NWD 92-4

Russian/Soviet Nuclear Warhead Production

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June 12, 1992

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Table of Contents

Preface i
Early History 1
Atomic bomb developments 1
Thermonuclear weapons developments 6
Overview of the Nuclear Weapons Production Complex 8
Ministry of Atomic Energy 10
Nuclear Weapon Design Laboratories 12
All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16, the "Installation," or "Khariton's Institute") 13
All-Russian Scientific Research Institute of Technical Physics (Chelyabinsk-70) 15
Nuclear Warhead Production Facilities 17
Nuclear Weapon Materials Production 18
Plutonium and Tritium Production Sites 20
Mayak Chemical Combine (Chelyabinsk-65, formerly Chelyabinsk-40, "The Kyshtym Complex") 21
Graphite Reactors 24
A-Reactor 24
IR Reactor 25
AV-1 Reactor 25
AV-2 Reactor 25
AV-3 Reactor 26
Heavy Water Reactor 26
Chemical Separation Facilities 26
RT-1 Radiochemical Plant 28
MOX Fabrication Plant 29
South Urals Project (BN-800 LMFBRs) 29
Radiation Exposure to Workers 31
Waste Management Activities 32
Discharge of Waste into the Techa River 32
Lake Karachay (Reservoir 9) 35
Lake Staroe Boloto (Old Swamp) 38
Waste Explosion in 1957 38
High-Level Waste Tanks 44
Waste Vitrification 45
Solid Waste Burial 47
Contamination Today 47
The Siberian Chemical Combine (Tomsk-7, Seversk) 48
Siberian Atomic Power Station 49
Chemical Separation Plant 50
Plutonium Processing 50
Waste Management Activities 51

Uranium Enrichment Plant 52
Fissile Material Storage Facility 52
Mining and Chemical Combine (Krasnoyarsk-26, Zhelenogorsk, "Devatka," "Atomgrad," Dodonovo) 53
Graphite Reactors 55
RT-2 Spent Fuel Storage and Chemical Separation Plants . . . 56
Waste Management Activities 57
Military Conversion Activities 59
Plutonium and Tritium Production Estimates 59
Uranium Enrichment 62
Early History 62
Enrichment Plant Sites 64
Enrichment Technology and Production 64
Civil Reactor Fuel Cycle (the Back End) 66
Reprocessing 66
Mixed Oxide (MOX) Fuel Fabrication 67

Table 1. Principal Nuclear Weapon Research, Testing, and Production Facilities . . . 68
Table 2. Organizational Chart of the Ministry of Atomic Energy . . . 69
Table 3. Facilities at the Mayak Chemical Combine (Chelyabinsk-65) . . 72
Table 4. Occupational Radiation Exposures at Chelyabinsk-65 . . . 73
Table 5. Organ Dose Estimates (External and Internal) for Inhabitants of Some Villages along the Techa River . . . 74
Table 6. Radioactive Contamination in the Chelyabinsk-65 Reservoirs . . 75
Table 7. Characteristics of the Radioactivity Released in the 1957 Accident . . . 76
Table 8. Land Contaminated by the 1957 Accident at Chelyabinsk-65 . . 77
Table 9. Solid Waste Burial Sites at Chelyabinsk-65 . . . 77
Table 10. Estimated Plutonium-Equivalent Production by the Five Graphite Reactors at Chelyabinsk-65 . . . 78
Table 11. Estimated Plutonium-Equivalent Production by the Heavy Water Reactor at Chelyabinsk-65 . . . 79
Table 12. Estimated Plutonium-Equivalent Production by the Five Graphite Reactors at Tomsk-7 . . . 80
Table 13. Estimated Plutonium-Equivalent Production by the Three Graphite Reactors at Krasnoyarsk-26 . . . 81
Table 14. Estimated Tritium Production . . . 82

Figure 1. Reservoirs and Lakes at Chelyabinsk-65 (Satellite Photo) 83
Figure 2. Radioactivity Discharged into the Techa River, 1949-1956 88
Figure 3. Radioactive Fallout From the 1957 Accident at Chelyabinsk-65 89

Appendix 1. Glossary of Key Figures in the Soviet Nuclear Program . . . 90
Appendix 2. Flerov letter to Stalin, April 1942 . . . 105

Bibliography . . . 107
About the Authors . . . 113
The NRDC Nuclear Weapons Data Center . . . 115
Nuclear Weapons Data Center Publications . . . 116

Preface

Since the publication in 1989 of *Soviet Nuclear Weapons,* Volume IV of the *Nuclear Weapons Databook,* information from several sources has added significantly to our knowledge of Soviet nuclear weapons production. We thought it would be useful to assemble this information, which we have done here. This is the fourth revision of this Working Paper, first published in August 1990, which we will continue to update as new information becomes available. In this regard readers' additions and corrections are welcomed and appreciated.

The history of the U.S. Manhattan Project is extensively documented. A bibliography could run to thousands of entries. In contrast, the Soviet program to build the atomic bomb, and later the hydrogen bomb, remains largely shrouded in secrecy. In recent years some new information has come to light. Sakharov's *Memoirs,* for example, provides new details about some aspects of the atomic and hydrogen bomb programs, notably the names of many hitherto unknown participants (see Appendix 1). Nevertheless, a comprehensive official account is needed to fill in what former President Gorbachev called the Soviet Union's "blank pages of history."

Early History

Atomic bomb developments[1]

Following the discovery of nuclear fission by Otto Hahn and Fritz Strassman in Berlin in December 1938, Leningrad (since renamed St. Petersburg) became a leading center for nuclear fission research with Igor V. Kurchatov at the Leningrad Physico-Technical Institute (LFTI) a prime mover.[2] He coordinated the research not only at his own laboratory, but also of scientists working at the Radium Institute, directed by V.G. Khlopin from 1939, and the Institute of Chemical Physics, directed by Nikolai N. Semenov.[3] In early 1940, two of Kurchatov's junior colleagues, Georgiy N. Flerov and L.I. Rusinov, established that each fissioned nucleus of uranium emitted between two and four neutrons, thus indicating a chain reaction might be possible. Also in early 1940, two physicists at the Institute of Chemical Physics, Yakov B. Zeldovich and Yuliy B. Khariton, investigated the conditions under which a chain reaction would take place in uranium and concluded that an experimental attempt to achieve a chain reaction could now be undertaken. In the same year Flerov and K.A. Petrzhak, working under Kurchatov's close direction, discovered spontaneous fission of uranium. Inspired by these results, Kurchatov and his colleagues wrote to the Presidium of the Academy of Sciences, urging an expansion of work on nuclear fission. In June 1940, the Academy set up a Uranium Commission, with Khlopin as chairman, to direct research on the uranium problem. Research proceeded at a slow pace during the next year, and then was brought to a halt altogether after the German invasion on June 22, 1941.

