Nuclear Weapons Databook

New Perspectives on Russia's

Ten Secret Cities

By

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Table of Contents

List of Tables

List of Figures

Introduction

The core of the Russian (and formerly Soviet) nuclear weapons complex is composed of ten closed secret cities. What transpired at these locations throughout the Cold War was a central security concern for the United States and West Europe for more than forty years. This complex researched, developed, tested, and produced the nuclear weapons that were provided to Soviet armed forces and which were deployed widely against western militaries.

Today, though that once dangerous arms race is diminished, what happens throughout the complex continues to be a security concern of the first magnitude. The complex continues to provide for the safety and security of the Russian nuclear arsenal, although at a much reduced level. It plays the central role in the dismantlement of thousands of obsolete and redundant weapons. It has the principal responsibility for decontamination, decommissioning, and environmental cleanup of the nuclear weapons production legacy in Russia. Most importantly, the complex, already managing large amounts of weapons-useable nuclear materials, will assume responsibility for the security and, eventually the disposition of hundreds of tons of highly-enriched uranium (HEU) and plutonium from dismantled warheads, by far the largest portion of Russia's weapon-grade fissile materials outside of deployed weapons.

Ten years ago virtually nothing was known or written about the ten secret cities. Consistent with traditional Soviet secrecy practices these sites (and the closed cities that support them) were not found on any Soviet maps. In addition to their primary names, these secret sites were code-named after cities 50 to 100 kilometers away, followed by a postal zone number (e.g., Arzamas-16). Their precise locations were not always known. Beginning in 1989, several sites were opened to limited visits by the Russian press and sometimes to foreigners, but other sites still have not been visited nor have their specific missions been fully declassified or revealed.

In the intervening decade, especially since the dissolution of the Soviet Union, much new information has become available. Five years ago we published a book describing in some detail what was known at the time.[1] With new information to draw upon we feel it is time for a revision and an update of some of the information presented in the earlier work. Among the useful new sources is the Corona satellite imagery that has become available to researchers.[2] We have used selected imagery and other information to provide new perspectives on the past and present activities conducted at the secret cities.

Soviet Nuclear Weapon Production Complex: An Overview

[1] Thomas B. Cochran, Robert S. Norris and Oleg Bukharin, *Making the Russian Bomb: From Stalin to Yeltsin* (Boulder, CO: Westview Press, 1994).

[2] A number of images, that were used in this report, are from Joshua Handler of Princeton University. Some close-up photographs were provided by Charles Vick of the Federation of American Scientists. (An extensive collection of Corona satellite photographs of Russia's nuclear weapons facilities can be found at the FAS Web site http://www.fas.org/eye) If not indicated otherwise, the imagery in this report is from Oleg Bukharin. Bukharin's effort to acquire and research the imagery was greatly assisted by the progress made by Charles Vick and Joshua Handler.

Early History

The Soviet nuclear research & development program was initiated on February 11, 1943 in response to intelligence information about nuclear weapons research in other countries. Laboratory No. 2 (currently the Kurchatov Institute) was established to coordinate and lead research activities in the area of fissile material production and processing. Igor Kurchatov became the scientific director of the program and the director of the Laboratory No. 2. The scale of the program, however, remained limited until August 1945.

Following the United States' use of atomic weapons against Hiroshima and Nagasaki on August 6th and 9th, the Soviet Union initiated a crash nuclear weapons program. On August 20, 1945, the State Defense Committee adopted decision No. 9887 to establish the Special Committee, headed by Lavrenty Beria, to solve the nuclear problem. On August 29, 1945, the USSR Council of Ministers established the First Main Directorate (PGU) that was charged with administration and coordination of the atomic program. PGU received virtually unlimited access to personnel and materiel resources.

To accelerate the program, the Soviet government transferred to PGU tens of research institutes, design bureaus, and production factories. PGU also established a number of new sites and facilities. In 1945-47, decisions were taken to construct HEU production facilities in Novouralsk (Sverdlovsk-44) and Lesnoy (Sverdlovsk-45), a plutonium production complex in Ozersk (Chelyabinsk-65), and a warhead design center in Sarov (Arzamas-16). These facilities subsequently formed the basis of the Soviet nuclear weapons complex in the 1950s.

The Growth Phase: 1950s-1980s

The USSR's first nuclear bomb was essentially produced at two facilities of the First Main Directorate.[3] Plutonium production and the manufacture of plutonium components took place at Chelyabinsk-65. Warhead development and final assembly was carried out at Design Bureau Number 11 (KB-11) at Sarov. After its initial test in late August of 1949 the Soviet Union began to expand its complex, driven by the development of thermonuclear weapons, new, more sophisticated designs for fission warheads, and the quantitative growth of the nuclear arsenal.

The complex grew rapidly as new sites were constructed and existing facilities were expanded. By the late 1960s, the Soviet Union had developed a thoroughly integrated and redundant complex of research and design institutes, plants to produce fissile materials, and final assembly facilities to mass-produce nuclear weapons by the thousands. The complex

[3] Numerous other research institutes, design bureaus, and production facilities, including NII-6, GSKB-47, NII-504 of the Ministry of Agricultural Machinery, and NII-88 of the Ministry of Armaments, contributed to designing and manufacturing USSR's first nuclear explosive device. (V.N. Mikhailov, A.M. Petrosyants, et al., eds., *Creation of the First Soviet Nuclear Bomb* (Moscow: EnergoIzdat, 1995), pp. 221-225) NII-6 was developing synchronous detonators. NII-504 (subsequently the Central Design Bureau 326 of the Ministry of Communication Equipment) was developing the automatic altimeter fusing and detonator power systems. Design Bureau 47 worked on the bomb casing. The Design Bureau of the Kirov Plant in Chelyabinsk worked on some of the automatic components. NII-88 was involved in designing a gun-type explosive device.

was managed by the Ministry of Medium Machine Building (MSM) which was established after Stalin and Beria's deaths in 1953. In addition to overseeing nuclear weapons activities the Ministry supported fundamental scientific research, the naval nuclear propulsion and civilian nuclear power programs. By the late 1980s the nuclear complex comprised some 150 institutes and facilities and employed over one million people.

In 1989, to improve oversight and management of the nuclear program in the wake of the Chernobyl disaster, the MSM and the Ministry of Atomic Power (responsible for nuclear power plant operation) were merged into the USSR's Ministry of Atomic Energy and Industry (MAEP). On January 29, 1992, following the dissolution of the USSR, MAEP became the Ministry of Atomic Energy of the Russian Federation (Minatom).

Nuclear weapons development and production take place at the facilities of three of Minatom's main departments (see Table 1). The Nuclear Fuel Cycle Department (formerly the Fourth Main Directorate) is responsible for the operation of Russia's enrichment plants, plutonium and tritium production reactors, and radiochemical facilities. The Directorate also operates chemical and metallurgical plants in Ozersk (Chelyabinsk-65) and Seversk (Tomsk-7) that fabricate plutonium and HEU components of nuclear weapons. The Nuclear Weapons Development and Testing Department (formerly the Fifth Main Directorate) oversees the research institutes and design bureaus responsible for nuclear weapons research, design and stockpile surveillance. The Department of Nuclear Weapons Production (formerly the Sixth Main Directorate) is responsible for the assembly, modernization, servicing and dismantlement of nuclear weapons.

Several other Minatom departments, directorates and organizations provide support to the nuclear weapons program. The Production Association "TVEL" (formerly the Third Main Directorate) produces fuel for the plutonium and tritium production reactors. The 16th Main Directorate is responsible for nuclear reactor technology development. And the Main Scientific and Technical Directorate provides scientific support in special areas such as material science and radiochemistry.

The interface between Minatom and the military services is provided by the 12th Main Directorate of the Ministry of Defense. The 40,000-strong Directorate is responsible for the development of military requirements to nuclear weapons quality control at Minatom's production facilities (through a system of military representatives), safety and security of nuclear weapons in storage and in transit, and operation of the nuclear test site at Novaya Zemlya.

Table 1: Russia's Nuclear Weapons Production Complex

Facility/ location	**Nuclear weapons production functions**

Minatom's Nuclear Fuel Cycle Department (formerly Fourth Main Directorate)

Siberian Chemical Combine/ Seversk (Tomsk-7)	Production of plutonium HEU production Fabrication of HEU and plutonium weapon components
Production Association "Mayak"/ Ozersk (Chelyabinsk-65)	Production of plutonium Production of tritium HEU production Fabrication of HEU and plutonium weapon components
Mining and Chemical Combine/ Zheleznogorsk (Krasnoyarsk-26)	Production of plutonium
Angarsk Electrolysis and Chemical Plant/ Angarsk	Uranium enrichment
Urals Electro-Chemical Combine/ Novouralsk (Sverdlovsk-44)	HEU production
Electro-Chemical Plant/ Zelenogorsk (Krasnoyarsk-45)	HEU production

Minatom's Nuclear Weapons Development and Testing Department (formerly Fifth Main Directorate)

Institute of Experimental Physics, VNIIEF/ Sarov (Arzamas-16)	Nuclear warhead design Stockpile support
Institute of Technical Physics, VNIITF/ Snezhinsk (Chelyabinsk-70)	Nuclear warhead design Stockpile support
Institute of Automatics, VNIIA/ Moscow	Nuclear warhead design Design of non-nuclear components
Institute of Impulse Technologies, VNII IT/ Moscow	Nuclear test diagnostics
Institute of Measurement Systems, NII IS/ Nizhni Novgorod	Design of non-nuclear components and support equipment
Design Bureau of Road Equipment, KB ATO/ Mytischy, Moscow region	Nuclear warhead transportation and handling equipment

Minatom's Department of Nuclear Weapons Production (formerly Sixth Main Directorate)

Electrochimpribor/ Lesnoy (Sverdlovsk-45)	Nuclear warhead assembly/disassembly
Electromechanical Plant "Avangard"/ Sarov (Arzamas-16)	Nuclear warhead assembly/disassembly
Production Association "Start"/ Zarechny (Penza-19)	Nuclear warhead assembly/disassembly
Device-Building Plant/ Trekhgorny (Zlatoust-36)	Nuclear warhead assembly/disassembly
Production Association "Sever"/ Novosibirsk	Production of non-nuclear weapon components
Production Association "Molnia"/ Moscow	Production of non-nuclear weapon components
Urals Electromechanical Plant/ Yekaterinburg	Production of non-nuclear weapon components
Nizhneturinsky Mechanical Plant/ Nizhnyaya Tura	Production of non-nuclear weapon components
Kuznetsk Machine-Building Plant/ Kuznetsk	Production of non-nuclear weapon components

The Nuclear Weapons Complex in Transition

The nuclear program reached its peak activity in the early 1980s and by the end of the decade had begun to decline rapidly. The production of highly enriched uranium (HEU) for weapons ceased in 1988. A phase out of the production of plutonium for weapons was formalized as a part of the national defense conversion program. Ten of the thirteen graphite-moderated plutonium production reactors were shut down between 1987 and 1992. The principal mission of the three reactors still in operation is to produce heat and electricity for the local populations. The Russian government declared that starting in October 1994, freshly produced plutonium would be placed in storage and would no longer be used to make nuclear weapons. The United States and Russia are currently working to convert the reactors to new higher-burnup fuel with the goal of ceasing the production of weapon-grade plutonium altogether.

