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Science

NATIONAL INTELLIGENCE SURVEY

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This chapter supersedes the scientific coverage in the General Survey dated March 1971.

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Science

A. General (S)

The U.S.S.R. from the time of Lenin has emphasized the importance of science and technology to industrial progress and as a means of achieving national political, military, and economic objectives. The Soviets have encouraged the improvement and advancement of both basic and applied research and the expansion of scientific institutions and support facilities. The rapid growth in scientific and engineering manpower and facilities, particularly since 1965, is evidence of the large investment the regime is making in many branches of science. The U.S.S.R. has applied its growing scientific and technological capability to solving problems of national importance. Priority is given to the development of new weapon systems and the improvement of existing weapons and systems as well as to the space program.

Soviet science, despite its considerable progress, remains second to that of the United States in many critical areas, and Soviet civilian technology generally lags that of the leading Western countries and also that of some other Eastern European countries, at least in some sectors. Nevertheless, the U.S.S.R. has made some spectacular advances in military and space technology through concentration of its efforts and resources, and overall scientific and technical capabilities are improving steadily.

Soviet control over science and technology is maintained by a nationally coordinated planning program, but in spite of these efforts, leaders have been dissatisfied with the ability of science to provide a basis for a stronger and more versatile industry. A joint resolution in 1968 by the government and the Communist Party of the Soviet Union (CPSU), aimed at increasing the utility of science to industry, introduced the concepts of profit and financial incentive to motivate institutes to increase the applicability of their research to production. There has been some resistance by scientists to the efforts to redirect their research, however, and it is not evident that party-government pressures to strengthen industrial research capabilities have produced major benefits. There have been definite emphasis on applied and less emphasis on basic research in recent years. According to Chairman V. A. Kirillin of the State Committee for Science and Technology (GKNT) on 16 July 1973, about 85% of the research and development effort in the U.S.S.R. is applied, i.e., in industrial rather than academic institutes (80,000 research workers in academic institutes—basic research; 570,000 research workers in industrial research and development institutes and universities—applied research).

Improved relationships between scientific theory, experimentation, and application have been in large measure the objectives of several reorganizations of the administration of Soviet science and of reforms in the educational system. A related program, still underway, is the geographic dispersal of scientific facilities and activities to help advance the economies of Siberia, the Far East, and other regions.

In addition to extensive acquisition and exploitation of Western technical publications, the Soviets have employed intelligence and subterfuge to obtain technical information and designs to assist in overcoming important research and development problems. Much has been obtained from open sources, however, as well as from samples of foreign

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equipment. Numerous Soviet developments have been based on original Western work, and in some technical fields progress also has been accelerated by aggressive technical intelligence collection programs. In addition, the U.S.S.R. has drawn openly on and exploited to some extent the scientific and technical resources of Eastern European and other countries.

Science has been an important tool of political strategy. Soviet achievements in space and other aspects of technology have increased national scientific prestige. The U.S.S.R. has attempted to exploit this prestige in the East-West power struggle by cultivating the image of the Soviet system as best suited for achieving social and economic advancement and military strength. This image is projected through propaganda, trade fairs, exhibitions, and technical aid to less developed countries.

In recent years Soviet leaders have increased their participation in international scientific affairs, including exchanges, meetings, and some cooperative projects, and they have become more aggressive in obtaining positions of leadership in international scientific organizations. However, Soviet leaders are still reluctant to allow some scientists to travel abroad and from time to time have taken restrictive actions that discourage scientific cooperation with the West. Among the East European Communist countries the U.S.S.R. has fostered the coordination of national research plans and cooperative scientific and technical programs under the auspices of the Council for Economic Mutual Assistance (CEMA), partly as a means of satisfying a desire for international prestige and of increasing the flow of scientific and technical information into the Soviet Union.

B. Organization, planning, and financing of research (S)

1. Organization

Research and development are controlled by the Council of Ministers and administered through various ministries, state committees, and other agencies, including the academies of sciences. General policy is set by the Communist Party of the Soviet Union and controlled through party representation at all levels down to the individual research facility. The party concentrates on establishing general policy, expediting high priority projects, and monitoring plan fulfillment with the objective of solving broad problems. Management of the overall effort is left to the governmental apparatus, which is organized to insure that most research and development projects directly support specific sectors of the economy (Figure 1).

The research structure has undergone a series of reorganizations since the major decentralization of 1957. Reorganizations in 1961, 1963, and 1968 resulted in a partial return to highly centralized management. Since 1968 greater emphasis has been placed on improving the efficiency of research and development and speeding their utilization in industry. The U.S.S.R. has about 5,000 scientific institutions, most of which fall under the following elements of the state administrative structure: the Academy of Sciences and the 14 union republic academies of sciences, which together are sometimes referred to as the academy system; the Ministries of Defense, Agriculture, Health, and Higher and Secondary Specialized Education; a large number of industrial ministries; various state committees; the State Committee for Science and Technology; the State Planning Committee (*Gosplan*); and various administrations and main administrations.

The Academy of Sciences is the leading scientific institution in the Soviet Union, and many of the most important scientists and research facilities operate under it. The academy has the prime responsibility for basic and theoretical research and conducts applied research in key technical fields. In addition, it advises the government on such other matters as the exploitation of resources and on various aspects of economic planning. It also provides postgraduate training for some of the best students, as well as other training designed to increase the capabilities of scientific workers. The academy has four sections—Physical-Technical and Mathematical Sciences; Chemical-Technological and Biological Sciences; Earth Sciences; and Social Sciences—with 16 subordinate departments (Figure 2). Each department acts as a national coordinating center, responsible for guiding research in its specialized fields in institutes of the academy and in other institutes throughout the country working in the same fields. Recent policies have stressed the development of the resources of eastern regions of the Soviet Union. As a result, the Siberian Department, the Far East Science Center, and the Urals Science Center were formed in the academy. These centers, which are organized on a regional rather than a substantive basis, are subordinate to the presidium and have their own general assembly and presidium. They are responsible for scientific and technical activities designed to benefit their own areas, especially those furthering economic development.

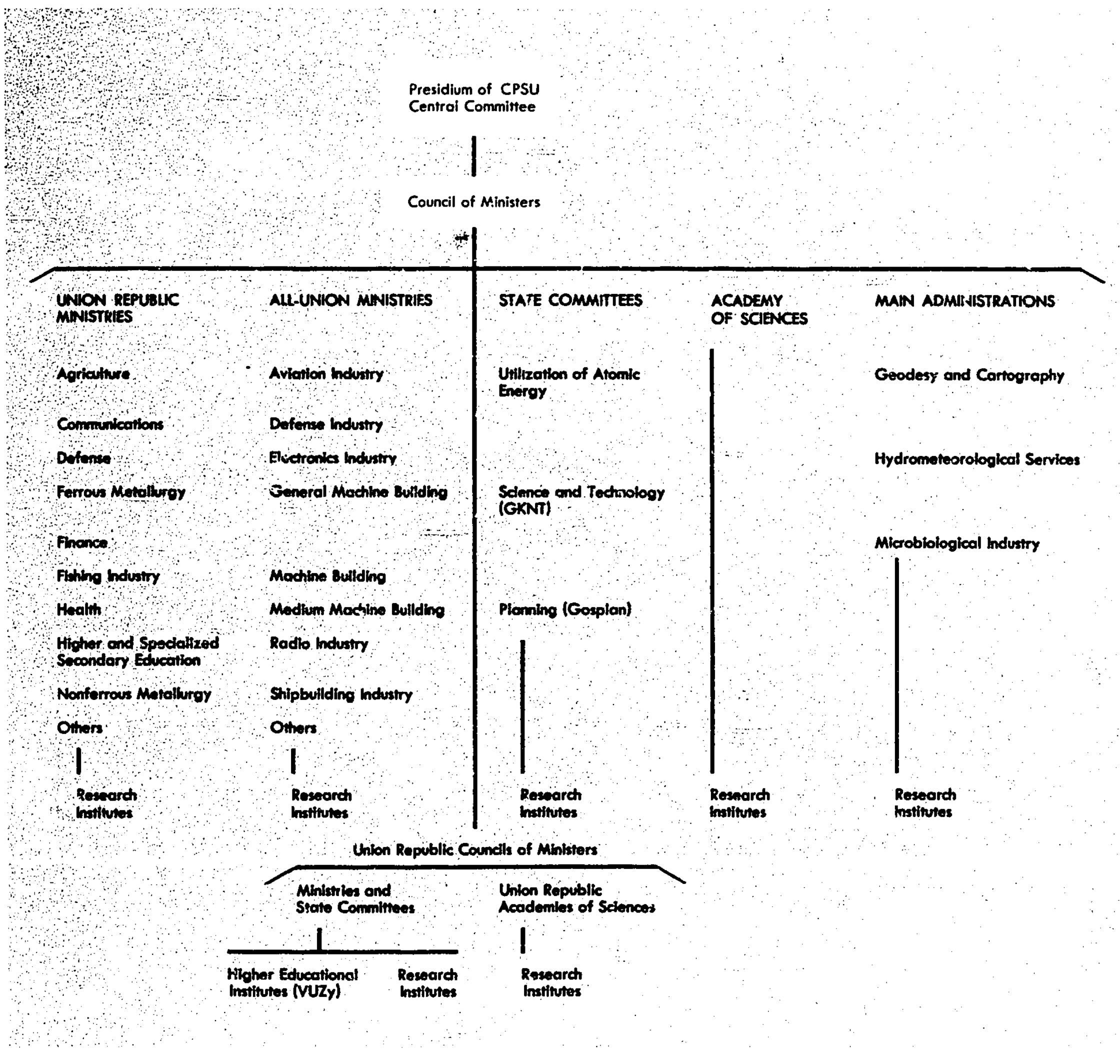

FIGURE 1. Organization of science and technology (C)

Most of the academy's research institutions, which represent between 4% and 5% of the Soviet total number of 5,000, are administered by the departments; the presidium administers some directly. The academy also has 10 affiliates, which are separate institutes or groups of institutes—little "academies of science"—often in remote areas. The primary function of the affiliates is to study the natural resources of the local regions and to aid in industrial development. Four of the affiliates are under the Siberian Department, and the other six are administered by the presidium of the academy.

There are also 14 republic academies of sciences. The Academy of Sciences has considerable authority over the planning and financing of their research, primarily to avoid duplication of effort. The republic academies do research in depth, usually on problems of particular concern to their own union republics.

Most of the applied research and engineering development is carried out in facilities subordinate to the appropriate all-union ministries and state committees, councils of national economy, or to similar agencies of the union republics. Military research and development are performed predominantly by facilities of defense-related industrial ministries, including the All-Union Ministries of Defense Industry, Aviation Industry, Shipbuilding Industry, Radio Industry, Electronics Industry,

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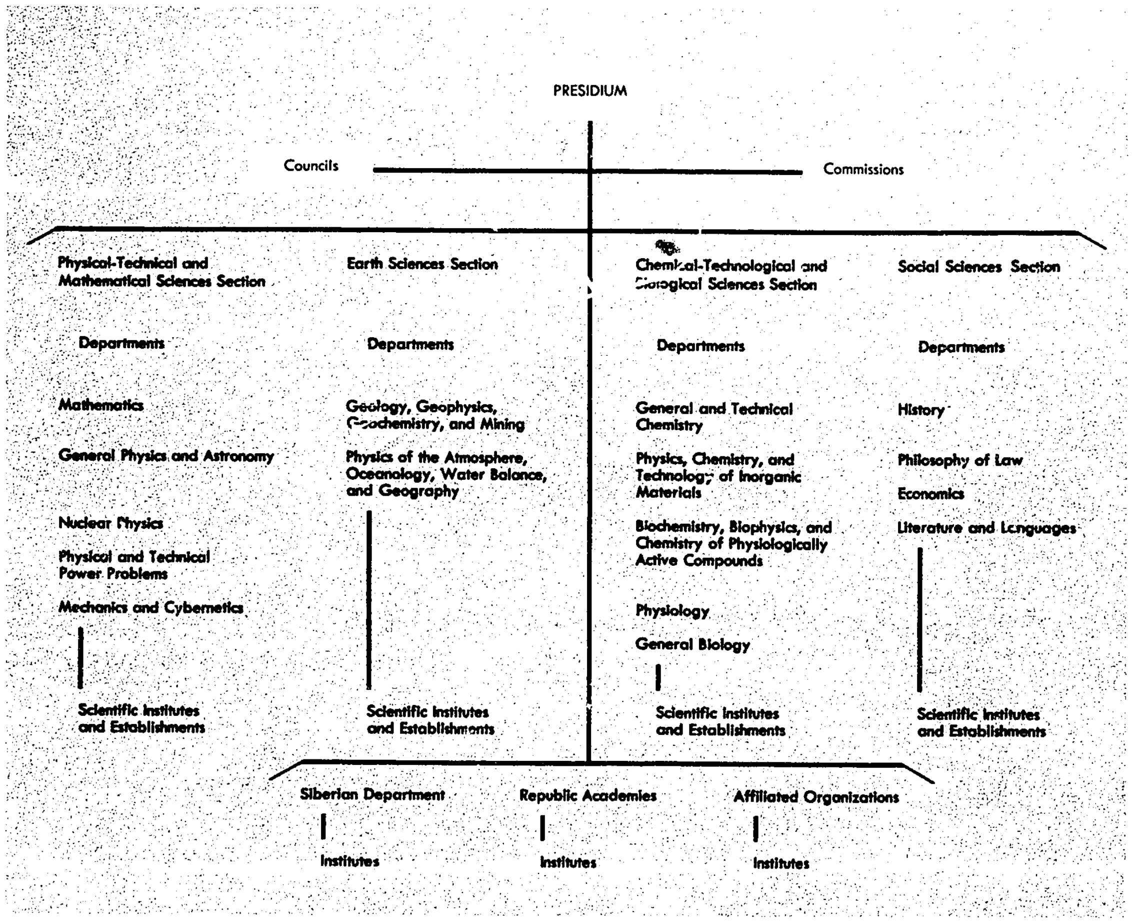

FIGURE 2. Organization of the Academy of Sciences (C)

Medium Machine Building, General Machine Building, and Machine Building. These ministries control a large number of research institutes, design bureaus, testing facilities, proving grounds, and experimental production plants designed to meet the needs for new and improved weapons, support equipment, and supplies.

Soviet agricultural and medical research fall within the jurisdiction of the Ministry of Agriculture and the Ministry of Health, respectively. Each ministry controls research institutions either directly or through corresponding ministries at the union republic level. The most important research institutes of these ministries comprise specialized academies: the All-Union Academy of Agricultural Sciences *imeni* V. I. Lenin and the Academy of Medical Sciences.

The Ministry of Higher and Secondary Specialized Education supervises research at higher educational institutions (VUZy), although many VUZy are administratively subordinate to various agencies at the union republic level. Fundamental and theoretical research at the VUZy, as at other organizations, is guided by the Academy of Sciences. Much of the applied research is done on a contract basis for industrial organizations and is guided by them. Although the quality of research is high at a few VUZy, they play a lesser role in the total Soviet research effort than do higher educational institutions in Western countries. One reason is that the system of Soviet academies of sciences has assumed leadership in research areas held in other countries by universities.

2. Planning

Scientific and technical plans are an integral part of national economic and military planning and are developed by *Gosplan* based on policies laid down by the CPSU Central Committee and on directives of the Council of Ministers. Research and development plans span 5-year periods and are based in part on 15- to 20-year projections of future technical developments and needs. The current research and development plan covers 1971-75. The *Gosplan* is assisted on scientific and technical matters by GKNT, which has overall responsibility for scientific and technical planning, specifically for applied research and development. The GKNT is an all-union organization charged with maintaining a unified national scientific and technical policy and insuring that research results are utilized effectively. It coordinates scientific and technical activities, especially in priority areas; plans capital investments for science; approves organizational changes, including the creation of new research facilities or the elimination of ineffective ones; manages the dissemination of scientific and technical information; monitors the funds budgeted for science; and controls the development of scientific and technological relations with foreign countries. It also can require ministries and other organizations to submit general and specific plans for using science funds. Although the GKNT incorporates military product research and development plans in the unified national scientific and technical plan, it has little influence in controlling or directing military product research and development programs or plans.

The GKNT, which is headed by V. A. Kirillin, Chairman of the Committee, is composed of 24 departments. Its information unit, called the All-Union Institute of Scientific and Technical Information (VINITI), provides information storage and retrieval and drafts statutes on the technical-economic justification of applied research, on intrainstitute cost accounting, and on the rights, duties, and responsibilities of scientific organizations. The institute also provides abstracting service of domestic and foreign literature. About 80% of all world scientific literature is abstracted. VINITI employs 30,000 people, but 26,000 are part-time.

The Academy of Sciences is responsible for coordinating and approving national research plans for the natural and social sciences. Similarly, the Academy of Medical Sciences is responsible for medical science planning and the All-Union Academy of Agricultural Sciences for agricultural science planning.

Soviet research and development priorities in nonmilitary areas are based on key national problems, selected by about 50 scientific councils and approved by the GKNT. The scientific councils under the GKNT and the Academy of Sciences are composed of outstanding specialists who are designated by the GKNT or the academy and who are selected from research and development organizations, VUZy, and industry. In the 1971-75 plan, 250 priority research and development problems were selected for solution. Twenty-five percent of the entire annual research and development budget is allocated for funding these problems, according to Kirillin. The councils are assisted by head institutes officially designated by the GKNT or the responsible academy as the outstanding national research facility in a field, based on the quality of personnel and equipment that are expected to provide leadership to other facilities having the same related interests. Advisory councils in each research facility review programs continuously and evaluate progress. The projects proposed by individual institutes are the basic input to the national plans and provide continuity to the complex planning process.

3. Financing

For many years the Soviet Union has attempted, without much success, to improve the practical utilization of civilian research and development. Research results often are not used by industry for many years and frequently are never used. The latest attempt began in 1968 with a joint resolution of the CPSU and the Council of Ministers for improving the efficiency of research and for speeding the utilization of its findings. The resolution has evolved into a major program to extend the principles of the current economic reform in industry—profit and financial incentive—to the scientific sector, including the academies and institutes under VUZy. Even fundamental and theoretical research must be justified in some way to warrant funding. Wages and bonuses for individuals engaged in research and development and the profits of individual institutions are determined partly by the economic effectiveness of their work. This is the first Soviet attempt to apply economic standards and measurement criteria to scientific and technical activities and has caused some delays and confusion. The resulting reorganizations and changes in work rules also have caused much dissatisfaction and maneuvering for advantages. Although both the party and the government are pushing the program, bureaucratic inertia and opposition may limit the long term benefits.

Much research and development is financed directly by the government as budget allocations for specific research institutions or indirectly through the budgets of individual ministries and state committees of the U.S.S.R. or union republic councils of ministers. A growing portion of research in academy and VUZy

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institutes, as well as elsewhere, is funded through contracts with industrial enterprises. The GKNT controls the state science budget, although some 30% of the funds provided to the Academy of Sciences may be unallocated and held for use by the president of the academy at his discretion.

