The sign of stellar magnitude of the satellite or rocket carrier is noted by the method shown below.

$Ч_1Ч_1М_1М_1М_1$ - hours and minutes and tenths of a minute of right ascension of satellite or rocket with ordinal number П.

$Д_1Д_1Д_1$ - declination of satellite or rocket with ordinal number П in degrees and tenths of degrees.

З - sign of declination. When declination is positive, 0 is placed in spot З; when it is negative, it is placed in spot 1.

Б - estimate of measurement accuracy

Satellites with a positive stellar magnitude are designated: 1) uncertain, 2) satisfactory, and 3) good.

Satellites having a negative stellar magnitude are designated: 6) uncertain, 7) satisfactory, 8) good

If a magnitude is not determined or is determined with less accuracy (e.g., the tenths of a second of the moment of observation are not determined) the appropriate digit is replaced by the letter X. Example (made up): СП064 02425 20531 20220 16582 Ivanov 00500 11510 16283 05498 Ivanov 00500 12505 16300 05517 Petrov Sidorov

Decipherment: Station no. 24 observed on the 25th satellite no. 2 at $5^h31^m20.2^s$, UT, with stellar magnitude of plus 2.0; right ascension, $16^h58.2^m$; declination, plus 20°.2; observation certain. Ivanov observer.

Ivanov saw the rocket of the first satellite at $5^h00^m11.5^s$. Stellar magnitude was minus 1.0; right ascension, $15^h28.3^m$; declination, plus 54°.9; observations good. Petrov saw the same rocket at $5^h00^m12.5^s$. Stellar magnitude was 0.5; right ascension, $16^h30.0^m$; declination plus, 55°.1; observations satisfactory.

The sum of all digits beginning from the second group of five is 164, consequently the control number is 64.

Each independent observation is signed by the surname of the observer. The entire telegram is signed by the surname of the individual responsible for observations and is sent to: Moskva-Kosmos.

In cases where observations were unsuccessful, the station reports the fact using the following type of telegram: СПООХ НННДД ЧЧММА signature

OX - designates unsuccessful observation

ННН - station number

ДД - date, ЧЧ - hours, ММ - minutes UT indicated in the ephemeris telegram

A - reason for failure

0 - observations were impossible because of bad weather

1 - observations were conducted but the object was not spotted

2 - the object was seen, but the coordinates and time could not be determined.

Appendix II: Code for the Transmission of Telegrams With Satellite Coordinates to USSR Observation Stations

The following information is contained in the telegram:

The city in which the station is located

Code word: СПУ (from the word "sputnik")

Symbolic code form: СПУКК ННHДД ПЧЧММ АААВВ and, if necessary, the additional groups - ПЧЧММ АААВВ - in cases when an additional point is indicated for the same satellite or the ephemeris for another.

Key:

КК - control number equal to the sum of the ciphers in the five-character groups after КК (if the sum exceeds 99, then the hundreds number is dropped).

ННН - station number conducting the satellite observations.

ДД - day for which the data are communicated using Universal Time

П - ordinal, based on launch time, number of satellite (rocket carrier of the first satellite is designated by cipher 0).

ЧЧММ - hours and minutes in UT when it is possible for station ННН to observe the satellite or rocket carrier with ordinal number П.

ААА - astronomical azimuth (in degrees) of the satellite or rocket carrier with ordinal number П.

ВВ - height (in degrees) of the satellite or rocket carrier with ordinal number П.

Example (made up): АБАСТУМАНИ СПУ62 00305 21048 12130 10752 01835 КОСМОС

Decipherment: At station number 3 on the fifth of the month, the second, based on launch time, satellite will be observable at 10^h48^m GMT (at 13^h48^m Moscow Time); its astronomical azimuth is 121; height, 30. The first, based on launch time, satellite will be seen at 07^h52^m; azimuth, 18; height, 35. Control number 62.

Telegrams must always end with the word "КОСМОС"

Appendix III. COSPAR World List of Satellite Tracking Stations [Soviet Bloc]

NATIONAL CORRESPONDENTS OF OPTICAL TRACKING STATIONS

Bulgaria

Prof. Nicolas Bonev
Section "Astronomie"
Academy of Sciences of Bulgaria
Ul. "7 noemvri" 1, Sofia

Czechoslovakia

Dr. Ladislav Sehnal
Astronomical Observatory
Ondrejov

German Democratic Republic

Prof. Dr. J. Hoppe
Arbeitsgruppe für Interplanetare Materie am
Heinrich-Hertz-Institut
DDR-1199 Berlin-Adlershof

Hungary

Dr. I. Almar
M.T.A. Csillagvizsgalo Intezete
Konkoly Thege Ut. 13/17
Budapest 12

Poland

Dr. Ludoslaw Cichowicz
Committee for International
Geophysical Cooperation
Polish Academy of Sciences
Pałac Kultury i Nauki p. 2313
Warsaw

Rumania

Prof. C. Popovici
Observatoire Astronomique de Bucarest
Str. Cuțitul de Argint 5
Bucarest

U.S.S.R.

Miss N. P. Slovokhotova
Astronomical Council of the
U.S.S.R. Academy of Sciences
Ul. Vavilova 20
Moscow V-312

LIST OF OPTICAL TRACKING STATIONS

Definition of Column Headings

Column No.

I - Station

II - Coordinates: 1) Longitude, measured in degrees, minutes and seconds East
2) Latitude, North positive, South negative
3) Altitude

III - Station Code Number

IV - Type of Observations: visual = v; photographic = p

V - Accuracy a) Positional
b) Timing

VI - Tracking Facilities

VII - Timing Facilities

VIII - Address: 1) Postal
2) Telegraphic and teleprinter

IX - Coordinating Center

X - Datum to which coordinates refer and accuracy of coordinates in respect to datum

XI - Tracking Power of the Camera

XII - Period of Operation (hours per week)

Station Code Number (Column III):

These code numbers form a worldwide unified system and, with very few exceptions, embody those originally given to the station by one of the co-ordinating centers. A number of optical tracking stations have more than one code number listed against them. Arrangements have now been made with the co-ordinating centers which assigned these numbers that, in future, only a single number shall be used for each station in the transmission of coded messages. Brackets are placed around the numbers which will no longer be used. It is important that a record of all the numbers given to a station should be retained in the list as it may be necessary to refer to them in handling records of past observations.

Station Address (Column VIII):

Where no station address is given, that of the coordinating center should be used for communications.

Explanation of Column Notes

The figures in brackets which appear in columns V, VII, IX, XI and XII of the List refer to the following notes:

(i) No details are available for this particular station but stations of this type have timing facilities ranging from the equivalent of a crystal clock, in a very few instances, to stopwatches, used in conjunction with tape-recorders, audio techniques, etc., to correlate with radio time signals, in about 90 per cent of the stations.

(ii) No definite values for accuracies are available, but for stations of this type, positional accuracy ranges from 0.05 to 0.75 degrees of arc, and timing accuracy, from 0.05 to 0.3 seconds.

(iii) No details are available for this particular station, but stations of this type have timing facilities ranging from radio time signals to shutters driven by crystal-controlled synchronous motors.

(iv) No definite values for accuracies are available, but for stations of this type positional accuracy ranges from 0.1 degrees of arc (field-reduced photographs) to 2-6 seconds of arc (on largest cameras), and timing accuracy from 0.1 - 1.0 seconds (unrecorded radio time signals) to possibly a few milliseconds (crystal-controlled shutters).

(v) This station is included in the U.S.A. Baker-Nunn Photographic Tracking Network which is coordinated by the Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge 38, Mass., U.S.A.

(vi) This station is included in the U.S.A. Phototrack network which is coordinated by the National Aeronautics and Space Administration, 1520 H Street, N. W., Washington 25, D. C., U. S. A.

(vii) This station is included in the U.S.A. Moonwatch network which is coordinated by the Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, Mass., U.S.A.

(viii) The number of hours per week takes no account of failure to observe because of weather. The actual useful observing time is approximately 1/4 of this.

(ix) Stationary Power (Duration of exposure 1 sec.)

(x) Tracking Power (angular velocity of satellite 1°/sec.)

(xi) Activity limited in the summer months by the short nights at this latitude

COORDINATING CENTERS FOR

OPTICAL TRACKING STATIONS

COLUMN IX

A. Radio and Space Research Station
Satellite Orbits Group
Ditton Park, Slough
Bucks., England

B. Bulgarian Academy of Sciences
Department of Astronomy
ul."7 Noemvri"1
Sofia, Bulgaria

C. Astronomical Institute of the
Czechoslovakian Academy of Sciences
Ondrejov, Czechoslovakia

D. Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Mass. 02138, U.S.A.