Thus, the HEU and plutonium production facilities are no longer involved in the nuclear weapons program. Instead, they provide fuel cycle services to domestic and foreign customers and are involved in a range of other nuclear and non-nuclear commercial projects. Some of the fissile material centers are also involved in the HEU down-blending activities under the 1993 U.S.-Russian HEU agreement.

Beginning in the late 1980s, the USSR unilaterally reduced its own nuclear stockpile and engaged in a series of arms treaties with the United States. As a result of the INF and the START I treaties, the Bush-Gorbachev reductions of 1991 in tactical weapons, and the retirement of obsolete weapons, the Russian stockpile is estimated to have declined to approximately 14,000 operational and reserve warheads. Of the retired 20,000 or so warheads, an estimated 11,000 warheads have been taken apart, with the remaining warheads placed in storage pending dismantlement. Further reductions to 3,000-4,000 operational and reserve warheads are expected to occur by 2007. The production of new warheads in Russia has dropped to less than ten percent of its 1990 level.[4]

Because of reduced defense requirements and budgetary shortages the Russian government is under pressure to downsize and consolidate the nuclear weapons program. In the summer of 1998 it adopted the Nuclear Complex Reconfiguration Program. According to the program, Minatom is to:

- consolidate warhead assembly work in Lesnoy (Sverdlovsk-45) and Trekhgorny Zlatoust-36) in 2000;
- stop warhead dismantlement work in Sarov (Arzamas-16) and Zarechny (Penza-19) in 2003;
- phase out nuclear weapons work at one of the two fissile material processing plants in 2003;

[4] Assuming a 1990 stockpile of 30,000 warheads and an average warhead life-time of approximately 10-15 years, the complex was (re-)manufacturing approximately 2,000-3,000 warheads per year.

- cut the number of defense program personnel in the closed cities from 75,000 to 40,000 by 2005;[5] and
- cut the number of personnel at serial production facilities from over 40,000 to approximately 15,000 in the next few years.[6]

Certain production functions are to be transferred from the serial manufacturing facilities to the pilot production plants associated with the warhead design institutes. There is also an effort to downsize and consolidate facilities producing non-nuclear components of nuclear weapons.

The downsizing process has been slowed because of the difficulties of redirecting excess personnel to productive non-weapons work. The first defense conversion program, based on large, federal-level subprograms, was adopted in 1988. Two of the subprograms related to environmental cleanup and advanced reactor technologies. The other six focused on microelectronics, processing equipment for agriculture, fiber-optic technology, advanced materials, medical equipment, and electric and gas equipment.[7] The plan was that nuclear facilities would enter the commercial markets in 1992 and 1993, but the program failed to accomplish its goals, because of insufficient investment, lack of entrepreneurial skills, poor understanding of the market, secrecy, inflexible institutional bureaucracies, and the high cost of production.

The defense conversion program was revised in 1995 to focus on projects for industrial users in the local regions. By that time, however, Russia's internal markets had essentially collapsed. The serious economic crisis of August 1998 created further difficulties for defense conversion of Russian nuclear weapons facilities.

Russia's Closed Nuclear Cities

The core elements of the Soviet nuclear weapons program were located in ten closed cities (see Table 2 and Figure 1). Ozersk (Chelyabinsk-65), Zheleznogorsk (Krasnoyarsk-26), Seversk (Tomsk-7), Zelenogorsk (Krasnoyarsk-45) and Novouralsk (Sverdlovsk-44) were built to produce and process fissile materials for weapons. (Uranium enrichment also took place in the open city of Angarsk.) Sarov (Arzamas-16) and Snezhinsk (Chelyabinsk-70) were the locations of the primary weapon design centers. Assembly and disassembly of nuclear weapons took place in Sarov (Arzamas-16), Zarechny (Penza-19), Lesnoy (Sverdlovsk-45), and Trekhgorny (Zlatoust-36). The existence of the closed nuclear cities was not officially acknowledged until 1992. Currently the cities have the status of "closed territorial-administrative units."

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[5] Remarks by Minatom's Deputy Minister Lev Ryabev at the 7th Carnegie Endowment Nonproliferation Conference, January 11-13, 1999, Washington, DC. (According to Minister Ryabev, the total number of workers in the ten closed cities is approximately 150,000.)

[6] Interview with Nikolai Voloshin, *Nuclear Control*, No. 5 (September/October 1999), pp. 29-32.

[7] Production facilities of the Sixth Main Directorate, for example, were tasked with production of telecommunication equipment, physical security hardware, instrumentation and control equipment for oil- and gas pipelines and nuclear power plants, medical equipment, transportation containers, and consumer goods. Research institutes of the Fifth Main Directorate were focused on supporting the nuclear power sector and oil and gas industries, development of batteries and accumulators, development of medical equipment, and high-voltage switching devices and instrumentation.

Approximately 750,000 people live in the closed cities. An estimated 130,000 work at nuclear facilities, half of them in defense programs.

To prevent sabotage and to protect the secrecy of what went on at the nuclear installations, the Soviet government implemented extraordinary security measures in the closed cities. Each city occupies a restricted area surrounded by double fences and guarded by troops of the Ministry of Internal Affairs (MVD). Nuclear facilities are located in isolated secure areas inside the general restricted area that are also surrounded by double, or triple, fences and patrolled by MVD forces. Access to the cities is limited and is controlled by the Federal Security Service. It typically takes a minimum of 45 days for a foreigner to receive an access visa to enter a closed city. To date, no foreigners have been allowed to visit Trekhgorny (Zlatoust-36) or Lesnoy (Sverdlovsk-45) where warhead production and dismantlement activities take place.

Figure 1: Russia's Closed Nuclear Cities

New name	**Former code name**	**Nuclear weapons activities**
Sarov	Arzamas-16	nuclear weapons R&D serial production of nuclear weapons
Snezhinsk	Chelyabinsk-70	nuclear weapons R&D
Lesnoy	Sverdlovsk-45	serial production of nuclear weapons
Zarechny	Penza-19	serial production of nuclear weapons
Trekhgorny	Zlatoust-36	serial production of nuclear weapons
Ozersk	Chelyabinsk-65	plutonium production production of HEU, plutonium, and tritium components of nuclear warheads
Seversk	Tomsk-7	plutonium production HEU production production of HEU and plutonium components of nuclear warheads
Zheleznogorsk	Krasnoyarsk-26	plutonium production
Zelenogorsk	Krasnoyarsk-45	HEU production
Novouralsk	Sverdlovsk-44	HEU production

The cities are largely independent of the regional authorities. In the past, the cities enjoyed special privileges, including a plentiful supply of food and consumer goods. The collapse of the command economy has disrupted the centralized supply and dramatically reduced the living standards in the cities. The local populations, however, continue to favor the separation of the cities from the surrounding regions as a measure of protection against crime.

Closed Cities on the Corona Satellite Photographs[8]

The Corona satellite photography program began in August 1960 and continued to May 1972 and involved over one hundred missions.[9] The program provided an extensive (but not continuous) coverage of the Soviet nuclear weapons complex, including its fissile material production and nuclear warhead design and manufacturing facilities.

The latest generation photo-reconnaissance satellites, used by the Corona program between 1967 and 1972, known as KH-4B, had a resolution of six feet, which is sufficient to discern roads, isolation zones associated with perimeter fences, pipelines and individual buildings.[10]

The closed nuclear cities, as seen on the Corona imagery, exhibit a number of distinct signatures. A typical nuclear city occupies a large restricted area, the perimeter of which is often clearly visible on Corona photographs. Inside the restricted area is a compact modern town for the facility workforce and several isolated technical areas that house nuclear installations. Each city has a railroad link with spurs to technical areas and loading/unloading stations. Some cities also have airfield or heliport facilities.

Photographs of the fissile material production sites (with the exception of Krasnoyarsk-26, where the production facilities are located underground) readily reveal the primary production facilities—the enrichment plants, production reactors, and reprocessing buildings. A variety of support facilities, including electric switchyards, cooling-water systems, and waste-management installations, are also visible and can be identified. Published memoirs by veterans of the Soviet nuclear industry, official historical information from Minatom, and recent accounts of Western visitors to these locations further facilitate the task of interpreting the Corona imagery of the fissile material production centers.

Nuclear warhead production facilities are not as distinct and their imagery is more difficult to interpret. The lack of historic information about these facilities and the continuing secrecy further complicate the task. There are, however, three signatures observable on satellite photographs that could be indicative of nuclear weapons production activities. These include high-explosive (HE) processing and storage buildings, warhead assembly cells, and warhead storage bunkers. In addition, warhead

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[8] For a detailed analysis of Corona photographs of the Soviet nuclear weapons production complex see Oleg Bukharin *Corona Satellite Imagery Indicators of Soviet Nuclear Weapons Production Activities*, PU/CEES Report No. 316, June 1999.

[9] Kevin C. Ruffner, ed., *Corona: America's First Satellite Program* (Washington, DC: Center for the Study of Intelligence, Central Intelligence Agency, 1995).

[10] Actual resolution was often worse due to atmospheric conditions, off-focus observation and other factors.

production facilities feature a variety of other structures. Some that are presumably associated with the production and assembly of non-nuclear warhead components and sub-assemblies, auxiliary equipment, and related manufacturing equipment. Other are used for administration and security, HVAC (heat, vacuum, air-conditioning), and other miscellaneous storage and support purposes.

The Corona imagery is now 30 years old. Significant changes have taken place at the Russian nuclear weapons production facilities over the years. The township areas have expanded. New buildings have been built and old ones have been modernized or demolished. However, many of the technical areas and buildings visible on Corona photographs still exist. Moreover, the complex that was largely built in the 1950 and 1960s retains many significant features that can be seen in the Corona photographs.