Announced expenditures for science have grown rapidly over the past decade. Total science expenditures in current prices, including funds for space programs, have increased from about 4 billion rubles in 1960 to 12 billion in 1970. A major portion of total science funds can be attributed to the financing of military research and development and space activities. In constant 1970 prices, these expenditures are estimated to have grown from about 2.6 billion rubles in 1960 to over 7 billion rubles by 1970.

C. Scientific education, manpower, and facilities (S)

The Soviet Union has over 500 higher educational institutions, including more than 50 universities, and about 400 engineering and technical institutes. Total VUZy enrollment is about 5,000,000. The engineering and technical institutes generally concentrate on a specific applied field, such as metallurgy or agronomy, whereas the universities are concerned primarily with academic studies, including basic sciences, such as physics, biology, and mathematics. Although the specialized institutes do a good job of preparing students for a particular field of work, their graduates tend to lack general competence in broad areas. The quality of higher education varies considerably among the VUZy and according to the specialty studied. Quality is generally best in VUZy in the larger cities, such as Moscow, Leningrad, Khar'kov, and Kiev; an exception is the university at Novosibirsk, which is outstanding despite its provincial location.

Students continue to be selected by competitive entrance examinations, with successful applicants assigned to a specific department of a VUZy under a quota system. Unsuccessful applicants can obtain a higher education by attending evening and correspondence schools; about half of all college level enrollment is part-time students.

Postgraduate training, available to outstanding students, is provided at designated VUZy and research facilities of the academies, ministries, and other agencies. Physics and mathematics students go directly into graduate school, so that they can begin research during their most creative years; others must complete 2 years of teaching or industrial work before admission. The most important postgraduate degree is *kandidat* of sciences (about equivalent in most science and engineering fields to the U.S. doctoral degree). Graduates can also obtain this degree without formal training by passing the *kandidat* minimum examinations and preparing and defending a dissertation containing original scientific work. The highest degree, *doktor* of sciences, is awarded for outstanding original scientific work and frequently also as an honor for achievements over a period of years.

Soviet leaders have trained the largest scientific and engineering manpower force in the world; however, the average quality of Soviet engineers, although improving, is below that of leading Western countries. The best Soviet scientists do research on a par with that of leading Westerners. The U.S.S.R. in 1971 had about 2.6 million engineers who have completed higher education and about 552,000 scientists.[1] About one-third of the Soviet engineers works in research, development, or educational institutions. The number of advanced degree holders (*kandidat* or higher) in natural sciences and engineering is about 154,000.

Scientific and technical pay scales are graduated according to academic achievement, experience, and the responsibility of the position held and are accompanied by extensive fringe benefits that permit a style of living far above that of the average Soviet citizen. An extensive use of prizes and other honors adds further to the prestige of scientists and engineers and is intended to stimulate originality and encourage research and development, especially in areas most likely to be of immediate practical value.

The Soviet Union continues to increase and expand its research and development facilities at a rapid pace, but it has not been able to keep up with the needs for space and equipment. Most facilities are located in the Moscow-Leningrad area, the Ukraine-Black Sea region, or western Siberia; the concentration is especially high in the Moscow area. As a result, a program is underway to create some 75 new science cities and science centers throughout the country. As of 1970 the Novosibirsk and Irkutsk centers have made the most progress among the new cities; some of the older science centers, such as Krasnaya Pakhra, also have been expanded considerably. Major centers also have been created in the Ukraine and the far east.

[1]This figure is taken from Soviet statistics for "scientific workers," a term applied by the Soviets to persons with responsible positions in research institutes and higher educational institutions. It does not represent the number of persons who have completed higher education in scientific fields and is therefore not comparable with the figure for the number of engineers. The latter represents all employed persons who have completed higher education in engineering.

They are used to test various solutions to scientific and technical administrative problems, including the development of means for expediting the conversion of research findings into practical industrial applications.

D. Major research fields (S)

1. Air, ground, and naval weapons

a. Aerospace systems

The U.S.S.R. is developing a wide variety of manned military aircraft and is adapting older civil and military types to fly special-mission secondary roles. The classical interceptor, tactical fighter, transport, and bomber systems are supplemented by aircraft warning and control (AWAC), antisubmarine warfare (ASW), signal intelligence (Sigint), and electronic countermeasures (ECM) systems. The Soviets have at least two, possibly three, new fighter aircraft and at least one bomber under advanced development. This work confirms their continued emphasis on developing a spectrum of military aircraft needed in upgrading the effectiveness of their military forces. The research on variable geometry (or swing-wing) aircraft, vertical-takeoff-and-landing (VTOL) and short-takeoff-and-landing (STOL) aircraft furnishes the Soviets with a number of tactical options available for future development. Such active programs also give researchers valuable design and development experience upon which to advance their state-of-the-art in the aircraft field. Aircraft technology is aimed at providing a wide variety of new systems as well as increasing the performance, versatility, and usefulness of contemporary systems.

The most advanced military aircraft developed to date is the Backfire swing-wing bomber (Figure 3). The most advanced civil aircraft is the Tu-144, a Mach 2 supersonic transport (SST). Two of the Tu-144 SST aircraft remain in flight test, following the crash of one prototype at the Paris airshow on 3 June 1973. Tu-114 passenger transport aircraft have been converted to serve as platforms in the development of an AWAC system. An-12A aircraft have been converted to the Sigint role and An-12B aircraft produced for the ECM role. The IL-18 passenger transport design was used for the ASW IL-38 design, and an ASW model of the Tu-95 has been developed. The An-24 has been fitted with a side-looking radar for ice reconnaissance. Some of the known transport aircraft under development include the IL-86, a 350-passenger airbus, and the Yak-42, a 100 passenger trijet. The An-22 (Figure 4) is the largest long-range heavy logistic carrier in service with Soviet Military Aviation.

The applied research underway in aerodynamics and airframe design, propulsion, structures, materials, and manufacturing processes covers the low subsonic to hypersonic regimes of flight. Adequate test facilities are available to obtain experimental verification of results and to refine conceptual designs. Most of the applied aerodynamics and structures research and associated simulated environmental testing is accomplished by the Central Aerohydrodynamics Institute, Moscow (Figure 5). Significant theoretical investigations and extensive wind tunnel and flight tests on laminar flow control schemes have been conducted at the Institute for Theoretical and Applied Mechanics, Novosibirsk.

Research and development continue on all types of air-breathing engines. For turbine engine types, performance improvements are achieved with high-mass-flow supersonic compressors and internally cooled high-temperature turbines. In the past turbines were required to operate at moderate temperature levels because of inadequate quality control being maintained in the metal forming of the high-temperature components rather than from a deficiency of alloy composition. Although effective-impingement-convention, air-cooled turbine nozzle vanes have been in operational use for many years, the Soviets have been slow in adopting cooled buckets to increase turbine inlet temperatures. The Soviets have demonstrated excellent compressor technology in achieving high-flow capacities and high-stage pressure rise in their designs. However, the level of compressor-pressure ratio selected for use on turbine engines has been rather moderate, which, in turn, has increased specific fuel consumption. Thus, the projected rate of compressor-pressure ratio increase for future engines is expected to follow closely the turbine inlet temperature trend.

While all types of chemical rocket propulsion systems have been investigated, the bulk of such work is still on liquid systems for large engine applications. Advancements of a technological nature have resulted from improved engine cycles, components, and system integration schemes, rather than from the introduction of advanced propellant combinations. High-performing, closed-loop cycles, regeneratively cooled double-walled thrust chamber construction and nozzles integrated into the vehicle base have all contributed to the excellent performance of rocket engines. Flight testing of metallized fuels/fluoridated oxidizers and liquid oxygen/liquid hydrogen propellants is considered imminent. Cryogenic liquid propellant systems continue to be employed in space booster engines, with liquid oxygen being the prime oxidizer. Tetralin has been used as an additive in

FIGURE 3. Model of Backfire bomber aircraft (U/OU)

FIGURE 4. An-22 long-range heavy logistics carrier (U/OU)

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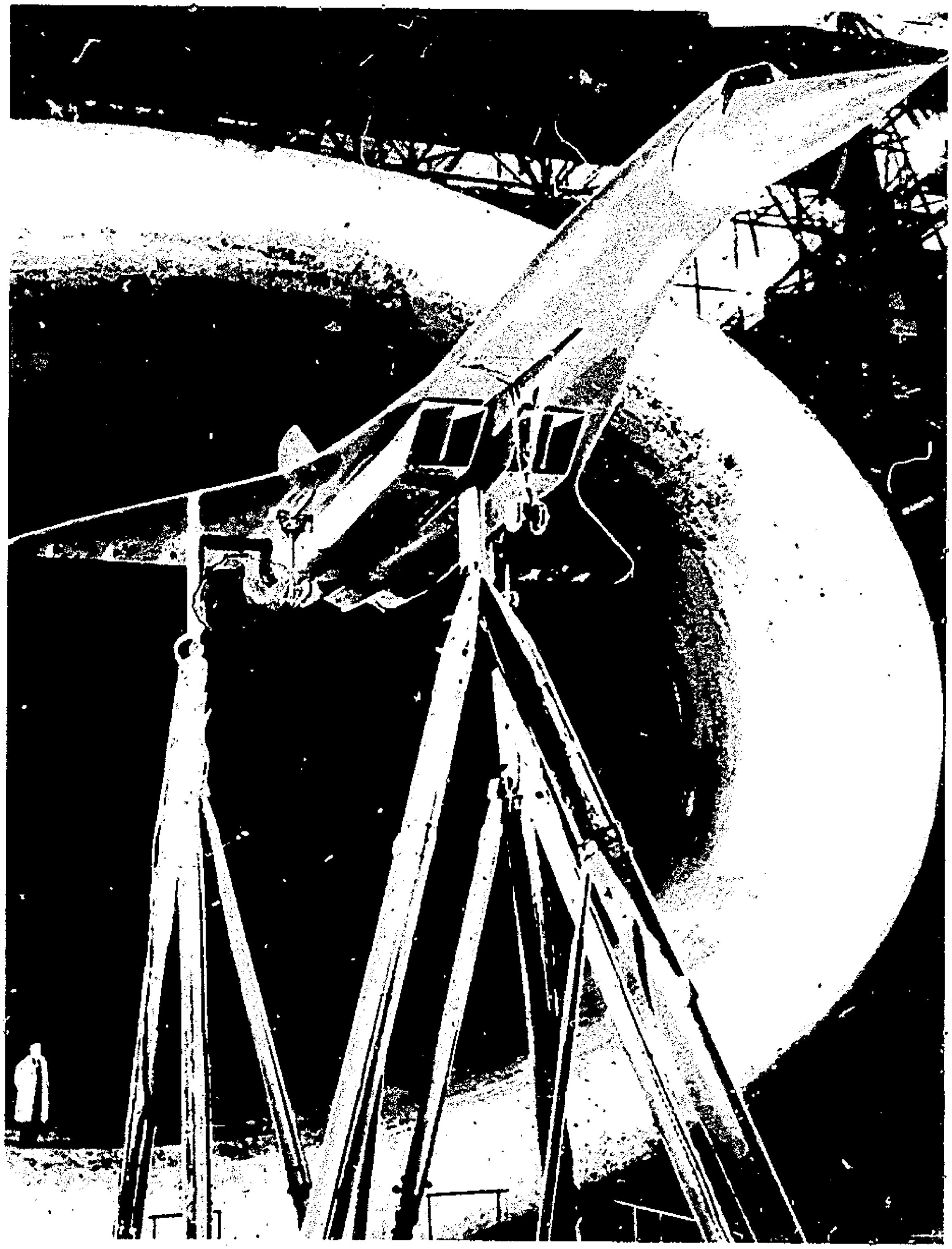

FIGURE 5. TsAGI wind tunnel (U/OU)

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cyclohexane-liquid oxygen systems and found to produce faster ignition times. Storable propellants, such as hydrazine-type fuels and nitrogen containing oxidizer, are used in the liquid propellant missile systems. Increased interest in hydrogen-oxygen indicates the Soviets may be developing a liquid propellant hydrogen-oxygen rocket engine. Research in supersonic combustion continues, using such fuels as hydrogen, methane, acetylene, organometallics, slurries, and hybrids.

Large solid-propellant motors in the 1.5-million pound thrust class are under development, as are advanced propellants with ingredients such as beryllium and fluorine. Much success is achieved with additives of metals, metal hydrides, and metal alloys in order to generate high-burn rates and combustion tailoring. Developments in using ultra-fine aluminum, magnesium, or aluminum-magnesium alloy powders as metallic additives to achieve fast-burning is a step toward realizing high impulse composite-modified double-base solid propellants.

Structures research has concentrated on the use of composite materials and sandwich/multilayered forms. Studies on composites have centered on optimizing design for minimum weight, analyzing behavior in a vacuum, determining creep at elevated temperatures, and the calculation of stress concentrations in plates being subjected to thermal gradients. In sandwiched/multilayered plates and shell structures, attention has been directed toward optimal design for minimum weight, effects of cut-outs in giving rise to stress concentrations, thermal stresses, and thermally induced vibrations. Soviet knowledge of both sandwiched construction and shell structures is adequate to permit their effective application in advanced aerospace vehicle design.

In materials research the Soviets have developed an aluminum alloy which is at least 10% lighter than conventional aluminum alloys. Their titanium casting technology is superior to that of the United States, while their beryllium technology lags. Soviet research is underway to increase the ultimate stress of high-strength steels from 225,000 psi to 260,000-425,000 psi; to reduce structural weight, maraging steels are being developed and carefully evaluated. Except for the most advanced cast nickel-based alloys, such as the Zh-6 series, which are 10 to 40°C inferior to the best U.S. alloys, Soviet superalloys have the same temperature capability as U.S. materials but less service life. This drawback is being overcome by improvements, such as electroslag melting, directional solidification, better design, coatings, and constituent alloys. The U.S.S.R. lags the United States in the development and production of coatings for refractory metals but has adequate coatings for short-time military use.

The Soviet Union has the most advanced conventional welding processes in the world, and it introduced a number of welding firsts, such as the glue welding process. There are 20,000 welding engineers, and some 2,000 new engineers in this field are graduated each year. Also the U.S.S.R. has the largest forging (75,000 metric tons) and extrusion (20,000 metric tons) presses in the world; a 50,000-metric ton special press is being constructed to investigate effects of high pressures on materials; one goal is to form metallic hydrogen.

The Soviets have vigorously pursued a broad and diversified missile research and development program. This program has resulted in a full range of missiles from the short-range tactical types to the intercontinental ballistic missiles (ICBM's). Seven liquid-propellant ICBM's have undergone development, including a mobile system. Of these seven systems, four are operationally deployed, and another continues in service as the launch vehicle for the largest space payloads. A solid propellant ICBM has been developed also and is deployed in limited numbers, and four new systems—one solid and three liquid propellant—have entered flight testing. A large new liquid propellant missile has entered the flight test phase. This emerging generation of weapon systems will probably incorporate qualitative improvements in guidance and reentry subsystems. Other missile programs in progress include several specialized research projects involving post-boost maneuvering and new guidance techniques.

Developments cover a rather complete range of offensive missile weaponry and include the following:

1) The SS-12, a single-stage, liquid-propellant, mobile, strategic, short-range ballistic missile (SRBM) system (operational).

2) The SS-11 Mod 3 ICBM, a system intended to deliver three reentry vehicles in a very limited impact footprint (operational in 1973).

3) A probable new small liquid-propellant ICBM (SS-X-17) which may be intended as a replacement for the SS-11 (not expected to be operational before 1975).

4) A new small solid-propellant ICBM follow-on to the SS-13 (could reach operational status in 1975).

5) A new long-range (about 4,200 nm nonrotating earth) liquid-propellant, submarine-launched ballistic missile (SLBM), designated the SS-N-8, operational in early 1973; it will probably be deployed in the D-class submarine.

Research on defensive missiles also is broad in scope. There has been a steady evolution of surface-to-air

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missile (SAM) system design, both of the ground-launched and naval-launched types. Since 1955 a major effort has been underway to develop an antiballistic missile (ABM) defense. One such system, the ABM-1, is deployed around Moscow.

The U.S.S.R. has a well-founded, comprehensive, expanding but only moderately successful space program, which aside from probing the unknowns of space, actively pursues certain military objectives. The military orientation of the program is indicated by the fact that over 400 spacecraft launched since 1957 have performed military or military-related functions. A fractional orbital bombardment system and antisatellite (ASAT) system have been developed and tested, and photo- and Elint-reconnaissance, communications relay, navigation, and meteorological/geodetic space systems are operational. Activity noted during 1971 and 1972 indicates that a possible ocean reconnaissance space system could be operational by the 1975-77 period. Now that original problems with the SL-12 launch vehicle have apparently been solved, it is believed that the Soviets can place the existing orbital interrogator into geostationary orbit with the accuracy required for nonnuclear kill. However, they have conducted no tests of such a capability. During this decade additional follow-on/modifications of existing military systems are expected.

In addition to developing military space systems, the Soviets have pursued a purposeful scientific/exploratory space program. The Soviets manned the world's first space station, *Salyut* I, for 23½ days in 1971, and they attempted, unsuccessfully, to launch a second space station in 1972. *Salyut* II was launched on 3 April 1973, but a manned *Soyuz* crew transfer craft was not launched to dock with it. Radar observations indicate that a major malfunction occurred on 14 April 1973. Another *Salyut* launch was attempted on 11 May 1973, but apparently this station also malfunctioned, since the Soviets gave it a Cosmos designation. Although Soviet manned lunar landing efforts have not been successful, *Luna*-19 was a successful lunar orbiter, and *Luna*-20 landed on the moon and returned to earth with a lunar soil sample. The Soviets have also landed capsules on the surfaces of Venus and Mars, and they reportedly have obtained data concerning the atmospheres of the two planets. Follow-on space station operations, lunar missions, and extensive planetary exploration by the Soviets are expected during this decade.

b. Ground weapons and equipment

Ground weapons and equipment development programs reflect a high degree of technical capability. In the armored vehicle category, greatest emphasis has been placed on the development of a medium tank—currently considered as the main battle tank. Development work was carried out in the 1960's for a new light tank to replace the PT-76. Although no conventional light tank has appeared, there is a new light tank for air drops armed with a 76-mm smoothbore gun and a Sagger-type antitank guided missile launcher. The latest Soviet developments in ammunition are the 100- and 115-mm armor-piercing discarding-sabot (ADPS) types. The 100-mm projectile is fired at a muzzle velocity of 1,451 meters per second (m/s) and the 115-nm round is fired from at a muzzle velocity of 1,615 m/s. The Soviets have an ongoing research program on combustible or consumable cartridge cases. Further emphasis is to be devoted to rocket-assisted ammunition and to new and improved tank armament, antitank weapons, and associated warheads or ammunition. For more than 25 years the Soviets have led the world in the development and tactical employment of free-flight rockets fired from multiple rocket launchers. The Soviets also have developed a series of accurate long-range, single-fired rockets (FROG's) to provide the primary means, within their maneuver divisions, to deliver nuclear warheads.