E. Prof. Dr. Max Kneissl
Deutsches Geodätisches
Forschungsinstitut, Zentralleitung,
8000 Munich, Arcisstrasse 21,
Federal Republic of Germany

F. Observatoire de Meudon
92-Meudon, France

G. Astronomical Council of the
U.S.S.R. Academy of Sciences
Ulitsa Vavilova 20
Moscow, U.S.S.R.

H. MTA Csillagvizsgalo Intezet
Konkoly Thege Ut. 13/17
Budapest 12, Hungary

I. Comitato Ricerche Spaziali
Consiglio Nazionale delle
Ricerche
Piazzale delle Scienze, 7
Roma, Italia

J. University of Utrecht
Lab. v. Ruimte-Onderzoek
Huizingalaan 121
Utrecht, Netherlands

K. Polish Committee for IGC
Palac Kultury i Nauki
Warsaw, Poland

L. Precision Optical Satellite
Tracking Station
P. O. Box 73, Orange Grove
Johannesburg, South Africa

M. Associaçao Astronómica de
Angola
Luanda, Angola

N. Tokyo Astronomical Observatory
Mitaka, Tokyo-To, Japan

O. Geodetic Survey Institute
1000, 7-chome, Meguro-ku
Tokyo, Kami-Meguro, Japan

P. Hydrographic Bureau
1, Tsukizi 5-chome, chuoku
Tokyo, Japan

Q. Dominion Observatory
Ottawa, Ontario, Canada

R. National Research Council
Ottawa, Ontario, Canada

EUROPE (INCLUDING U.S.S.R.)

I	II	III	IV	V (a)	V (b)	VI
BULGARIA						
Belogradchik	22°40'35" +43°37'23" 610m	1103	v	0.1°	0.1^s	AT-1 telescopes, binoculars
Sofia	23°20'50" +42°41'02" 572m	1101	v	0.1°	0.1^s	AT-1 telescopes, binoculars
Stara Zagora	25°37'53" +42°25'54" 231m	1102	v p	0.1° 1'	0.2^s 0.01^s	AT-1 telescopes, binoculars kinetheodolite
Varna	27°55'27" +43°12'10" 12m	1104	v	0.1°	0.1^s	AT-1 telescopes, binoculars
CZECHOSLOVAKIA						
Bratislava I	17°06'17" +48°10'18" 260m	1144	v	0.5'- 1'	0.1^s	Somet-Binar, telescopes, AT-1, Zeiss 1080 telescopes
Bratislava II (Pezinok)	17°16'21" +48°17'47" 170m	1172	v	2'	0.1^s	Somet-Binar telescopes, At-1 telescopes
Brno	16°35'17" +49°12'15" 304m	1143	v p	0.05° 0.1'	0.2^s 0.02^s	Somet-Binar telescopes, AT-1 telescopes camera (f500mm,1:5)
Prague	14°23'58" +50°04'56" 327m	1145	v p	0.1° 3"	0.1^s 0.004^s	Somet-Binar telescopes, Aerophoto camera (f75 cm 1:6.3)
Skalnate-Pleso	20°14'41.55" +49°11'20" 1783m	1142	v	0.1°	0.1^s	Somet-Binar telescopes

VII	VIII	IX	X	XI	XII
stopwatch, chronometer, crystal clock	Narodna Astronom. Observatoria Belgradochik	B	1964 0.5"		15
stopwatch, chronograph, crystal clock radio time signals	Bulgarian Academy of Sciences, Dept. of Astronomy, Tracking Center, ul."7 Noemvri" 1, Sofia	B	1957 0.1"	(ix)	15
stopwatch, chronograph, crystal clock	Narodna Astronom. Observatoria Stara Zagora	B	1962 0.5"		15
stopwatch, chronometer, crystal clock	Narodna Astronom. Observatoria Varna	B	1964 0.5"		15
stopwatch, chronometer, Glasshütte	Astronomicky Ustav SAV, Dubravska Cesta Mstavy SAV, blok A Bratislava-Patronka Astronomical Institute Bratislava	C			
stopwatch	ditto	C			
stopwatch, chronograph, time signals	Astronomical Institute of the J. E. Purkyne University, Kotlarska 2, Brno	C			
chronometer, time signals	People's Observatory Petrin, Strahovska 205 Prague People's Obs., Prague	C		3^m	
stopwatch, time standard, Satori clock	Astronomical Institute SAV, Skalnate-Pleso Observatorium, Tatry	C			

I	II	III	IV	V (a)	V (b)	VI
GERMAN DEMOCRATIC REPUBLIC						
Bautzen	$14^{\circ}26'16''$ $+51^{\circ}11'16''$ 233m	1120 (8144)	v	0.1°	0.1^{s}	Theodolite Zeiss 80/500 mm, AT-1 telescope
Eilenburg	$12^{\circ}37'39''$ $+51^{\circ}27'5''$ 124m	1184 (0707)	v p	0.1°	0.1^{s}	AT-1 telescope, balloon theodolite camera of 71/250mm (1:3,5)
Potsdam I	$13^{\circ}03'58''$ $+52^{\circ}22'55.7''$ 107m	1121 (8145)	v p	5' 1'	1^{s} 0.01^{s}	Binoculars f= 400mm Camera 170/240mm (1:1,5)
Potsdam II	$13^{\circ}04'01.8''$ $+52^{\circ}22'55.2''$ 108 m	1181 (8143)	p	2"	2ms	Zeiss reflector 5.6/1000, Zeiss tracking camera, Flat field Schmidt-optics, 420/500/760 (1:1,8)
Rodewisch	$12^{\circ}24'43''$ $+50^{\circ}31'51''$ 467m	1185 (2733)	v p	1'	0.01^{s}	AT-1 telescope Camera of 170/240 mm (1:1,5)
Schwerin	$11^{\circ}25'28''$ $+53^{\circ}37'7''$ 67.5m	1180 (8150)	v	5'	0.2^{s}	AT-1 telescope
HUNGARY						
Baja	$18^{\circ}57'35''$ $+46^{\circ}10'52''$ 101m	1113	v p	3' 5"	0.05^{s} 2ms	TZK-1 photo, NAFA 3c/25/4" f/2.5
Budapest	$18^{\circ}57'57''$ $+47^{\circ}29'56''$ 485m	1111	v	5'	0.05^{s}	TZK-1 photo
Miskolc	$20^{\circ}42'19''$ $+48^{\circ}6'3''$ 206m	1114	v	3'	0.05^{s}	TZK-1 photo
Szombathely	$16^{\circ}37'27''$ $+47^{\circ}13'54''$ 232m	1112	v p	5'	0.05^{s}	TZK-1 photo paralactic camera 4" f/3.6

VII	VIII	IX	X	XI	XII
stopwatch, radio time signals, crystal clock	Sternwarte Bautzen DDR-86 Bautzen 1 Postschliessfach 65 Telex: 0198742	G (vii)	$m_{lim(v)}$ = 11^m		
radio time signals, chronograph	Volks-u. Schulsternwarte "Juri Gagarin" DDR-728 Eilenburg Am Mansberg Cable: Sternwarte Eilenburg Telex: 051515	G (vii)			
printing chronograph, radio time signals	Astrophysikalisches Observatorium DDR-15 Potsdam Telegraphenberg Telex: 015251	G	$m_{lim(p)}$ = 6^m $m_{lim(v)}$ = 9^m		
crystal clock, radio time signals, printing chronograph	Geodätisches Institut Potsdam - DDR-15 Telegrafenberg Potsdam Geodaet Telex: 015251	G (vii)			
Box chronometer, chronograph, crystal clock	Schulsternwarte u. Satellitenbeobachtungsstation DDR-9706 Rodewisch/Vogtland Cable: Sternwarte Rodewisch Telex: 0578833	G (vii)	m_{lim} = $+6,5^m$		
crystal clock, printing chronograph, radio time signals	Sternwarte u. Planetarium Schwerin, Satellitenbeobachtungsstation DDR-27 Schwerin Weinbergstr. 17 Telex: 012259	G (vii)	m_{lim} = $+7^m$		
crystal clock, chronograph	Csillagvizsgáló Intézet Baja, Tóth Kálmán, u 19 Csillagvizsgáló,Baja	H	2"	1.0	40
crystal clock, chronograph	MTA Csillagvizsgáló Budapest 114/67 Csillagvizsgáló Intézet, Budapest, Konkoly u 17	H	2"		40
chronograph, radio time signals	Csillagvizsgáló Miskolc III Dorottya u 1 Csillagvizsgáló Miskolc	H	2"		40
crystal clock, chronograph, photometer	Gothard Obszervatórium, Szombathely PF 173 Csillagvizsgáló Szombathely	H	2"	0.75	20