In early 1942, the possibility of an atomic bomb became a serious issue for the Soviet leadership, as a result of information obtained about British, American and German work on the bomb.[4] In the university library at Voronezh in early 1942, Flerov noticed that articles on nuclear fission were no longer being published in the West, a sign to him that secret work was under

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[1] For a good overview of the early history of the Soviet nuclear weapon developments see David Holloway, *The Soviet Union and the Arms Race*, (New Haven: Yale University Press, 1983), Chapter 2.

[2] The LFTI was directed by Academician Abram Fedorovich Ioffe in the early 1930s. In late 1932, Ioffe organized at the institute an atomic nucleus laboratory under his direction. In 1934 LFTI had four laboratories working in nuclear physics, under the direction of Kurchatov, A.I. Alikhanov, L.A. Artsimovich, and D.V. Skobel'tsyn.

[3] Other institutions that were involved included the Kharkov and Tomsk physico-technical institutes, and the Leningrad Pedagogical Institute.

[4] Holloway, p. 17. By October 1941, Klaus Fuchs had begun to supply information to the Soviet Union; Leonid Shebarshin, Deputy Chairman of the USSR State Security Committee (KGB), interviewed by *Pravda*, as reported in *Tass*, April 22, 1990. See also, Robert Chadwell Williams, *Klaus Fuchs, Atom Spy*, (Cambridge, MA: Harvard University Press, 1987), pp. 60-61.

way on an atomic bomb. In May, Flerov wrote to S.V. Kaftanov, who was responsible for science in the State Committee of Defense (GKO), and to Stalin that "we must build the uranium bomb without delay."[5] In November 1942, Stalin summoned four leading academicians: A.F. Ioffe, Pyotr L. Kapitsa, Khlopin and V.I. Vernadsky to the Kremlin and asked about the possibility of developing an atomic bomb in a relatively short time frame.[6] The scientists unanimously confirmed the possibility.[7] While worried about the high cost of development, Stalin nonetheless initiated a small-scale project and asked for a suitable leader for the project: preferably not too prominent nor too young.[8] Stalin decided that a younger man would be preferable, for whom the project would become 'the main cause of his life.' Ioffe suggested Kurchatov and A.I. Alikhanov.[9]

Kurchatov was selected by Stalin in late 1942 with the State Defense Committee confirming the appointment in March 1943, when it announced Kurchatov's appointment as director of Laboratory No. 2 in Moscow.[10] This laboratory was the Soviet equivalent to Los Alamos. By 1947, Laboratory No. 2 had been renamed "Laboratory for Measuring Instruments" (LIPAN).[11] Subsequently it was renamed I.V. Kurchatov Institute of Atomic Energy (*Institut atomnoy energii imeni I. V. Kurchatov*, or IAE) and it goes by that name today.

On the Politbureau level, Vyacheslav Molotov, then Foreign Minister, was charged with overseeing the bomb program.[12] The selection of Molotov for the supervisory role is unexplained, although he had other defense industry connections such as supervising the critical tank production program in his role as senior member of the State Defense Committee (GKO).[13] At its inception during the war, work on the bomb was under the direction of the secret police, then the People's Commissariat for State Security or NKGB (Narodnyy Komissariat Gosudarstvennoy Bezopasnosti), headed by Lavrenti

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[5] The letter was first published in the *Moscow News*, No. 16, 1988, and is reproduced in Appendix 2.

[6] "Atomic Energy - The Bomb," *USSR Technology Update*, April 19, 1990, p. 1.

[7] Ibid.

[8] Ibid.

[9] Steven J. Zaloga, "The Soviet Nuclear Bomb Programme -- The First Decade," *Jane's Soviet Intelligence Review*, April 1991, p. 175.

[10] "Atomic Energy - The Bomb," *USSR Technology Update*, April 19, 1990, p. 1. See also, Andrei Sakharov, *Memoirs*, (New York: Alfred A. Knopf; 1990), p. 159.

[11] Sakharov, *Memoirs*, p. 93.

[12] "Atomic Energy - The Bomb," *USSR Technology Update*, April 19, 1990, p. 1.

[13] Zaloga, "The Soviet Nuclear Bomb Programme, p. 175.

P. Beria, who was, in effect, the second most powerful man in the Soviet Union. Sakharov tells us that at the beginning of 1943, on orders from Beria, Nikolai Pavlov was appointed representative of the Central Committee and Council of Ministers at Laboratory No. 2 in Moscow. Pavlov was to become an important official of the First Main Directorate (renamed in 1953 the Ministry of Medium Machine Building),[14] who rose rapidly through the ranks to become an exceptional administrator.

Kurchatov at the time of Stalin's appointment was not even a full member of the Academy of Sciences, which reduced his influence among the more senior physicists.[15] Kurchatov drew up a plan of research with three main goals: to achieve a chain reaction in an experimental reactor using natural uranium; to develop methods of isotope separation; and to study the design of both U-235 and plutonium bombs. According to Khariton, Kurchatov "suggested to me that I should attend directly to the development of nuclear weapons because he knew that I had been involved to some extent with weapons development and that I was very excited by these questions."[16] Kurchatov, assisted by Fursov, undertook development of an atomic pile using graphite as the moderator. A.I. Alikhanov developed a pile using heavy water as the moderator. Isotope separation technologies were divided into three sections: thermal diffusion (under A.P. Aleksandrov); gaseous diffusion (under I.K. Kikoin); and electromagnetic separation (under L.A. Artsimovich).[17] The Soviet bomb program was small during the war. Fifty scientists were working in Kurchatov's new laboratory by the end of 1943, a figure which doubled by the end of 1944. Key administrators of the program included: Boris L. Vannikov, the chairman of the Scientific and Technical Council for the Uranium Project under the USSR Council of People's Commissars and Mikhail G. Pervukin.

Small scale mining operations for uranium at old radium mines in the Fergan valley area near Leninabad, Tadzhik SSR, were initiated by the NKVD's Ninth Directorate, and given the codename 'Combine 6.'[18] In late 1944, Kurchatov wrote to Beria, head of the NKVD, complaining of the incompetence of Molotov and the desperate need for uranium. Kurchatov

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[14] The Ministry of Medium Machine Building was renamed in mid-1989, the Ministry of Atomic Power and Industry and on January 29, 1992, became the Russian Ministry of Atomic Energy. The current Minister of Atomic energy is Victor N. Mikhailov.