Research and development on armored personnel carriers have been directed toward providing a greater number of vehicles with a larger main armament. A new category of vehicle—the infantry combat vehicle—has been developed. These vehicles, designated BMP, can operate in proximity with main battle tanks, and their main armament is capable of destroying armored vehicles. The Soviet explosives research and development program is very extensive, especially nitrochemistry and the study of detonation phenomena. Studies on gaseous explosives, radiation effects on explosives, and new explosive applications are increasing and provide excellent data and new technological developments.

Considerable research is underway in ground weapon-related technologies involving metallurgical and polymeric materials. Laminated steels are under consideration for armor application and machine building. The State Planning Institute for Enterprises Engaged in the Production of Plastics and Semifinished Products is probably the controlling facility for production technology on plastics and reinforced plastics for both military and civilian organizations. Reinforced plastics are used in at least three Soviet weapon systems. V. I. Serenkov and coworkers at the Mendeleyev Institute have published research concerning the properties of polyethylene copolymers that have been filled with a variety of metallic fillers. This research is applicable to the plastic interior liner used next to the hull in some combat vehicles; other uses involve a glass-reinforced phenolic in the bodies of antitank missiles and a glass-reinforced launch tube for antiaircraft missiles.

There is strong evidence that the Soviet Union conducts its organic materials program jointly with other Warsaw Pact nations. The U.S.S.R. is involved in developing high-temperature polymers and new polymeric materials which are used in fibers, resins, films, and adhesives for military applications. The top polymer scientist, V. A. Kabanov, as well as the leading expert on polymer mechanics, A. A. Il'yushin, work at Moscow State University. Kabanov's research on matrix polymerization, using the one polymer as a matrix or template for the stereospecific polymerization of another, has attracted widespread interest and may make possible the production of specifically tailored bicomponent polymers.

The major transport fleet of the Soviet Army is upgraded continually, with the major design effort concentrated on medium- and heavy-payload vehicles. Light vehicle development has been minimal. The Italian automotive firm, FIAT, however, provides technical assistance in the construction and operation of the Togliatti plant in the U.S.S.R.; this assistance may have a significant impact in the future.

The U.S.S.R. has a large, well-organized research and development effort directed toward air cushion technology in three basic areas: an operational amphibious air cushion vehicle fleet for naval infantry and army use, a very large wing-in-ground effect machine for use as a military long-range, high-speed transport, and sidewall air cushion vehicle to improve inland river transport.

Results of research and development on tactical bridging during the past decade have been impressive, particularly with the introduction of the "ribbon bridge" concept for the crossing of wet gaps and the multispan truck-launched short-span fixed bridging for the crossing of dry gaps or minor wet gaps. The Soviets can assemble ribbon bridges at a rate of 20 linear feet of bridge per minute and can install the light and heavy mechanized treadway bridges in minutes instead of hours. For rear area bridging, the U.S.S.R. developed a floating railway bridge that can carry both rail and vehicular traffic simultaneously; no country in the West has such a bridge for military use.

Soviet topographic equipment developments are evident in every category from simple lensatic compasses to relatively complex photogrammetric and land-navigation systems. Nearly a decade of operational experience with the latter systems has led to the development of advanced systems for automatic survey for mobile tactical missile operations. The U.S.S.R. has an active but limited research, development, and production program concerned with engineer construction equipment; this equipment is used primarily by the military. Most items are copies of older foreign-designed models, and when newer specialized equipment is required, attempts are made to purchase it from the West. The Soviets have mass-produced large quantities of low-output thermoelectric (TE) generators, and a few moderate output units are in use in remote regions. One of the objectives of the extensive Soviet TE research and development program is the development of a lightweight, high-output TE generator for space vehicles.

The U.S.S.R. is a pioneer in the development of rotary-wing aircraft (helicopters) and has placed great emphasis on the development of such aircraft for both civil and military uses. Soviet helicopter design bureaus reflect a high degree of technical knowledge and creative capability. During the past 10 years major emphasis has been concentrated on heavy-lift helicopter developments. These heavy-lift helicopter designs can be attributed to long and steady development efforts in contrast to short-term, maximum-effort programs. At a result, the Soviets have a significant lead over the West in heavy-lift development. The Mi-12, a lateral-rotor design, has a projected gross takeoff weight of about 230,000 pounds and is capable of carrying 200 troops. The latest helicopter, HIND, appears to be the result of an accelerated program to develop a combat assault helicopter with a dual armed and transport capability.

c. *Naval weapons*

The ships, submarines, and naval aircraft produced in the U.S.S.R. during the 1960's are vivid testimony to the existence of a very large, well-coordinated naval research and development establishment. This establishment has demonstrated its capability to design and to develop successfully large, complex, and unique weapon systems, some of which have no counterparts in any Western navy. Beginning with the 1970's emphasis is placed on the navy's utility as an instrument in support of national policy abroad. The naval research and development community has redoubled its tempo with the infusion of increased priorities, funding, and resources. New types and classes of ships are entering the naval inventory at a high rate, while older classes are being upgraded through conversion and modernization. The more spectacular achievements of the combined efforts of naval research and development establishment and the shipbuilding industry since 1960 include the following:

1) A large force of diesel and nuclear-powered submarines armed with surface-to-surface, homing-type, antiship missiles. At least one class can launch its missiles while submerged.

2) The *Moskva* class guided-missile helicopter cruiser equipped with hull-mounted sonar and a variable depth sonar, surface-to-air missiles, and antisubmarine warfare (ASW) missiles, rockets, and torpedoes.

3) The first large surface warship powered entirely by gas turbines—the *Kashin*-class ASW frigate.

4) One of the most heavily armed guided missile cruisers in the world. The *Kara*-class is armed with two separate surface-to-air missile systems, two separate antiaircraft gun systems, a surface-to-surface missile system, and three ASW weapon systems. The cruiser is equipped also with a variable depth sonar and a helicopter facility.

5) The introduction of over 30 new classes of Soviet surface combatants in the last 12 years.

Soviet submarine development has produced seven new types of submarines since 1968. These are the Y-class, 16-ballistic missile nuclear-powered submarine; the V-class fast nuclear-powered attack submarine; the C-class guided missile nuclear-powered submarine with a short range subsurface-to-surface antiship missile armament; the B-class, a diesel-powered submarine; the A-class nuclear-powered submarine; the P-class, which is nuclear-powered and probably armed with cruise missiles; and the D-class, a nuclear-powered ballistic missile submarine armed with missiles which have a significantly longer range than those carried on the Y-class. The above submarines, which are nuclear-powered, are second-generation and have significant speed and power advantages over their U.S. counterparts, although they tend to be far more noisy.

Soviet interest continues in ground effects machines (GEM) and hydrofoils. One class of GEM, the Gus, is in series production. Recently a new hydrofoil-type subchaser, the *Turya*-class, has been observed also in apparent series production. Research in the 1970's appears to be concentrating on ASW, acoustics, anticarrier and antitask force weapons, and newer, larger warships. A new aircraft of 35,000 to 40,000 tons reportedly is under construction and will probably carry a mixture of rotary wing and VV/STOL fixed-wing aircraft and/or helicopters. The Soviets continue a high level of research and development of more flexible, powerful, and economical propulsion plants, as is evidenced by the use of all gas-turbine installations, pressure-fired boilers in steam turbine propulsion systems, and combined gas turbine diesel propulsion.

The research and development establishment supporting naval weapon developments is guided and directed by the Scientific and Technical Committee of the Navy and the Directorate of Warship Construction and Armaments of the Navy. More than 20 individual scientific research institutes and universities and over a dozen design bureaus specializing in various aspects of the naval research and development program have been identified, and many more are believed to exist. One of the most noted of these is the Central Scientific Research Institute *imeni* A. N. Krylov in Leningrad, which is the Soviet equivalent of the U.S. Naval Ship Research and Development Center (NSRDC). The above institute appears to have facilities generally similar to those of NSRDC and, in addition, has built a new variable pressure circulating water channel with a free surface. This facility is unequaled in the West. It permits the Soviets to take a new approach to experimental research on cavitation problems related to the hydrodynamic designs of high-speed warships and very large tankers.

2. Biological and chemical warfare

a. Biological warfare

Although the Soviets have neither confirmed nor denied that they were engaged in the development and production of biological agents for military application, they have the scientific personnel and research facilities capable of supporting a strong biological warfare (BW) research and development programs. Open literature reveals that the U.S.S.R. has the competence to engage in the research and testing necessary for agent development and is fully knowledgeable of potential delivery systems. No institute or facility has been positively identified as a site where BW agent development occurs. Numerous biological research institutes located throughout the Soviet Union have been suspected for many years because of the work done with the causative agents of plague, tularemia, cholera, brucellosis, and anthrax, all of which are prime candidates for BW agent development. The Soviets claim only public health interests. Some of these institutes have been reported by several sources to be under military control, which is consonant with military medical research facilities.

Soviet investigators continue to publish the results of studies designed to enhance the virulence of a number of microorganisms. Recent studies report the transfer of antibiotic resistant factors to the causative organism of plague, dysentery, and cholera; the induction of antibiotic resistance in the organisms causing anthrax, typhoid fever, dysentery, and plague; and the creation of hybrid enteric organisms which differ serologically from either parent. Typical organisms such as these complicate detection and treatment in the event of a biological attack. Soviet virologists have published numerous studies concerning the effects of chemical mutagens on a wide variety of arboviruses. Stable mutants with decreased virulence were selected because of their potential for use as live vaccine agents. Mutants having increased virulence also resulted from these treatments. The Soviets continue to do extensive studies on the viral agents causing tick-borne encephalitis. Efforts are made to develop live vaccines having a greater effectiveness than are now in use.

The Soviets are world leaders in aerosol research. Much of the work has application BW, and is of high quality. Recently published reports concern improved devices for collecting and analyzing biological aerosols of various particle sizes. The Soviets have developed several types of instruments for studying biological aerosols. Advances in this instrumentation could be applied to the development of an automatic biological agent detection/warning device for military use. There is no evidence that a satisfactory prototype detector has been developed. The Soviets claim to have had good success in simultaneously immunizing large numbers of people with aerosolized vaccine preparations. Furthermore, this technique has been applied by the Soviet Military Medical Service in the field, with the aerosol being generated in tents. How effective this would be in reducing casualties in the event of a biological attack is debatable, but it might be a useful means of giving booster immunizations for such diseases as tetanus and gas gangrene, which are of significance on the battlefield.

The Soviets are knowledgeable about microbial fermentation of microorganisms of BW interest, agent stabilization, and agent drying. Recent reports show that they apply mathematical modeling to continuous fermentation processes. Of note among these is one in which the conditions for optimum yield of organisms were determined for the vaccine strain of typhoid bacteria. The Soviets are engaged in finding better methods for stabilizing and/or drying live vaccines for longer storage life over a fairly broad range of temperatures (4°C to 50°C).

Numerous books and articles published in the Soviet Union detail the defensive measures to be taken by both military and civilian populations in the event of a biological attack. Topics emphasized include ways to recognize a biological attack, the use and care of protective masks and clothing, rules of personal hygiene, the need to protect water and food supplies from contamination, and personal decontamination of skin and clothing. Practical exercises in the procedures to be followed in a biologically contaminated environment are a part of the training of all soldiers. The level of defensive BW training for both civilians and military personnel probably is the highest in the world.

b. Chemical warfare

The specific direction of research and development in the Soviet chemical warfare (CW) program is difficult to discern. A large volume of basic and applied research that is related and could be applied to CW research appears in open literature. In most instances it is virtually impossible to separate research done specifically for CW purposes from that for pharmaceutical or insecticide purposes. At least 50 institutes in the U.S.S.R. perform research and development which could be related to chemical warfare. Research is conducted on a very broad front in fields that have potential applications to the development of more lethal agents, as well as the physically and mentally incapacitating compounds. The Soviets, however, are not known to have incapacitating agents in their arsenal. A substantial amount of research underway has CW application: studies related to toxic agent development, detection, protection, decontamination, and prophylaxis and therapy.

The Soviets are synthesizing and testing various kinds of new organic compounds for anticholinesterase activity, but there is no firm evidence that they are seeking more toxic anticholinesterases. There are some indications, however, of increased interest in compounds of the type that may be "antidote-resistant." Organophosphorus chemistry is probably one of the best developed fields of chemistry in the U.S.S.R., especially in areas related to CW nerve agents. In contrast to random methods prevalent in the early 1960's, the overall state-of-the-art in nerve agent chemistry is maintained by a more selective and refined approach to toxicity studies, as increased attention is directed to the molecular interactions of anticholinesterases with the cholinesterase enzyme in the living body.

Current research on organophosphorus compounds as well as on other compounds exhibiting anti-cholinesterase activity, such as carbamates and thiocarbamates, is particularly active in the insecticide industry. Statements by researchers appearing in Soviet technical literature, however, indicate that the Soviets consider carbamates to be of little importance as potential CW agents. Notable among the numerous personalities working in CW-related organophosphorus chemistry are I. L. Knunyants and K. A. Petrov at the Military Academy of Chemical Defense, Moscow, and M. I. Kabachnik, the most widely known Soviet organophosphorus chemist, who has laboratories at the Institute of Elementoorganic Compounds, also in Moscow.

Soviet interest in natural poisons is essentially similar to the interests of the United States and other Western countries. Natural poison research is generally more sophisticated in the U.S.S.R. than in other Communist countries. The Soviets continue to show strong interest in the important bacterial toxins (botulinum, gas gangrenes, tetanus, staphylococcus, diphtheria, and pestis), plant and animal poisons and their derivatives, and the means of disseminating aerosolized toxins or toxoids for immunization purposes. Studies on bacterial toxins of CW interest also involve production, purification, characterization, detection, and detoxification. These toxins do not present serious health problems. Soviet interest in them might stem from their possible usefulness in CW.

Because of its high degree of toxicity, botulinum toxin could be a desirable CW agent, and current Soviet research on this toxin could provide a data base that would be useful in any future crash program. The interest in botulinum toxin appears to surpass that generated by other bacterial toxins. It is the most toxic of any known natural or synthetic neurotoxic poisons. A limited amount of research continues to be devoted to such marine poisons as tetrodotoxin and jellyfish poisons. Although this work is apparently oriented toward public health, it could lead to the discovery of highly toxic substances that are applicable to chemical warfare.

In addition to the above compounds, other classes of chemicals of CW interest continue to be under investigation. Soviet scientists have accumulated extensive information on plant extracts that affect the mind. The characterization of psychotropic components from these purified plant extracts has prompted the Soviets to synthesize new potent psychochemicals containing the indole, piperidine, quinuclidine, and glycolic acid moieties. The Soviets have knowledge also of the psychotropic properties of the piperidine derivatives of benzilic acid, some of which appear to be more potent, yet simpler to produce than BZ, the U.S. standard incapacitating agent. Curariform agents which block the neuromuscular system also are being investigated. Soviet scientists have investigated the chemical structure-activity relationship between the bis-quaternary ammonium compounds and the cholinergic nervous system. Several of these compounds were found to induce cholinolytic action, while others appeared to have the effect of anticholinesterases. These compounds also could serve as adjuncts to atropine therapy for nerve agent poisoning.

An aggressive aerosol program is conducted by competent research groups whose basic studies are concerned with the generation of aerosols. Other research that could have CW application includes work on self-igniting incendiary agent fuels. CW research is conducted to improve methods for monitoring pollutants in the air and water. Research concerned with the detection of organophosphorus pesticides in the air and cyanide in water has direct application to the detection of CW agents. Colorimetric, spectroscopic, and electrochemical methods of detection are studied.

The Soviets have placed much emphasis on preventive and therapeutic measures against CW agents. Numerous studies have been undertaken on the reaction mechanism of toxic agents to develop more effective methods for prophylaxis and therapy. The limitations of nerve agent prophylaxis and therapy have apparently prompted attempts to develop substances that are capable of greater specificity and potency with a minimum of understandable side reactions. Numerous compounds with atropine-like (cholinolytic) activity have been synthesized; some of these compounds hold promise as atropine substitutes. Cholinesterase reactivators have been investigated as possible adjuncts to atropine. The Soviets apparently are endeavoring to discover a single compound or pharmaceutically compatible mixture of compounds with combined cholinolytic and cholinesterase reactivating properties that would be effective, regardless of route of administration. Despite the fact that psychochemicals are not known to have been standardized as CW agents in the U.S.S.R., considerable research activity is evident in the search for antidotes against psychochemicals used in psychiatric care.

The Soviets have an active program for defensive equipment development. They have developed protective clothing, protective masks and canisters, and decontamination and detection equipment; they also continue efforts to improve the equipment currently in use. CW research is directed toward the development and improvement of individual and collective protective equipment. There is a trend to hoseless protective masks. In these new versions the canister is mounted on the faceblank.

3. Nuclear energy

The nuclear energy program continues to be a priority effort, with the greatest emphasis on military applications. The nuclear weapon program has grown rapidly, and the Soviets have achieved great progress in weapon development. Tests of a wide variety of devices, with yields up to about 55 megatons, have been detected. A number of these nuclear explosions have been detonated for various peaceful purposes. The U.S.S.R. has a large number of nuclear reactors for research, materials testing, production of electric power and process steam, production of plutonium and tritium for the weapon program and propulsion of submarines and icebreakers. Uranium enriched in U-235 is produced for military and nonmilitary uses in four large gaseous diffusion plants The Soviets have ample uranium ore reserves to meet their needs for the predictable future. They have a viable and extensive research and development effort, with major programs directed toward the development of nuclear power

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systems for space applications and of controlled thermonuclear reactions (CTR).

Responsibility for all production aspects of the nuclear energy program rests with the Ministry of Medium Machine Building. A separate State Committee for the Utilization of Atomic Energy of the Council of Ministers supervises work on reactor design and research, the industrial use of atomic energy, civilian nuclear power development, foreign liaison and cooperation, and information activities. The Academy of Sciences both advises and conducts supporting research for the ministry and the State Committee for the Utilization of Atomic Energy.

As of 31 July 1973 the United States had detected 330 Soviet nuclear tests: 186 before the Limited Test Ban Treaty went into effect in 1963 and 144 following 1963. Analyses of geophysical data and of nuclear debris from the tests held through 1962 indicated that the Soviets had developed a wide range of fission and thermonuclear (TN) weapons suitable for delivery by the systems assigned to the various branches of their armed forces. The absence of usable debris from the post-treaty underground tests has precluded analysis of weapon progress.