Nuclear Warhead R&D and Serial Production

Sarov (Arzamas-16)

Sarov, formerly Arzamas-16, was established on April 13, 1946 as a home to the Design Bureau No. 11 (KB-11), currently the Russian Federal Nuclear Center—or the All-Russian Scientific and Research Institute of Experimental Physics (VNIIEF), Russia’s first nuclear weapons design center.

The construction of KB-11’s facilities began in May 1946 and its first phase was completed in the fall of that year. Research and design activities began in the spring of 1947. KB-11’s principal mission was to design and produce a nuclear explosive device for testing and to develop a deliverable nuclear bomb. In the summer of 1947, the security forces began to build a perimeter and access control facilities around the closed area. The isolation of Sarov (Arzamas-16) from the outside world was complete by 1948. In 1947, the name of Sarov was erased from all maps and documents. The existence of the closed administrative-territorial unit (ZATO) of Arzamas-16 was not made public until the 1990s.

Sarov is located on the lands of the former Sarov Monastery, 75 kilometers (km) south-west of Arzamas in the Nizhegorod region, approximately 400 kilometers from Moscow. At present, Sarov is a home to two nuclear weapons facilities: the VNIIEF warhead design institute and the Avangard serial warhead assembly/disassembly facility. The population of Sarov is approximately 83,000, of which 18,000 work at the institute and 3,000-5,000 at the Avangard plant.

VNIIEF’s Mission and Organization. VNIIEF is the older of Russia’s two principal warhead design institutes, the Los Alamos of the Soviet Union. The other is the Institute of Technical Physics at Snezhinsk (Chelyabinsk-70) (see below). The Institute has the responsibility for nuclear warhead development and modernization, certification and surveillance of deployed weapons, R&D support of serial production and dismantlement activities, and technical support of accident response activities.

Organizationally, VNIIEF has five research divisions (combined in a science sector), two principal design bureaus, and a production sector (see Figure 2).

The science sector divisions conduct theoretical and experimental research into nuclear weapons physics and computer modeling of nuclear explosion processes. Design Bureau No. 1 is responsible for physics package design and testing activities. Design Bureau No. 2 conducts weapon engineering and integrates physics packages into weapon systems. The production section consists of a material science division and two pilot production facilities. Plant No. 2 produces high-explosive components of nuclear warheads.[11] The "Kommunist" Plant assembles experimental and pilot warheads and devices. These two VNIIEF's plants were the USSR's only warhead assembly facilities until 1951, when the first serial production plant, Avangard was completed and went into operation at Sarov (Arzamas-16).

Warhead R&D activities are supported by an extensive experimental and testing complex, which includes multiple sites for conducting experiments with chemical high-explosives and facilities for environmental and life-cycle testing of nuclear weapons and components.

The VNIIEF employment peaked in the 1980s at 25,000 and has decreased since then to about 18,000. In 1999, the VNIIEF management has indicated that it would like to reduce the employment level to approximately 12,000, of whom 7,000 would be involved in state-funded defense and scientific programs.[12]

As of 1998, approximately 50 percent of the activities at VNIIEF were defense related. The institute management would like to reduce defense work to 30 percent. VNIIEF also conducts a wide range of theoretical and applied research ("dual-use research," according to the Russian terminology) and develops industrial and manufacturing technologies.[13] This dual-use work is considered essential for maintaining a broad scientific and technological base to support the weapons programs. The share of dual-use research in the total R&D effort at VNIIEF is estimated at approximately 30 percent.

VNIIEF is also pursuing a number of conversion projects in the areas of conventional weapons, nuclear power plant safety, gas and oil production and transport, mathematical modeling, diamond cutting, use of high-explosives for industrial purposes and others.

The Electro-mechanical Plant "Avangard." The Avangard Plant at Sarov was the USSR's first serial warhead production facility. The decision to build the Avangard

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[11] Paul Podvig, ed., *Russia's Strategic Nuclear Weapons*, (Moscow: IzDat, 1998), p. 85.
[12] "Hope is the Only Thing Left," *Gorodskoy Kuryer*, No. 34, 1998.
[13] In particular, the institute conducts research in materials sciences, high-energy physics, nuclear physics, radiation physics, strong magnetic field, physics of lasers, and computational physics. The technology development effort focuses on welding and soldering, computer design, instrumentation and control, technologies of explosives, and others.

plant (originally, Plant 551) was made in March 1949.[14] By 1951 the plant's primary production shops had been built and were operating. Initially, the plant consisted of 20 buildings with the total area of 21,000 square meters and employed approximately 1,000 people. In December 1951, in cooperation with the Pilot Plant 1 of the KB-11 at Sarov (Arzamas-16), the plant produced its first RDS-1-based gravity bomb, which was designated as "item 501."

The Avangard plant worked in close cooperation with other facilities.[15] Plant 219 of the Ministry of Aviation Industry (Minaviaprom) in Balashikha cast metal shells for explosive devices. After machining, the shells were sent to the "Bolshevik" plant in Leningrad for assembly. Plant 12 in Electrostal produced uranium components. Plant 48 ("Molnia") in Moscow made aerodynamic bomb casings. Minaviaprom's plant 25 (currently the Institute of Automatics) produced automatic components. Plant 80 in Dzerzhinsk (Gorki region) manufactured high-explosive components designed by the KB-11. Combine 817 in Ozersk (Chelyabinsk-65) manufactured plutonium components. Plant 551 was responsible for the final assembly of physics packages and finished weapons.

Initially, the production process involved the assembly of each individual weapon by hand. The plant was designed to produce two or three bombs per month. Very soon, however, the production levels increased well beyond the capacity. New types of warheads entered production: thermonuclear bombs (1954), IRBM warheads (1956), air-defense missile and torpedo warheads (1957), ICBM and SLBM warheads (1960), peaceful nuclear explosive devices (1969).[16] In addition, the plant was producing equipment to maintain and service deployed nuclear weapons. The USSR Government resolved to upgrade the facility. By 1960, new instrumentation, electro-mechanical, and final assembly shops were constructed.[17] The plant also established special facilities to assemble physics packages and process special radioactive materials (such as polonium-210).

Another modernization cycle took place in the early 1970s as the plant started to manufacture more advanced and complex weapons. During this period the facility introduced automated production lines and advanced processing equipment. New construction and modernization of Avangard facilities continued into the 1980s.

Avangard was the smallest of the four serial production facilities in the Soviet Union. *Komsomolskaya Pravda* described the work of an "engineer-fitter" that worked in a shop of about 30 people engaged in the final assembly of bomb and missile warheads.[18] He claimed to have assembled several thousand nuclear warheads over 14-year period, suggesting that Avangard's production capacity might be on the order of several hundred warheads per year. The facility is believed to specialize in tactical

[14] Yu. Zavalishin "'Avangard' – First Serial…," *Atom*, 1/96, pp. 11-12.
[15] Podvig, *Russia's Strategic Nuclear Weapons*, p. 89.
[16] Bella Nekhorosheva "Avangard is 50," *Gorodskoy Kuryer*, No. 11, March 18, 1999.
[17] Yu.Zavalishin "'Avangard' – First Serial…," *Atom*, 1/96, pp. 11-12.
[18] Jonathan Lyons "Bomb-Builder Gives Rare Look at Soviet Arms Industry," *Reuter*, February 6, 1992.

weapons. The Russian government has resolved to phase out warhead assembly work at Avangard in 2000 and to stop warhead dismantlement activities in 2003-2005.[19] Currently, the plant employs approximately 3,000-5,000 workers.

After the dismantlement program is fulfilled, the plant will primarily focus on manufacturing conventional weapons.[20] (Certain nuclear weapons related activities would continue in cooperation with VNIIEF.) In 1989, Avangard initiated a defense conversion program. The initial effort was on medical equipment and general consumer goods. The primary focus, however, appears to be on equipment for physical security applications, including sensor systems, and anti-terrorism and bomb-squad equipment.[21]

Sarov (Arzamas-16) Site Layout. As can be seen in the Corona photographs (see Figure 3) the Sarov city and research and production facilities are located within a hexagonal restricted area of some 232 square kilometers. The township of Sarov occupies approximately 29 square kilometers and is located in the northern part of the restricted area, south of the airport. VNIIEF's main administration building is located near the Sarov Monastery, the symbol of Sarov (Arzamas-16). There are several protected areas within the city, which are probably associated with VNIIEF. The Avangard plant is located in the western part of the restricted area. The southern part of Sarov (Arzamas-16) is covered with woods and contains multiple experimental facilities.

Snezhinsk (Chelyabinsk-70)

A policy decision to establish a second warhead design center was made by the USSR Council of Ministers on July 31, 1954 (Resolution No. 1561-701). It was thought that with the rapidly expanding scope of weapons design work (due to thermonuclear designs) a second center would reduce the burden on Arzamas-16 and accelerate the weapons development program. The center also would provide for a peer-review mechanism for the two institutes, and enhance war-time survivability of the nuclear weapons complex.

To implement the political decision, on April 5, 1955 the Minister of Medium Machine Building issued an order to organize a Scientific and Research Institute No. 1011. In 1967 the institute was renamed the Institute of Device-Building, VNIIP. In 1989 it finally became the VNII of Technical Physics.

The new institute was built in the Urals, 20 kilometers north of the plutonium production complex in Ozersk (Chelyabinsk-65). The proximity of the institute to the other nuclear weapons facilities in the Urals region facilitated closer relations between the warhead designers and the manufacturers. The location permitted the new weapons institute to use Chelyabinsk-65's industrial infrastructure to accelerate the construction of research facilities and residential housing the initial units of which were completed in 1957.

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[19] Remarks by Minatom's Deputy Minister Lev Ryabev at the 7th Carnegie Endowment Nonproliferation Conference, January 11-13, 1999, Washington, DC.

[20] L.Saratova "How do You Live, the Weapons Plant?" *Gorodskoy Kuryer*, No. 3, January 23, 1999.

[21] See, E. Zhuravlev "Conversion at 'Avangard'," *Atompressa*, No. 30 (314), August 1998, p. 4.

To jump-start weapons work at VNIITF, approximately one third of personnel from the Arzamas-16 warhead design center were relocated to Snezhinsk (Chelyabinsk-70). By 1957 the institute was already participating in designing and testing the USSR's first deployed thermonuclear weapon.