[15] Steven J. Zaloga, "The Soviet Nuclear Bomb Programme – The First Decade," *Jane's Soviet Intelligence Review*, April 1991, p. 175.

[16] Moscow Teleradiokompaniya Ostankino Television First Program Network in Russian, April 23, 1992, 2000 GMT.

[17] Ibid.

[18] Ibid, p. 175.

noted that after over a year, the surveys of the Leninbad deposits had not even been completed.[19] By the spring of 1945, Beria managed to usurp control of the program from Molotov and became the central administrator for the bomb program. Beria likewise succeeded in taking over many other high technology programs, including the ballistic missile effort.[20]

Beria's role in the program was critical. Due to his control over the GULAG, Beria was able to provide unlimited amounts of prison labor for large scale construction of the reactors. Beginning in 1945, the NKVD's Ninth Directorate, in support of the Ministry of Nonferrous Metallurgy, began an extensive survey program to discover additional uranium sources in the USSR.[21]

Beria also controlled the overseas espionage network, which by 1945 had several critical assets related to nuclear weapons. The most famous of these were Klaus Fuchs, Julius Rosenberg, and Donald Maclean.[22] The role of atomic espionage will no doubt need reevaluation in light of the things we are likely to learn when the former Soviet archives are opened.

The defeat of Nazi Germany opened the opportunity to recruit German nuclear scientists. In May 1945 Manfred von Ardenne was persuaded to visit the USSR to discuss his role in the program. Von Ardenne was absorbed into the 'first circle' of the GULAG and placed in charge of a team of conscripted German scientists working on the isotope separation problem at prison lab Sukhumi on the Black Sea.[23] He was later joined by other German engineers, including Dr. M. Steenbeck, who was primarily involved in gas centrifuge techniques.[24]

By the time of the Potsdam Conference, which began the day after the "Trinity" test, on July 17, 1945, the Soviet Union had a serious, albeit small (especially compared to the burgeoning Soviet missile program), atomic bomb project underway. On July 24, President Truman casually mentioned to Stalin after one conference session that the U.S. had a "new weapon of unusual destructive force." Stalin told Truman he hoped the U.S. would make "good

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[19] Ibid.

[20] Ibid., p. 175.

[21] Ibid. GULAG is the acronym for the Chief Administration of Corrective Labor Camps.

[22] Williams, *Klaus Fuchs, Atom Spy*; Ronald Radosh and Joyce Milton *The Rosenberg File: A Search for the Truth* (New York: Vintage Books; 1984); Verne W. Newton *The Cambridge Spies: The Untold Story of Maclean Philby*; and *Burgess in America* (Lauham, MD: Madison Books, 1984), esp. pp. 145-185.

[23] Mark Walker, *German National Socialism and the Quest for Nuclear Power 1939-1949* (Cambridge: Cambridge University Press, 1990), pp. 183-184. Others who were "invited" or volunteered to go were Werner Czulius, Nikolaus Riehl, Günther Wirths, Karl Zimmer, Robert Döpel, Gustar Hertz, Heinz Pose and Peter Thiessen.

[24] Ibid.

use of it against the Japanese." He also told Kurchatov to speed up his work.

The Kurchatov team at Laboratory No. 2 in Moscow learned of the successful test of the first American A-Bomb in the summer of 1945, but this development alone did not push the program into full gear since the full implications of the successful test may not have been comprehended by the upper leadership of the Soviet Union, Beria and Stalin in particular. This all changed in August 1945 when the United States employed the first two atomic bombs against Hiroshima and Nagasaki, Japan. On August 7, 1945, Stalin put his secret police chief, Beria in charge of a Soviet version of the Manhattan Project. In the middle of August, Stalin summoned B.L. Vannikov, the People's Commissar of Munitions, and his deputies to the Kremlin. There they were met by Kurchatov. 'A single demand of you, comrades,' said Stalin. 'Provide us with atomic weapons in the shortest possible time. ...' Administration of the program was undertaken by the new First Chief Administration of the USSR Council of Ministers (PGU-SM), headed by Vannikov. Overall control of the nuclear program at the Politbureau level remained in the hands of Beria, attesting to the importance Stalin then attached to this effort. The First Main Directorate reporting directly to the Politbureau was created.[25] Within the secret police, Beria had previously created the Ninth Directorate to oversee the atomic project. Beria maintained control of the bomb program through the Special Committee (Spetskom) which he headed. Beria's main aide in supervising the program was Colonel General Avraami Zavenyagin, whose official title was chief representative of the USSR Council of Ministers. Zavenyagin was a metallurgist by training, and his role in the Soviet programme was in some respects similar to that of General Groves in the American Manhattan Project.

Ye.P. Slavskiy, who later was to head the Soviet nuclear program almost continuously from 1957 to 1986, was brought in to supervise the production of very pure graphite needed for Kurchatov's nuclear pile experiments. Slavskiy had been a classmate of Zavenyagin in the mining academy and at the time he was deputy chief of the Aluminum, Magnesium and Electronics Industry. Slavskiy eventually was placed in charge of metallurgical extraction and processing aspects of the early bomb program.

By the end of 1946, work on the graphite moderated pile, dubbed 'the boiler' and designated F-1, was nearing completion at Laboratory No. 2 in Moscow under Kurchatov's and Fursov's direction. The pile was first put into operation on 25 December 1946.

In July 1948, Lt. Gen. Nikolai L. Dukhov of the Army Engineers was drafted into the bomb program and became the right-hand man, on the

[25] "Atomic Energy - The Bomb," *USSR Technology Update*, April 19, 1990, pp. 1-2.

engineering side, of Kurchatov.[26]

Thermonuclear weapons developments

The initiative to create a Soviet hydrogen bomb project appeared in 1946 in a special report to the government by Isai I. Gurevich, Yakov B. Zeldovich, Isaak Y. Pomeranchuk, and Yuliy B. Khariton.[27]

Toward the end of June 1948, the Council of Ministers and the Party Central Committee created a special research group at the P.N. Lebedev Physics Institute of the Academy of Sciences (FIAN) under the direction of Igor E. Tamm.[28] Tamm's group included Andrei Sakharov (who had been a graduate student at FIAN under Tamm, receiving his degree in 1947), Semyon Belenky, Vitaly Ginzburg, and Yuri Romanov.[29] The group's task was to investigate the possibility of building a hydrogen bomb, and specifically, to verify and refine the calculations of Yakov Zeldovich's theoretical group at the Institute of Chemical Physics.[30] Sakharov was a member of Tamm's group at FIAN until he was assigned to the "Installation" in March 1950, where he was employed until his clearance was revoked in July 1968.[31]

Soviet progress on the hydrogen bomb closely parallels developments in the United States. It was clear that to support a thermonuclear reaction one needed a temperature of several tens of millions of degrees. The initial Soviet concept, being pursued by Zeldovich's group, was to install a layer of liquid deuterium in an ordinary atomic bomb between the fissile material (the hollow sphere made of uranium-235 or plutonium-239) and the surrounding chemical high explosive.[32] It was noted, however, that the lack of heat and compression of the deuterium resulted in practically no thermonuclear reaction in the deuterium.[33] To increase the reaction rate, two improvements in the design

[26] Gen. Dukhov's previous claim to fame was as the designer of the Stalin tank. After the first thermonuclear test, Dukhov moved in early 1954 into the ICBM program where he headed a design bureau. He was a three-time recipient of the title Hero of Socialist Labor—in 1945, for his tank work, in 1949, for the atomic bomb, and in 1954 for the hydrogen bomb; *New York Times,* November 11, 1984.