The pre-1963 tests occurred at either the Semipalatinsk Proving Ground, the Novaya Zemlya area of the western Arctic, or the Kapustin Yar or Sary Shagan Missile Test Ranges. The Semipalatinsk site was used for two underground tests, airbursts, groundbursts, and tower shots with yields in the low kiloton to low megaton range. The Novaya Zemlya area was used both for a few apparently naval-related underwater, surface, and low-yield airbursts tests, and for many airbursts of high yield, undoubtedly intended for strategic aircraft and missile systems. The Kapustin Yar tests may have been for the development of surface-to-air missile warheads, while the high-altitude bursts near Sary Shagan in 1961 and 1962 appear to have been experiments designed to test portions of the Soviet antiballistic missile (ABM) system in a nuclear environment and particularly to study radar blackout caused by the detonations.

Following the Limited Test Ban Treaty, the Soviet underground test program got underway in earnest in March 1964. Most of the tests were held in the Semipalatinsk area and ranged from low through intermediate yield; nine were held in the Novaya Zemlya area, including the largest underground test ever conducted by the U.S.S.R. on 14 October 1970, with an estimated yield of 3 to 6 megatons. Tests conducted at at least 20 locations and from the established weapon test areas indicate that the Soviets have an active program for the peaceful use of nuclear explosions. One of the events near Karshi extinguished a gas well fire that had burned for almost 3 years. At bilateral talks in Moscow and Vienna in 1969 and 1970 and at several peaceful nuclear explosions conferences under the sponsorship of the International Atomic Energy Agency, the Soviets described a number of peaceful uses experiments they had conducted or planned to conduct, including the stimulation of unproductive gas and oil fields, creation of underground storage cavities, canal and dam construction, and overburden removal and ore crushing for mining purposes.

The Soviets have established national nuclear weapon stockpile sites throughout the country. Operational nuclear storage sites have been identified at many of the major Soviet airfields and have been associated with naval and ground forces. Handling facilities probably exist at strategic missile sites as well.

Most of the advanced research and test reactors in the U.S.S.R. are found at three facilities: the Institute of Atomic Energy *imeni* I. V. Kurchatov, Moscow; the Institute of Physics and Power Engineering, Obninsk; and the Scientific Research Institute of Atomic Reactors, Dmitrovgrad. These reactors play an important role in the development of nuclear physics and nuclear power engineering in the Soviet Union.

The Soviet nuclear electric power generating capacity as of late 1972 was approximately 2,500 megawatts electrical (MWe). A large portion of this nuclear power is produced from the dual-purpose reactors located at Tomsk in Siberia, which reportedly produced about 1,000 MWe in 1966. The remainder of the nuclear power is produced by reactors in Novovoronezh, Beloyarsk, Obninsk, and Dmitrovgrad.

The fourth reactor at Novovoronezh became operational in early 1973; it brought generating capacity of the station to about 1,450 MWe. Also announced for this site is its fifth reactor, a 1,000-MWe pressurized-water reactor (PWR) to be operational in 1975. A large sodium-cooled, fast-breeder reactor (BN-350) capable of power generation (150 MWe) and desalination (200-MWe equivalent energy) was built near Shevchenko on the eastern shore of the Caspian Sea and achieved criticality in November 1972. In July 1973 it generated at about 8-10 MWe. Power generation will gradually be increased to full capacity by the end of 1973 or early 1974. It is the first large power reactor of its type in the world. A 600-MWe fast reactor (BN-600) is also under construction at Beloyarsk and is scheduled for completion in 1976. In the far north a small nuclear power station consisting of four 12-MWe graphite-moderated reactors is under construction at Bilibino on the Chukotsk Peninsula. In addition to the above, the Soviets have planned or have under construction large nuclear power stations near Leningrad, Kursk, Chernobyl' (north of Kiev), Smolensk, Yerevan, and on the Kola Peninsula. The first four stations will each consist of two 1,000 MWe light water-cooled graphite-moderated pressure tube reactors. Each of the latter stations will consist of two 440-MWe pressurized water reactors of the Novovoronezh type; this type reactor is exported to Finland and East European countries as a standard commercial item. The Soviets expect to have a nuclear electric generating capacity of about 14,500 MWe by 1978.

The amount of uranium ores mined and processed in the U.S.S.R. and European Communist countries provides an annual production adequate for the estimated Soviet need for feed materials. The amount of uranium present in reserves is sufficient for the expected requirements of the nuclear energy program at least through the 1970's.

The main uranium mining and ore concentrating areas are the Krivoy Rog iron ore district in the Ukraine, the Central Asia areas, and the Caucasus. The Zheltaya Reka ores are concentrated at the Zheltiye Vody mill, but most other ore from the Krivoy Rog district is shipped to concentrating plants at Dneprodzerzhinsk. Uranium is produced in the Fergana Valley area in Central Asia. Mines and concentrating plants are located at Taboshar at the western end of the valley and at Kermen in the eastern part. A second uranium district in Central Asia, near Frunze, is believed to be mining sediments, subbituminous coals, and probably some veins. The Pyatigorsk area of the northern Caucasus is another uranium producing area which produces uranium from hydrothermal vein deposits in the laccolithic mountains of the area, as well as from deposits in the sediments immediately adjacent to them. The Soviet concentrating plants are well designed, and most have capacities of over 1,000 tons of ore per day and are using modern ion-exchange and solvent extraction recovery methods. The Soviet Union obtains a large share of its uranium from European countries; their total annual contributions amount to more than half the total Soviet availability of uranium. East Germany is by far the largest contributor of uranium, followed by Czechoslovakia, Bulgaria, and Hungary.

Uranium metal and other feed materials are produced at Elektrostal near Moscow, at Glasov, just west of the Urals, and at Novosibirsk in Central Siberia. The combined output of these plants is considered adequate to meet all Soviet needs. Lithium and beryllium are produced in amounts sufficient for the needs of the program and industry in general, while other necessary raw materials are available in adequate quantities. A sufficient amount of heavy water is obtained from six or more small plants, and a large artificial graphite industry provides adequate quantities of reactor-grade graphite. High-purity magnesium, calcium, and zirconium metals are believed to be available in adequate amounts. The uranium metals plant capacity is large enough to support estimated Soviet needs.

Plutonium equivalent (plutonium or other reactor products using an equivalent amount of reactor power) is produced in large quantities, and while tritium production cannot be uniquely determined, it appears that quantities are adequate for all weapon and research requirements. As of mid-1972 the Soviet cumulative production of plutonium equivalent was estimated to be between 53 and 69 metric tons, with an annual production rate of about 5 metric tons. Production reactors and a plant for the chemical separation of plutonium from uranium and fission products have been in operation in Kyshtym since 1948. A similar graphite-moderated, water-cooled production reactor probably began operation in 1955 at the nuclear site north of Tomsk. In 1958 the first dual-purpose reactor (produces plutonium and electricity) was placed in operation at the site. Other dual-purpose reactors and a chemical separation plant have been built at Tomsk since 1958.

Enriched uranium is produced by four large gaseous diffusion plants located at Verkh-Neyvinskiy in the Urals and at sites near the Siberian cities of Tomsk, Angarsk, and Zaozerniy. Cumulative production in terms of weapon-grade (93% U-235) uranium was estimated to be between 295 and 632 metric tons in mid-1973. The Soviets probably have excess productive capacity over requirements for their current weapon and nonweapon needs. In 1969 they expressed a willingness to provide enrichment services for nonnuclear Western countries that require low enriched uranium as power reactor fuel. One small contract has been signed to enrich a quantity of French uranium beginning in 1973 for use in a power reactor under construction in Fessenheim, France. The Soviets also have discussed possible contracts for uranium enrichment services with several other countries, including Sweden, Finland, West Germany, Japan, and Switzerland. No Soviet-owned uranium has been offered for sale to date, either in the natural form or as enriched in U-235. The Soviets are alert to the possibilities of other potentially commercial uranium enrichment processes, particularly the gas centrifuge process, in which they had an early introduction. They may be building gas centrifuge pilot plant/test/manufacturing facilities at some of their gaseous diffusion plant sites, in addition to upgrading their older diffusion plant equipment.

Since 1966 the Soviets have introduced six new classes of nuclear submarines. Four of these new classes have been produced in considerable numbers and appear to be very reliable. In addition, the Soviets have succeeded in overcoming the difficulties experienced with their early class nuclear submarine, and most of the early class units are now sufficiently reliable to conduct long duration patrols.

The nuclear ice breaker *Lenin*, which probably experienced some type of accident involving its reactor system in 1966, was refitted with a new and improved reactor system and returned to service in 1970. It apparently has operated since that time without any major difficulties. The Soviets currently are building another nuclear icebreaker, the *Arktika*, at the Baltic Shipyard in Leningrad and have announced plans to build a second icebreaker of the *Arktika* class, the *Antartika*. Both of these new icebreakers probably will be powered by a nuclear system very similar to the improved reactor plant installed in the *Lenin*.

The Soviets have shown considerable interest in electric propulsion systems for space applications, for example, ion and plasma engines. However, such propulsion systems using a nuclear power source are still in an early stage of development. The Soviets have a sizable effort directed toward the development of the thermionic reactor concept and currently have the third model of a 10-kw thermionic reactor in operation. However, a thermionic reactor suitable for use in a space electric propulsion system is still at least a decade away from becoming operational. They are also exploring all the other major energy conversion systems, including thermoelectric, magnetohydrodynamic, and turboelectric generators.

The Soviet CTR research program is the largest in the world in terms of funding and manpower. Their lead in overall achievement appears to have vanished, and they are about on a par with the West in most areas. Work is conducted in several institutes, but the Kurchatov Institute of Atomic Energy and the P. N. Lebedev Institute of Physics do the majority of the work. The Soviet device, Tokomak 3, was the first of its kind in the world and achieved significant results, but they have been surpassed in Western laboratories with similar devices. The Soviet device, Tokomak T-10, expected to be in operation in 1974, could recapture the lead for the Soviet Union. The Kurchatov Institute has expanded its activities to a new location at Krasnaya Pakhra, laser-fusion CTR experiments are underway or being constructed. Their effort in this laser-fusion research is one of the largest and most diversified in the world. The Soviets have also shown interest in fusion by relativistic electron beams. These alternate approaches to CTR, which demonstrate Soviet scientific inventiveness and competence in a very advanced technological field, underscores their commitment to controlled fusion.

4. Electronics

The U.S.S.R. is a world leader in the quality and quantity of electronics research and development. Although lagging the United States in certain subfields, the Soviet work has continued to expand and has successfully closed many technological gaps. One of the major bottlenecks in research and development has been the time-consuming and somewhat uncoordinated conversion from basic research to a finished product. The establishment of Science Cities, such as that near Novosibirsk, may have been effective in helping to counter this problem. The Novosibirsk scientific community, a suburb known as Akademgorodok, has a population of approximately 30,000, including 10,000 scientific personnel. A satellite town to Akademgorodok is planned and will contain specialized research and development institutes of various ministries and enterprises. The purpose is to achieve greater interaction between applied and fundamental research. In addition to recreational and cultural facilities, this complex includes educational, research, and some development facilities. Computers are utilized extensively throughout these phases of research.

Some of the larger and more advanced electronics research facilities are located in or near Moscow. The Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation (IZMIRAN), near Moscow, conducts extensive studies of the ionosphere and its effect on long-range radio communications, with probable emphasis on nonorthodox propagation methodologies that would be especially resistant to electronic countermeasures. The Moscow Electrotechnical Institute of Communications, in addition to its educational functions, conducts research into various communications equipment and their components. Another large research facility in Moscow is the Institute of Radio Engineering and Electronics. Basic research in semiconductors, lasers, and millimeter wave propagation is included in the work done here. The Moscow Institute of Control Problems addresses, among other areas, pattern recognition and automation control. This research is applicable to the military as well as to industry. Two of the major microwave tube research facilities are the Scientific Research Institute for Electrotechnics, formerly known as NII-160, in Fryazino, and the Scientific Research Institute for Electronic Instruments, Moscow. A related production facility is the Svetlana Plant complex near Leningrad, employing nearly 30,000 people in semiconductor, ferrite cores, and vacuum tube production.

Soviet design philosophy for electronics equipment is based on a desire to achieve optimum performance and simultaneously achieve ruggedness of equipment and simplicity of operation. The tendency to use existing components when designing new equipment has alleviated the spare parts logistic problem. Once operational, equipment installations frequently provide redundancy either through overlapping coverage, as in the case of land-based surveillance radars, or multiple installations of similar equipment, such as navigational radars aboard surface combatants.

The Soviets have significantly advanced their research and development capability in the communications field. In the past the need to provide basic communications systems and equipment severely strained the production capacity of industry; development and application of advanced technology had to be forestalled. However, in the past few years the Soviets have made significant advances in electronics research and development standardization of production and automation of their nationwide telecommunications system. Although mass production techniques still lag U.S. standards, select communications technologies and applications have approached Western state-of-the-art. Indigenous research and development efforts in communications are directed toward advanced modulation techniques, which include intrapulse code modulation, phase code modulation, and spread spectrum techniques requiring sophisticated computer processing. The Soviets have also conducted research using error detection/correction coding systems. The coding systems have direct application for satellite communications. The Soviets also have been doing extensive research in short-duration signal techniques, random access discrete address (RADA), and wideband digital communications systems. Research and development efforts in the very low frequency (VLF) range have been extensive also, including work on conjugate point research and the effects on the ionosphere. Current research is conducted using VLF modulation techniques and time integration, which would allow communications reception by submarines at a greater depth. This is an apparent attempt on the part of the Soviets to use existing VLF systems rather than constructing extremely low frequency (ELF) sites.

The Soviet prewar high-frequency (HF) airborne communications equipment has been replaced gradually by 100- to 150-megahertz (MHz) air-to-ground equipment, ground control intercept data links, and higher powered HF sets with 250- to 440-watt capability. The trend toward more channel capability and selectivity can be traced through past and present equipment. The Soviets are likely to continue the use of 100- to 150-MHz range and to add the 225 to 400 MHz-band of aircraft command communications in the near future.

The U.S.S.R. leads all other Communist countries in the design, development, and production of avionics (aeronautics and space-associated electronics) equipment. The Soviets have not accomplished any breakthroughs in the avionics field, nor are their capabilities any stronger than those of the more advanced non-Communist countries. Nevertheless, the magnitude of their research and development effort and the importance the Soviets have accorded the entire field of study narrow the lead that Western countries have enjoyed in past years, both in quality and quantity of the avionics equipment produced.

In the past few years the Soviets have made significant advances in radar electronics. By 1959 they had replaced most lend-lease radars with those of domestic design. This trend toward independence from Western world radar technology is increasing. Also, equipment design varies significantly, depending on the intended environment. An example is the shipboard Peel Group and land-based Low Blow, both controlling virtually the same Goa missile, but differing greatly in the type of track-while-scan and other features. In 1971 the Soviets introduced a new point defense system, Pop Group, which in a single assembly contains the means for detecting, identifying, designating, acquiring, and tracking a target, as well as tracking the missile and supplying the necessary data for its inflight control. Another important trend in sensors is toward improvement of low-altitude coverage by rejection of clutter and second-time-around echoes and through employment of optical/electrooptical devices. These latter devices simultaneously enhance the electronic counter-countermeasure (ECCM) features of the sensor system. The Soviets are increasingly employing airborne radars in the J-band frequency range and are technically capable of frequencies up to 35 gigahertz (gHz). Frequency diversity and agility and simultaneous dual frequency operation are presently employed. Improved navigational accuracy has been achieved through development of a doppler radar. In inertial navigation, the Soviets have closely followed and exploited Western gyro and autopilot technologies.

The Soviet Union has given high priority to digital and analog computer research and development, and work on central processor designs has advanced at the expense of peripheral equipment. Major difficulties are still experienced in translating prototype designs into mass-produced finished products. The recent initiation of production of third-generation models, identified as ASVT and RYAD series, is consistent with Soviet goals for greatly expanding the use of computers employing products from East European as well as from their own industry. The effective resolution of problems with maintenance and support and production in fulfilling the goals remain to be seen.

Scientists have continued to work in diverse areas of computer logic. Development of discrete component circuits has been sustained, along with more recent emphasis on thin-film hybrid and monolithic integrated circuits. Tunnel diode logic activities have diminished as a result of improved supplies of high-speed transistors. Increased Soviet emphasis on high-frequency circuit design and new logical and architectural design concepts is indicative of an effort to construct computers suitable for problems beyond their present models. Military interests probably motivate the most advanced efforts.

Emphasis on hardware development has continued. Internal magnetic core memory capacity has been increased for several existing computer models, and specifications for computers under development indicate core memory capacities comparable to existing general purpose Western computers. Other technologies, such as plated wire, also are applied to build new types of internal stores for computers. Magnetic bubble research is conducted vigorously at the Moscow Institute of Control Problems and presumably elsewhere. In addition, efforts are being made to improve auxiliary computer storage devices. Prototype magnetic disc memories have been developed, but some technical problems remain unsolved. New magnetic tape units have been developed and conform to Western standards. Entry into the minicomputer area was made with development of the Electronika K-200, reportedly an integrated circuit machine designed for process control applications. Interest in making greater use of minicomputers is reflected by imports of East European and Western models. Overall reliability of computer systems has increased, although still falling short of Western standards.

With the entry of the ASVT, a series of third-generation compatible computer, and the future manufacture of the larger RYAD computers, the Soviets recognize the importance which software plays in using new complex machines. The need for efficient operating systems software, which more fully utilizes the central processor, has been filled partially by the appearance of new systems for the BESM and MINSK computers. A high level of interest in languages and translators continues, as evidenced by the availability of several new software products. On the other hand, Soviet provision for software maintenance continues to be inadequate.

Computers are assuming a role of ever-increasing importance in military applications. Classified work at the Institute of Cybernetics in Kiev has been associated with employing an automated system for determining optimal solutions to subsystem and operational control on submarines, including the Y-class submarine. Gun fire-control systems continue to employ analog computers primarily, but there is an increased trend toward use of digital computers in other military systems.

The Institute of Precision Mechanics and Computing Techniques, Moscow, under the direction of S. A. Lebedev, is the prime facility for large digital computer development and is credited with the BESM series. Analog and hybrid computer developments since the early 1950's have been centered in Moscow at the Scientific Research Institute for Computer Machine Building and the Institute of Control Problems. The Institute of Applied Mathematics, Moscow, and the Institute of Cybernetics, Kiev, support the development of advanced computers for both military and industrial projects

5. Electrooptical research

The laser program in the U.S.S.R. continues to expand at a substantial rate. The Soviets have improved and developed new versions of all three basic types—solid state, gas, and semiconductor—and applications-oriented activities have become more evident. The Lebedev Physics Institute remains the leading Soviet laser research institute, with new facilities added at both the Moscow site and the Krasnaya Pakhra area. Science cities at Krasnaya Pakhra, Novosibirsk, and Tomsk also have expanding laser research and development efforts, and a new institute devoted to quantum electronics research has been built near Yerevan.