During the next 40 plus years, the institute developed dozens of strategic and tactical warheads. Warheads for some types of weapons systems were designed in parallel with Arzamas-16. Warheads for SLBMs, gravity bombs, and artillery shells, however, were designed primarily at VNIITF in Snezhinsk (Chelyabinsk-70). As of 1997, approximately 60 percent of all strategic, and over one-half of the tactical warheads, in Russia's operational stockpile were designed at Snezhinsk (Chelyabinsk-70). By service, the approximate percentages are 65, 65, and 50 for the Army, Air Force and the Navy respectively.

In 1961 the institute tested an all-VNIITF gravity bomb that was subsequently deployed as a strategic weapon system with the Air Force. VNIITF also developed a 50 Megaton super-bomb, a physics package of which was designed by Arzamas-16. (In working on the parachute system for the super-bomb, VNIITF designers developed a lasting relationship with the Institute of Parachute and Airborne Troop Systems. Subsequently, the two institutes have worked together on a variety of gravity bomb systems.)

Following these initial successes, Chelyabinsk-70 became the primary designer of all subsequent models of gravity bombs. In the late 1950s and early 1960s the institute proposed to the Ministry of Defense to start working on smaller, externally carried tactical bombs. Chelyabinsk-70 also worked on anti-submarine depth charges (including for under-ice use) and gravity bombs with a lay-down capabilities. To date, the institute has designed and transferred to the stockpile approximately 20 types of strategic and tactical gravity bombs.

The decision to develop a nuclear-armed SLBM in the Soviet Union was made in response to the deployment of the Polaris SLBM system in the United States. The primary responsibility for the project was assigned to the Design Bureau of Machine-Building in Miass (currently Makeev's KBM) and Chelyabinsk-70. In 1960, Chelyabinsk-70 completed the development of its first SLBM warhead for the SS-N-4 (R-13, complex D-2) surface-launched ballistic missile deployed on Golf I and Hotel I class boats (projects 629 and 658).[22] In 1963, the institute transferred to the Navy a warhead for the SS-N-5 (R-21, complex D-4) underwater launched missile which was installed on Golf II and Hotel II (projects 629A and 658M) submarines.[23] Chelyabinsk-70 became the primary designer for SLBM warheads and developed 16 types of warheads for single-warhead and MIRVed missiles that were operationally deployed.

[22] SS-N-4 missiles were equipped with one 1 MT warhead; the reentry vehicle weighed 1600 kg. The missile remained in service from 1961 to 1972. Podvig, *Russia's Strategic Nuclear Weapons*, p. 273.

[23] SS-N-5 missiles were equipped with 1 MT and 0.8 MT warheads; the reentry vehicle weighed 1200 kg. The missile remained in service from 1963 to 1989. (*Ibid*., p. 275-276.)

The nuclear artillery program began in the 1960s after the Soviet Union learned of the development of 203 mm and 155 mm nuclear artillery shells in the United States. The responsibility was assigned to Chelyabinsk-70 and the Design Bureau of the Ministry of Machine-Building. The first 203-mm artillery shell was transferred to the military in 1977. Subsequently, in the late-1970s and 1980s, the VNIITF designed ten types of nuclear artillery shells and mines.

VNIITF has also worked on warheads for a variety of other strategic and tactical weapon systems. In 1960s and 70s, it developed and transferred to serial production five models of warheads for the KBM-designed SCUD (Luna) tactical missile.

In the 1960s, the Soviet government tasked VNIITF to develop a warhead for the SS-11 SEGO (UR-100) ICBM, which was being developed by the Chelomey's Central Design Bureau and which turned out to be the Soviet missile produced in the greatest numbers.[24] In later years, cooperation with the Chelomey Bureau continued and Chelyabinsk-70 designed ICBM warheads for both single-warhead and MIRVed missiles some of which remain in service

In the late 1960s, the institute developed two warhead designs for air-defense missiles and one for an ABM interceptor, all three of which entered production and were deployed. Subsequently, this work was transferred to Arzamas-16 due to Chelyabinsk-70's already large portfolio of weapons design projects.

Chelyabinsk-70 has been the principal design center for specialized nuclear explosive devices for peaceful applications. The institute developed devices of 14 types. Nine types were used in 70 explosions from 1968 to 1988 for seismic sounding, intensification of oil and gas production, making underground cavities, closing gas channels, waste burial, and reducing the danger of methane explosions in mines. For deep-underground applications, such as intensification of oil and gas production, Chelyabinsk-70 developed compact, dial-a-yield 1-40 Kt thermonuclear devices capable of withstanding high pressures and temperatures (750 atmospheres and 120^{o} C). For earth moving and excavation purposes it developed thermonuclear devices which had 99.85 percent of yield from thermonuclear reactions and produced relatively little residual radioactivity due to fission products.

VNIITF'S Mission and Organization. The original mission of Chelyabinsk-70 was to design nuclear warheads and provide scientific support to nuclear weapons throughout their life-cycle. In the post-Cold War period, VNIITF's principal missions

[24] SS-11 missiles were armed with one 1.1 Mt warhead; the reentry vehicle weighed 760-1500 kg. The missile was flight-tested in 1965-66 and entered service in 1967. The missile was subsequently modernized with newer versions designated UR-100M, UR-100K, and UR-100U. The UR-100K (SS-11 Mod 2) and UR-100U (SS-11 Mod 3) were equipped with one 1.3 Mt and three 350 kt warheads respectively. All SS-11 missiles were retired by 1994. (*Ibid*., p. 178-180).

are nuclear weapons safety improvements through warhead modernization, stockpile surveillance, and support to warhead life-time extension activities.[25]

VNIITF has an array of facilities that are used for stockpile stewardship purposes. Most importantly, there is an extensive experimental infrastructure to conduct studies in the area of high explosives and radioactive materials (tritium and fissile materials). It is actively involved in studying high explosive (HE) aging and HE behavior under accident scenarios. The experimental infrastructure includes a test site capable of experiments with up to 1000 kg of HE. The institute also has a radio-chemical center that is capable of producing neutron-generator targets, tritium purification and handling, and uranium and plutonium material science research and processing.

The structure of the institute reflects the needs for an integrated (cradle-to-grave) warhead development cycle and includes (see Figure 4) a group of theoretical and experimental divisions (reporting to First Deputy of VNIITF's Science Director), two design bureaus (reporting to Physics Package Chief Designer and Nuclear Warhead Chief Designer respectively), and a production and technology group (reporting to Chief Engineer). VNIITF's director (since 1996 also Science Director) relies on the Science and Technology Council for shaping the institute's technical policy and the management for day-to-day operations of the institute.

VNIITF's primary weapons science and development units (see Box) are supported by the auto- and rail transportation divisions and by the power-generation division, which, in part, have recently been transferred under municipal control. The institute has a specialized testing complex for environmental testing of physics packages and warheads. Additionally, VNIITF has a laboratory that supports safety oversight activities throughout the warhead production complex. Finally, the institute has established six specialized centers to support relatively new work in the areas of international cooperation, MPC&A, arms control analysis, nuclear reactor safety, forecasting of environmental impacts of nuclear accidents, and accident response.

VNIITF's Primary Weapons Design And Production Units

Theoretical and experimental physics group. The group conducts applied and basic physics research in support of warhead design activities. The group includes:

- a physics package physics division, which is responsible for conceptual design work and stockpile surveillance;
- a division of physics and mathematical models and software;
- a computational division; and
- a division of experimental physics.

Under the stockpile stewardship effort, the theoretical and experimental divisions are responsible for the development of improved physics models of nuclear weapons, analysis of past nuclear test data, improved computational capabilities. The experimental physics division has a number of facilities that will

[25] Missile and Space Technology, *Russia's Arms Catalog*, vol. VI (Moscow: Military Parade Ltd, 1996-97), p. 386.

be used in stockpile stewardship effort, including impulse reactors (to study radiation hardening effects), a laser facility, electron accelerators and facilities to evaluate fissile material components.

Design Bureau 1 (KB-1). Design Bureau 1 is responsible for the warhead-design thrust 1 phase—design and life-cycle support of physics packages. The Bureau includes:

- a division of experimental hydrodynamics, which is responsible for hydrodynamic tests and warhead accident analysis;
- a physics package design division (which is also responsible for science oversight and support during the phases of serial production field deployment); and
- a nuclear testing division, which is currently involved in subcritical experiments, CTBT verification, and accident contamination cleanup.

In 1996, the Bureau established a division of conversion technologies and conventional munitions. Among other products, the division has developed perforators for the oil industry and is working on conventional warheads for surface-to-air and air-to-air missile systems.

Design Bureau 2 (KB-2). Design Bureau 2 is responsible for the warhead-design thrust 2 phase—weaponization of tested physics packages into nuclear warheads and their life-cycle support. The KB-2 includes:

- a division of automatics systems and warhead development;
- a division of nuclear warhead engineering;
- a design division;
- a division of automatics and instrumentation;
- a division of warhead testing (flight testing); and
- an experimental complex, which produces warhead components and mock-ups.

The KB-2 also has established a Center of Conversion Projects, which, for example, is working on super-plastic metal forming technologies.

Scientific-research testing complex (NIIK). The complex operates facilities for environmental testing of nuclear warheads with respect to such factors as vibrations, shocks, hydrostatic pressure, accelerations, heat, humidity, electricity discharges, and missile-defense effects. The complex consists of approximately 20 buildings and several testing areas.

Production and technology group. The production group is responsible for the transfer of Snezhinsk (Chelyabinsk-70)-designed warheads into serial production. During the design phase, VNIITF's production facilities manufacture up to 100 pilot units of warhead components and support equipment. The production group includes two pilot plants and a technological division (which primarily focuses on material science and fabrication processes). State Pilot Plant 1 is capable of manufacturing a wide variety of non-nuclear components (instrumentation, electrical equipment, casings, etc.). Plant 2 produces, among other things, HE and lithium deuteride components and subassemblies, as well as assembles nuclear warheads. The plants produce experimental and pilot units of physics packages and nuclear warheads for the purpose of laboratory testing (in the past, underground nuclear testing). In the past, the plants also produced PNE nuclear explosive devices.

Peak Cold-War employment at the Chelyabinsk-70 warhead design institute was 15,000. Approximately 14,000 worked in the institute in 1997. The employment was reduced to 11,000 in 1998 after VNIITF transferred some of its support divisions to the municipal authorities. An additional cut of 3,000 or so jobs from the defense programs in Snezhinsk (Chelyabinsk-70) was reported to be imminent with deeper reductions expected in the future.