I	II	III	IV	V (a)	V (b)	VI
POLAND						
Borowiec (near Poznań)	17°04'30" +52°17'00" 80m	1156	p	4"	0.001^s	Paralactic camera
Cracow I	19°58'30" +50°04'00" 221m	1153	v	5'	0.01^s	Astrograph
Cracow II	19°55'30" +50°04'00" 227m	1162	v	0.1'	0.01^s	Theodolites, T2K Telescopes
Józefosław (near Warsaw)	21°01'30" +52°06'00" 110m	1160	p	3"-4"		NAFA 3c/25 camera
Olsztyn	20°27'00" +53°45'00" 110m	1151	v p	5' 1'	0.01^s 0.01^s	Theodolites, fixed camera, T2K Telescopes
Poznan	16°52'30" +52°24'00" 80m	1154	p	4"	0.001^s	Paralactic camera
Warsaw I	21°01'30" +52°13'00" 130m	1155	v	0.1'	0.01^s	Theodolite, telescope
Warsaw II	20°54'00" +52°15'00" 110m	1159	v p	0.1'	0.1^s	Theodolite, fixed camera
Wrocław	17°06'00" +51°07'00" 117m	1152	p	5'	0.01^s	Fixed camera
RUMANIA						
Bucharest	26°05'47.7" +44°24'50.4" 86m	1131	v	0.1° 0.1^m	0.1^s	Binoculars (d=8mm field 7.4 x 10)
			p	0.1° 5"-10"	0.01^s 3-5ms	Theodolite 1", Camera NAFA
Cluj	23°25'52" +46°45'34" 412m	1132	v	0.1°	0.1^s	AT-1 telescopes, Balloon theodolite
Timişoara	21°13'45" +45°44'15"	1133	v	0.1°	0.1^s	Theodolite 1', Binoculars

VII	VIII	IX	X	XI	XII
crystal clock	Stacja Szerokosciowa PAN, Borowiec koło Kórnika	K			
chronograph	Obserwatorium Astronomiczne, U. J. Krakow Kopernika 27	K			
chronograph	Katedra Geodezji Wyższej AGH Kraków, al. Mickiewicza 30	K			
chronograph, crystal clock	Katedra Astronomii P. W. Warszawa, Koszykowa 75	K			
chronograph	Studium Geodezji Olsztyn-Kortowo	K			
crystal clock	Obserwatorium Astronomiczne, Poznań, ul. Słoneczna 36	K			
chronograph	Obserwatorium Astronomiczne, U.W. Warszawa, al. Ujazdowskie 4	K			
chronometer	Katedra Geodezji Warszawa 49, Bemowo	K			
chronograph	Obserwatorium Astronomiczne, Wrocław, ul. Kopernika 11	K			
astronomical clock, crystal clock, tape recorder	Astrophysical Section Bucharest Observatory Str. Cuțitul de Argint 5, Rumania	G (vii)	Astronomical 0.20" 0.15"	+0.3	10
astronomical clock, tape recorder	Astronomical Observatory, University Babes-Bolyai, Str. Republicii 109 Cluj, Rumania	G	Astronomical 0.5" 0.5"		10
astronomical clock, tape recorder	Astronomical Observatory, University Timişoara	G	Astronomical 3"		3

I	II	III	IV	V (a)	V (b)	VI
U.S.S.R.						
Abakan	91°26'18" +53°4[illegible]'18" 247m	1001	v p	0.1°	0.1^s	AT-1 and TZK telescopes, small aperture "Leningrad" camera
Abastumani	42°49'30" +41°45'18" 1600m	1003	p	6"	0.005^s	Camera (NAFA 3c/25)
Alma-Ata I	76°57'27.6" +43°11'16.62" 1450m	1067	p	6"	0.005^s	NAFA 3c/25 camera, Meniscus telescopes
Alma-Ata II	77°00' +43°15' 810m	1002	v	0.1°	0.1^s	AT-1, TZK telescopes
Arkhangelsk	40°34' +64°32' 10m	1004	v p	0.1°	0.1^s	AT-1 and TZK telescopes, small aperture "Leningrad" camera
Ashkhabad I	58°21'00" +37°57'18" 295m	1006	v	0.1°	0.1^s	AT-1 and TZK telescopes
Asbkhabad II	58°06'36" +37°57'18" 600m	1074	v p	0.1° 6"	0.1^s 0.005^s	AT-1, TZK telescopes, NAFA 3c/25 camera
Birsk	55°30' +55°25' 150m	1085	v	0.1°	0.1^s	AT-1,TZK telescopes
Blagoveshchensk	50°15' +127°30' 130m	1010	v	0.1°	0.1^s	AT-1, TZK telescopes
Bukhara	64°24'42" +39°46'42" 228m	1011	v	0.1°	0.1^s	AT-1 and TZK telescopes

VII	VIII	IX	X	XI	XII
chronograph, radio time signals, stopwatches, marine chronometer	Pedagogical Institute, 82, Lenin Avenue, Abakan Abakan, SVN	G			
Ditto	Astrophysical Observatory, Kanobili Mountain, Abastumani Abastumani, Observatory	G			
Ditto	Astrophysical Institute of Kaz. Academy of Sciences, Kamanskoe Plateau, Alma-Ata Alma-Ata Astrophysics	G			
marine chronometer, radio time signals, stopwatches	Pedagogical Institute Komsomolskaya Str., 31, Alma-Ata Alma-Ata, Sputnik	G			
chronograph, radio time signals, stopwatches, marine chronometer	Pedagogical Institute Arkhangelsk, 6 Arkhangelsk, Planet	G			
Ditto	State University, 31, Lenin Avenue, Ashkahabad Ashkhabad, State University	G			
Ditto	Inst. of Physics of the Earth and Atmosphere, Turkmen Academy of Sciences, Firiuza, Ashkhabad Ashkhabad, Firiuza, Observatory	G			
Ditto	Pedagogical Institute, International Str., 10, Birsk Birsk, Bashkirsk, Rocket	G			
Ditto	Pedagogical Institute, Lenin Str., 104, Blagoveshchensk Blagoveshchensk, Amursk, Observatory	G			
Ditto	Pedagogical Institute, 35 Ninoshvili Street, Batumi Batumi, Sputn[illegible]	G			

I	II	III	IV	V (a)	V (b)	VI
Chernovitsi	25°57' +48°17' 240m	1062	v	0.1°	0.1^s	AT-1, TZK telescopes
Chita	113°29'30" +52°01'36" 681m	1064	v	0.1°	0.1^s	AT-1, TZK telescopes
Curgan	65°21'06" +55°26'00" 75m	1029	v	0.1°	0.1^s	AT-1, TZK telescopes
Dnepropetrovsk	35°02'42" +48°26'6" 145.5m	1017	v	0.1°	0.1^s	AT-1, TZK telescopes, "Leningrad" and "Zenith" small aperture cameras
Dushanbe I	68°49' +38°35' 834m	1047	v	0.1°	0.1^s	AT-1, TZK telescopes
Dushanbe II	68°46'52.08" +38°33'39.94" 820m	1068	v p	0.1°	0.1^s	AT-1, TPZ telescopes, NAFA 3c/25 camera
Englehardt	48°48'56.1" +55°50'20.2" 9m	1076	v p	0.1° 6"	0.1^s 0.005^s	AT-1, TZK telescopes, NAFA 3c/25 camera
Enisseisk	92°10' +58°25' 80m	1078	v	0.1°	0.1^s	AT-1, TZK telescopes
Erevan	44°30' +40°11' 960m	1018	v	0.1°	0.1^s	AT-1, TZK telescopes, NAFA 3c/25 camera
Frunze	74°34'36" +42°52'54" 750.6m	1058	v	0.1°	0.1^s	AT-1, TZK telescopes
Gorky I	43°59'12" +56°15'36" 163m	1016	v	0.1°	0.1^s	AT-1 telescopes

VII	VIII	IX	X	XI	XII
chronograph, radio time signals, stopwatches, marine chronometer	State University Chernovitsi Chernovitsi, Sputnik	G			
Ditto	Pedagogical Institute, 140 Chkalov Street, Chita Chita Pedagogical Institute	G			
Ditto	Pedagogical Institute, 63 Soviet Str., Curgan Curgan, Sputnik	G			
Ditto	State University, Dnepropetrovsk	G			
Ditto	The Lenin Tadjik State University, 17 Lenin Street, Dushanbe Dushanbe, Alkor	G			
Ditto	Astrophysical Institute, 4 Sviidenko Street, Dushanbe Dushanbe, Observatory	G			
Ditto	Kazan State University, Station Observatory, Zelenodolsky Region, TASSR Tatar Astronomical Observatory, Judino	G			
Ditto	Pedagogical Institute, Kirov Str., 62 Enissoisk, Krasnoyarsk distr. Enisseisk, Vega	G			
Ditto	State University, Erevan Erevan, Sputnik	G			
Ditto	Kirghiz State University, Frunze Frunze State University	G			
Ditto	Latitude Station, Gorky 62 Gorky, 9, Sputnik	G		No longer active	