Various types of CO_2 lasers have emerged as the most important lasers for potential projected energy weapon applications because of their capability to develop high average power levels at relatively high efficiencies. Soviet efforts in the development of high energy CO_2 laser systems appear to be behind the United States. The Soviets have developed gas dynamic laser systems and have achieved high volumetric efficiencies with high-pressure CO_2 laser systems employing electron beam preionization; however, it is not known if high-power operation of CO_2 systems approaches U.S. results. Some significant chemical laser research has been conducted by the Soviets. A 70-kilowatt (70 millijoule) pulsed power output has been obtained with a hydrogen fluoride system, and low-power, continuous-wave chemical laser action has also been achieved.

The development of other gas lasers also continues. Helium-neon lasers have been built for laboratory and industrial applications, and excellent work on stabilizing the wavelength of gas laser systems has been performed. Researchers at the Institute of Semiconductor Physics in Novosibirsk reported recently the operation of an argon ion laser at a continuous output power of 500 watts. This is the most powerful continuous laser source in the visible region of the spectrum. Its operation at blue-green wavelengths makes it attractive for potential underwater applications, although its overall electrical efficiency is quite low. The Soviets have also developed a copper vapor laser with a maximum average power output at green and yellow wavelengths of 15 watts, capable of operating at pulse repetition frequencies of up to 20 kilohertz. Copper vapor systems, which are much more efficient than argon, receive attention for potential weaponry and underwater applications also.

The principal solid-state laser devices under study are ruby and neodymium. The Soviets have continued to develop high-power, short-pulse neodynium glass oscillator-amplifier systems for CTR investigations. A nine-path, multistage system employing 17 glass rods and capable of producing 1,300 joules at nanosecond pulse widths was developed in 1971. Soviet improvements in producing neodymium: YAG lasers may result in increased activity on the development of rangefinders, target designators, and illuminators.

The Soviets have developed a wide variety of semiconductor lasers and have devoted much attention to optical and electron beam pumping techniques. Recent investigations have emphasized computer and television-like display applications. The Soviets have also produced several dye and liquid laser systems. Scientists at the Institute of Physics in Minsk were awarded a U.S.S.R. State Prize in 1972 for their work on a continuously tunable dye laser.

Although no military laser systems have been identified positively, the use of lasers in applications-oriented activities is increasing. Results of communications and ranging experiments, both in the laboratory and over outdoor paths, continue to be released. Underwater laser propagation research and airborne laser experiments have been performed. The Soviets have conducted ranging experiments against cooperative satellites and revealed interest in placing lasers aboard satellites to provide meteorological data. Applied laser work has been noted also in the areas of rotational rate sensors, holography, medicine, and metalworking.

The U.S.S.R. continues to expand its activities in the scientific and military applications of infrared (IR) technology. The most significant Soviet military application of IR continues to be systems and devices for night observation of ground forces. The U.S.S.R. has deployed active near-IR devices for these purposes more extensively than any other country. Several Soviet air-to-air missiles, including the AA-2 (Atoll), have IR terminal guidance (homing) as well as IR fusing. Naval uses include a number of devices for visual operations from ships under blackout conditions, such as station keeping, docking, and possible use as a backup to some radars for fire control. Since 1967 the Soviets have been discussing experiments using IR scanning devices for surveying natural resources. No information is available on any military use of IR scanning devices. Space applications of IR include horizon sensors for satellites and probably for space probes. IR also is used in meteorology for determinations of the thermal balance of the earth as well as for weather satellite surveys.

Extensive and high-quality basic research programs in physics, electronics, and optics support the infrared program. The Soviet Union has an across-the-board capability equal to or better than the United States in the basic research and development of far-IR detector materials. The Soviets apparently have failed to exploit fully the laboratory work, however, by not being able to develop devices for applications. Much of the IR research and development activity is concentrated in the Moscow and Leningrad areas. Moscow State University, the Lebedev Physics Institute, the Institute of Radio Engineering and Electronics, and the Institute of Crystallography are most important facilities in the Moscow area, and in Leningrad the Institute of Semiconductors, the Physico-Technical Institute, Leningrad University, and the Vavilov State Optical Institute are active in IR work. The last facility is probably the most significant for basic IR research for the development of military IR devices and systems and for trial or limited production of some items.

6. Medical sciences

The quality of Soviet medical research is improving steadily, and significant achievements are being made in individual areas, particularly in biochemistry and biophysics, epidemiology, and neurophysiology. Progress is still generally inhibited by dependence on imports of sophisticated research instrumentation and the need for foreign expertise, especially in pharmaceutical science.

Biochemical research is clearly progressing, and some of the recent work compares favorably with research in advanced Western countries. Modern concepts have been developed on mechanisms of action in living processes, photosynthesis, regulation of enzyme activity, and biological energy exchange. Molecular biological approaches are stressed in the study of the chemistry and functions of nucleic acid with respect to storage and transmission of genetic information and the synthesis of proteins in the cell. Soviet biochemists are undertaking an intensive investigation of the genetics of microorganisms, bacterial pathogenicity, resistance of bacteria to drugs, and to exogenous physical and chemical factors.

The Academy of Sciences is particularly interested in the elaboration and industrial development of methods of chemical synthesis and biosynthesis of proteins, including enzymes and hormones; methods are being improved to identify and exploit microorganisms and enzymic systems that can synthesize selected organic compounds and produce steroids and vitamins. A State Prize has been awarded for development of the scientific principles underlying microbiological production of edible proteins from petroleum hydrocarbons. A Soviet-Czechoslovak exchange of information on microbial protein projects is underway. A U.S.-U.S.S.R. cooperative research program has achieved crystallization of an anticancer enzyme. Biochemists study the metabolic features of tumor tissue and the antigenic changes which occur during the process of cancerogenesis, and antitumor compounds have been synthesized which have a cytotoxic group coupled to normal products of metabolism.

A tremendous improvement has occurred in the quality of Soviet biophysical research as a result of considerable interaction of biology with physics. The work in individual instances is comparable in quality to current U.S. and West European research. Soviet research emphasis on optical biophysical methods is unusually extensive, and some is of the highest quality. Their biophysical research continues to be plagued by inadequate instrumentation, although the situation is improving. High-quality biophysical research is still limited to a very few research centers.

Neurochemical and biochemical studies of the nervous system have been criticized favorably by Western scientists. Competent research has been completed on denervation and muscle regeneration. Valid contributions are being made to the role of cell membranes in the regulatory mechanisms of metabolic processes, in electrolyte exchange, in neural processes, and in the action of medicinal and toxic substances. Excellent work is underway on determination of the mode of action of hemoglobin at various levels of hydrogen ion concentration. A method has been devised for rapid computer analysis and identification of biological structures, e.g., chromosomes and tumors. Considerable research has been reported on the action of physical factors on the body, especially sound, vibration, and electromagnetic radiation.

Competent but not original research in pharmacology reflects advances made by Western scientists. Attention of pharmacologists is focused chiefly on the mechanism of action of agents in relation to their chemical structure. A molecular pharmacological approach has been adopted to some extent and work is directed to examination of the effects of drugs on the structural components of the cell, on the regulation of functioning of the cellular genetic apparatus, and on penetration of cell membranes by ions and metabolites. In the development of pharmaceutical agents, emphasis has been placed on development of hormones, enzymes, vitamins, antimetabolites, neuroleptics, analgesics, tranquilizers, and antiallergy and anti-inflammatory agents. The conditional reflex is one of the most popular of behavioral reactions in studies of psychotropic agents. The U.S.S.R. does not rank among world leaders in pharmaceutical research and production, and it still relies for scientific support on the achievements of East European laboratories, especially Hungary and Czechoslovakia. Research programs now stress the need for creation of new types of physiologically active polymers, e.g., synthetic analogs of the nucleic acids. Drugs which affect memory and learning are screened.

While research on the chemotherapy of cancer is not as advanced as in the United States, Soviet scientists have directed considerable priority to chemotherapy in combating cancer, and they have presented several of their compounds to the United States for research testing within a U.S.-U.S.S.R. exchange agreement. Products developed include alkylating substances, antimetabolites, antibiotics, and agents which stimulate immune mechanisms. Although it has not pioneered in the development of antiviral agents, the U.S.S.R. has committed considerable resources to an aggressive program of synthesis and pharmacological trials of new antiviral drugs. Prophylaxis of influenza is being tested with Soviet-produced amantadine and interferon.

Research in hematology and blood transfusion is highly centralized in laboratories in Moscow, Leningrad, and Kiev. The large volume of work in hematology is competent but essentially confirmatory of non-Soviet advances. Research in the field of cryogenics is nearly on a par with the West and is oriented to the practical problems of freezing cells and tissues. No unique contributions have been made, but extensive work is underway on the fractionation of blood plasma and the preparation of plasma substitutes. Trials are made on the use of human bone marrow transplants for treatment of anemias and of cancer through exposure to the destructive action of radiation or lethal doses of cytostatic drugs. Prostheses for blood vessels, heart valves, and filters for blood transfusions have been completely designed and employed by the Soviets.

In radiobiological research the Soviets have strived to stay abreast of Western research. Interest is devoted to the identification of radioprotective chemicals among the thiol, amine, and hypoxic agent groups. Good results have been achieved in the use of radioisotopes in the study of local ventilation and blood flow in the lungs and in the location of brain tumors. Medical radiologists have developed algorithms for computer assistance in X-ray diagnosis of disease. Successful induction of bone sarcomas in monkeys through chronic administration of radioactive substances has contributed to the clinical evaluation of this disease. In the field of radiation genetics, the Institute of Genetics and Selection of Industrial Microorganisms is doing good work on microbial mutagenesis. Ultraviolet radiation and radiomimetic chemical agents are used to induce desirable mutations in microorganisms. The Soviets have shown an interest also in research on the combined effect of irradiation and microbial infection on animals.

In microbiology the Soviets place strong emphasis on the development of techniques for control of infectious diseases. Work is centered on the variability of microorganisms and bacteriophages, rickettsiae, natural foci of infection of man, and chemotherapeutic control of disease agents. Infectious disease research is a major component of the general public health program. Investigations of plague and hemorrhagic fever are excellent. Research of priority interest is devoted to human viral diseases endemic to the Soviet Union. This work emphasizes mathematical modeling of viral epidemics, the study and production of interferons, control and prevention of arbovirus infections, and a comprehensive study of leukemia and tumor viruses. Microbiologists have also accepted responsibility for the development of organisms for exploitation in microbiological synthesis. The thrust of current immunological work is to develop vaccines against a number of endemic hemorrhagic fever viruses. In additon, there is much interest in broad spectrum antiviral preparations, including exogenous and endogenous interferons, chemicals, and polyvalent vaccines.

Major emphasis in epidemiological research is given to the application of mathematical and computer methods to epidemic disease surveillance, modeling, and prediction, and medical geographical studies produce excellent atlases of communicable diseases based on these new approaches. The U.S.S.R. probably has the world's most extensive network for disease monitoring aimed at forecasting and reporting incidence of disease. Microbiologists are upgrading the efficiency of this system through the development of a data base and an efficient communication system based on teletype from the epidemiological stations throughout the country.

The areas of general physiology being researched by the Soviets have been explored thoroughly elsewhere with better techniques as long as 5 to 10 years ago. This situation has prevailed because the U.S.S.R. has lacked a native source of sophisticated bioelectronic instrumentation, and because higher priority, financial support, and manpower are assigned to basic neurophysiology and some categories of applied physiology. Moderately good work is done in the development of prostheses and of contact and noncontact physiological detectors for both humans and water-born mammals. However, the excellent work done in researching new ways to sense physiological signals is often the product of Soviet engineering sciences and not the result of advances in general physiology. Soviet neurophysiology receives the benefit of political attention, tremendous prestige, and financial support from the Academy of Sciences not provided for other areas of physiology. Research is directed to whole body effects rather than to the Western approach of isolation and experimentation on nervous subsystems within the central or peripheral nervous system. Soviet neurophysiologists and psychologists have begun to study non-Pavlovian or operant conditioning, following rapidly in the footsteps of Western "biofeedback" researchers. The quality of these investigations and the interest of the young scientists involved indicate that Soviet autonomic nervous system research in the next decade may be on a par with Western work.

Soviet research claims in parapsychology are receiving increased attention in the West. Neurophysiological laboratories at Leningrad State University, the Ministry of Medical Industry Building in Moscow, and a naval military Institute for Electronic Instrumentation in Leningrad have made striking advances in so-called parapsychological fields. These advances include the development of very high-frequency, high-voltage photographic techniques for both plant and human organisms and the induction of exceptionally high electrostatic charges on the hands and forearms of human subjects, which permit the subjects to displace 200 to 400 gram objects on smooth table top surfaces without touching them. During the past 20 years psychological research has transitioned from primarily Pavlovian experimentation to studies spanning a wide and varied range of psychological phenomena. Research associated with military and space programs deals primarily with problems related to human engineering, personnel selection, training and placement, psychological stress, and behavior control and modification. Psychologists are shifting from reliance on Western publications and research results to reporting the results of studies conceived and completed by Soviet scientists. The quality of their research in most areas is not on the level of Western work; a single exception is physiological psychology, in which the quality of research equals and possibly surpasses that of the West. Efforts are underway to improve research through judicious application of an improved computer technology and of advanced research and statistical data analysis techniques.

The Soviet Union makes a major effort in the application of cybernetic research to medical diagnosis and public health problems. Work in computer-aided medical diagnosis, especially of cardiovascular diseases, has been expanding rapidly in the last few years. Medical cybernetics research teams concentrate on automated diagnosis. This work as yet has not applied any mathematical or computer techniques that are unknown in the West, and theoretical concepts have probably not advanced beyond those of the West. Nevertheless, the huge data bases of the U.S.S.R. permit it to apply techniques to clusters of symptoms, and this could significantly increase the accuracy of Soviet machine diagnosis. The U.S.S.R. has initiated the development of a national medical automated data processing system that encompasses diagnosis, treatment, patient monitoring, hospital administration, patient services, financing, and accounting.

A central medical computer system was established in 1970 in Moscow at the All-Union Scientific Research Institute of Social Hygiene and Public Health Organization *imeni* Semashko. This center reportedly is to be the hub of a regional and republic network of medical automatic data processing centers, which are to be linked to local automated hospital systems. One of the first functioning national systems of computerized handling of medical records in the U.S.S.R. was created at the Scientific Statistical Center of the Serbskiy Medical Institute of Forensic Psychiatry, Moscow. Soviet researchers also direct their efforts to achieving a highly automated medical emergency service. The Special Design Bureau of Biological and Medical Cybernetics of the Northwest Polytechnic Institute, Leningrad, is developing such a system, which is expected to become operational in Baku during 1973.

Soviet clinical medicine has continued to show rapid progress and improvement. Influenza has been selected as the infectious disease of greatest economic impact for which the development of an extensive computerized surveillance and prediction system has proven effective. Cancer and cardiovascular diseases receive a great deal of research attention. By far the greatest amount of support for cancer is for treatment; treatment includes various forms of ionizing radiation and associated therapy. The caliber of this work is high, but startling new discoveries have not yet been forthcoming. Cancer research also emphasizes the study of oncogenic viruses, probably the most promising current approach to cancer research throughout the world today, and cancer immunology, a field in which Soviet scientists have achieved preeminence. Cardiovascular surgery has been carried out with success in some centers, but it has not yet approached the quality of U.S. achievements.

The Soviets conduct a great deal of biomedical research in support of their manned space effort. In recent years this research is almost completely mission-oriented and is directed to insuring the well-being of man on prolonged missions, particularly on earth orbital stations, and secondarily in lunar environments. The Soviet bioastronautic effort is comprehensive, but it offers no unique solutions to supporting man on long-duration flights. Investigators have focused on evaluation of radiation hazards and research on cardiorespiratory, vestibular, hemostatic, and other physiological effects of prolonged weightlessness on man, and his tolerance to deceleration forces during and after return to earth. Priority has been given to the development of spacecraft life support systems, particularly to environmental control systems, food, water, and oxygen supply, and waste disposal. Research and development have been expanded on human factors relating to crew performance. They include the effects on man of isolation and confinement, group interaction, and better methods of monitoring and assessing the cosmonaut crew during flight operations. Nearly all key bioastronautic facilities, which include the Institute of Medical and Biological Problems, the Institute of Aviation and Cosmic Medicine of the Soviet Air Force, the Institute of Psychology, and the Institute of Biological Engineering, have been expanded in the last several years. Cosmonaut evaluation and training facilities have been enlarged also at the Cosmonaut Training Center at Zvezdnyy Gorodok near Shchelkovo.

Soviet military medicine research and development are conducted by well-trained and capable personnel; its quality ranges from good to excellent. Facilities and equipment generally are better than those available to civilian medical researchers, although the Soviets depend heavily on civilian medical institutes to provide research and development support for the military. The Learned Medical Council, Main Military Medical Directorate, Ministry of Defense, plans and supervises military medical research and

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development. The Military Order of Lenin Medical Academy *imeni* S. M. Korov coordinates all military medical research and development activities in both military and civilian institutions. Military liaison and coordination exist with the Academy of Sciences and with the Academy of Medical Sciences. Current research emphasizes environmental physiology for space and submarine purposes, vaccine development, troop acclimatization, field surgery, infectious diseases, nutrition, and automatic processing of medical data.

The armed forces medical service devotes major time and effort to acclimatization and training in mountainous areas and studies the adaptive reactions of the body to hypoxia (oxygen deficiency), fatigue, and temperature stress. Extensive research is conducted on the effect of physiogeographic conditions on the development of disease vectors, hosts, and microorganisms. Extensive research in the military is underway also on shock, blood diseases, blood typing, immunology of vascular cellular elements, bone marrow transplantation, and blood transfusion, particularly in relation to radiation sickness.

7. Other sciences

a. Chemistry, chemical engineering, and metallurgy

(1) *Chemistry and chemical engineering*—Research and development in chemistry and chemical engineering receive high priority in the U.S.S.R., primarily because of their importance to advances in many military and civilian programs. The Soviets conduct some respectable basic research in all of the major fields of chemistry, and their best work is generally on a par and in some specialized areas is ahead of the United States. Some of their technology has been purchased by other countries, including the United States and Sweden. On the other hand, a large part of their work is significantly lower in quality, especially as it moves toward applications, than the average in the West because of insufficient numbers of modern instruments, a lack of effective incentives, unimaginative management, and little cross-fertilization of ideas from other disciplines. Another handicap is the lack of sufficient industrial laboratories where promising basic research can be moved quickly into development and application.

Physical chemistry is a field of research in which the Soviets are quite active, with sizable programs in catalysis, electrochemistry, radiation chemistry, high pressure research, and crystallography, as well as other subfields. Catalysis research has long received strong support and has produced some noteworthy findings, both theoretical and experimental. Two groups of researchers have recently made notable progress in the laboratory toward the development of catalytic processes for the fixation of atmospheric nitrogen under mild conditions of temperature and pressure, which could lead to improved processes for the production of ammonia and hydrazine. The Soviets have demonstrated also their competence in the application of analytical techniques, such as electron spin resonance, to the study of catalytic structure and mechanisms. On the other hand, they have conducted little research on process-related problems and have tended to emphasize academic questions of little practical importance; this has contributed to their inability to exploit their own research discoveries in catalysis, some of which have been picked up and commercia[illegible]ed in the West.