Geographic Location and Site Layout. Snezhinsk (Chelyabinsk-70) is located between Lakes Sinara and Silash, 20 kilometers north of Kasli and about 80 km south of Yekaterinburg. The institute started at Site 21, which is located on the peninsula between Lake Sungul and Lake Silash, about midway between Snezhinsk and Kasli to the south. By 1958, the weapons design center had outgrown Site 21 and over the next decade work shifted to new facilities constructed at Site 70, about 10 kilometers to the north (Figure. 5). (At present, Site 21 is within the controlled area but outside of the city's restricted area.)

As can be seen in the Corona photograph the Snezhinsk (Chelyabinsk-70) restricted area is a rectangular area measuring six by ten kilometers. The fence encloses both the town of Snezhinsk on Lake Sinara, and most of VNIITF's facilities, including the Site 20 testing area six kilometers west of the town.[26] The VNIITF main technical area is approximately two kilometers south of Snezhinsk and a presumed high explosive facility is to the southwest. The Institute's headquarters are located in Snezhinsk. In 1998, Snezhinsk had a population of 49,000.

Lesnoy (Sverdlovsk-45)

The closed city of Lesnoy, formerly Sverdlovsk-45, was established in 1947 as a home to Plant 418–an electromagnetic separation (calutron) facility to produce HEU.[27] An industrial-scale separation facility, SU-20, was completed at Plant 418 simultaneously with the first Soviet gaseous diffusion plant, D-1 in Novouralsk (Sverdlovsk-44). Initially, the SU-20 facility was used to increase the level of enrichment of uranium received from the D-1 plant from 70 to 90 percent uranium-235. Improvements in the gaseous diffusion technology have subsequently eliminated the need in electromagnetic separation of uranium isotopes and the SU-20 facility was redirected to enrich non-uranium isotopes.

In the late 1950s, a portion of Plant 418 was adapted to house a nuclear warhead assembly/disassembly facility—the Combine "Electrochimpribor."[28] The Combine was established to duplicate the Electro-Mechanical Plant "Avangard" at Sarov (Arzamas-16) in assembling physics packages and nuclear warheads. Eventually, it became Russia's largest warhead assembly complex.

Lesnoy is located near Nizhnyaya Tura, approximately 160 kilometers north of Yekaterinburg. Its population is 58,000 of which some 10,000 work in the warhead production complex.

As can be seen in the Corona photographs (see Figure 6), Lesnoy (Sverdlovsk-45) occupies a roughly rectangular area. The town of Lesnoy is located on the northern shore of the lake Bol'shaya. East of Lesnoy and the production complex is Nizhnyaya Tura, which is separated from the Lesnoy (Sverdlovsk-45) restricted area by a brick wall. Nizhnyaya Tura also has a facility managed by the Department of Nuclear Weapons

[26] Cochran, et al., *Making the Russian Bomb*, p. 45.
[27] A. K. Kruglov *How the Soviet Atomic Industry was Created* (Moscow: CNIIatominform, 1995) p. 198.
[28] Podvig, *Russia's Strategic Nuclear Weapons*, p. 90.

Production: the Nizhneturinsky Mechanical Plant is thought to produce certain non-nuclear warhead components.

The production facility is located north of the residential area and consists of four large, identifiable technical areas. High-explosive component and warhead assembly activities presumably take place in the northern-most area which features a group of bermed structures. Approximately two kilometers west of the high-explosives technical area is another group of bermed buildings that are likely to be associated with high-explosive component testing. West of the residential area is a rail terminal and a helicopter pad.

Approximately three kilometers west of the rail terminal is a large, national-level warhead storage facility located within the Lesnoy (Sverdlovsk-45) restricted area. The storage facility includes residential and support areas and a number of caverns dug into a mountain. The facility is connected with the main rail terminal at the production complex by a rail spur. Outside of the Lesnoy (Sverdlovsk-45) restricted area, approximately five kilometers north of the first warhead storage area, is another national-level storage facility. Both storage facilities probably operate in support of the Sverdlvosk-45 warhead assembly/disassembly complex.

Zarechny (Penza-19)

The closed city of Penza-19, currently Zarechny, was established on July 20, 1954 as a site for a serial production facility to manufacture electronic and automatic components of nuclear warheads. The construction began in April 1955 and the plant produced its first output in 1958.[29]

In the 1960s, the plant was renamed the Penza Device-Building Plant. Later, the Production Association "Start" was established. In addition to the Device-Building Plant, the "Start" complex includes the Kuznetsk Machine-Building Plant producing specialized equipment for the warhead production complex. Zarechny (Penza-19) is also a home to the Institute of Radio and Electronic Equipment (NIKIRET). NIKIRET is a branch of the Moscow-based Association Eleron, Minatom's leading designer of physical security equipment.

At present, "Start" manufactures detonation systems, permissive-action link (PAL) devices, and other electro-mechanical and electronic components and subassemblies of nuclear weapons. In addition, the facility produces physical protection equipment and automated instrumentation and control systems.[30]

In 1998, the Russian government resolved to phase out nuclear weapons activities in Zarechny (Penza-19) by 2003. (Although, the production of certain warhead components is likely to continue beyond 2003.) As of 1999, the military production in Zarechny (Penza-19) was minimal and the city was on the verge of becoming open.[31]

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[29] Podvig, *Russia's Strategic Nuclear Weapons*, p. 89.
[30] I. Ushakov, "The Pearl of the Defense Industry," *Sovershenno Otkryto*, No. 5, 1995, p. 4-17.
[31] L.Saratova "How do You Live, the Weapons Plant?" *Gorodskoy Kuryer*, No. 3, January 23, 1999.

The town of Zarechny (Penza-19) is located east of Penza. Its population is 64,000. Of them, approximately 10,000 work at the Start complex. Zarechny (Penza-19) occupies a crane-shaped restricted area (see Figure 7). The town of Zarechny and some technical and support areas are situated in the northern part of the restricted area. Approximately 2 kilometers to the south is a technical area with blast-resistant bermed buildings that are presumably associated with high-explosives operations. Zarechny (Penza-19) is located on the Kuybushev branch of the central railroad system and has a presumed helicopter pad south of the restricted area. Approximately 6 kilometers east of Zarechny (Penza-19) is the Leonidovka chemical-weapons storage site featuring rows of concrete igloos inside a walled out area. At present, the Leonidovka site houses approximately 17 percent of the Russian chemical weapons stockpile.

Trekhgorny (Zlatoust-36)

Zlatoust-36, currently Trekhgorny, was established as a site of the Device-Building Plant – a warhead assembly/disassembly facility. The town has a population of approximately 33,000. As of 1997, 6,400 worked at the warhead production facility.[32] The Device-Building plant assembles nuclear warheads from physics packages that are produced by other serial warhead assembly facilities. It is possible that the plant also manufactures depleted uranium components of nuclear warheads.[33]

The defense program employment is expected to decline to 2,800 by 2001.[34] To create jobs for excess workers, the facility is developing manufacturing capacities to produce instrumentation and control equipment for nuclear power plants, equipment for high-voltage electrical systems, and back-up power sources. Other defense conversion areas include re-conditioning of tram cars, production of polyethylene pipes, and a variety of consumer products.

Trekhgorny (Zlatoust-36) occupies an irregular diamond-shaped area (see Figure 8). The town of Trekhgorny is in the northern part of the diamond and is connected with the production complex by a bridge across Yuruzan' River. The production complex consists of three large technical areas. A number of smaller areas are probably associated with loading stations and other support operations. The high-explosive component area, located at the southern edge of the restricted area--identifiable by a group of bermed buildings--may also manage nuclear warheads and physics packages outside of storage and transportation containers. Approximately 8 kilometers east of Trekhgorny (Zlatoust-36) is a MOD-controlled national-level warhead storage facility, consisting of a residential area and two lines of bunkers. The production complex and the warhead storage facility are connected by a road.

HEU and Plutonium Production

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[32] "Plans of Trekhgorny," *Atompressa*, No. 13 (344), April 1999, p. 3.
[33] Podvig, *Russia's Strategic Nuclear Weapons*, p. 90.
[34] "Plans of Trekhgorny," *Atompressa*, No. 13 (344), April 1999, p. 3.

Ozersk (Chelyabinsk-65)

Chelyabinsk-65 (formerly Chelyabinsk-40), currently Ozersk, was established in 1948 to produce plutonium for nuclear weapons. The construction of the Combine 817, currently the Production Association Mayak, began in 1947.[35] The first production reactor (Reactor A) went into operation on June 19, 1948, and the first radiochemical plant (Plant B) began operating on December 22, 1948 and produced the first batch of plutonium on February 26, 1948. This plutonium was fabricated into nuclear device components at the plutonium finishing plant (Plant V). The Chelyabinsk-65 nuclear complex continued to expand throughout the next four decades and is currently one of the largest and most diverse nuclear facilities in Russia.[36]

Ozersk (Chelyabinsk-65) is located about 15 kilometers north-east of Kyshtym on the east side of the southern Urals in Chelyabinsk Oblast. It occupies an area of approximately 200 km^2 around Lake Kyzyltash, in the upper Techa river drainage basin among numerous other lakes with interconnecting watercourses. The industrial area bordering the southeastern shore of the Lake Kyzyltash, where the plutonium production complex is located, is approximately 90 km^2. The town of Ozersk is located 10 kilometers north-east of the plutonium production complex between the Lakes Kyzyltash and Irtyash (see Figure 9). The production complex comprises several other industrial areas related to fissile material storage and processing. Ozersk (Chelyabinsk-65) has a population of 88,000 of which approximately 12,000 work at the nuclear facility.

Plutonium production at Ozersk (Chelyabinsk-65) took place primarily in five uranium-fueled, graphite-moderated, water-cooled reactors (A, IR-AI, AV-1, AV-2, and AV-3) commissioned between 1948 and 1955 and shut down between 1987 and 1990. The production complex has also constructed and operated several of heavy water and light water-moderated reactors (OK-180, OK-190, OK-190M, Ruslan and Lyudmila) primarily to produce tritium and other isotopes for the nuclear weapons program and civilian applications. The reactor areas are located approximately 1 kilometer north of Lake Kyzyltash.