I	II	III	IV	V (a)	V (b)	VI
Gorky II	44°00'12" +56°19'36" 139m	1050	v	0.1°	0.1^s	AT-1, TZK telescopes
Irkutsk	104°20'36.0" +52°16'44.3" 458m	1079	v p	0.1° 6"	0.1^s 0.005^s	AT-1, TZK telescopes, NAFA 3c/25 camera
Kaliningrad	20°30' +54°45' 30m	1093	v	0.1°	0.1^s	AT-1, TZK telescopes
Kazan	49°07'15.45" +55°47'23.9" 80m	1020	v	0.1°	0.1^s	AT-1, TZK telescopes
Khabarovsk	135°04'48" +48°29'12" 120m	1059	v p	0.1° 6"	0.1^s 0.005^s	AT-1, TZK telescopes NAFA 3c/25 camera
Kharkov	36°13'56.2" +50°00'10.9" 140.5m	1060	v p	0.1° 6"	0.1^s 0.005^s	AT-1, TZK telescopes, NAFA 3c/25 double camera
Kiev I	30°30'07.05" +50°27'11.43" 184m	1023	v p	0.1° 6"	0.1^s 0.005^s	AT-1, TZK telescopes, NAFA 3c/25 camera
Kirov	49°40' +58°35' 140m	1092	v	0.1°	0.1^s	AT-1, TZK telescopes
Kishinev	28°52'00" +46°57'24" 129m	1024	v	0.1°	0.1^s	AT-1, TZK, TPZ telescopes
Komsomolsk-na-Amure	137°01'24" +50°32'24" 23.4m	1025	v	0.1°	0.1^s	AT-1, TZK telescopes
Krasnodar	38°58'42" +45°01'42" 40m	1027	v p	0.1°	0.1^s	AT-1, TZK telescopes, small aperture cameras

VII	VIII	IX	X	XI	XII
chronograph, radio time signals, stopwatches, marine chronometer	Pedagogical Institute 1, Ulianov Street, Gorky Gorky, Pedagogical Institute	G			
Ditto	Observatory, State University, Irkutsk, 9 Irkutsk, 9 Observatory	G			
marine chronometer, radio time signals, stopwatches	Pedagogical Institute, Chernyshevsky Str., 56 Kaliningrad District Kaliningrad District Zenit	G			
chronograph, radio time signals, stopwatches, marine chronometer	State University, 18 Lenin Street, Kazan Kazan, Sputnik	G			
Ditto	Pedagogical Institute, 64, K. Marx Street, Khabarovsk Khabarovsk, Vega	G			
Ditto	Astronomical Observatory, State University, 35 Sumskaya Street, Kharkov, 22 Kharkov Observatory	G			
Ditto	Astronomical Observatory of Kiev University, 3, Observatory Str. Kiev, 53 Kiev, SUN	G			
Ditto	Pedagogical Institute, Lenin Str., 111, Kirov Kirov Sputnik	G			
Ditto	State University, Kishinev, 3 Kishinev, State University	G			
Ditto	Pedagogical Institute, 18 Pioneer Str., Komsomolsk-na-Amure Komsomolsk-na-Amure, 25	G			
Ditto	Pedagogical Institute, 4 Sedin Street, Krasnodar Krasnodar, Moon	G			

I	II	III	IV	V (a)	V (b)	VI
Kustanai	63°40' +53°15' 155m	1095	v	0.1°	0.1^s	AT-1, TZK telescopes
Kzyl-Orda	65°30'24" +44°50'06" 127m	1022	v	0.1°	0.1^s	AT-1, TZK telescopes
Leningrad	30°16'15" +59°56'38.4" 15m	1030	v	0.1°	0.1^s	AT-1, TZK telescopes,
			p	6"	0.005^s	NAFA 3c/25 camera
Lvov	24°01'46.95" +49°49'57.6" 330m	1031	v	0.1°	0.1^s	
			p			NAFA 3c/25 camera, small aperture "Kiev"camera
Minsk	27°32'48" +53°53'42" 230m	1033	v	0.1°	0.1^s	AT-1, TZK telescopes
Moscow	37°32'40.215" +55°41'59.2" 200m	1034	v	0.1°	0.1^s	AT-1, TZK telescopes,
			p	6"	0.005^s	NAFA 3c/25 camera
Nalchik	43°36'06" +43°29'30" 507m	1080	v	0.1°	0.1^s	AT-1, TZK telescopes
Nikolaev	31°58'26.25" +46°58'18.0" 51.8m	1077	p	6"	0.005^s	NAFA 3c/25 camera
Novosibirsk	82°55'30" +55°02'24" 180m	1035	v	0.1°	0.1^s	AT-1, TZK telescopes, theodolite,
			p			small aperture "Tourist" camera
Odessa	30°45'28.95" +46°28'38.4" 53m	1073	v	0.1°	0.1^s	AT-1, TZK telescopes,
			p	6"	0.005^s	NAFA 3c/25 camera
Omsk	73°22'24" +54°59'00" 101.4m	1037	v	0.1°	0.1^s	AT-1, TZK telescopes

VII	VIII	IX	X	XI	XII
marine chronometer, radio time signals, stopwatches	Pedagogical Institute Tarana Str., 118 Kustanai Kustanai, Vzor	G			
chronograph, radio time signals, stopwatches, marine chronometer	Pedagogical Institute Kzyl-Orda	G			
Ditto	State University 33, 10th Line, Leningrad V-178 Leningrad V-178 Rainbow	G			
Ditto	State University, 8 Lomonosov Str., Lvov, 5 Lvov, Saturn	G			
Ditto	State University, Minsk Minsk, Sputnik	G			
Astronomical clock	Shternberg Astronomical Institute, Lenin Hills, Moscow V-234 Moscow, Shternberg Astronomical Institute	G			No longer active
chronograph, radio time signals, stopwatches, marine chronometer	State University, 97, Chernyshevsky Street, Nalchik, KBASSR, Nalchik, Cosmos	G			
Astronomical clock	Astronomical Observatory, Nikolaev Reg. Nikolaev Reg., Observatory	G			
chronograph, radio time signals, stopwatches, marine chronometer	Geodetic Institute, 27 Potanin Str., Novosibirsk Novosibirsk, Geodetic Institute	G			
Ditto	Observatory, Shevchenko Garden, Odessa, GSP-3 Odessa, Meteor	G			
Ditto	Pedagogical Institute 4a, Partizan Street, Omsk Omsk, TEZ	G			

I	II	III	IV	V (a)	V (b)	VI
Orenburgh	55°06'25" +51°45'30" 130m	1063	v	0.1°	0.1^s	AT-1, TZK tele- scopes,
Petrozavodsk	34°21'30" +61°47'12" 99m	1038	v	0.1°	0.1^s	AT-1, TZK tele- scopes, TZK-1 photo
Pulkovo	30°19'38.5" +59°46'13.7" 76.5m	1039	p	6" 20"	0.005^s 0.01^s	NAFA 3c/25 camera KPP camera
Riazan	39°45'10" +54°38'05" 114m	1042	v	0.1°	0.1^s	Theodolites, [illegible], TZK-1, AT-1M(with precise circles) telescopes,
			p	6"	0.005^s	NAFA 3c/25 camera, small aperture "Zenith", Zorky cameras
Riga I	24°07'01.26" +56°57'08.3" 39m	1040	v p	0.1°	0.1^s	AT-1, telescopes, 3-axis automatic camera
Riga II	24°07'01.26" +56°57'08.3" 39m	1084	p	6"	0.005^s	NAFA 3c/25 camera, camera with oscil- lating plate-holder
Rostov-Don	39°42'40" +47°13'31" 69m	1041	v p	0.1° 6"	0.1^s 0.005^s	AT-1, TZK tele- scopes, NAFA 3c/25 camera
Samarkand	39°40' +66°55' 690m	1043	v	0.1°	0.1^s	AT-1, TZK tele- scopes
Saratov	46°00'42" +51°32'12" 85m	1044	v	0.1°	0.1^s	AT-1, TZK tele- scopes
Sverdlovsk	59°33' +57°02' 300m	1045	v p	0.1° 6" 20"	0.01^s 0.005^s 0.01^s	AT-1, TZK tele- scopes NAFA 3c/25 camera, KPP camera
Semipalatinsk	80°15' +50°25' 210m	1094	v	0.1°	0.1^s	AT-1, TZK tele- scopes

VII	VIII	IX	X	XI	XII
chronograph, radio time signals, stop-watches, marine chronometer	Pedagogical Institute 19 Soviet Street Orenburgh Orenburgh, Sputnik	G			
Ditto	State University, 71 Lenin Avenue, Petrozavodsk, Petrozavodsk, State University	G			
Astronomical clock	Main Astronomical Observatory of the U.S.S.R., Acad. of Sciences, Pulkovo, Leningrad M-140 Leningrad M-140	G			
chronograph, radio time signals, stop-watches, marine chronometer	Pedagogical Institute 46 Freedom Street, Riazan Riazan, Sputnik	G			
Ditto	Latv. SSR State University, Riga Riga, Sputnik	G			
Ditto	Observatory, State University, 19 Rainis Boulevard, Riga Riga, Antares	G			
Ditto	State University 100, Gorky Street, Rostov-na-Don Rostov-Don NIFMI	G			
Ditto	University, Gorki Boulevard, 15, Samarkand Samarkand, Vega	G			
Ditto	State University, 83 Astrakhan Str., Saratov, 26 Saratov, State University	G			
Ditto	State University, 48a Kuibyshev str., Sverdlovsk Sverdlovsk, Sky	G			
marine chronometer, radio time signals, stopwatches	Pedagogical Institute, Sovetskaya Str., 100 Semipalatinsk Semipalatinsk, Pedinstitut	G			