[27] A. Romanov, "Father of the Soviet Hydrogen Bomb," *Priroda*, August 1990, p. 20.

[28] Sahkarov, *Memoirs,* p. 94; Romanov, "Father of the Soviet Hydrogen Bomb," p. 20.

[29] Sakharov, *Memoirs*, pp. 94-96.

[30] Ibid., p. 94.

[31] Ibid., p. 101.

[32] Ritus, "If Not Me Then Who?," p. 12, Romanov, "Father of the Soviet Hydrogen Bomb," p. 20.

[33] Ibid. The energy released by the atomic bomb is partitioned among the thermal energy of the electrons, the thermal energy of the nuclei, and the energy in the radiation field, i.e., the energy of the photons. In (continued...)

were proposed in 1948, one by Sakharov and the second by Vitaly Ginzburg.[34] Sakharov, in August or September 1948, proposed to increase the reaction rate of deuterium by surrounding it with a shell of natural uranium, effectively increasing the deuterium concentration at the deuterium-uranium boundary.[35] The deuterium shell also added to the yield of the device as a result of fast fission of the uranium-238 following capture of neutrons escaping from the thermonuclear burn - the so-called fission-fusion-fission design principle. Sakharov's variant has also been described as a heterogeneous construction made of alternating layers of thermonuclear fuel, e.g., deuterium, tritium, or their chemical compounds, and a heavy substance, e.g., uranium-238.[36] Sakharov called it "sloyka," ("layer cake").[37] His colleagues referred to Sakharov's approach as "sugarization" (in English Sakharov means "of sugar").[38]

It also was recognized early on that the situation would be much improved if tritium were substituted for some of the deuterium, since the cross section for the DT reaction is about 100 times the DD cross section at the same temperature.[39] Because tritium is not found in nature in any abundance, it must be produced in reactors by irradiating lithium-6 with neutrons, in the reaction

$$^{6}Li + n \rightarrow {}^{4}He + T + 4.8\ MeV,$$

a process that is expensive. Moreover, tritium is radioactive, decaying with a 12.3 year half-life, and thus, it must be replenished on a regular basis. Soon after Sakharov proposed his "First Idea," Ginzburg proposed substituting lithium-6 for some of the deuterium, as a means of generating tritium in the weapon itself.[40] Ultimately, perhaps by Ginzburg's suggestion, the lithium-6

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[33](...continued)
this simple design too much of the energy is lost to the radiation field and the electrons; and the heavier deuterium nuclei fail to heat up to the desired temperature.

[34] "If Not Me Then Who?," pp. 12-13. See also, Sakharov, *Memoirs*, p. 102, where Sakharov refers to these as the "First Idea" and the "Second Idea."

[35] Ritus, "If Not Me Then Who?," p. 12; Sakharov, *Memoirs*, p. 102.

[36] Romanov, "Father of the Soviet Hydrogen Bomb," p. 21.

[37] Ibid.

[38] Ibid.

[39] Ibid., p. 20.

[40] Ritus, "If Not Me Then Who?," p. 13.

was incorporated in the weapons as a chemical compound lithium deuteride (^6LiD).

These two ideas, ^6LiD and "sugarization," were incorporated into the first Soviet thermonuclear test on August 12, 1953.[41] Identified as "Joe 4" by the U.S., this test was a single-stage boosted fission weapon with a yield in the 200-300 kiloton range.

Sakharov, Zeldovich, and Khariton are generally credited as the three principal developers of the Soviet hydrogen bomb. The idea of using radiation implosion to compress and ignite a physically separate thermonuclear secondary (in the U.S. program this invention is attributed to Edward Teller and Stanislaw Ulam in the spring of 1951) was developed by Sakharov ("one of the chief authors"[42]) and several of his colleagues in the two theoretical departments (Zeldovich's and Sakharov's) at the Installation. In his *Memoirs*, Sakharov refers to it as the "Third Idea," and claims that Zeldovich, Yuri Alekseyevich Trutnev and others undoubtedly made significant contributions.[43] Something like the Third Idea had been the subject of earlier speculation, but this two stage approach became a serious research option in 1954.[44] The first Soviet test of a device of this type occurred on November 22, 1955.

Overview of the Nuclear Weapons Production Complex

The Soviet Union since 1949, has produced an estimated 55,000 nuclear warheads, of which just over 30,000 are still in the active stockpile or in storage awaiting disassembly. Since the nuclear warhead production complex and most of the arsenal were concentrated in Russia, upon the breakup of the Soviet Union in late-1991, the nuclear weapons production program was taken over by Russia, and the arsenal is in the process of being consolidated there. The research, development, and production of nuclear weapons in Russia is now administered by the Russian Ministry of Atomic Energy (MAE), headquartered in Moscow. MAE was created out of the Soviet Ministry of Atomic Power and Industry (MAPI) in 1992. Prior to 1989, MAPI was called the Ministry of Medium Machine Building.

The design, testing, and production of nuclear warheads and the production of fissile material for warheads takes place at 13 principal facilities located at 12 sites, now all in Russia (see Table 1). There are two nuclear weapons design laboratories; one remaining nuclear weapons test site; two

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[41] Ibid.

[42] Sakharov, *Memoirs*, p. 102.

[43] Ibid., p. 182.

[44] Ibid.

warhead assembly plants, one of which is also manufactures electronic components; a ballistic missile reentry vehicle assembly plant; three plutonium (and tritium) production sites, one of which is collocated with one of the enrichment plant sites; and four uranium enrichment sites, one of which is collocated with one of the plutonium production sites. Consistent with the traditional Soviet secrecy practices, ten of these sites (and the closed cities that support them) are not found on any maps.[45] In addition to their primary names, these closed sites are code-named after cities 50 to 100 kilometers (km) away followed by a postal zone number (e.g., Arzamas-16). Their precise locations are not always known. Beginning in 1989, several sites have been opened to limited visits by foreigners, but others sites still have not been declassified as to their specific missions and locations. Each is guarded by a special regiment of the Ministry of Internal Affairs.