Table 3: Chelyabinsk-65 Production Reactors

Reactor	Year operational	Type	Purpose	Power, MW_t (initial/max)
A	June 19, 1948 to June 16, 1987	light water-cooled, graphite-moderated, once-through	plutonium production	100/530
IR-AI	Dec. 22, 1951 to May 24, 1987	light water-cooled, graphite-moderated, once-through	plutonium production	50/65
AV-1	July 15, 1950 to Aug. 12, 1989	light water-cooled, graphite-moderated,	plutonium production	300/~2000

[35] Kruglov, *How the Soviet Atomic Industry was Created*, p. 61.
[36] For a detailed description of the history and the status of the Mayak complex see: Cochran, et al., *Making the Russian Bomb*, pp. 71-136.

		once-through		
AV-2	April 6, 1951 to July 14, 1990	light water-cooled, graphite-moderated, once-through	plutonium production	300/~2000
AV-3	Sept. 15, 1952 to Nov. 1, 1990	light water-cooled, graphite-moderated, once-through	plutonium and tritium production	300/~2000
OK-180	Oct.17, 1951 to 1965	heavy water-moderated, light water-cooled, dual-loop	plutonium and tritium production	100/250
OK-190	Dec. 27, 1955 to Nov. 8, 1965	heavy water-moderated, light water-cooled, dual-loop	plutonium and tritium production	100?/?
OK-190M (in OK-180 space)	April ?, 1966 to 1986	heavy water-moderated, light water-cooled, dual-loop	plutonium and tritium production	?/?
Ruslan	June 16, 1979 to present	light water-moderated, light water-cooled, dual-loop	tritium, isotopes production	not available
Ludmila	1987 to present	heavy-water-moderated, light water-cooled, dual-loop	tritium, isotopes production	not available

In 1949, high-level radioactive wastes from the B plant were routed to a tank farm in Complex C (east of Plant B and within the plants isolated area), and low-level wastes were discharges into the Techa River, which originates from Lake Kyzyltash (reservoir 2, which was used as a source of cooling water for the plutonium production reactors). However, in 1950, in order to reduce the volume of material going into tanks in Complex C, a process for "decontamination" of high-level wastes was introduced, with a portion of the radioactivity directed to the tanks and a portion released to the river. In July 1951, it was discovered that this process did not work as intended, and that during this period high concentrations of radionuclides had been released to the river. Also during this time cooling water from the Complex C tanks was discharged into the Techa River at the same location as the technological wastes. Leaks in the tank-cooling lines caused some of these discharges to be highly contaminated. These "wild releases" were unmonitored and unnoticed until 1951.[37] From the start-up of Plant B in December 1998 through 1956, 78 million m^3 of radioactive waste containing 2.75 MCi of beta activity was discharged into the Techa River. Between 1951 and 1964 a cascade of four artificial reservoirs (3, 4, 10, 11) were created along the Techa, just below Lake Kyzyltash to retain radioactivity already discharged.

[37] Vorobiova, et al., "Review of Historical Monitoring Data on Techa River Contamination," *Health Physics*, **76**, June 1999, pp. 606-607.

Beginning on October 28, 1951, radioactive waste from the B Plant was diverted to nearby Lake Karachay. By 1990 the lake had accumulated 120 MCi of radionuclides, including 98 MCi of cesium-137 and 20 MCi of strontium-90.

On September 29, 1957, one of the tanks in Complex C exploded releasing some 20 megacuries (MCi) of radioactivity and causing a contamination of some 15,000-23,000 km^2 to 0.1 Ci/km^2 (strontium-90) or greater. (This fallout footprint has become known as the East Urals Radioactive Trace.)

The Plant B underwent through several modernization efforts and continued to work until the early 1960s. The reprocessing of irradiated fuel from the production reactors was continued at the Plant BB, located next to the Plant B. (The two plants subsequently have been combined into a single industrial area—Area 235.[38]) Construction of the Plant BB, which was to replace Plant B, started in 1954. The first production line of Plant BB was completed in 1959. Due to its high productivity it was decided that there was no need to use the second line for the production of plutonium. Instead the second line was adopted to extract isotopes from irradiated targets from the Chelyabinsk-65's isotope production reactors. In 1987, after two of the five production reactors were shutdown, Plant BB was shut down and the production of weapon-grade plutonium in Ozersk (Chelyabinsk-65) stopped. Between 1987 and 1990, irradiated fuel from the graphite reactors still in operation was presumably shipped for reprocessing to Tomsk-7.

The plutonium product of the radiochemical facilities was transferred to the chemical and metallurgical Plant V (Plant 20, or the Tatysh plant), which was built in 1948-49 to produce plutonium metal and to manufacture warhead components.[39] The second line of the Plant V was designed to manufacture HEU weapons components. The Tatysh complex is located approximately 20 kilometers south-west of the plutonium production complex. At present, the chemical and metallurgical plant continues to process fissile materials and to fabricate weapons components.

In 1997, the chemical and metallurgical plant became involved in the disposition of HEU from dismantled weapons under the U.S.-Russian HEU agreement. The facility produces purified HEU oxide, which is subsequently shipped to Seversk (Tomsk-7) or Zelenogorsk (Krasnoyarsk-45) for fluorination and downblending. The Chelyabinsk-65 facility is capable of processing approximately 15 t HEU per year.[40] In 1998, the plant also started melting plutonium pits from dismantled nuclear weapons and recasting them into 2-kg plutonium spheres for long-term storage.

Ozersk (Chelyabinsk-65) was selected as a storage site for fissile materials recovered from dismantled nuclear weapons. The storage facility, which is currently

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[38] Cochran, et al., *Making the Russian Bomb*, p. 83.

[39] Kruglov, *How the Soviet Atomic Industry was Created*, p. 125.

[40] "The Combine 'Mayak' Will Increase the Capacity to Process HEU to LEU," Minatom RF, Interfax "Novosti", June 13, 1997.

being constructed with U.S. assistance, is located between Lake Kyzyltash and Reservoir 10 on the south side of the river Techa and east of the plutonium production complex.[41] The first phase of the facility with a capacity of 25,000 containers is currently planned for operation in 2002.

Chelyabinsk-65 has also been producing tritium and other special isotopes. An industrial tritium separation and purification facility was established at the reactor plant in 1962. At present, tritium and other isotopes (plutonium-238, cobalt-60, carbon-14, irridium-192, and others) are produced by the light-water reactor "Ruslan" (start-up in 1979), and heavy-water reactor "Ludmila" (start-up in 1987).[42]

Tritium is transferred to the Mayak's tritium plant, producing tritium components of nuclear warheads. The isotopes are transferred to the radioisotope plant (in operation since 1962), which manufactures alpha-, gamma-, and beta radiation sources, plutonium-238 and strontsium-90 thermal generators, and a wide range of radionuclides.[43]

The RT-1 plant brought into operation in 1976 absorbed parts of the Plant B. At present, three production lines of the RT-1 plant reprocess spent low-enriched uranium (LEU) fuel from VVER-440 reactors as well as HEU fuel from BN-600, naval propulsion, research and material production reactors. In addition to reprocessing of spent fuel, the RT-1 plant is a storage site for approximately 30 t reactor-grade plutonium, and is involved in radioactive waste management (including high-level waste vitrification), and research and pilot production of uranium-plutonium MOX fuel.

In 1984, the Soviet Union began the construction of three BN-800 fast breeder reactors (located at the north-western edge of the reservoir 10) and an industrial-scale MOX fuel fabrication facility (Area 300). The construction of the partially-built facilities was stopped in 1989 because of the lack of funding and public opposition.

Chelyabinsk-65's primary facilities are supported by an extensive research and technological infrastructure, including the central plant laboratory, device-building plant, tool-building plant, machining and repair shop, and specialized construction unit.

In addition to nuclear technologies, Cheylabinsk-65 is manufacturing non-nuclear commercial products, including instrumentation and control equipment and general consumer goods.

Seversk (Tomsk-7)

Tomsk-7, currently Seversk, was established in 1949 to produce and process fissile materials for the nuclear weapons program. The Siberian Chemical Combine

[41] Cochran, et al., *Making the Russian Bomb*, p. 95.
[42] Kruglov, H*ow the Soviet Atomic Industry was Created*, p. 40.
[43] Prospectus, "*The Production Association Mayak: 45 Years*," June 12, 1993.

(originally the Combine 816) is Russia's largest plutonium production and fissile material management complex.[44]

Seversk (Tomsk-7) is located on the Tom' river in Tomsk oblast, about 12 kilometers northwest of the city of Tomsk. The Seversk (Tomsk-7) sanitary protection area is approximately 200 km^2. The industrial areas are located north-east of Seversk and include: the fuel complex and a fossil fuel plant, a uranium hexafluoride (UF_6) conversion and enrichment plants, two reactor areas, chemical and metallurgical plant, a reprocessing plant, waste injection wells (sites 18 and 18a), and support and storage areas (Figure 10).

Seversk has a population of 110,000 of which approximately 15,000 work at the nuclear complex.

The production of plutonium took place in the reactors I-1, EI-2, ADE-3, ADE-4, and ADE-5, which were brought into operation from 1955 to 1967. The reactors are located in two technical areas northeast of Seversk: Area 0-5 (I-1, EI-2, and ADE-3 reactors) and Area 0-45 (ADE-3 and ADE-4 reactors). The Area 0-5 reactors were shut down between August 1990 and August 1992. The ADE-4 and ADE-5 reactors are still in operation and produce heat and electricity for the nuclear complex, as well as provide heat to Seversk and the nearby oil and chemical complex.

Table 4: Tomsk-7 Production Reactors

Reactor	**Year operational**	**Type**	**Purpose**	**Power, MW_t**
I-1	1955-1990	water-graphite, once-through	plutonium	600/1,200
EI-2	1956-1990	water-graphite, closed-circuit	plutonium	600/1,200
ADE-3	1961-1992	water-graphite, closed-circuit	plutonium	1,600/1,900
ADE-4	1964 to present	water-graphite, closed-circuit	plutonium	1,600/1,900
ADE-5	1965 to present	water-graphite, closed-circuit	plutonium	1,600/1,900

Irradiated reactor fuel is reprocessed at the radiochemical plant (Plant B), which began operating on August 31, 1961. The radiochemical plant is located in the area 0-15. Liquid radioactive waste from the Plant is pumped via double-wall pipes to the waste injection well areas 18 and 18a located approximately 2 kilometers north-east of the reprocessing plant. Tomsk-7 also has a number of surface reservoirs intended for temporary storage, blending, and precipitation of liquid radioactive waste.

[44] For a discussion of the Tomsk-7 complex see, Cochran, et al., Mak*ng the Russian Bomb*, pp. 137-148.