I	II	III	IV	V (a)	V (b)	VI
Syktyvkar	50°50'54" +61°38'42" [illegible]	1049	v	0.1°	0.1^s	AT-1, TZK telescopes
Tartu I	26°43'15" +58°22'48"	1083	v	0.1°	0.1^s	AT-1, TZK telescopes, theodolites
			p	6"	0.005^s	"Zenith" camera, NAFA 3c/25 camera
Tartu II	26°40' +58°20' 75m	1051	p	6"	0.005^s	NAFA 3c/25 camera, AT-1, TZK telescopes
Tashkent I	69°11'12" +41°21'00" 440.8m	1052	v	0.1°	0.1^s	AT-1, TZK telescopes
Tashkent II	69°17'37.14" +41°19'33.[illegible] 478m	1075	p	6"	0.005^s	NAFA 3c/25 camera
Tbilisi	44°46'52.5" +41°42'41.3" 450m	1053	v	0.1°	0.1^s	AT-1, TZK telescopes
Tobolsk	68°15' +58°10' 115m	1091	v	0.1°	0.1^s	AT-1, TZK telescopes
Tomsk	84°56'47.4" +56°28'06.3" 114.4m	1054	v	0.1°	0.1^s	AT-1, TZK telescopes
			p	6"	0.005^s	NAFA 3c/25 camera
Ufa	55°55' +54°43' 196.9m	1057	v	0.1°	0.1^s	AT-1, TZK telescopes
Ulan-Ude	107°34'30" +51°50'30" 416m	1056	v	0.1°	0.1^s	AT-1, TZK telescopes
Uzhgorod	22°18'01.2" +48°38'03" 190m	1055	v	0.1°	0.1^s	AT-1, TZK telescopes,
			p	6"	0.005^s	NAFA 3c/25 camera
				20"	0.01^s	KPP cameras
Vladivostok	131°53'31.2" +43°07'00" 65m	1013	v	0.1°	0.1^s	AT-1 and TZK telescopes, binoculars, comet-seeker

VII	VIII	IX	X	XI	XII
chronograph, radio time signals, stop-watches, marine chronometer	Pedagogical Institute 21, Communistic Street, Syktyvkar Syktyvkar, Pedagogical Institute	G			
Ditto	Astronomical Observatory of the Estonian Academy of Sciences, Tähetorn, Tartu, ESSR Tartu, Luno	G			No longer active
Ditto	University Iulikooli Str., 18, Tartu Tartu, Luno	G			
Ditto	State University, 32, K. Marx Street, Tashkent Tashkent State University	G			
Astronomical clock	Astronomical Observatory, Tashkent Astronomical Observatory, Tashkent	G			
chronograph, radio time signals, stop-watches, marine chronometer	State University, 1, Chavchavadze, Tbilisi Tbilisi, Moon	G			
Ditto	Pedagogical Institute, Rosa Luxemburg Str., 7, Tobolsk Tobolsk, Pedinstitute	G			
Ditto	State University, Tomsk p/010 Tomsk, Jupiter	G			
Ditto	Bashkir State University, Ufa Ufa State University	G			
Ditto	Pedagogical Institute, 11 Kanzhurov Street, Ulan-Ude Ulan-Ude, Reya	G			
Ditto	State University Ushgorod Ushgorod, Sputnik	G			
Ditto	Far Eastern State University, 8 Sukhanov Street, Vladivostok Vladivostok, 013	G			

I	II	III	IV	V (a)	V (b)	VI
Volgograd	44°31'30" +48°41'48" 50m	1048	v	0.1°	0.1^s	AT-1, TZK telescopes
Vologda	39°53'25" +59°13'20" 150m	1014	v p	0.1° 6"	0.1^s 0.005^s	AT-1 and TZK telescopes, NAFA 3c/25 camera
Yakutsk I	129°43'30" +62°01'12" 99m	1066	v	0.1°	0.1^s	AT-1, TZK telescopes
Yakutsk II	129°39' +62°00' 100m	1088	p	6"	0.005^s	NAFA 3c/25 camera
Yaroslavl	39°55' +57°35' 95m	1087	v	0.1°	0.1^s	AT-1, TZK telescopes
Yushno-Sakhalinsk	142°42'12" +46°56'42" 38m	1065	v	0.1°	0.1^s	AT-1, TZK telescopes
Zvenigorod	36°46'34" +55°41'37.7"	1072	v p	0.1° 6" 20"	0.1^s 0.005^s 0.01^s	AT-1, TZK telescopes, NAFA 3c/25 camera, KPP camera, camera with oscillating plate-holder
MONGOLIA						
Ulan-Bator	107°03'00" +47°51'56" 175m	1660	v p	0.1°	0.1^s	telescopes (AT-1), NAFA Camera
VIETNAM						
Hanoi	105°51' +21°01' 24m	1581	v	0.1°	0.1^s	theodolites, telescopes (AT-1)

VII	VIII	IX	X	XI	XII
chronograph, radio time signals, stop-watches, marine chronometer	Pedagogical Institute 27, Lenin Avenue, Volgograd Volgograd, Pedagogical Institute	G			
Ditto	Pedagogical Institute 6 Mayakovsky Str., Vologda Vologda, Orbit	G			
Ditto	State University 47 Yaroslavsky Street Yakutsk Yakutsk, Sputnik	G			
Ditto	Institute of Space, Physics and Aeronomy, Lenin Str., 61, Yakutsk Yakutsk Science NAFA	G			
Ditto	Pedagogical Institute Respublikanskaya Str., 108, Yaroslavl Yaroslavl, Sputnik	G			
Ditto	Pedagogical Institute 93 School Street Yuzhno-Sakhalinsk Yuzhno-Sakhalinsk Jusnis	G			
Ditto	Scientific Base "Atmosphere", Novoshikhovo Zvenigorod District Moscow Region Zvenigorod, Atmosphere	G			
chronometer, stopwatch, radio time signals	Dr. D. Radnaa, Astronomical Observatory, Academy of Sciences, Ulan-Bator, Mongolia	G			
chronometer, stopwatches, radio time signals	Nha Khi Tu'ong Dang Thai Than N4 Hanoi, Vietnam Meteo Hanoi Vietnam	G			

APPENDIX

THE PRINCIPAL CHARACTERISTICS OF INSTRUMENTS USED AT SOVIET AND SOME OTHER EASTERN EUROPEAN STATIONS FOR OPTICAL OBSERVATIONS OF ARTIFICIAL EARTH SATELLITES

AT-1	- wide-angle telescope, d = 50 mm magnification 6 x diameter of field of sight ~ 11°
TZK (TPZ)	- binocular on a theodolite mounting, magnification 10 x diameter of field of sight ~ 7°
TZK - 1 photo	- TZK telescope with a camera for photographing the circles
NAFA 3c/25	- camera with an objective "Uran-9" d = 100 mm, f = 250 mm field of sight 32° x 52° fast shutter connected with a chronograph
Maksutov meniscus telescope with a plane-parallel glass plate	- d = 500 mm, f = 1200 mm
KPP	- camera with a moving film without a shutter objective "Uran-12" d = 200 mm, f = 500 mm
Astrograph	- d = 400 mm, f = 1600 mm field of sight 10° x 10°
Double-camera	- two aerophotocameras with an objective "Industar - 17" d = 100 mm, f = 500 mm
Camera with an oscillating plate-holder	- objective "Uran-16" d = 210 mm f = 750 mm diameter of field of sight ~ 31.5°
Three-axis automatical photo-camera	- objective "Uran-16" d = 210 mm f = 750 mm diameter of field of sight ~ 31.5°

LIST OF RADIO TRACKING STATIONS

Definition of Column Headings

Column No.			
I	-	Station *	
II	-	Co-ordinates:	1) Longitude, measured in degrees, minutes and seconds East 2) Latitude, North positive, South negative 3) Altitude
III	-	Station Code Number	
IV	-	Type of observation and tracking facility	
V	-	Operational frequency	
VI	-	Accuracy	a) Positional, in terms of angle (interferometer), or angle and range (radar), or rate of change of range (Doppler). b) Timing
VII	-	Timing Facilities	
VIII	-	Address of station or address for communications	
IX	-	Operating Organization	

* Stations marked with an asterisk do not completely conform to the definition of a Radio Tracking Station (definition given in Resolution 13 of the COSPAR Meeting in Washington, May 1962) in that either their observations are not used primarily for the purpose of obtaining orbital or track information, or they do not operate on a reasonably regular program. They are included, nevertheless, in the list as they have necessary facilities for tracking.