Soviet research in electrochemistry has as one of its principal objectives the development of fuel cells, with the bulk of the work being conducted at the All-Union Scientific Research Institute of Current Sources and the Institute of Electrochemistry, Moscow. The Soviet fuel cell program covers all facets of research necessary to develop an effective power source for space and terrestrial or underwater application, but it is marked by a decided lack of originality. Basic work on electrode design and fuel selection as well as the design of modules and batteries tends to follow U.S. work. However, Soviet cells appear to have lower power densities, larger size, and shorter operating times than their U.S. counterparts. The Soviets have apparently recognized the advantages of fuel cells for spacecraft but may still have reservations regarding their use for manned space missions.

The U.S.S.R. is quite active in explosives research, particularly in studies of detonations and shock waves and the chemistry of explosive materials. An area of great emphasis appears to be the chemistry of polynitroaliphatic and fluoronitro-aliphatic compounds, which are potential heat resistant polymeric explosives. This work is done at the Institute of Chemical Physics and the Institute of Organic Chemistry, Moscow. The Soviets are also investigating a wide variety of applications of explosives, such as cladding and bonding metals, depositing films, and accelerating chemical reactions. No work has been noted, however, in the calculation of detonation parameters as is done by the United States. This may be because of limited computer facilities, or it could be because the work is classified.

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Crystallography is considered a separate discipline in the U.S.S.R. and is the subject of a large, generally high-quality effort to prepare and supply large, uniform, highly pure crystals for a wide variety of research and basic studies. Other areas, such as the computation of crystal structures, particularly complex structures of protein, from diffraction data are probably still hindered by a lack of computer facilities at some institutes, which may also retard Soviet progress in other developing sectors of physical chemistry, i.e., spectroscopy and quantum mechanical calculations.

A sizable portion of Soviet work in both organic and inorganic chemistry is oriented toward developing a wide variety of nonmetallic materials with improved properties for military and civilian uses. Foremost among these efforts is the development of nonmetallic composite materials, which includes high quality work, generally comparable to the United States, on the analysis and design of sandwich, multilayer, fibrous, and filament types of structural materials. However, the Soviets are deficient in certain aspects of the development and production of all but the multilayer designs, where they are about on a par with the United States. Although their filament winding techniques and manufacturing capabilities appear equivalent to those in the West, especially with glass fibers, they appear to have experienced some difficulties in developing satisfactory fiber glass reinforced plastic cases for their solid propellant rocket motors. Nevertheless, the Soviets consider this a very high priority program, which suggests they plan substantially increased use of this means of propulsion. There is an active research program on the development and use of carbon fibers in high-strength composite materials, but there are no indications of interest in boron fibers for this purpose, in spite of publicized U.S. interest in them.

The Soviet Union conducts substantial high-quality research aimed at the development of heat resistant polymers, much of which is carried out by groups under V. V. Korshak at the Institute of Elemento-Organic Compounds (IEOS), Moscow, and A.A. Berlin at the Institute of Chemical Physics, Moscow. These groups are comprised of capable scientists and are furnished with excellent equipment. In June 1973 A. L. Rusanov of IEOS was appointed to coordinate all Soviet high-temperature polymer research, which covers work on most polymer systems with potential for high-temperature applications, including the azo polymers, polyamides, polyimides, and polyarylates. Except possibly for a few of the polyimides, the Soviets have developed no polymers capable of prolonged use in a normal atmosphere above 400°C, although they are capable of producing a wide variety that could perform useful functions under specialized conditions at much higher temperatures, for example, in an inert atmosphere up to 600°C. An area of long-standing emphasis has been the development of organo-silicon polymers under K. A. Andrianov of IEOS, whose efforts have closely matched independent achievement in the United States. The Soviets appear to be looking for new species of polymers to raise temperature performance levels, but it is unlikely that many of those investigated will be made into end products on a large scale. Use of the best heat resistant polymers will probably remain confined to a few high-priority applications.

Soviet effort to develop radiation resistant polymers is concentrated primarily on studying radiation effects in existing polymers. Radiation damage investigations have been conducted on polyethylene, polytetrafluorethylene (Teflon), organic glasses, and high-temperature polymers. Attempts have been made to develop a polymer with improved radiation resistance by copolymerizing methyl methacrylate with alkyl phosphates. The Soviets have used epoxy resins and adhesives suitable for protective coatings for radiation protection as well. Research and development efforts on corrosion-resistant polymer coatings are extensive and for the most part competent. Generally, however, these efforts have followed Western leads and in some instances have trailed U.S. work by up to 5 years, with the result that the U.S.S.R. does no polymer coatings superior to those in the West. Nevertheless, coating materials research and development probably will receive increased emphasis over the next 5 years and will include work on polyurethanes, fluoropolymers, polycarbonates, silicon-containing polymers, and the high-temperature resistant polyimides.

The Soviets have been fairly active in research on epoxy resins, particularly in attempting to increase their thermal stability. Improved stability has been claimed for resins modified with furfural or furan, tetraphenol, and hexaphenol, but the upper temperature limit for unfilled epoxies reported by the Soviets has not exceeded 250°C as contrasted to 288°C achieved in the United States. A notable recent accomplishment was the development of a class of polyfluorinated epoxides reported by B. C. Dyatkin, of IEOS, in November 1972. Synthetic fibers are the subject of a fairly extensive research and development program in the Soviet Union, but almost without exception, the materials involved have been studied previously in the West. In spite of the reasonable quality of the work, the Soviet synthetic fiber industry is unable to take care of needs and depends heavily on Western assistance in the construction and start-up of synthetic fiber plants to meet planned production goals.

The Soviets are among the world leaders in the development and availability of ultrahard materials, due primarily to the work of L. F. Vershchagin, of the Institute of High Pressure Physics, Krasnaya Pakhra, and V. N. Bakul, of the Institute of Superhard Materials, Kiev. The Soviets have developed an ultrahard polycrystalline cubic boron nitride, similar to the U.S. material "Borazon," as well as a material called *Slavutich*, from which oil-well drilling bits have been manufactured, thought to be a form of polycrystalline diamond.

Chemical engineering in the Soviet Union seriously lags that in the United States, Japan, and Western Europe. Most of the Soviet research in this field is routine and is carried out in unimpressive laboratories with instruments that are mediocre compared with Western facilities.

In their research on unit operations, the Soviets have maintained a fairly broad effort on heat transfer, and S. S. Kutateladze, Director of the Institute of Thermal Physics, Novosibirsk, has been their most active researcher. Until about 1970 the Soviet Union was considerably behind the United States in boiling metal heat transfer, but a new need for information on heat transfer in two-phase systems for nuclear breeder reactors and magnetohydrodynamics (MHD) generators spurred a greater theoretical and experimental effort since that time. Research on heat pipes has been fairly active but has not resulted in any significant applications. Chemical reactor design activities are in general unimpressive, with the possible exception of the work of M. G. Slinko, Deputy Director of the Institute of Catalysis, Novosibirsk, who has had considerable success in the computer modeling of catalytic reactors. A fluid bed reactor of advanced design reportedly was also developed at this institute.

The Soviets are considerably behind the West in overall chemical plant technology and rely heavily on foreign assistance, principally in the form of purchases of complete modern chemical plants, to overcome their deficiencies. Even in these cases, however, the Soviets frequently encounter difficulties when they take over and attempt to operate the foreign-built plants.

Soviet capabilities in the field of cryogenics appear to satisfy their requirements for liquid oxygen as a cryogenic missile propellant, for cooled infrared detectors, and for low-temperature physics research. The Soviets have shown considerable competence in the development and use of the helium-3/helium-4 dilution refrigerator to attain ultralow temperatures and in the design and production of helium liquefaction equipment. Although there is a chronic shortage of helium in the U.S.S.R., there appears to be enough to fill priority needs, including the more important low-temperature physics research.

The Soviets have a fairly extensive research program for new missile propellants. They use a methodical approach resulting in the utilization of new propellants as the requirement dictates. Solid-propellant research and development have been extensive, and many solid-propellant missile systems are under development. However, only one has been deployed and to a very limited extent. A continuous production process for manufacturing double-base propellants has been developed.

(2) *Metallurgy*—Metallurgy has long been an area of active research and development, and Soviet achievements have generally matched those of the West. The Soviets have experienced no serious difficulties in providing adequate materials and finished components for their priority needs and are now turning increasingly toward meeting the needs of their civilian economy and increasing their exports. Much of the earlier work was aimed at becoming self-sufficient in solving materials problems, whereas over the last several years, for example, they have been trying to improve the quality of their mill products to compete more successfully in world markets.

The Soviets have active research and development programs in many areas of metallurgy applicable to the development and production of improved weapon systems, such as aircraft, missiles, and submarines. In the field of superalloys used in the hot sections of jet aircraft engines, the Soviet Union has developed wrought materials comparable to those used in U.S. engines, but their cast polycrystalline alloys may suffer a significant 10°C to 40°C disadvantage in operating temperature. Their directionally solidified, monocrystalline cast superalloy turbine blades appear competitive with those of the West, and their basic research on directionally solidified eutectic superalloys appears adequate to support future applications. Additionally, their use of electroslag and plasma arc remelting is advantageous in producing high-quality, superalloys, and, in the case of electroslag, melting at a low-cost. On the other hand, the Soviets appear to have difficulty in casting thin parts and in providing protective coatings. One of the more competent Soviet researchers in superalloy development is F. F. Khimiushin, of the All-Union Institute for Aviation Materials in Moscow.

Considerable research on process metallurgy and technology for the production of titanium is carried out by the Soviets, in spite of the fact that they have a surplus of this metal and a technology that is already well developed and generally ranks with that of the United States. The Soviets are ahead in overall process integration for the production of titanium and are able to produce a very high quality metal sponge; both their sponge and titanium metal are available on world markets at prices below those of other countries. The Soviets have the capability to fabricate submarine pressure hulls, underwater research vehicles, and armored vehicles from titanium, but there is no evidence they are doing so. On the other hand, they probably are using titanium alloys in much of the airframe of the Mach 3 fighter aircraft Foxbat. Their persistant efforts to increase the production of titanium, however, suggest that more large-scale military applications may be in store for the future.

Soviet technology for the production of high-strength steels for submarine pressure hulls probably is equal to that of the United States and may lead in the application of high-strength steel to submarine pressure hulls. Most of their active submarine fleet probably employs steels of the AK series comparable to HY-80 and HY-100 steels used in U.S. submarine pressure hulls. The Soviets are believed to be developing still stronger steels of the HY-150 and HY-180 varieties for their submarines. They probably have applied their ESR technology in the direct production of slabs weighing up to 15 tons for rolling into submarine plate. A great deal of work has been done by metallurgists associated with submarine applications on high-manganese steels, but the implications of this work are unclear. Many of the experts on structural materials for naval applications work at the Central Scientific Research Institute 45 (TsNII-45 and TsNII-48), both in Leningrad.

In the field of metal matrix composites, the U.S.S.R. is probably behind the United States in producing high-quality continuous filaments of materials such as boron and silicon carbide on tungsten substrates. On the other hand, the Soviets are increasing significantly their work on continuous graphite fibers, suggesting greater use in the future as a reinforcing material. Additionally, they are preparing mullite, alumina, and zirconia fibers to reinforce important metals, including nickel, and are attempting to reduce excessive interaction between tungsten and nickel in composites by treating the tungsten surfaces with aluminum. The Soviets are reportedly testing composite metal felts for use in gas turbine blades. Also worthy of note is their long-standing research program at the Baykov Institute of Metallurgy, Moscow, on whiskers for use in composite materials, including the incorporation of whiskers of aluminum oxide (sapphire), silicon carbide, and aluminum nitride into high-strength composites.

The Soviets are actively investigating a wide variety of advanced fabrication and processing techniques applicable to the construction of military products and have put a number of them into practice. A. P. Gulyayev, of the Central Scientific Research Institute of Ferrous Metallurgy, Moscow, has conducted high-quality research on the thermomechanical treatment (TMT) of metals. Reportedly the Soviets have used TMT to attain ultimate tensile strengths of 300 to 400 kilopounds per square inch in low alloy steels. Recent work has stressed high-temperature TMT, above the recrystallization temperature, which affords improved ductility, toughness, and greater strength. Soviet TMT work on nickel-base superalloys has provided improvements in hot strength and fatigue properties.

Glue welding, a combination of spot welding and adhesive bonding, was developed by the Soviets and later adopted by the United States. It is used widely in Soviet aircraft, helicopters, hydrofoils, and air-to-air missiles, and it offers improved shear properties and reduced weight over riveted parts. Current research is aimed at developing new adhesives suitable for use at higher temperatures in glue welded parts. The Soviets have a large, expanding research and instrument development program in nondestructive testing (NDT) involving at least 10 individual institutes. The U.S.S.R. appears to be equal to the United States in ultrasonic, eddy current, radiographic, and magnetic testing methods, but has been less active in liquid penetrant techniques. Published Soviet work on fracture mechanics is highly theoretical and does not appear to have much computer support. Moreover, there is a great deal of Soviet interest in U.S. applied work, suggesting a Soviet weakness in this area. The best Soviet fracture mechanics facility is the Institute of Mechanics in Moscow.

Two areas of considerable metallurgical competence and achievement are electroslag remelting (ESR) and plasma arc remelting (PAR), both highly successful techniques for producing high-quality steels and alloys in sufficient quantities for large-scale applications. B. I. Medovar, of the Institute of Electric Welding *imeni* Ye. O. Paton (IES), Kiev, has been the principal individual responsible for the development of Soviet ESR technology, which is used to process more than 200 grades of steel and alloys, including maraging steels for aircraft. Soviet ESR units are capable of producing single ingots weighing up to 40 tons, although they have been building a new furnace to produce 100-ton ingots. PAR units used by the Soviets have excellent operating characteristics and are very versatile systems capable of operating at pressures from 10^{-3} Torr to several tens of atmospheres under reducing, neutral, or oxidizing conditions. Six to eight production plants in the Moscow area produce various shapes from titanium alloys, high-nitrogen stainless steels, and precious metals by PAR. The leading world authority on PAR technology is V. I. Lakomskiy, of IES.

The Soviets generally lag the United States in ceramic materials. However, they have demonstrated the capability to produce ceramic materials which would be suitable for rocket engine nozzle components and probably could fabricate high beta reentry vehicles from ceramic materials if they choose to do so. Interesting work on magnesium boron carbonitride and mullite-reinforced chromium oxide and aluminum nitride has been conducted at the Institute for Problems of Materials Science, Kiev.

b. Physics and mathematics

(1) *Physics*—The Soviets are highly competent in most areas of basic physics research, particularly the theoretical aspects. They also perform considerable experimental work, some of which is the equal of the best Western efforts, but much lags the West, principally because of a lack of readily available standardized instrumentation and equipment. As a consequence, many Soviet research groups design and fabricate their own experimental apparatus, including many items that could be purchased in the West. This delay tends to slow their rate of progress and to render their efforts less efficient. Nevertheless, by means of large numbers of researchers and considerable persistence and dedication, the Soviets have been able to achieve some notable successes in the fields of particle, plasma, and solid-state physics, optics, and infrared technology.

Theoretical nuclear physics research, centered at the Joint Institute of Nuclear Research (JINR), Dubna, and the Institute of Theoretical and Experimental Physics, Moscow, emphasizes nuclear structure. It is of high quality, but receives very low priority. Experimental research involving neutron bombardment is conducted largely with nuclear reactors having high neutron fluxes, such as the pulsed reactor at JINR.

The Soviets have developed numerous low-energy charged particle accelerators, both for nuclear physics experiments and for a wide range of industrial applications. They have emphasized the use of radiation—X-rays, gamma rays charged particles and neutrons—in industrial applications, although many of the processes would not be competitive in the West. A large facility for manufacturing low-energy accelerators, principally for industrial use, is located at the Institute of Nuclear Physics, Novosibirsk.

Of great significance to the Soviet research program in medium-energy particle physics is the plan to build a 600-megaelectronvolt "meson factory," similar to a facility in the United States. The Soviets do not expect to complete this facility, which will be located in the Moscow area, until 1978, thus putting them at least 5 years behind the United States. They have several medium-energy synchrocyclotrons in operation, including a 1-gigaelectronvolt proton accelerator at the Institute of Nuclear Physics, Leningrad, which is the largest machine of its type in the world. They are also actively conducting research on heavy ion acceleration, principally at JINR, for the production of superheavy elements. The 76-gigaelectronvolt proton synchrotron at the Institute of High Energy Physics, Serpukhov, is the best accelerator in the U.S.S.R. for high-energy physics research. Good research results are still achieved at Serpukhov, despite its lack of adequate computer support. It is reported that plans are currently being developed to enlarge the Serpukhov facility. A 1,000-gigaelectronvolt (GeV) synchroton is envisaged, with the current 76-GeV installation serving as the injector.

In order to achieve higher energies at a fraction of the cost of standard techniques, the Soviets have been actively investigating collective acceleration and colliding beam techniques. Scientists under the direction of V. P Sarantsev at JINR are the only group thus far to succeed in accelerating ions in the electron ring accelerator, a collective acceleration machine. Bolstered by this success, the Soviets have begun construction of a large electron ring accelerator, which will use both superconducting magnets and radio-frequency cavities for the first time on a Soviet accelerator. The colliding beam machines built thus far at the Institute of Nuclear Physics, Novosibirsk, have not yet proven very useful for high-energy physics research, but work continues on a 25-gigaelectronvolt proton-antiproton colliding beam device, which, if completed, would become the only one of its kind in the world.

In high-current electron accelerators, the Soviets have achieved power levels of only 10^{11}watts at currents of tens of kiloamperes versus 10^{13}watts and hundreds of kiloamperes reached in the United States. This lag is due largely to the weak capacitor bank technology used in conjunction with accelerators. At least one Soviet machine however, the RIUS-5, is more compact than comparable U.S. devices, since it operates on the transformer principle. The machine is being used to simulate nuclear weapons effects.

The Soviet program in plasma physics emphasizes theoretical work in support of CTR and MHD research. A number of published papers deal with beam-plasma interactions that could be of possible application to linear collective acceleration techniques or electron beam induced fusion. Experimental work appears to stress turbulent heating. Among the most notable Soviet plasma physicists are Ya. B. Faynberg, at the Khar'kov Physico-Technical Institute, and R. Z. Sagdeev, of the Institute of High Temperatures, Moscow.