Until recently, plutonium was transferred to the chemical and metallurgical plant (Plant M which began operating on July 16, 1961) located in the area 0-25, west of the ADE-4/5 reactor area, where it was converted to metal and fabricated into warhead components. Since October 1, 1994, newly produced plutonium is converted to plutonium dioxide and is placed in storage. The chemical and metallurgical plant also was designed to manufacture HEU warhead components. In 1994, the plant began to convert HEU weapons components into HEU oxide that is subsequently down-blended to low-enriched uranium reactor fuel under the U.S.-Russian HEU agreement. In 1996, an HEU fluorination and down-blending facility was brought into operation in Seversk (Tomsk-7) as well.[45] In 1999, the Tomsk-7 complex is projected to have a capacity to oxidize and fluorinate 30 tonnes HEU per year (t HEU/y) and to down-blend 8 t HEU/y.[46]

The Tomsk-7 enrichment plant was built and brought into operation in 1953 and was USSR's second enrichment facility. The enrichment complex is located north of Seversk in the area 0-1 and consists of several interconnected enrichment cascade halls. Cooling water is provided from the Tom' River via a system of channels.

The enrichment plant was designed to enrich uranium recovered from irradiated fuel of the plutonium production reactors. Currently the plant accounts for 14 percent of Russia's total enrichment capacity. It also is involved in HEU down-blending under the U.S.-Russian HEU agreement. In addition, Tomsk-7 operates one of Russia's two large conversion facilities producing UF_6, the feed material for enrichment facilities. (There was possibly no conversion plant at Tomsk-7 during the time of the Corona program.) The primary production activities are supported by numerous auxiliary facilities, including research and analytical laboratories, a design bureau, mechanical and instrumentation shops, and fossil fuel power plant.

Tomsk-7 managers believe that the facility will remain primarily a nuclear technology center with a focus on nuclear power production, management of excess fissile materials, and uranium enrichment and processing. Tomsk-7, however, is also pursuing non-nuclear commercial products such as high-energy magnets, ultra-dispersed powders, stable isotopes, and general consumer products.

Zheleznogorsk (Krasnoyarsk-26)

Krasnoyarsk-26, currently Zheleznogorsk, was established in 1950 to produce plutonium for weapons. The facility's original name was the Combine 815. Currently it is known as the Mining and Chemical Combine.[47]

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[45] Andrew Bieniawski and Vladislav Balamutov "HEU Purchase Agreement," *Journal of Nuclear Materials Management*, February 1997, pp. 7-8. See also, Valeriy Privalikhin, "Perekuyem mechi na orala," *Rossiyskaya Gazeta*, November 21, 1996, No. 223, p. 2.
[46] G. Khandorin "Conversion of the Siberian Chemical Combine has Occurred," *Atompressa*, No. 4 (335), February 1999, p. 1.
[47] Cochran, et al., *Making the Russian Bomb,* pp. 137-149-169.

Zheleznogorsk (Krasnoyarsk-26) is located on the Yenisei river approximately 50 kilometers northeast of Krasnoyarsk. The production facility is located approximately 10 kilometers north of the residential area (Figure 11). Facility workers are shuttled to work from the residential area by an electric train. Zheleznogorsk has a population of 100,000 of which some 8,000 work at the nuclear complex. Several thousand more are employed by the Production Association of Applied Mechanics, producing communication satellites.

The Zheleznogorsk (Krasnoyarsk-26) industrial production area (a fenced off area on the surface) is about 17 km^2. The sanitary-protection area is 131 km^2. The plutonium production complex comprises the reactor plant, the radiochemical plant, the reactor coolant preparation plant, the partially completed RT-2 radiochemical plant, and the engineering plant. A distinctive feature of the plutonium production complex in Zheleznogorsk (Krasnoyarsk-26) is that the reactor plant, radiochemical plant, laboratories, and storage facilities are located 200-250 meters underground, in a multi-level system of underground tunnels inside a mountain. To the north-west of the underground complex are underground reprocessing waste injection wells (the Northern test site).

The Krasnoyarsk-26 reactor plant began operating on August 25, 1958, and, by 1964, the plant consisted of three graphite reactors (AD, ADE-1, and ADE-2). The AD and ADE-1 reactors were shut down in 1992. The third reactor generates heat and electricity for the local populations and cannot be shutdown before a replacement source of power becomes available.

Table 5: Krasnoyarsk-26 Production Reactors

Reactor	**Year operational**	**Type**	**Purpose**	**Power, MW_t**
AD	1958-1992	water-graphite, once-through	plutonium	1,600/1,800
ADE-1	1961-1992	water-graphite, once-through	plutonium	1,600/1,800
ADE-2	1964 to present	water-graphite, closed-circuit	plutonium	1,600/1,800

In 1964, a reprocessing plant began operation at Zheleznogorsk (Krasnoyarsk-26). Between 1958 and 1964, the irradiated fuel was reprocessed by the radiochemical plants in Ozersk (Chelyabinsk-65) and/or Seversk (Tomsk-7). Plutonium dioxide—the final product of the Combine—was transferred to the chemical and metallurgical plants in Ozersk (Chelyabinsk-65) and/or Seversk (Tomsk-7) for conversion to metal and fabrication into nuclear weapon components. Since October 1994, separated plutonium is stored on-site as plutonium dioxide.

In 1972, the Soviet Union began construction of a complex to store and reprocess fuel from light-water power reactors. The construction of the fuel storage facilities, which are located between the old underground complex and the waste injection wells, was completed in 1976. The construction of the reprocessing plant started in 1984 but was halted in 1989 due to the lack of funding and public opposition. The RT-2 reprocessing plant will probably never be completed.

The facility and Minatom managers are currently considering the possibility of constructing in Zheleznogorsk (Krasnoyarsk-26) a long-term storage facility for spent fuel from foreign reactors. Krasnoyarsk-26's principal non-nuclear defense conversion project is a facility to produce electronic-grade silicon for Russian and international customers.

Novouralsk (Sverdlovsk-44)

Sverdlovsk-44, currently Novouralsk, was established in 1945 to produce highly-enriched uranium for the nuclear weapons program. The Urals Electrochemistry Combine (originally the Combine 813) is the oldest and largest uranium enrichment facility in Russia.

Novouralsk (Sverdlovsk-44) is located in the Sverdlovsk region, approximately 40 kilometers north-west of Yekaterinburg. Its population is 96,000. As of the early 1990s, approximately 15,000 (including support personnel and farmers) were employed at the enrichment complex.

The resolution to build an industrial gaseous diffusion plant to produce HEU for weapons was adopted by the USSR's Council of Ministers on December 1, 1945.[48] It was decided by the First Main Directorate (PGU), responsible for the Soviet nuclear program, to construct the plant in Verkh Neyvinsk. The location was selected because of a) the existence of a railway and power lines; b) the availability of two deep artificial lakes to cool the plant,[49] and, most importantly; c) the existence of a large, almost finished U-shaped building with the total floor space of 50,000 m^2, which was originally designed as an aviation plant (presumably Building 0, see Figure 12).[50]

The gaseous diffusion plant, designed by the GSPI-11 design bureau (currently VNIPIET) in St. Petersburg, received the designation D-1. The construction of the plant and a satellite town commenced in January 1946. The plan was to complete the first phase of D-1 in 1948 and to bring the plant to its design capacity in 1949.

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[48] For the early history of the Sverdlovsk-44 enrichment complex see Kruglov, *How the Soviet Atomic Industry was Created,* p. 379; and N. M. Sinev *Enriched Uranium for Atomic Weapons and Nuclear Power: On the History of the Soviet Industrial Technology and Infrastructure to Produce Highly-Enriched Uranium (1945-1952)* (Moscow: CNIIAtomInform, 1991), p. 139.

[49] The lakes, known as Demidov's Ponds, were created by constructing dams across the River Neiva in the 18th century by Demidov, a prominent entrepreneur from the Urals region, to support a small metallurgical plant.

[50] Combine 813 (also known as the State Verkh-Neivinsk Machine-Building Plant) was built on the basis of the Plant 261 of the People's Commissariat of Aviation Industries.

The first phase of the D-1 plant was commissioned in May-June 1948. In 1948-49, however, the facility experienced very significant difficulties due to malfunctioning of compressor unit electric motors and, more importantly, decomposition of uranium hexafluoride gas. The UF_6 losses were so great that even with an inefficient double use of the top enrichment cascade, the plant could produce uranium enriched only to 70 percent U-235. To increase the level of enrichment to 90 percent, the D-1 product was shipped to the electromagnetic enrichment facility (calutron) in Lesnoy (Sverdlovsk-45).

It was established that the principal causes of UF_6 decomposition were high surface temperature of equipment and elevated humidity. To resolve the problem, all enrichment equipment was installed inside an air-tight steel canyon; a dry-air shop was constructed to reduce humidity inside the canyon; and a liquid-nitrogen cooling station was built to maintain cooling water at 8-10^{o}C. The D-1 plant began to produce 90-percent HEU in 1950. The plant continued to work until 1955 when it was shut down because of low efficiency and as larger enrichment plants were brought into operation.

In January 1949, the USSR Council of Ministers issued a resolution to build a second gaseous diffusion plant at Novouralsk (Sverdlovsk-44), with the designation, D-3. The first phase was completed in 1951. The enrichment cascades were installed in a U-shaped building, which was built next to the D-1 plant (presumably, Building 1). Gaseous diffusion compressors were accommodated inside air-tight canyons; support equipment was installed in side-galleries; and sublimation and de-sublimation stations were located in separate buildings. The D-1 and D-3 plants were connected, with the D-3 plant serving as the top enrichment cascade. The integrated D-1/D-3 cascade included over 9,500 machines: 7,284 machines (organized in 61 stages) of the D-1 plant plus 2,242 machines of the D-3 plant. The production capacity was increased by more than a factor of six, approximately to 45,000 separative work units per year (SWU/y).

In 1950, the Soviet government resolved to build another enrichment plant, designated, D-4. The first phase was completed in December 1952 and the top cascade became operational ten months later in summer 1953. The D-4 plant was presumably located in Building 2.

While constructing the D-4 plant, a decision was made to build an even larger plant—D-5.[51] The D-5 building (presumably, Building 3) had a floor space of 130,000 square meters (m^2). By 1953, 15,000 machines were operating at Novouralsk (Sverdlovsk-44), consuming 250 megawatts-electric (MW_e). The enrichment complex employed 3,500 workers.