RADIO TRACKING STATIONS

COLUMN IX

(Operating Organizations)

1. Geophysical Institute
Czechoslovak Academy of Sciences
Praha 4, Sporilov
Bocni II, Czechoslovakia

2. Ionosphären-Institut
7814 Breisach
Federal Republic of Germany

3. Smithsonian Astrophysical Obs.
60 Garden Street
Cambridge, Mass. 02138, U.S.A.

4. Sternwarte der Stadt Bochum
4630 Bochum
Blankensteiner Strasse 200a
Federal Republic of Germany

5. Funkkontrollmessdienst
61 Darmstadt
Federal Republic of Germany

6. Deutsche Bundespost, FTZ
61 Darmstadt, Rheinstrasse 110
Federal Republic of Germany

7. Deutsche Forschungsanstalt für
Luft-u. Raumfahrt
33 Braunschweig, Flughafen
Federal Republic of Germany

8. Deutsche Versuchsanstalt für
Luft-u. Raumfahrt
8031 Oberpfaffenhofen
Federal Republic of Germany

9. German Astronautical Society
German Democratic Republic

10. National Committee for Space
Research
P.O.B. 7112
Tel Aviv, Israel

11. Consiglio Nazionale delle Ricerche
Piazzale delle Scienze 7
Rome, Italy

12. Chalmer's Institute of Technology
Uppsala, Sweden

13. Katedra Geodezji Politechniki
Warszawskiej
Plac Jedności, Robotniczej 1
Warsaw, Poland

14. Hungarian Academy of Sciences
Committee of Satellite Tracking
and Politechnical University
of Budapest
Budapest, Hungary

15. Instituto Nacional do Tecnica
Aerospacial
Serrano 43
Madrid, Spain

16. National Aeronautics and Space
Administration
Washington D.C. 20546, U.S.A.

17. Radio and Space Research Station
SRC, Ditton Park
Slough, Bucks., England

18. University of Manchester
Nuffield Radio Astronomy Labs
Jodrell Bank
Chesire, England

19. Ministry of Aviation
Royal Radar Establishment
Leigh Sinton Road
Malvern, Worcs., England

20. Astrophysical Laboratory of the
Latvian Academy of Sciences
Turgenev Str., 19
Riga, U.S.S.R.

21. Centre National d'Etudes Spatiales,
Centre d'Opérations
B.P. No. 4
Bretigny-sur-Orge (91), France

22. National Institute for Tele-
communications Research
C.S.I.R.
University of Witwatersand
Johannesburg, So. Africa

23. Radio Research Laboratories
Kokubunji, P. O., Koganei-Shi
Tokyo, Japan

24. Department of Supply
339 Swanston Street
Melbourne, Victoria
Australia

25. Defence Research Telecommunications
Establishment, Defense Research
Board, Dept. of National Defense
Ottawa, Ontario, Canada

26. Space Research Facilities Branch
National Research Council
Ottawa, Ontario, Canada

27. Applied Physics Laboratory
John Hopkins University
Baltimore, Maryland, U.S.A.

28. Crimea Astrophysical Observatory
U.S.S.R. Academy of Sciences
Crimea, U.S.S.R.

29. Uppsala University
Uppsala, Sweden

LIST OF RADIO TRACKING STATIONS

EUROPE

I	II	III	IV	V
CZECHOSLOVAKIA				
Panská Ves	14°34.2' +50°31.7' 312 m		Radio Doppler Frequency Measurement, Faraday Fading	20 - 360 Mc/s
GERMAN DEMOCRATIC REPUBLIC				
Berlin	13°23'48.5" +52°30'49.9" 58 m		Radio Doppler Frequency Measurement	30kHz - 35MHz 120kHz - 30MHz 87kHz - 300MHz
HUNGARY				
Budapest	19°00'08" +47°31'35" 261 m		Radio Doppler Frequency-shift meter, field strength meter Telemetry decoding	1.5 - 30 Mc/s 110 - 185 Mc/s 30 - 110 Mc/s 180 - 460 Mc/s
POLAND				
Bemowo, Warsaw	20°46'30" +52°15'12" 116 m		Radio Doppler frequency and field intensity measurement	Frequency 15 - 60 Mc/s, intensity 20 - 100 Mc/s

VI (a)	VI (b)	VII	VIII	IX	X	XI
f/f=10^{-8} 10^{-1}-10^{-2}c/s	0.01^{s}	Crystal controlled time standard	Geophysical Institute, Czechoslovak Academy of Sciences, Praha 4, Sporilov, Bocni II	1		45
	0.001^{s}	small crystal clock, double recorder, tape recorder	108 Berlin 8 Mohrenstrasse 36/37	9		
100m/s	≤0.01^{s}	crystal clock	Polytechnical University of Budapest, Radio Tracking Station, Elméleti Villamosságtan Tanszék, Budapest XI, Egry J.u.18.	14		10
10s/s		crystal controlled time standard (precision 2.10^{-8})	Radio Tracking Station, Committee on International Geophysical Co-operation, Polish Academy of Sciences, Palace of Culture & Sciences, Warsaw	13		

I	II	III	IV	V
U.S.S.R.				
*Abastumani	$42^\circ 49'$ $+41^\circ 45'$ 1600 m		Frequency Measurement	20 Mc/s
*Crimea	$34^\circ 01'$ $+44^\circ 43'$ 575 m		Radio telescope, Radio spectrograph	200 Mc/s 3000 Mc/s 100 - 150 Mc/s
*Moscow	$37^\circ 19'$ $+55^\circ 28'$ 178 m		Radio Doppler Frequency Measurement	
*Riga	$24^\circ 15'$ $+56^\circ 45'$ 60 m		Radio Doppler Frequency Measurement	183 Mc/s

VI (a)	VI (b)	VII	VIII	IX	X	XI
	0.1^s	printing crystal chronograph, precise time signals	Astrophysical Observatory, Georgian Acad. of Sciences, Mount Kanobili, Abastumany, Georgian S.S.R. Abastumany Georgian Observatory			
	0.01^s	printing crystal chronograph, precise time signals	Nauchny Bakchisaraisky District, Crimea Nauchny Crimea Observatory	28		
	0.5^s	chronometers, precise time signals	Institute of Terrestrial Magnetism (IZMIRAN), USSR Academy of Sciences, Post Office Vatutenki, Lenin District, Moscow Region Izmiran Moscow			
	0.1^s	marine chronometer, precise time signals	Astrophysical Lab. of the Latvian Acad. of Sciences, Turgenev Str. 19, Riga Observatory, Baldone, Latvia			

Appendix IV. Chinese Satellite Observation Stations

Code number	Station	Latitude	Longitude	Height above sea level (m)
271	Peking	+39 56 09.51	116 19 43.8	53
272	Nanking	+32 03 59.9	118 49 15.3	267
273	Lanchow	+36 03 18.44	103 51 45	1514.9
274	Kunming	+25 01	102 43	1918
275	Lasa	+29 39 00	91 07 30	3658
276	Canton	+23 08 34.20	113 20 11.20	31.6
277	Sian	+34 15 03	108 55 01	407.9
278	Shanghai	+31 11 31.00	121 25 43.35	7
279	Wuchanghb	+30 32 30.13	114 20 34.2	45
280	Changchun	+43 52 36	125 18 24	237
281	Urumtsi	+43 49 05.03	87 33 43.95	841
282	Tientsin I	+39 06 07.36	117 09 48.75	20
283	So-se	+31 05 48.0	121 11 12.3	100
284	Harbin	+45 45 23	126 39 37 55	154
285	Huhehaote	+40 50 04	111 39 17	1077
286	Sinin	+36 36 15.4	101 38 21.9	2300
287	Chengchow	+34 44 22.37	113 37 24.00	120.25
288	Chendu	+30 38 05.58	104 05 01.44	501
289	Tsingtao	+36 04 11.5	120 19 06.0	80
290	Foochow	+26 02.7	119 18.4	65
291	Nanning	+22 48	108 18	77
292	Shantow	+23 21.547	116 40.659	9
293	Tientsin II	+39 08 02.23	117 03 27.255	5
295	Tsinan	+36 39 10	117 02 14	

SOURCE: Rezul'taty nablyudeniy Sovetskikh iskusstvennykh sputnikov Zemli, no. 36, 1961, p. 38—39.

Plate 1

Source: AN SSSR. Vestnik, no. 5, 1959, p. 90.

Caption: AT-1 viewfinder (Yerevan station head— B. Ye. Tumanyan).

Plate 2

Source: AN SSSR. Vestnik, no. 5, 1959, p. 91.

Caption: AT-1 viewfinder with camera attachment.

Plate 3

Source: AN SSSR. Vestnik, no. 5, 1959, p. 92.

Caption: AT-1 with theodolite attachment.