The two weapon design laboratories are the All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16) at Sarova; and the All-Russian Scientific Research Institute of Technical Physics (Chelyabinsk-70) in the Urals region. The only operational nuclear weapons test site, recently named the Central Test Site, is at Novaya Zemlya (there are two test areas, northern and southern, on these two islands north of the Arctic Circle). A second, and what use to be the primary Soviet nuclear weapons test site, was near Semipalatinsk in Kazakhstan. It was closed permanently by order of the Kazakh President Nursultan Nazarbayev in August 1991, when Kazakhstan became independent after the failed coup. One of the two principal nuclear warhead assembly (and disassembly) plants is Sverdlovsk-45 (with its closed city called Rusnoy) at Nizhnyaya Tura in the Urals. The second is either Penza-19 (with its closed city Zarchinuy), near Penza, which is south of Arzamas-16 and southeast of Moscow, or Zlatoust-36 (with its closed city

[45] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, November 17, 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, November 21, 1991, p. 3.) published, from what was said to be a classified Russian document, the following list of 10 closed cities (all in Russia) where nuclear weapons research and manufacture takes place (the city's code-name with postal zone number, and population are contained within parentheses):

1. Kremlev (Arzamas-16, 80,300)
2. Snezhinsk (Chelyabinsk-70, 46,300)
3. Ozhorsk (Chelyabinsk-65, 83,500)
4. Seversk (Tomsk-7, 107,700)
5. Zhelenogorsk (Krasnoyarsk-26, 90,300)
6. Zelnogorsk (Krasnoyarsk-45, 63,300)
7. Novouralsk (Sverdlovsk-44, 88,500)
8. Rusnoy (Sverdlovsk-45, 54,700)
9. Zarchinuy (Penza-19, 61,400)
10. Torifugornuy (Zlatoust-36, 29,800)

From what we know from other sources about most of these cities, the list appears to be authentic. Due to the usual transliteration problems of 'r' and 'l' out of Japanese the *FBIS* translation misspelled Kremlev as "Kremryuv,"Snezhinsk as "Sunezhinsk," and presumably misspells Zhelenogrosk as "Zherzunogorsk and Zelnogorsk as "Zernogorsk," and misidentified Sverdlovsk-44 (population 88,500), as "Sverdlovsk-45 (population 63,300)."

Torifugornuy), near Zlatoust, in the Urals west of Chelyabinsk.[46] Penza-19 is the site of an electronics plant, probably similar to the Kansas City Plant in the United States. Assembly of ballistic missile reentry vehicles takes place at Zlatoust-36. This may be at or near the Zlatoust Machine Building Plant where submarine-launched ballistic missiles are assembled. The three plutonium (and tritium) production sites are Mayak Chemical Combine (Chelyabinsk-65; formerly Chelyabinsk-40)) near Kyshtym in the Urals, the Siberian Chemical Combine (Tomsk-7) in Siberia, and the Mining and Chemical Combine (Krasnyarsk-26) near Dodonovo in Siberia.[47] Plutonium and tritium production at Chelyabinsk-65 has now ceased. The four operating uranium enrichment plants are the Urals' Electromechanical Plant[48] at Sverdlovsk-44 (with its closed city called Novouralsk) near Verkh-Neyvinsk (formerly Kefirstadt), near Yekaterinburg (which was called Sverdlovsk before the breakup of the Soviet Union); the Siberian Chemical Combine (collocated with the production reactors) at Tomsk-7; the Electrochemistry Plant (Krasnoyarsk-45) between Krasnoyarsk and Kansk; and the Electrolyzing Chemical Combine at Angarsk near Lake Baikal.

Prior to the breakup of the Soviet Union there were thought to be some 29 nuclear weapons production/storage sites in the Soviet Union. The locations of most of these is are not publicly known.

The CIA estimates that some 900,000 people in the former Soviet Union have clearances to work with nuclear weapons in one way or another, including both military personnel responsible for nuclear operations and the employees of the nuclear weapons complex. Of these, an estimated 2000 reportedly have detailed knowledge of weapons design, and 3000 to 5000 more have worked in uranium enrichment or plutonium production.[49]

Ministry of Atomic Energy

The Russian Ministry of Atomic Energy (MAE) (in Russian, Minatom), whose counterpart in the United States is the Department of Energy

[46] V. Filin, "Nuclear Bomb Assembly Technology. Yardman Minayev Speaks," *Moscow Komsomolskaya Pravda*, February 6, 1992, p. 2 (translated in *Foreign Broadcast Information Service-SOV-92-026*, February 7, 1992, p. 3.). Experimental and prototype warheads are fabricated at the two design laboratories, Arzamas-16 and Chelyabinsk-70.

[47] There is no tritium production at Krasnoyarsk-26.

[48] It has also been referred to as the Urals' Electrochemistry Combine.

[49] Elaine Sciolino, "U.S. Report Warns of Risk in Spread of Nuclear Skills," *The New York Times*, January 1, 1992.

(DOE),[50] is responsible for the research, development, testing and production of nuclear warheads. Once produced, the warheads are delivered by MAE to the Main Administration for Nuclear Weapons (the Twelfth Main Administration or Directorate) of the Ministry of Defense. By decree of President Yeltsin on January 29, 1992, the Russian MAE was created out of what had previously been the Soviet Ministry of Atomic Power and Industry (MAPI) (in Russian, abbreviated "Minatomenergoprom"), assuming its functions and acquiring its assets in Russia. Three years earlier, in mid-1989, MAPI had been created out of, and assumed most of the duties of, the Ministry of Medium Machine Building (MMMB) (in Russian, Obshchesoyuznoye ministerstvo srednego mashinostroyeniya, abbreviated "Minsredmash"). MAE, as did its predecessors MAPI and MMMB, supervises the entire chain of production for nuclear weapons, from the mining of uranium ore through the fabrication of warheads, and is responsible for the production of all nuclear materials, uranium enrichment, production reactors, nuclear waste management, and warhead research, development, testing and production. Analogous to the U.S. DOE, MAE is also responsible for research and production of civilian nuclear power technology and utilities, high-energy physics, lasers, and other civil programs including the production of dairy equipment.[51]

The governmental organizations and the personnel involved the bomb program during World War II, and through the late 1940s until 1953, is very sketchy. A special "semi-ministry" called the First Main Directorate administered the bomb program from 1945 until 1953 under the direction of secret police chief Lavrenti P. Beria. In 1953 the MMMB was created. The principal administrators of the nuclear weapons program after the creation of the MMMB (after Beria) were:

Malyshev, V.A. - Minister, MMMB, June 1953-1955.
Zavenyagin, A.P. - Minister, MMMB, 1955-December 31, 1956.
Vannikov, B.L. - Minister, MMMB, January-May, 1957.
Pervukhin, M.G. - Minister, MMMB, May-July 1957.