Novouralsk (Sverdlovsk-44) played a central role in the development and deployment of the Soviet centrifuge enrichment technology. A pilot centrifuge plant was commissioned in Sverdlovsk-44 on October 4, 1957. The industrial-scale centrifuge plant was built in three phases from 1962 to 1964. Presumably this industrial centrifuge

[51] The first phase (SU-3) of the D-5 plant was to produce medium-enriched uranium.

plant was housed in the 1,100-meter long Building 4. Prior to the termination of the production of HEU in 1988, Building 4 served as the top HEU production cascade of the Sverdlovsk-44 complex.[52] HEU production for weapons was halted in 1988.

In 1973, the installation of centrifuges began at the D-5 plant.[53] The transition process included the dismantlement of the gaseous diffusion cascades and the installation in the existing buildings of new centrifuge equipment. The last gaseous diffusion cascade was shut down in December 1987.

Since 1960, there have been two generations of centrifuges at the Sverdlovsk-44 complex. In the mid-1970s, the plant was equipped with centrifuges of the fourth generation. A transition to seventh-generation machines began in 1997. Currently, some of the HEU enrichment stages in Building 4 are being dismantled and replaced.[54]

Sverdlovsk-44 has a capacity of 10 million SWU/y, and accounts for approximately 50 percent of Russia's enrichment capacity. Uranium enrichment takes place in the Buildings (Modules) 1, 2, 3, and 4. Building 0 is no longer used for uranium enrichment.

The enrichment complex entered the Western enrichment market in 1973 and has been the Russia's primary producer of enrichment services for Western customers.[55] The plant operates cascades that are dedicated to enrich natural (as opposed to reprocessed) uranium and, thus, are not contaminated with reactor-generated isotopes of uranium. Also, the plant has an infrastructure (a toll-station, etc.) to handle 30B cylinders for enriched uranium product that are standard in the West. (The toll-station is reportedly in the Building 3.)

The Urals Electrochemical Combine is the only facility, which has Gosatomnadzor permission to enrich uranium to 30 percent U-235. (The other three plants are permitted to enrich uranium to only 5 percent.) As of the mid-1990s, however, no uranium for research reactors or other HEU users were produced in Novouralsk (Sverdlovsk-44).

The combine is involved in down-blending HEU from weapons under the U.S.-Russian HEU agreement. The plant produces 1.5-percent enriched blend-stock. The facility receives HEU as UF_6 from Seversk (Tomsk-7) and Zelenogorsk (Krasnoyarsk-45). Highly-enriched UF_6 is subsequently blended down by mixing it with the 1.5-percent

[52] The Building 4 facility, which is often toured by Western delegations, has 660,000 centrifuges with a combined capacity of 1 M SWU/y. Approximately 20,000 machines work in parallel at the feed point.

[53] "To the 50th Anniversary of the Urals Electrochemical Combine (Novouralsk)," *Atompressa*, No. 22 (353), July 1999, pp. 4-5.

[54] "Urals Plant Enriching Tails for both Minatom and Urenco," *Nuclear Fuel*, October 6, 1996, p. 3.

[55] As of 1997, the Sverdlovsk-44 plant had contracts with Nuclear Electric (UK), Enusa (Spain), an entity in Sweden, U.S. companies (six contracts total), and Siemens (Germany). In addition, the plant was enriching Urenco's tails to the level of natural uranium. ("Western Enrichment Contracts Strengthen," *Nuclear Engineering International*, November 1997, p. 4.

blend-stock in a Y-pipe device. Reportedly, the HEU down-blending facility is located in the upper corner of the Building 2.

In addition to uranium enrichment services, Sverdlovsk-44 produces instrumentation, compressors and power equipment, catalytic converters, electrical equipment, car batteries, and farm products. In the past, the plant was the primary producer of gaseous diffusion barriers for the Soviet enrichment complex.

Novouralsk (Sverdlovsk-44) has a gas-operated power plant supplying energy to both the production facilities and the city. The Beloyarsk Nuclear Power Plant (located near Yekaterinburg) is another major source of electricity for the production facilities.

Table 5: Sverdlovsk-44 Enrichment Buildings

Building/ Plant	Start-up/ shut down	Energy consumption, MW_e (gaseous diffusion period)	Floor space, m^2	Capacity. Comments
Module 0/ D-1	Initial operation in 1948; reached capacity in 1950;shut down in 1955	50	50,000	Designed capacity 7,500 SWU/y (100 g/day 90% HEU). The plant contained 7040 machines organized in 56 stages. The Building 0 is currently not used for uranium enrichment.
Building 1/ D-3	First phase in 1951.	75	40,000	The D-3 plant contained 2242 machines. The plant was connected (as a top cascade) to the D-1 plant. The cumulative capacity 45,000 SWU/y.
Building 2/ D-4	First phase in December 1952; full capacity in summer 1953	100	40,000	The building contains the HEU-down-blending facility.
Building 3/	First phase		130,000	The building contains a toll-

D-5	(medium-enriched uranium) in full capacity in 1953			station.
Building 4	1962-64		74,000	Presently, 1 million SWU/y. The plant was built as a centrifuge facility. It contained the top HEU cascade.

Zelenogorsk (Krasnoyarsk-45)

The closed city of Krasnoyarsk-45, currently Zelenogorsk, was established to produce enriched uranium for the Soviet nuclear weapons program. The decision to build an enrichment facility was made on December 14, 1955 and January 1956 is considered Zelenogorsk's official "birthday."

The construction of a gaseous diffusion plant probably began in December 1961 and the plant started to produce enriched uranium in October 1962. (In 1964, the U.S. intelligence community predicted that the plant would reach its design capacity in 1967.[56]) In parallel, the construction of a large fossil fuel and hydro-electric plant (GRES-2) began to provide the enrichment complex and the town with heat and electricity. The power plant has an installed capacity of 1,250 MW_e and is currently the second largest power plant in the region.

In the 1960s, the Soviet Union began replacing gaseous diffusion machines with centrifuges. The last gaseous diffusion cascade in Zelenogorsk (Krasnoyarsk-45) was shut down in 1990.

The HEU production at Zelenogorsk (Krasnoyarsk-45) was stopped in 1987. Currently, the Electrochemical Plant produces low-enriched uranium (up to 5 percent U-235) for nuclear power reactors and re-enriches depleted uranium tails from past production. The plant produced 40 percent of all the enriched uranium produced in the Soviet Union and currently accounts for 29 percent of Russia's enrichment capacity. In addition to uranium, the complex also separates isotopes of tungsten, molybdenum, krypton, xenon, germanium, iron, sulfur, oxygen, and carbon.[57]

Since 1997, the facility has been involved in down-blending HEU from dismantled weapons under the U.S.-Russian HEU agreement. The Electrochemical Plant receives HEU oxide powder from Ozersk (Chelyabinsk-65), converts it to UF_6 which is subsequently mixed in an Y-pipe device with 1.5-enriched uranium to produce 4.9-percent LEU hexafluoride for deliveries to the United States. Some of highly-enriched

[56] "The Soviet Atomic Energy Program," NIE-11-2-64, July 16, 1964, p. 21 (partially declassified June 26, 1997).
[57] G. Scorynin "EkhZ – City's Main Plant," *Sovershenno Otkryto,* No. 2, 1994, p. 10-12.

UF_6 is sent for down-blending to Novouralsk (Sverdlovsk-44). Presumably, the plant also produces 1.5-percent enriched feed material for down-blending.

In 1993-96, as a part of the defense conversion effort, Krasnoyarsk-45 began to manufacture audio and VCR tapes. Initially, the facility used BASF technology and equipment, which were provided by German utilities in exchange for uranium and enrichment services. According to a 1996 press conference statement by then Deputy Minister of Minatom Yuri Tychkov, the facility cost $215 million and produces 25 million audio and 30 million video cassettes, one third of which is for export.[58] In 1998, the plant installed more efficient video-tape production equipment from Otari, Japan.[59] Krasnoyarsk-45's Device-building Shop also manufactures TV sets and other consumer electronics.

Zelenogorsk (Krasnoyarsk-45) is located on the River Kan, approximately 70 km east of Krasnoyarsk. Zelenogorsk has a population of 67,000, of which an estimated 10,000 work at the enrichment complex. The production facility is located approximately 3.5 kilometers west of the township (Figure 13). The enrichment complex consists of four interconnected buildings that are approximately 1-km long. Cooling water for the enrichment cascades is pumped from (and is subsequently discharged into) the River Kan. Approximately 3 km north of the enrichment plant is the hydro- and fossil fuel power plant. South of Zelenogorsk is the Production Association "Sibvolokno", Russia's only facility that produces synthetic cotton.

Angarsk

The Angarsk Electrolyzing and Chemical Combine was established in the 1950s to produce enriched uranium for the Soviet nuclear program. The construction of the gaseous diffusion plant (Combine 820) in Angarsk began on March 10, 1954 and the facility attained its full capacity in 1964. At the time, the Angarsk complex was believed to be the most efficient of the existing Soviet enrichment facilities.

The enrichment plant in Angarsk has never produced HEU. Instead, its partially enriched uranium product was probably sent to other Soviet enrichment facilities to produce HEU. At present, the Combine accounts for 8 percent of Russia's enrichment capacity. The production of enriched uranium in Angarsk, however, has declined considerably in recent years.[60] In addition, the complex operates one of Russia's two large conversion facilities producing UF_6, the feed material for enrichment facilities.[61]

The facility is located in the open city of Angarsk, approximately 30 km north-west of Irkutsk and 50 km north of the western tip of Lake Baikal. The uranium enrichment complex is located north of the Angarsk residential area, approximately 7 km west of Angara river (Figure 14). Cooling water for the enrichment complex is diverted from and discharged to the river through a system of canals. Approximately 7 km

[58] Tychkov, Yuri; press conference, April 17, 1996. Federal Information System Corporation.
[59] "Another Line Brought On Line," *Atompressa*, No. 46-47 (330-331), December 1998, p. 7.
[60] "Entombment for Industrial Radioactive Waste to Be Built," Itar-Tass, June 21, 1999.
[61] Podvig, *Russia's Strategic Nuclear Weapons*, p. 84.

southeast of the enrichment complex is a fossil fuel plant, which presumably provides heat and electricity to the enrichment complex. Between the enrichment complex and the river is a large waste discharge area that probably serves both the enrichment facility and the power plant.

The enrichment complex consists of two production areas that are located within a common perimeter. The enrichment plant includes four 1 km long interconnected buildings. South of the enrichment plant is a presumed uranium conversion facility.

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