The U.S.S.R. has the largest MHD research and development program in the world. Most of the Soviet work in MHD is aimed at developing open-cycle MHD generators for large-scale commercial power generation to take advantage of the abundant supply of fossil fuels. The leading institutes in the Soviet MHD program are the Institute of High Temperatures of the Academy of Sciences and the Krzhizhanovskiy Power Engineering Institute under the Ministry of Power and Electrification, both in Moscow. The largest and most important Soviet prototype plant is the U-25, developed by the Institute of High Temperatures, which is designed to generate 25 MWe from MHD and 50 MWe from a steam turbogenerator. The Soviets expect to achieve this output before 1977. As of September 1972 the U-25 had produced 4 MWe of MHD power for 1 to 3 hours. According to one scientist in the field, a 1,000-MWe unit, combined MHD and thermal, is currently in the design stage.

Plasma physics research in the space program is directed toward development of electric propulsion engines. The Soviets concentrate chiefly on the mercury ion bombardment engine. Except possibly for materials problems which would limit operating lifetimes, their work on this type of electric thruster appears nearly as good as that of the United States. Additionally, the Soviets have done excellent research on plasma thrusters and on thermal arc jets that use high-current electrodes and lithium propellant. Both of these experiments were performed at power levels at least a factor of five greater than U.S. experiments. Although the Soviets have tested various ion and plasma electric thrusters on satellites, they have not yet employed any of them in an operational mode.

The Soviets are generally competent in most areas of solid-state physics, such as semiconductors, thin films, and superconductivity. Their ability to prepare high-purity silicon, for example, is comparable with that of the United States, with the exception of that needed for electronic devices with low noise requirements. The Soviets continue to improve their technique for producing high-quality silicon. Their studies of germanium are more thorough than those of any other conventional semiconductor material, and the knowledge acquired is used as a reference in studying new materials. The Soviets also study the properties of other conventional semiconductors, such as the sulfides, tellurides, and related compounds.

A large number of binary and ternary amorphous and crystalline compound semiconductors have been prepared and tested, giving the Soviets a large selection of new, high-purity compounds. The amorphous semiconductors are more radiation resistant and less sensitive to impurities than the crystalline semiconductors. Currently the Soviet efforts are the largest in the world in the preparation and study of the properties of these materials.

Soviet gallium arsenide solar cells, which have been used in several satellites, reportedly are as efficient as silicon solar cells and have the advantages of being more radiation resistant and operable at higher temperatures and lower levels of light illumination. Additionally, the Soviets have developed and are believed to have a limited production capability for heterojunction gallium aluminum arsenide solar cells, which are more efficient than any other solar cell developed to date. The Soviets also produce some of the best electronic grade silicon carbide in the world for applications such as high-temperature radiation detectors and light emitting diodes. The Soviets have an intense program underway to determine the basic properties of semiconductor thin films, particularly the electrical characteristics. In thin film research based on vacuum evaporation, the Soviets appear to be using much poorer vacuums than the West uses, and they also appear to lag the West in the preparation of thin films by sputtering techniques.

The Soviets have a broad, good quality research program on the development of superconducting materials. Their principal objective is the production of materials having critical temperatures significantly higher than the boiling point of liquid helium, ca. 4°K, and specifically higher than the boiling point of liquid hydrogen, 20.4°K. The best high critical temperature material, however, niobium-tin, is generally unavailable in the U.S.S.R. except for research. Research on vanadium alloys and compounds is more extensive in the Soviet Union than in the United States and may result in the discovery of a new, important superconductive material. One of their foreign purchases includes vanadium-gallium from the Japanese. In applied superconductivity, the U.S.S.R. is currently embarking on a concentrated program to develop superconducting electric motors and generators. An allocation of 800,000 rubles has been made to this end in the 1971-75 five year plan, with the principal responsibility being assigned to the Institute of Electromechanics, Leningrad, the leading Soviet institute in this field. In 1971 the institute successfully operated a 10- to 20-kilowatt superconducting ac generator for 10 hours and is constructing a 1,000 to 1,200 kilowatt research ac generator. This device, presently nearing completion, is considered as advanced as anything in the West. The Kurchatov Institute of Atomic Energy is the only one to have built small superconducting machines.

(2) *Mathematics*—The U.S.S.R. continues to expand its very high capabilities in mathematics. Soviet mathematicians are among the world leaders in every important area of modern mathematics. There has been a strong emphasis on applied research to solve immediate problems, but excellent basic work continues in such subjects as algebra, functional analysis, mathematical logic, and topology. The greatest volume of work has been on differential equations, numerical analysis, and other subjects related to practical applications.

Soviet mathematicians have maintained their traditional strength in ordinary differential equations, with major emphasis given to topics related to automatic control theory. Mathematicians also have an impressive capability for research on partial differential equations, as well as considerable strength in applying the results of their research to the solution of practical problems in physical sciences and engineering. Many highly competent young mathematicians have joined such internationally renowned researchers as M. A. Lavrentyev, S. L. Sobolev, I. V. Vekua, and M. V. Keldysh in doing strong research on problems related to hydrodynamics and mechanics, fields which have a broad range of application in military and space efforts.

There is a large and growing effort on subjects pertinent to the development of improved computational techniques, with emphasis on methods suitable for use with computers. In numerical analysis much of the work has concerned the solution of practical problems at computing centers; some of the most notable work is by A. A. Dorodnitsyn, at the Computing Center at the Academy of Sciences in Moscow, and by G. I. Marchuk, at the Computing Center of the Siberian Department of the Academy of Sciences in Novosibirsk, on computational methods for applied hydrodynamic problems. Research in functional analysis by such leading figures as I. M. Gelfrand, M. G. Kreyn, and L. V. Kantorovich is aimed at improving methods for approximating the solutions of equations and supports improved practical computational techniques. The need for better computational methods in economic planning also has motivated a considerable volume of recent work, and many eminent mathematicians throughout the U.S.S.R. have been concerned with the methods of linear and dynamic programing.

Research on various aspects of pattern recognition (the information science of classifying sets of data) has been performed in the Soviet Union for over a decade. Only occasional successes have come from this research, primarily because of the complexity of the problem. Specific areas of research include optical scanning devices, computer recognition of digital patterns, and adaptive or learning systems based on pattern recognition. Pattern recognition is a major component of robotic systems. Military applications of this technology include missile terminal guidance systems and remotely operated devices to work in hostile or explosive environments on land, underwater, in the air, and in space.

The Institute of Mathematics *imeni* V. A. Steklov of the Academy of Sciences in Moscow, with branches in Leningrad and Sverdlovsk, has a central role in Soviet mathematics. The Institute of Mathematics of the Siberian Department of the Academy of Sciences in Novosibirsk, which includes several outstanding mathematicians formerly in the institute in Moscow, also has achieved prominence as a research center for mathematics, especially in subjects related to computer design and applications. Another important center for mathematical research related to computer applications is the Institute of Applied Mathematics of the Academy of Sciences in Moscow; it was formed from a department of the Institute of Mathematics that was concerned with problems in space mechanics and missile control. The departments of mathematics of major universities have strong programs in a broad range of topics. Individuals and small groups in educational and research facilities also make significant contributions in specialized subjects.

c. *Astrogeophysical sciences*

The U.S.S.R. carries out a large and comprehensive research program in the astrogeophysical sciences. Soviet scientists are recognized as among the world leaders in these fields, but the overall quality of their research and their accomplishments generally lag those of the leading scientists in the most advanced Western countries. In almost all areas of the

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astrogeophysical sciences, a lack or shortages of the more sophisticated instruments found in the West probably account for at least some of the lag. The use of outmoded data processing techniques also is a contributing factor. Nevertheless, some very good research is conducted in almost all of the astrogeophysical fields. The large Soviet geophysical research effort in the Polar regions contributes directly to the support of military plans and operations, many of which must be carried out in the Arctic.

(1) *Meteorology*—A strong research program in meteorology makes the U.S.S.R. one of the world leaders in the field. As in almost all countries, a large percentage of the research is devoted to improving the quality of weather forecasting and expanding and improving other forms of meteorological services. Much of the research is conducted under the leadership of the Main Administration of the Hydrometeorological Service (GUGMS). The army, navy, and air force all depend on GUGMS for operational and research and development support. A large part of the effectiveness of GUGMS and its relationship to the Soviet military service is related directly to the strength and stature of Academician Ye. K. Federov, a meteorologist well known in international circles, who has directed GUGMS since 1962. Federov and his many deputies control and supervise the largest environmental service organization in the world.

The quality of meteorological research is generally excellent. Research is strongest in the theoretical area, partly at least because of the strong physical and mathematical background of many meteorological researchers. Applied meteorological research is somewhat lower in quality than the theoretical research, but there are no serious deficiencies. One recurring problem that hampers progress somewhat is the unavailability of adequate numbers of computers to carry out some of the most advanced research. Instrumentation and data processing equipment also are generally less advanced than those employed by many Western countries, although in some instances the Soviets have been able to acquire or copy Western equipment.

Research and development in important areas, such as numerical weather prediction, weather modification, and satellite and aviation meteorology, receive vigorous support. The Soviets also provide considerable support to areas such as agricultural meteorology and especially Arctic studies, probably because a large portion of their territory is located in polar and subpolar regions. Research carried out by military personnel or sponsored by military organizations is noticeably missing in Soviet publications.

Soviet research in numerical weather prediction has kept pace with U.S. work in the theoretical aspects. However, the Soviets have fallen behind in the applied aspects because of a shortage of sizable computers. The need for more advanced computers is even more keenly felt in the associated area of atmospheric modeling, in which the Soviets have been able to run only a few models on computers. The most significant research on theoretical numerical weather prediction and atmospheric modeling is conducted under G. I. Marchuk, at the Computing Center of the Siberian Division, Academy of Sciences, Novosibirsk. Applied research in the field is concentrated at the Hydrometeorological Center of GUGMS in Moscow.

Soviet research on weather modification is conducted largely by facilities subordinate to GUGMS, under the leadership of Ye. K. Federov. Early in their weather modification program, the Soviet policy was to direct large efforts toward solving specific problems. Accordingly, a sizable program was carried out in the 1950's to develop operational techniques to dissipate cold clouds and fogs, followed in the 1960's by work directed toward protection against damaging hailstorms. The Soviets claimed to have solved the hail problem in principle by the latter part of the 1960's, using antiaircraft shells and rockets loaded with cloud seeding nuclei to induce premature precipitation from potential hail clouds. By reducing hail storms, test cases have shown that the gross crop yield could be increased by 5% to 10%. A project for dissipating fog at airports progressed so rapidly that operational programs are conducted at several airports in the Soviet Union with a high degree of success. Creditable work is carried out in precipitation augmentation; this work led to attempts to use the technique in controlling serious forest fires in 1972. The results of the efforts are not known, but newspaper reporting did not attribute any great degree of success to them. The Soviets also study methods for dissipating warm clouds and fog. This work appears to have significant military support, particularly by the air force, but details of the extent and nature of this support are unknown.

After considerable delay the Soviets began devoting attention to satellite meteorology. Although an experimental weather satellite program has been underway since 1966, it was not until 1969, when Meteor I was launched, that the program became operational. The Soviet satellite was equipped with television and infrared sensors that provided cloud photos of both the daylight and dark sides of the earth. The IR sensors also were employed to provide data on earth and cloud surface temperatures and on the general radiation balance of the earth. Through June

1973 the Soviets launched 15 satellites in the Meteor series. This program has been carried out under GUGMS, although the military also clearly is interested in the developments and uses the data collected by the satellites. The military may also participate in planning some of the operational procedures for these satellites. The Soviet hydrometeorological service operates meteorological satellite receiving stations at Novosibirsk, Khabarovsk, Moscow/Obninsk, and Tashkent.

The development of instrumentation capable of determining atmospheric temperatures at various altitudes represented a significant advance in the field. Such instruments were flown successfully by the United States in 1969 and by the Soviets in 1971 on Meteor 8. This instrumentation was not used operationally by the Soviets, however, and there is no evidence that similar instruments have been flown on later Meteor satellites. Nevertheless, such instruments are expected to become standard equipment, with measurements being made both in the infrared and microwave regions of the spectrum. The Soviets have also indicated that they are developing radar and laser instrumentation for future weather satellites. Such instruments could provide data which could be used for some very sophisticated research in atmospheric and cloud physics. The Central Aerological Observatory, subordinate to GUGMS, is the major facility engaged in instrument development for weather satellites. The Hydrometeorological Center and the Main Geophysical Observatory, also under GUGMS, are the most important facilities engaged in analysis of the data. However, the Academy of Sciences and university facilities also are engaged in data analysis and research, but to a more limited extent.

(2) *Space and upper atmospheric sciences*—The Soviets have maintained a very active scientific space research program since 1957. Strong support for lunar and planetary exploration has been demonstrated consistently, and it is clear that this aspect of the unmanned scientific space program receives high priority in the U.S.S.R. Nearly every available opportunity has been used since the early 1960's to launch planetary probes to Mars and Venus, and many times two or three spacecraft have been launched during a launch window. Although the success rate of the planetary probes has not been high, the Soviet Union has been the only country to obtain *in situ* data from the atmosphere and soft-land a spacecraft on the surface of Venus. The Soviet lunar exploration program has been highlighted for its use of automatic, unmanned devices both to pick up and bring back to earth small lunar rock samples and to investigate various surface features in the vicinity of the landing site.

Soviet space research in the vicinity of the earth has received lower priority than the lunar and planetary program, although the scope of the program is still fairly broad and second only to that of the United States. The Cosmos series of satellites, ostensibly launched solely for the purpose of carrying out scientific investigations, in reality is used primarily to carry out missions related to military intelligence, such as photo-reconnaissance, electronic surveillance, navigation, communications relay, and geodesy. Over 500 Cosmos satellites have been launched through 1972; only about 7% have had an entirely scientific mission. The Soviets have included piggyback scientific experiments on many of their photo-reconnaissance satellites that have helped compensate for the low number of purely scientific launches. The photo-reconnaissance satellites provide stable, earth-oriented platforms for the scientific package, but they severely limit the altitude regime over which the scientific measurements can be made. The time in orbit is also very limited (at most, 14 days), since the scientific package ceases to operate after the photographic package is returned to earth.

The U.S.S.R. appears to be placing added emphasis on cooperative projects with other countries to carry out their scientific space program. They have launched nine Interkosmos satellites in cooperation with several East European countries and the Oreol satellite in cooperation with France. Aside from the piggyback payloads on photo-reconnaissance satellites, these five cooperative launches constituted the bulk of the Soviet unmanned scientific program during 1970-72. The Soviets have established the Interkosmos council, headed by B. N. Petrov to initiate and carry through these cooperative projects. The Institute of Space Research and IZMIRAN, of the Academy of Sciences are the most important facilities for conducting scientific space investigations.

Many of the measurements carried out by the Soviets in earth orbit recently seem to be directed toward collecting data pertaining to the effects of solar phenomena on the environment of near-earth space. This has involved measurements of solar particles, together with simultaneous measurements of ionospheric and magnetospheric conditions, with emphasis on conditions in the auroral regions. Such measurements have been made on several of the Interkosmos satellites, the Oreol spacecraft, and *Prognoz* 1 and 2. The last two have very elongated orbits that have allowed the collection of data from relatively close to earth through the magnetospheric boundary region and into interplanetary space with the same satellite.

The program for lunar exploration has been marked by several successful flights during the past few years, beginning with the *Luna* 16 mission in 1970, which successfully returned lunar rock samples to earth. This mission was essentially duplicated in February 1972 by *Luna* 20, which soft-landed in a mountainous region of the moon. The amount of lunar material returned by these two missions was limited, but it was sufficient to contribute to an understanding of the early history of the moon. The sample collected by *Luna* 20 was particularly important, because it came from a region that had been inaccessible to any of the U.S. manned flights. *Luna* 17, which delivered the automatic *Lunokhod* mobile laboratory to the surface of the moon in November 1970, probably was the most successful Soviet lunar experiment to date. *Lunokhod* carried out a series of surface measurements over a time period that far exceeded the design lifetime of the vehicle. *Lunokhod* 2, which landed on the moon on 16 January 1973, did not last as long as *Lunokhod* 1, but covered much more distance on the moon and provided considerably more data.

In planetary exploration, the Soviets have had their greatest success in exploring Venus. *Venus* 4, launched in 1967, was the first Venus probe to penetrate successfully the Venusian atmosphere. Although the Soviets originally thought that *Venus* 4 had reached the surface of Venus, they now privately admit that the landing capsule probably imploded before reaching the surface. *Venus* 5, 6, and 7 were also all intended as landing craft and met with varying degrees of success, but *Venus* 8, which landed on the surface in July 1972, probably was the most successful of all the Soviet probes. The Venus program has provided Soviet scientists with direct measurements of the atmospheric conditions on Venus, whereas in this area U.S. scientists have relied more on remote measurements by Mariner spacecraft.

The Mars program has been far less successful than the Venus program. *Mars* 2 and 3, which arrived in the vicinity of Mars in late 1971, had primary missions of delivering landing craft to the surface. *Mars* 2 probably crashed, and *Mars* 3 apparently landed successfully but returned almost no data. However, *Mars* 2 and 3 also contained instrumented capsules which were placed into orbit around Mars and returned a small amount of video and remote sensing data, somewhat similar to the U.S. Mariner.

The Soviet solar flare prediction effort appears to be making some progress. A. B. Severnyy and his group at the Crimean Astrophysical Observatory (CAO) have modified their process of solar flare prediction, which was based almost solely on the magnitude of magnetic field gradients in active areas. They include information on the spatial distribution and time evolution of these field gradients, as well as other factors, such as radio emissions and X-ray bursts from solar flares. Severnyy has stated that he can predict important flares over a 2- to 4-day period with 80% success, a figure questioned by Western solar physicists. Some of the recent measurements by satellites, particularly *Prognoz* 1 and 2, should provide useful inputs into the Soviet flare prediction effort. The solar telescope at the CAO reportedly was modernized and enlarged and was to have been operational in the summer of 1972. A large solar radio telescope is to be built near Irkutsk. It will be a 128-antenna cruciform array, with each arm longer than 600 meters and each antenna 2.5 meters in diameter. Both instruments should provide useful data for improving the flare prediction effort.

The program for conducting earth resources surveys from space is presently closely linked with efforts to establish a long-term manned orbital space station. The first comprehensive earth resources observations from space were conducted during the *Soyuz*-6, -7, and -8 mission in 1969. The *Soyuz*-9 mission in June 1970 repeated the experiments of the previous *Soyuz* mission but covered more extensive areas. The most comprehensive Soviet earth resources investigations from space were conducted during the *Soyuz*-11/*Salyut* mission from 6 to 29 June 1971. Observations included multispectral photography of approximately 20 meters resolution, polarimetric measurements of reflected visible light, microwave radiometry, and spectral measurements of light reflected and emitted from the surface of the earth. Improved camera systems, microwave radiometers, and spectrophotometers are scheduled for future manned space station missions, and the Soviets plan eventually to include scientific specialists among the crews to assist in the observations.