[50] Three agencies have previously overseen these activities: from June 1942 to December 31, 1946 the Manhattan Engineer District (MED) or "Manhattan Project," from January 1, 1947 to 1974 the Atomic Energy Commission (AEC), and from 1975 to 1977, the Energy Research and Development Administration (ERDA). The Department of Energy formally came into existence on October 1, 1977.

[51] Prior to the Chernobyl disaster in April 1986, the Ministry of Medium Machine Building was responsible for design and construction of nuclear power plants, while the operation of these plants was the responsibility of the Soviet Ministry of Power Industry and Electrification. These two ministries were subordinate to different structures within the Council of Ministries of the USSR. The State Committee for Hydrometeorology and Environmental Control, responsible for Radiation Monitoring, and the State Nuclear Inspection of the USSR, responsible for nuclear safety, also acted in parallel. After Chernobyl the Ministry of Nuclear Power Industry was formed. Subsequently the Ministry of Nuclear Power Industry was dissolved and its functions reassigned to the Ministry of Medium Machine Building, which then became the Ministry of Atomic Power and Industry, and now the Russian Ministry of Atomic Energy.

Slavshy, Ye.P.	-	Minister, MMMB, 1957-1963.
	-	Chairman, State Production Committee for MMMB, 1963-1965.
	-	Minister, MMMB, 1965-1986.
Ryabev, L.D.	-	Minister, MMMB, 1986-1989.
Konovalov, V.F.	-	Minister, MAPI, from its creation in 1989, until he resign following the coup in August 1991.
Nikipelov, B.V.	-	acting Minister MPTI/MAE, September 1991-March 1992.
Mikhailov, V.N.	-	Minister, MAE, March 1992-present

The organizational chart of MAE, modified from a mid-1990 chart of MAPI, is given in Table 2. Victor N. Mikhailov was appointed the first minister of Atomic Energy in early-March, 1992, shortly after MAE was formed. Under Mikhailov, Vitaliy F. Konovalov (the former minister) is the first deputy minister and there are seven deputies.[52] Reporting directly to Mikhailov are two department heads responsible for nuclear weapons related activities: Boris V. Gorbets is responsible for nuclear weapons production; and Georgi P. Tsyrkov is responsible for nuclear weapons research and development (the nuclear weapons labs and the test site).

Nuclear Warhead Design Laboratories

As noted above, the principal center for atomic bomb research from 1943 to 1946 was Laboratory No. 2 (renamed LIPAN, then Kurchatov Institute of Atomic Energy), in Moscow.[53] Here the first Soviet nuclear reactor, called F-1 ("Physics-1"), was constructed and began operating on December 25, 1946.[54] Beginning in 1946 design work on the atomic bomb shifted to KB-11, now called the All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16, discussed below). The F-1 reactor and the cyclotron at Laboratory No. 2 continued to be used for physics experiments related to fission and fusion weapons research. Since the early 1960s, research at the Kurchatov Institute has been devoted primarily to civilian nuclear power

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[52] In mid-1990, when Konovalov was minister, the first deputy for nuclear materials and warhead production was Boris V. Nikipelov, who is now an advisor to Mikhailov on fuel cycle and nuclear waste issues; and First Deputy Minister Victor A. Siderenko was responsible for civil nuclear activities, including the development of nuclear power plants. Under Nikipelov, Mikhailov (now the minister) was the deputy minister responsible for the Department of Defense Industry which covers nuclear warhead research (the design laboratories), testing, and production. In November 1991, Sidorenko was identified as a corresponding member of the Soviet Academy of Sciences and Deputy Chairman of the State Nuclear Inspection.

[53] There was no Laboratory No. 1.

[54] Construction of F-1 was completed by Boris Kurchatov, Igor's brother. As a prototype it produced microgram quantities of plutonium. Before it began operation, construction of the Chelyabinsk-40 complex, the site of the first Soviet production reactors had begun; "A.P. Aleksandrov Recounts Soviet Development of Atomic Bomb," Interview by Kim Smirnov, *Izvestiya*, July 23, 1988, p. 3. (translated into English in JPRS-UMA-88-029, December 16, 1988, pp. 55-60).

and general nuclear theory. While nuclear weapons research has been shifted to other facilities, some five percent of the 3000 employees at the Kurchatov Institute are working on military weapons.[55] Upon his death in 1960, Kurchatov was succeeded as director of the institute by Academician Anatoliy P. Aleksandrov. Thrice a Hero of the Soviet Union, Aleksandrov was also the President of the Soviet Academy of Sciences until 1986. Aleksandrov was succeeded as director of Kurchatov by Academician Evgeniy P. Velikhov.

In 1946, Laboratory No. 3 (later to become the Thermo-technical Laboratory, and subsequently the Institute for Theoretical Physics), headed by Academician Abram I. Alikhanov, was working on the development of nuclear reactors. In 1949, Alikhanov and his colleagues put into operation the first heavy water reactor in the Soviet Union at Chelyabinsk-40 (now called Chelyabinsk-65, see discussion below). Today research at the Institute of Theoretical Physics is devoted to theoretical high energy physics.

All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16, the "Installation," or "Khariton's Institute")

The All-Russian Scientific Research Institute of Experimental Physics (VNIIEF), the older of two principal nuclear weapons design laboratories in use today, was founded by government decree in 1946 as KB-11 [design bureau 11], and apparently came into being in 1947. Initially it was known as "Military Installation 'N,'" then as "Kremlev City," and prior to the dissolution of the Soviet Union its formal name was the All-Union Scientific Research Institute of Experimental Physics.[56] Also called Arzamas-16, it is situated on lands of the former Sorovskiy Hermitage (Sarov monastery), destroyed in 1927, at Sarova, in Nizhniy Novgorod Oblast at the Mordovian Republic border, 60 km southwest of Arzamas.[57] The closed city, which at one time was temporarily named Kremlev has a population of 80,300.[58] It is here that

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[55] "Brains for Sale" *Poznan WPROST*, in Polish, March 8, 1992, pp. 38-39 (translated in *Foreign Broadcast Information Service-SOV-92-054*, March 19, 1992, p. 8).