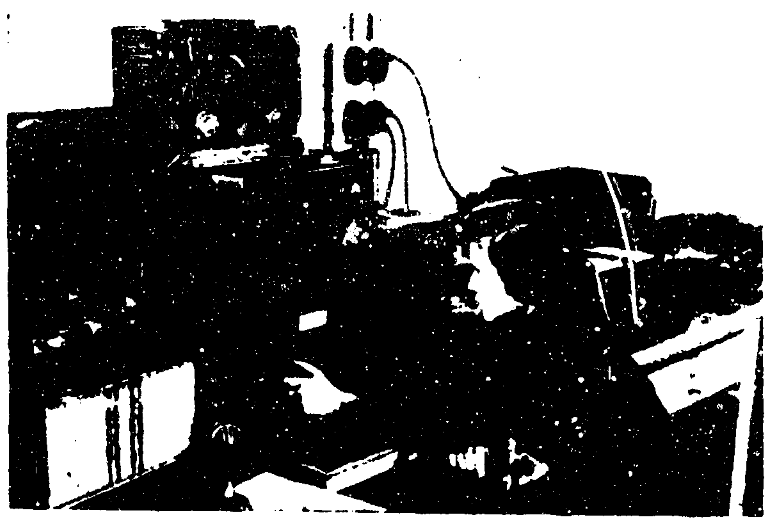

Plate 4

Source: AN SSSR. Vestnik, no. 5, 1959, p. 87.

Caption: Chronograph of Astronomical Council, Moscow.

Plate 5

Source: AN SSSR. Vestnik, no. 5, 1959, p. 87.

Caption: Meniscus telescope and accessories of the Kazakh Astrophysical Observatory.

(П - Vibrating glass plate interrupting satellite track;
О - oscillograph;
Х - printing chronograph;
Г - sound generator.

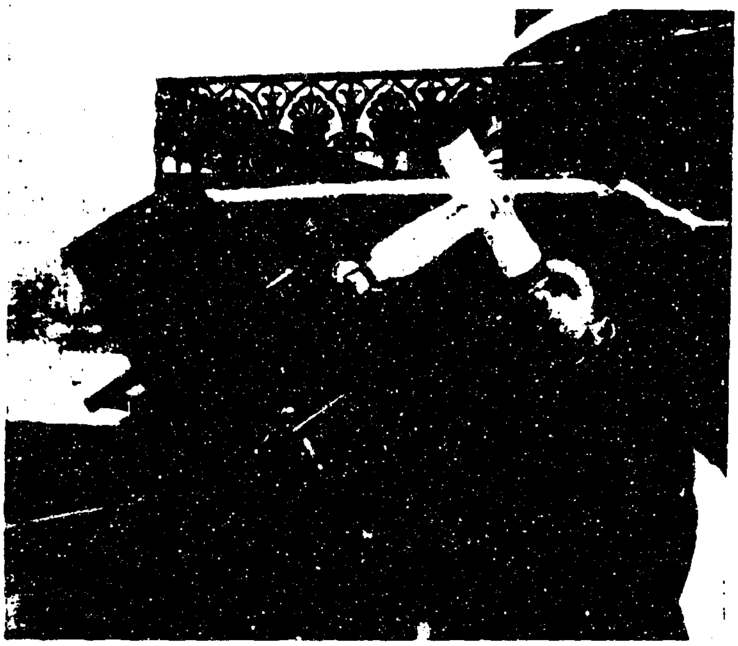

Plate 6

Source: AN SSSR. Vestnik, no. 5, 1959, p. 86.

Caption: NAFA-3c camera of Astronomical Council Station, Moscow

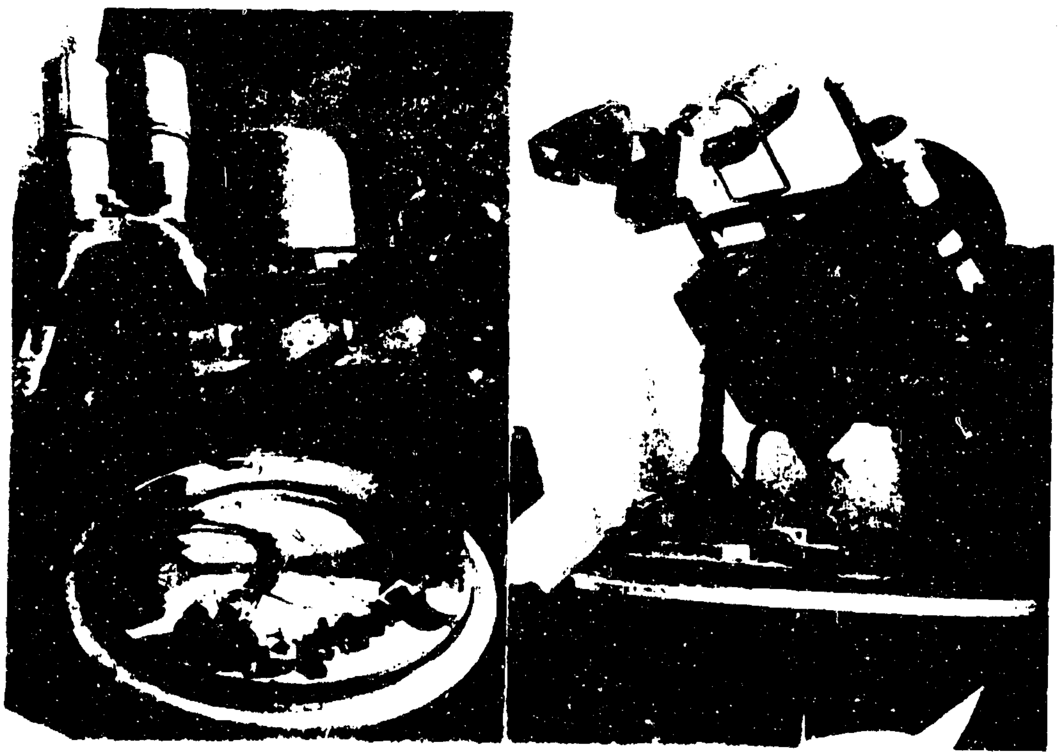

Plate 7

Source: D. King-Hele. Observing Earth Satellites. London, MacMillan, 1966. 220 p.

Caption: NAFA 3c/25.

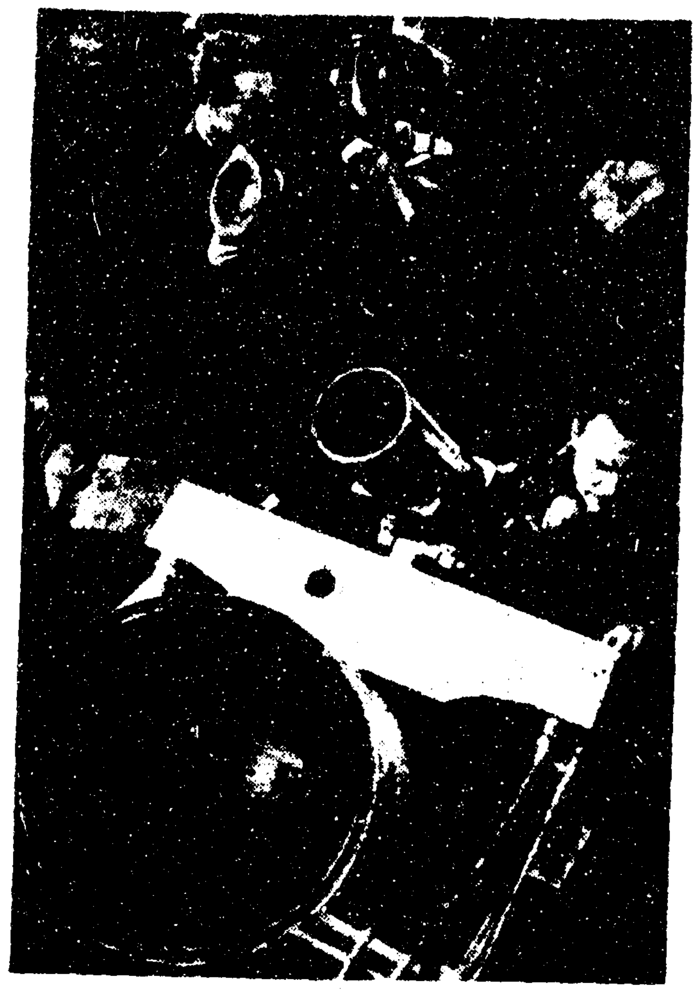

Plate 8

Source: Pravda, 20 March 1968, p. 3, cols. 5—6.

Caption: Tracking camera of Latvian State University (M. Abele and K. Lapushka).

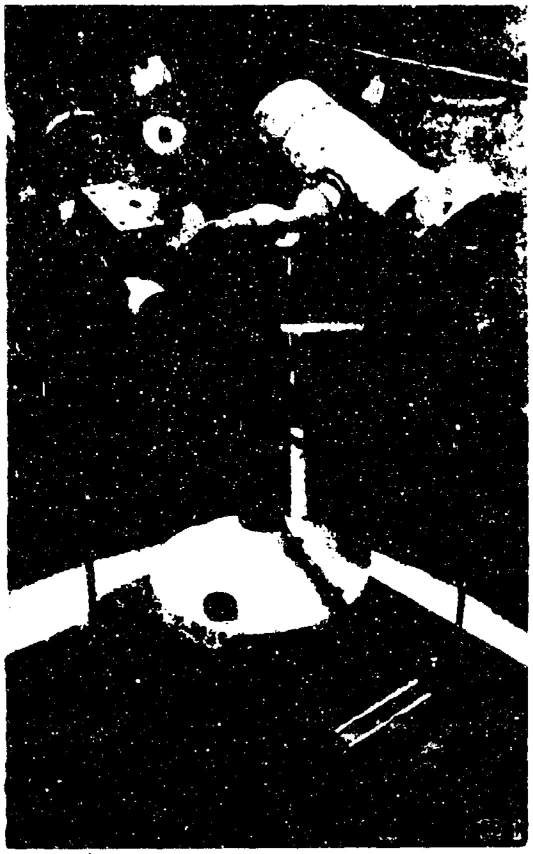

Plate 9.