The Soviet vertical rocket-sounding programs are designed to support satellite measurements by collecting a wide variety of data on the structure and composition of the upper atmosphere, on charged particle concentrations, and on characteristics of solar and corpuscular radiation. The Soviets rely primarily on the MR-12 rocket, which is capable of reaching 180 km and the M-100 rocket, which can reach 100 km. On several occasions, heavily instrumented rockets with a 500-km capability have also been launched. Soviet vertical rocket launching sites include Kheysa Island in Franz Josef Land, Kapustan Yar (Volograd),

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Molodezhnaya in the Antarctic, and several ocean-going research ships. In addition, the Soviets have launched approximately 90 M-100 rockets in cooperation with Indian scientists from the Thumba rocket launch station.

Soviet space instrumentation generally tends to lag the Western state-of-the-art, and, together with associated data processing equipment, may well be the weakest part of their space program. In fact, in a recent report a prominent Soviet aeronomer stated that the major limitation in Soviet upper atmospheric experiments is their computer capability. Although the Institute of Space Research has a BESM-6 computer, apparently only the smaller and slower BESM-4 (8,000 words and 20,000 operations per second) is available for their aeronomy work. In a few instances, however, especially with their scientific payloads piggybacked on photo-reconnaissance satellites, the Soviets have performed unique and advanced measurements. Microwave radiometers have been flown on three Soviet reconnaissance satellites and have provided significant meteorological and oceanographic data. Similar microwave radiometers probably will be incorporated into the Meteor weather satellite system in the near future. Another instrument which may become a permanent feature of Meteor weather satellites is a visible light polarimeter flown on *Meteor*-8 and the *Salyut*-1 space station. Its primary function was to determine whether cloud tops were in the liquid or frozen phase, but it also has possible applications to aerosol studies.

The *Salyut*-1 space station carried two additional notable instruments, a spark chamber to record high-energy particles and the Orion telescope to record the emission spectra of stars. These are indications that the Soviets will use manned space stations to a considerable extent in the future to collect scientific data and to test advanced instruments because of the spacecraft size and the presence of a human to operate and service the instruments. The Soviets appear to be far behind in the use of satellites as data relay platforms for information collected by remote ground and sea sensors. Very recent information, however, indicates that this lag may not be as great as formerly believed.

(3) *Terrestrial geophysics*—The U.S.S.R. maintains a large research effort in all areas of terrestrial geophysics, and in some areas this effort probably is the largest in the world. Despite this effort, however, the quality of Soviet research somewhat lags that of leading Western nations, probably primarily because of a weakness in the development and production of very accurate, highly sensitive instruments. There are also shortages of sophisticated data processing equipment and high-speed, high-capacity electronic computers. The Academy of Sciences directs most of the theoretical research on terrestrial geophysics. Under the Academy of Sciences, the Institute of Physics of the Earth and IZMIRAN are two of the most important institutes involved. The Ministry of Geology plays the most prominent role in carrying out applied geophysical research, most of which is directed toward geophysical prospecting.

The geomagnetics program has become the largest in the world—the excellence of Soviet geomagnetics research has received the acclaim of the worldwide scientific community. The Soviet program enjoys a high priority in the allocation of both scientific and monetary resources. The Ministry of Defense is a prime customer for this research, because the military is well aware of the many potential applications of geomagnetics. The Soviets have the largest magnetotelluric observational network in the world, and they have established several stations outside their territorial limits, many of which are operated in cooperation with other countries. One such station has been maintained for many years with the French on Kerguelen Island in the Indian Ocean. This station is magnetically conjugate to Sogra in northern U.S.S.R., and coordinated observations at these two points have resulted in several significant contributions to the understanding of geomagnetic micropulsations and natural VLF emissions. Such research contributes to the knowledge of plasma interactions and can also furnish useful information on ionospheric physics and electromagnetic wave propagation.

In 1974 the Soviets plan a cooperative project with the French that will involve a Soviet electron accelerator placed aboard a French rocket launched at Kerguelen. Electrons are to be directed up the magnetic field line, and studies will be made at Sogra on the effects of these electrons as they reenter the earth's atmosphere.

The Soviets for many years have carried out a strong research program in seismology. Much of the work has been used to study the structure of the earth's interior and to advance the state-of-the-art in seismic prospecting, particularly for oil. Other seismic research has been carried out to support the nuclear detection problem, and the Soviets have established a nuclear detection network. In recent years it appears that the Soviets have begun a large effort in seismic engineering and earthquake forecasting. Gravimetric research in the U.S.S.R. has lagged leading Western work for many years, apparently because of the rather poor instrumentation. Possibly for this reason, the

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Soviets have not stressed the use of gravity methods for mineral prospecting. In recent years, however, the Soviets have developed some respectable instruments which are being placed into service. Soviet gravity measurements at sea have suffered also from inadequate instrumentation as well as from poorly stabilized platforms on which to mount the instruments.

(4) *Geodesy*—The U.S.S.R. has an extensive and continually expanding research program in geodesy. Coordination of national research in the field is carried out under the auspices of the Multilateral Cooperation of the Academies of Sciences of Socialist Countries, the International Observations Program; the Council on International Cooperation in the Study and Utilization of Outer Space of the U.S.S.R. Academy of Sciences.

All civilian geodetic activities are conducted under the supervision of the Main Administration for Geodesy and Cartography (GUGK), which controls the Central Research Institute of Geodesy, Aerial Surveying, and Cartography in Moscow; the recently established Research Institute of Applied Geodesy, Novosibirsk; the Novosibirsk Institute of Engineers of Geodesy, Aerial Surveying, and Cartography; and the local aerogeodetic enterprises. All local agencies and organizations undertaking projects which involve geodetic data or surveys must obtain supervisory professional guidance and approval from the corresponding authority. GUGK schedules all geodetic control and mapping projects, with the exception of migrational boundary areas, certain strategic areas within the country, and foreign mapping. These exceptions are the responsibility of the Military Topographic Administration of the Ministry of Defense, whose activities are highly classified. Active research programs include geodetic surveying, triangulation, leveling, astronomic determinations, gravimetric and magnetic observations, spatial triangulation, and the construction of necessary technical equipment.

Goals of the geodetic effort are to extend the astrogeodetic and unified coordinate system through the country, to resolve differences between the Soviet data and recently adjusted Western European data, to establish firm connections with the North American data, and ultimately to establish a world geodetic system. The Soviets classify all gravity data for the U.S.S.R. and European Communist countries. As a result of published U.S. data, the Soviets enjoy an advantage in the reduction of geodetic error contribution to the miss-distance of future ICBM systems and probably will reduce these errors further with less difficulty than will the United States. The Soviets have recently begun a geodetic survey by means of satellite tracking to tie precisely in a line from Spitsbergen in the Arctic to Mirnyy in the Antarctic.

Soviet efforts in satellite geodesy have expanded considerably in the last few years. New overt optical tracking stations have begun or soon will begin operation in South America and Africa; the Soviets are approaching a worldwide optical tracking capability. At least one new covert station also has been discovered. All of their tracking stations are registered with the international system—Committee on Space Research.

In the fall of 1971 it was discovered that as part of their geodetic program the Soviets have been using flashing lights aboard some satellite vehicles which had been considered part of the Soviet navigational satellite program. Based on the location of these satellites during the times of flashing, it appears likely that several more covert stations exist than are known. The flashing lights on these satellites allow the Soviets a greater time period for tracking, since they are not dependent on reflected sunlight. The Soviets plan to improve their geodetic net accuracy further with the introduction of laser tracking, which was scheduled to begin in 1972. A prototype laser ranger built in Czechoslovakia has been used (in Czechoslovakia) with U.S. satellites equipped with laser retroreflectors. A similar instrument has now been set up in Riga, and the implementation of laser satellite ranging into their worldwide geodetic program may begin within the next year or so.

(5) *Oceanography*—The U.S.S.R. ranks second in world oceanographic research, closely following the United States but well ahead of Japan and the United Kingdom. The Soviets are expending tremendous efforts, using large numbers of scientists, technicians, research ships, instruments, and oceanographic facilities to achieve their committed naval and economic objectives. Their outstanding effort in applied oceanographic research has increased significantly.

Much of the Soviet oceanographic research effort is in support of the marine fisheries industry; however, a considerable part of the research is applicable to the Soviet undersea detection program. Particular emphasis is placed on the study of marine fauna and flora and their ecology. The Soviets have been concentrating on food protein technology, and its ultimate goal is to be the world leader in oceanic fisheries. Soviet research and development of fish protein concentrate still trails leading Western

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countries. The U.S.S.R. is giving attention to the exploitation of Antarctic fishing areas for krill, which they consider a fish product of great potential.

In addition to the considerable effort in marine fisheries research, significant emphasis is placed on internal waves, turbulence, and hydrooptics. The Soviets have a good capability in the theory and observation of oceanic turbulence. Their internal wave and turbulence instruments are adequate for a broad range of these studies and are operated from both buoys and ships. An increased number of these studies are directed toward support of naval operations, especially mine, submarine, and antisubmarine warfare. The development of underwater optical instruments is well advanced. Dolphin research, which continues to receive excellent financial support, focuses on methods of underwater navigation, hydrodynamics, and target discrimination. Naval applications for the studies of echo location capabilities of dolphins are likely to be the development of complex sonar equipment.

The Soviets are making detailed synoptic surveys of various large oceanic regions. To accomplish these surveys, they have been adding about nine modern research ships a year to their fleet. Finland has just completed seven oceanographic research ships of the 1,500 tons *Dmitriy Ovtsyn* class for the Soviets. The acquisition of these ships may indicate a trend toward smaller Soviet research ships. However, three modified *Akademic Kurchatov* class, 5,460-ton ships, have been ordered from East Germany, and at least two have been completed. The Soviet oceanographic research fleet now consists of approximately 200 ships (naval and civilian) of more than 100 displacement tons, and this does not include an estimated 125 vessels assigned to fisheries research.

The use of underwater habitats capable of 100-foot depths for subsurface observations is a relatively new research technique for oceanographers. Habitats capable of 300-foot depths are presently being developed. Several deep submergence vehicles have been designed, but the Soviets have reported production of only one 2,000-meter vehicle and have a second vehicle capable of operating to 600 meters. Meanwhile, the Institute of Oceanology has been unsuccessful in its attempts to purchase vehicles capable of 2,000- and 6,000-foot-depth capability from the United States, Canada, and France, although the Canadian purchase is being renegotiated.

For several years the Soviets have been using automatic buoy arrays in the Atlantic Ocean; the arrays are designed to provide synoptic temperature and salinity data and information on air-sea interaction. They have also established a hydroacoustic buoy system in the Barents and Norwegian Seas as well as in other areas. They plan to use buoys in the Indian Ocean to collect and transmit data to their meteorological satellites.

The Soviet polar oceanographic program does significant research in ice and ice forecasting, and active oceanographic, meteorological, and geophysical programs are conducted from several drifting ice stations in the Arctic Ocean. The Soviets have just established a new drifting ice station, SP-21. The U.S.S.R. deploys approximately 15 to 20 drifting automatic radiometeorological stations in the Arctic each spring and the same number in the autumn under the direction of GUGMS; however, nearly all are demolished during the severe Arctic winters. The active Soviet Antarctic program continues to include studies in oceanography, seismology, geophysics, meteorology, and glaciology. The 17th Soviet Antarctic Expedition (1971-72), their largest survey of this type, utilized research ships from the Arctic and Antarctic Scientific Research Institute, GUGMS, and the Institute of Oceanology. They operate six permanent stations in the Antarctic region and have recently established a seventh station.

Several institutes conduct geological studies in the Bering and Chukchi Seas. Offshore oil exploration in the Black Sea promises to open an extensive new field. The U.S.S.R. has a very active research program in earthquake prediction and is developing forecast techniques. Extensive seismic work has been accomplished in the Indian and Pacific Oceans. The All-Union Scientific Research Institute of Marine Geology and Geophysics, which was established in 1967, is responsible for ocean bottom mineral exploration.

The Soviets are hampered by problems of maintenance and development of instrumentation for their oceanographic program. To overcome these constant problems a rather large group of engineers has been formed at the Institute of Oceanology in Moscow. The group has developed some rather specialized and sophisticated instruments, but the majority of the Soviet-manufactured instruments are simple and rugged. However, a number of research ships are equipped with sophisticated electronic sampling and measuring devices.

The recently established All-Union Coordinating Committee for Oceanology in Moscow coordinates all oceanographic research conducted by the various Soviet and republic academies of sciences, the Hydrometeorological Service, and the Soviet Navy. Directly subordinate to the Council of Ministers, the coordinating committee replaces both the Interdepartmental Committee for Oceanography of the State Committee for Science and Technology and the National Oceanographic Committee of the Earth Sciences Section of the Academy of Sciences. The most important organizations responsible for oceanographic research are the Institute of Oceanology and the Acoustics Institute, Academy of Sciences, both in Moscow, and the Marine Hydrophysics Institute, Sevastopol, of the Ukrainian Academy of Sciences; the Hydrographic Service of the Navy, Leningrad; the Hydrometeorological Services; All-Union Scientific Research Institute for Marine Fisheries and Oceanography, Moscow, under the Ministry of Fish Industry.

Probably the most significant recent development in the Soviet oceanographic program has been a greatly increased interest in conducting cooperative surveys, international projects, and foreign exchange of data. The U.S.S.R. has long been an active member of all the prominent international oceanographic organizations. Iceland and the Soviet Union agreed to a cooperative oceanographic program, with emphasis on geological and geophysical research, to be conducted during the summers of 1971, 1972, and 1973. Chile and the Soviets concluded a fisheries research agreement involving exploration of the Chilean Continental Shelf and spawning grounds. Although not a member of the International Hydrographic Organization, the U.S.S.R. is cooperating with member countries of that organization in the compilation of a General Bathymetric Chart of the Oceans. Japan and the Soviets are conducting a joint seismic exploration of the offshore waters of Sakhalin Island. The United States and the U.S.S.R. recently signed an agreement for cooperation in oceanographic research and scientific exchanges.

The Soviets have been giving Cuba oceanographic support and cooperation for over a decade in general oceanographic observations, seismic explorations, and fisheries investigations. The Soviet Union and Cuba are participating in the Cooperative Investigation of the Caribbean and Adjacent Regions under the auspices of the Intergovernmental Oceanographic Commission, UNESCO. The U.S.S.R. is interested in developing an international ocean buoy data acquisition system in cooperation with other countries, particularly the United States. In October 1972 the Soviets agreed to participate with the United States in the Deep Sea Drilling Project.

(6) *Hydrology, hydraulics, and coastal engineering*—The U.S.S.R. ranks second to the United States in hydrological and hydraulic research; investigations are directed toward practical application aspects. Hydrological research is focused on problems of river regimes, seasonal variation of river discharge and runoff, regional water deficiencies, extension of test-well networks for ground-water studies, ice phenomena on large rivers and reservoirs, evaporation, hydrothermal characteristics of permafrost and frozen soils, protection measures against flash floods and mud and debris flow, and reclamation of swamp lands.

Hydraulic research is directed toward three-dimensional electrical modeling of seepage flow, superturbulent flow and rolling wave movement, routing of floods, and initiation of new techniques for hydraulic construction by using conventional and nuclear explosives. Research is directed also toward hydraulic construction in regions of subzero temperatures, unsteady regime in downstream pool, hydraulic resistance affecting head losses, developing pumped storage techniques, and aerated flow in open spillways and pressure pipes. Computers are used in studying discharge rating curves, plotting critical flood waves, programing reservoir volume, and estimating seasonal variation and control of reservoir balances. Several high-quality instruments, such as remote-control recorders, neutronic moisture tracers, gamma ray donsimeters, and underwater TV cameras, have been developed.

Practical application of research is directed to problems in five broad areas—electric power, inland waterways, irrigation, diversion of north-flowing rivers into arid regions of central Asia, and water pollution. Continuing construction of dams and locks on major river systems enhances Soviet capabilities in hydroelectric power, navigational inland waterways, and irrigational systems. North-flowing rivers are diverted to irrigate and sustain regional water levels in portions of the Ob River basin, and the Pechora-Kama Canal is planned to be constructed to divert one-third of the Pechora River flow southward through the Kama and Volga rivers into the drying Caspian Sea.

Soviet hydrologists and hydraulic engineers, some world renowned, are very active in national and international professional organizations. Several have been chosen as members of various working groups for the International Hydrological Decade (1965-74) of the International Association of Scientific Hydrology, which is under the auspices of UNESCO.

The U.S.S.R. ranks second to the United States as a world leader in coastal engineering research. New study techniques and equipment that facilitate exploration of shallow water mineral deposits have been developed. Also, new research techniques and equipment have been developed to assist in the study of littoral drift and sedimentation effects. These studies help to determine the type and placement of protective structures needed to prevent erosion of coast and beach areas and silting of ports and harbors, especially in the Black and Baltic Seas. In marine dynamics and protective works, emphasis has been placed on the origin and occurrence of storms and their effects on coastal and protective structures. Special emphasis has been given to the development and use of continuous-printing current meters to record storm currents and the dynamics of waters in the coastal zone of the Baltic Sea. A proposed dam and breakwater would enclose the Gulf of Finland and protect the city of Leningrad from these storm currents.

Coastal research and engineering programs in the fields of marine dynamics, shore processes, protective works, and instrumentation are carried out by approximately 40 organizations and establishments. The leading researcher, V. P. Zenkovich, heads the Laboratory of Dynamics and Morphology of Shores, an element of the Institute of Oceanology in Moscow under the Academy of Sciences. The Soviet Union is placing greater emphasis on the study of seas and coasts and plans to increase its research and engineering efforts. Recent studies, especially of shallow coastal waters, have achieved international recognition. Scientists participate fully at international meetings and conferences on coastal research and exert great influence on research conducted by the Eastern European countries.

Glossary (u/ou)

ABBREVIATION	RUSSIAN	ENGLISH
GKNT	*Gosudarstvenyy Komitet po Nauke i Tekhnike*	State Committee for Science and Technology
Gosplan	*Gosudarstvenyy Planovyy Komitet*	State Planning Committee
GUGK	*Glavnoye Upravleniye Geodezii i Kartografii*	Main Administration for Geodesy and Cartography
GUGMS	*Glavnoye Upravleniye Gidrometeorologicheskoy Sluzhby*	Main Administration for Hydrometeorological Services
IEOS	*Institut Elementoorganicheskikh Soyedineniy*	Institute of Elemento-Organic Compounds
IES	*Institut Elektrosvarki imeni Ye. O. Paton*	Institute of Electric Welding *imeni* Ye. O. Paton
IZMIRAN	*Institut Zemnogo Magnetizma, Ionosfery i Rasprostraneniya Radiovoli*	Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation
VINITI	*Vsesoyuznyy Institut Nauchnoy i Tekhnicheskoy Informatsii*	All-Union Institute of Scientific and Technical Information
VUZy	*Vysshiye Uchebnyye Zavedeniya*	Higher educational institutions

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