[56] Moscow Teleradiokompaniya Ostankino Television First Program Network in Russian, April 23, 1992, 2000 GMT.

[57] "Silent People Live Here," *Komsomolskaya Pravda*, November 25, 1990, p. 2. Sarova is located at 54° 55'N 43° 19'E; Arzamas at 55° 23'N 43° 50'E. According to Serge Schmemann, *New York Times*, February 8, 1991, p. A4, "In the 1920's the monastery was used to house war orphans, and in the 1930's it became a prison camp. On the eve of World War II, a detachment of the N.K.V.D. - predecessor to the K.G.B. - ringed the whole town with barbed wire, and it became known as Arzamas-16, a top-secret research center that was not even shown on maps."

[58] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, November 17, 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, November 21, 1991, p.3.); in the translation the town is misspelled "Kremryuv."

the first Soviet nuclear bomb was designed and assembled.[59] In his *Memoirs*, Sakharov referred to it as the "obyekt" (which translates "installation"), as this was the only word that could be used to refer to the facility for security reasons. It is also known informally as "Khariton's Institute," named after Academician Yuliy B. Khariton, who has been the laboratory's scientific director since its creation.[60]

There are about 25,000 employees at the institute. In 1990, the institute was reported to have two academicians, two corresponding members of the academy, close to 50 doctors, 500 candidate Ph.D.s, and 250 winners of Lenin and State prizes.[61]

The primary mission of Arzamas-16 is designing nuclear warheads. The institute fabricates experimental and prototype warheads.[62] Some factory production probably took place at Arzamas-16 in the early years. *Komsomolskaya Pravada* 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.[63] He claimed to have assembled several thousand nuclear warheads over a fourteen year period.[64]

In 1992 weapons-related work represented about 60 percent of the total effort, with a planned decline to 50 percent by 1995, and further cuts expected. At Arzamas-16 there is a 120 terawatt (12 channel) inertial confinement fusion (ICF) laser installation called "Iskra-5" (Spark-5), and a rapid impulse graphite reactor, called BIGR. Current nonmilitary research includes safety and security of nuclear power plants, mathematical modeling, participation in oil and gas exploration, high (10 megagauss) magnetic fields, elimination of chemical munitions, chemical waste, and weapons plutonium by means of underground "peaceful" nuclear explosions (PNEs), and development of the uranium-233/thorium fuel cycle. The institute is interested in

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[59] "Silent People Live Here," *Komsomolskaya Pravda*, November 25, 1990, p. 2. See also, *Moscow Pravitelstvennyy Vestnik*, No. 49, December 1990, p. 12.

[60] Kharaton was scientific director when Sakharov arrived in March 1950; Sakharov, *Memoirs*, p. 101. Academician Khariton was also a deputy director of the Kurchatov Institute in the 1950s.

[61] "The City that is Not on the Map," *Pravitel'stvennyy Vestnik* [Government Herald--the newspaper of the Council of Ministers], No. 49, 1990, p. 12.

[62] Victor Mikhailov, at the time Deputy Minister of MAPI, said that both Arzamas-16 and Chelyabinsk-70 had research and pilot production capabilities. The Los Alamos and Livermore National Laboratories in the U.S. have similar capabilities. Los Alamos, in particular, has the capability to produce on the order of 50 to 100 weapons per year. "Report of the Third International Workshop on Verified Storage and Destruction of Nuclear Warheads," held in Moscow and Kiev, December 16-20, 1991, Natural Resources Defense Council, p. 13.

[63] Filin, "Nuclear Bomb Assembly Technology. Yardman Minayev Speaks."

[64] Ibid.

pursuing nonmilitary research in these fields.

As is the case at other Russian weapons facilities the responsibility for managing the institute is shared by the scientific director (or scientific-leader) and the director, the latter serving as the administrator. As noted above Khariton, whose 88th birthday was February 27, 1992, is still the scientific director. The first deputy scientific director is Academician Yuri A. Trutnev, a theoretical physicist who in his early years at Arzamas-16 shared an office with Andrei Sakharov. The laboratory's current (1990-1992) director is Vladimir A. Belugin[65].

All-Russian Scientific Research Institute of Technical Physics (Chelyabinsk-70)

The second of the two existing principal nuclear weapons design laboratories, the All-Russian (formerly All-Union) Scientific Research Institute of Technical Physics (VNIITF). Also called Chelyabinsk-70, it located between Lakes Sinara and Silach, just east of the Urals, 20 km north of Kasli and about 80 km south of Yekaterinburg.[66] Its creation in 1955 parallels that of the Lawrence Livermore National Laboratory (LLNL) in the United States.

The institute started at Site 21, which is located on a peninsula between Lake Sungul and Lake Silach - about midway between Snezhinsky, the closed city which houses most of the Chelyabinsk-70 work force today, and Kasli to the south. Site 21 was a sanitorium prior to World War II, and was converted into a hospital during the war. After the war the site housed a 'Sharashka,' a GULAG administered scientific research facility staffed by camp inmates. Timothy Kesovsky, a famous biophysicist who had been at the Kaiser Wilhelm Institute, and his colleagues removed from Germany immediately after the war, conducted genetic experiments with radiation at this facility, which was also called the Sungul Radiological Laboratory.[67] In 1955, Site 21 was selected to house the new weapons design institute, in part, because there were already research and housing facilities present. Genetic research was halted and about one-third of the scientist from Arzamas-16 move to Site 21 to establish the new institute. By 1958 the weapons design institute had outgrown Site 21, and over the next decade work shifted to new facilities constructed at Site 70, about 10 km to the north. In 1988, when the institute

[65] "Silent People Live Here," *Komsomolskaya Pravda*, November 25, 1990, p. 2.

[66] The closed city of Snezhinsk is located at 56° 05'N 60° 44'E on the southern edge of Lake Sinara, headwaters of the Sinara River. Most of the institute facilities are scattered around the town, mostly a few km to the south. A small village is located at 56° 04'N 60° 46'E.

[67] Soviet President Mikhail I. Kalinin, stayed at a dacha at the site; A. Khokhlov, "The Emperor Bomb. First Ever Reportage from a City Which Held Mankind's Future in its Hands," *Moscow Komsomolskaya Pravda*, June 26, 1991, pp. 1,4.

began conversion to non-weapons work, a computer assembly and repair facility, called the Sungul Science Engineering Center, was created at Site 21.[68] There is also a children's camp at Site 21 on the shore of Lake Sungul.