IN: D.esden Technische Universitet Wissenschaftliche Zeitschrift, v. 14, no. 3, 1965, 679—681.

Caption: Potsdam Satellite Camera.

Plate 10

Source: Die Technik, no. 3, 1967, p. 196.

Captio SBG 420/500/760

Plate 11

Source: Feingerate Technik, no. 1, 1967.

Caption: Satellite camera built by Institute of Precision Instrument Engineering of Ilmenau Technical University (Prof. W. Bischoff, director).

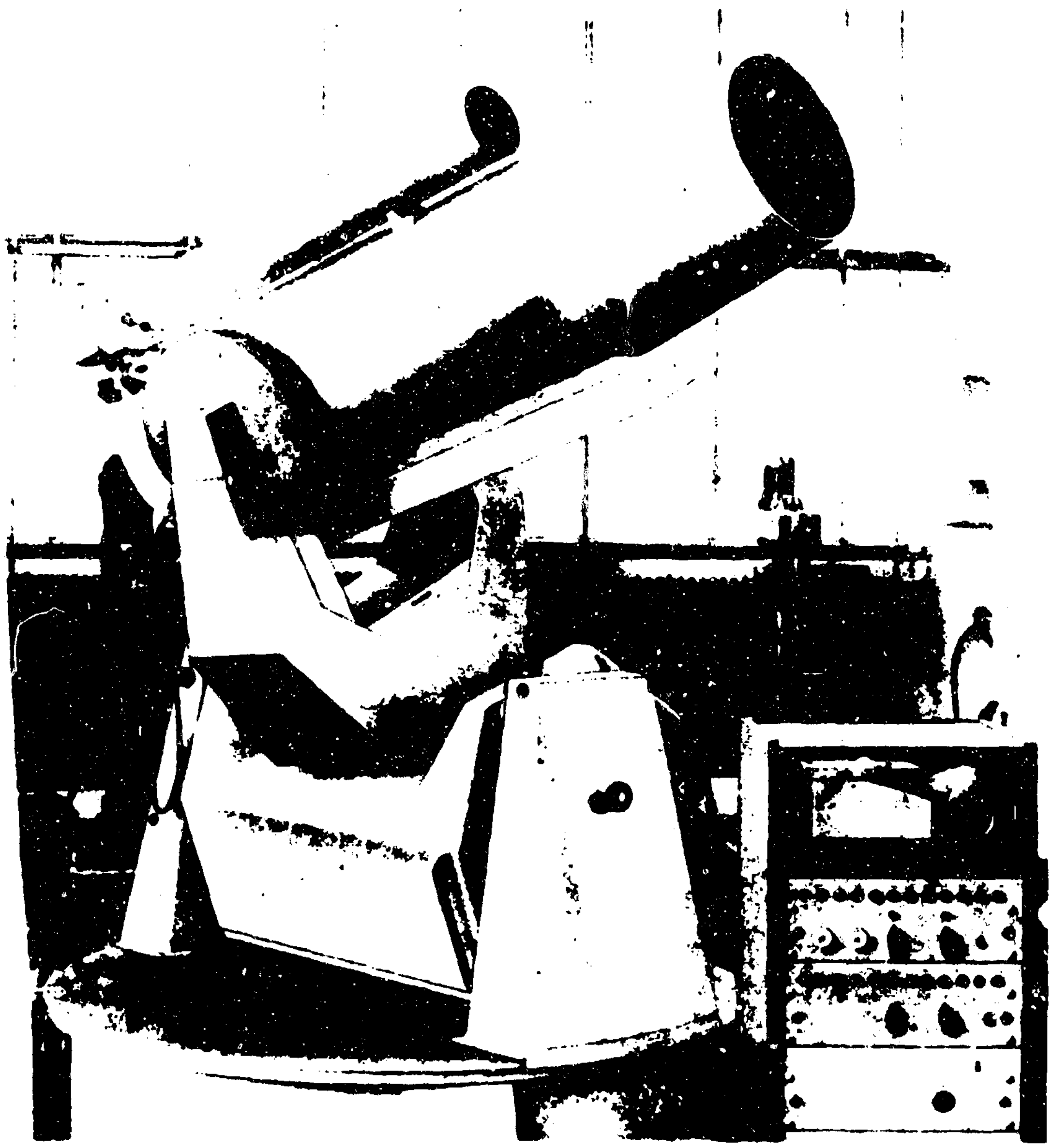

Plate 12.

Source: Jenaer Rundschau. Special Leipzig 'air Issue, 1967, p. 90.

Caption: SBG 420/500/760.

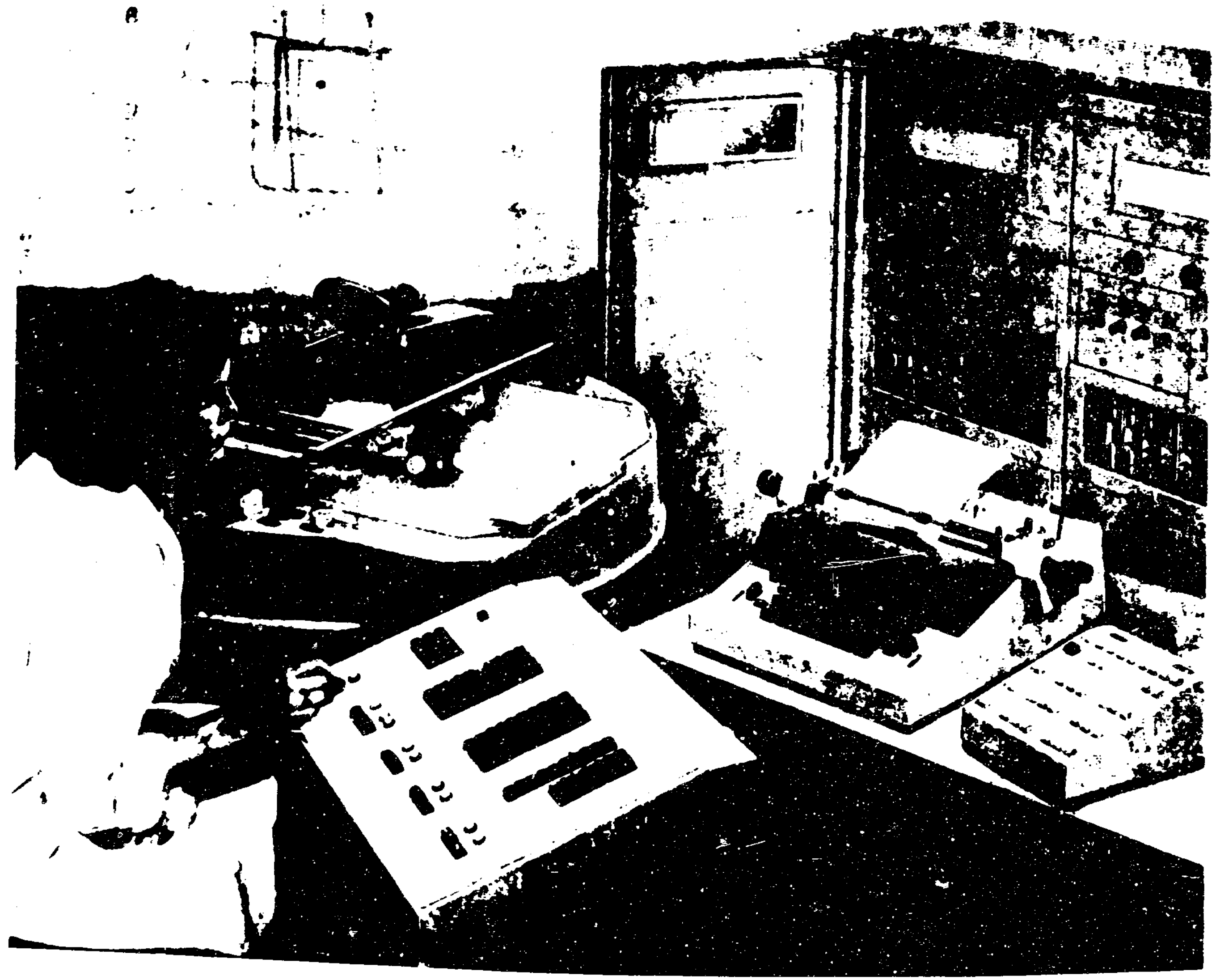

Plate 13

Source: Jenaer Rundschau, no. 6, 1967.

Caption: Overall view of the Ascorecard.

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