The closed town of Snezhinsk and most of the Chelyabinsk-70 facilities, including Site 20 6 km to the west of town, are enclosed by a rectangular fence about 6 km by 13 km that is visible in SPOT satellite images. The institute employs 16,000 people, of whom about 4000 are scientists, 3000 are production engineers, and 7000 technicians. There are 46,300 people in Snezhinsk,[69] which was previously called Semidesyatka ("Seventies town").

The primary mission of Chelyabinsk-70 is designing nuclear warheads. The institute fabricates experimental and prototype warheads, but has no factory production capability. There are extensive facilities for conducting chemical high explosive experiments (similar to Site 300 at the Lawrence Livermore National Laboratory in the U.S). The main test area is about 5 km to the northeast of Lake Itkul.[70]

Since 1988 Chelyabinsk-70 has been converting its research to civilian applications. In early-1992 roughly 50 percent of its research was military and 50 percent non-military, with further cuts on the military side expected.[71] The institute is pursuing nonmilitary commercial projects in fiber optic communications, nuclear medicine, and industrial diamond manufacture. About 10 percent of the institute personnel have been shifted to work on fiber optic communications.

Kirill I. Shchelkin, who had been Kharaton deputy at Arzamas-16, was the first scientific leader of Chelyabinsk-70 from 1955 until 1960. Academician Evgeny I. Zababakhin was the scientific leader from 1960 until his death in December 1984. He was succeeded by Academician Evgeniy N. Avrorin, who has been at Chelyabinsk-70 since its beginning in 1955. Boris V. Litvinov is currently the first deputy scientific leader and chief designer.

Dmitri Ch. Vasilyev was the first director of the institute from 1955 until his death in early-1961. He was succeeded by Boris N. Ledenyov, from 1961-1963; who in turn was succeeded by Georgii P. Lominskiy, from 1963-1986; followed by Vladimir Z. Nechai, who has been the director since 1986. Vladislav I. Nikitin is currently the deputy director.

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[68] The Center assembles and repairs personal computer for the institute and other organizations in the region. It has also expanded into software development.

[69] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, November 17, 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, November 21, 1991, p. 3).

[70] The high explosive test area is in the region 56° 11-12'N 60° 35-37'E.

[71] Thomas L. Friedman, "Ex-Soviet Atom Scientists Ask Baker for West's Help," *New York Times*, February 15, 1992, pp. 1,4.

Nuclear Warhead Production Facilities

The first Soviet atomic bomb was designed and assembled at Arzamas-16, and tested on August 29, 1949, at the Semipalatinsk test site. As noted above Arzamas-16 was probably the principal warhead assembly site in the early years.

Today there are two principal nuclear warhead assembly plants, Sverdlovsk-45, and either Zlatoust 36, or Penza-19. Like the U.S. Pantex facility, these plants also disassemble retired warheads. Sverdlovsk-45 (with its closed city called Rusnoy with a population of 54,700) is at Nizhnyaya Tura, on the eastern edge of the Urals, 200 km north of Yekatrinburg.[72] Sverdlovsk-45 has been referred to as the "Elektrochimpribor" Combine, which translates Electrochemical Measurement Combine.[73] It serves as one of the larger weapon storage sites in the former Soviet Union. Zlatoust-36, with its closed city of Torifugornuy (population 29,800), is no doubt close to the city Zlatoust, which is in the Urals in Chelyabinsk Oblast, 110 km due west of Chelyabinsk.[74] Its proximity to both Chelyabinsk-65 and Chelyabinsk-70 make Zlatoust-36 a more likely candidate than Penza-19 for the second assembly plant. Assembly of ballistic missile reentry vehicles takes place at Zlatoust-36. This may be the same site at Zlatoust where submarine-launched ballistic missiles are assembled. Penza-19, with its closed city called Zarchinuy (population 61,400) manufactures electronic warhead components, and may also be the second assembly plant.[75] Penza is a small city 550 km southeast of Moscow and 220 km south of Sarova, where Arzamas-16 is located.[76]

Two sources for the total capacity to assemble and disassemble warheads at the two facilities give values that differ by a factor of two. One source places the total capacity of the two facilities at about 8000 warheads per year.[77] In other words, this capacity could be used to assemble x

[72] Ibid. Nizhnyaya Tura is located at 58° 40'N 59° 48'E.

[73] "CPSU Central Control Commission Meets," *Moscow Tass International Service*, October 10, 1990, 1837 GMT. "Elektrochimpribor" sounds like another name for the Urals' Electromechanical Plant (or Electrochemical Combine), but this enrichment facility is at Sverdlovsk-44, as opposed to Sverdlovsk-45.

[74] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, November 17, 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, November 21, 1991, p.3.). The city of Zlatoust is located at 55° 10'N 59° 40'E.

[75] The electrical (and electronic) components of U.S. warheads are manufactured at the Kansas City Plant.

[76] The city of Penza is located at 53° 11'N 45° 00'E.

[77] "Report of the Fourth International Workshop on Nuclear Warhead Elimination and Nonproliferation," held in Washington,D.C., February 26-27, 1992, Federation of American Scientists and the Natural Resources Defense Council.

warheads and disassemble (8000-x) warheads per year.[78] Of the total some 3000 to 4000 units per year are said to be available for disassembly of the warheads to be retired under the Gorbachev and Yeltsin arms control initiatives of 1991 and 1992. The second source places the total capacity at "slightly more than the U.S. Pantex plant." Pantex has 13 assembly cells ("gravel gerties") and can assemble (or disassemble) 1500 warheads per year when operating one shift per day. If the Pantex plant were operated three shifts per day it could handled close to 4500 warheads per year.

There are other industrial plants and institutes under the authority of MAE that manufacture nuclear warhead components and equipment used in the production of nuclear weapon material and which serve as research institutes. The Impulse Technique R&D Institute on the outskirts of Moscow is responsible for the development of the diagnostic equipment used in nuclear weapons testing. The All-Russian (formerly All-Union) Automatics Research Institute is a MAE institute that manufactures commercial pulsed neutron generators and portable X-ray devices. It probably makes the neutron generators for nuclear warheads. The A.A. Bochvar All-Russian Scientific Research Institute of Inorganic Materials, founded in 1945 in Moscow, conducts research in several areas, including chemical separation and nuclear waste management processes and technologies. Numerous other MAE institutes involved in research, development, and manufacture of reactor and fuel cycle technologies and processes, electronic and other instruments, and machine tools are identified in the 1991 MAPI brochure describing its capabilities (see Table 2).

Nuclear Weapon Materials Production

According to one Russian estimate, Russia has produced 130 ± 15 MT of weapon-grade plutonium. Another Russian source estimates that Russia (and formerly the Soviet Union) has about 100 metric tons (MT) of weapon-grade plutonium, 30 kilograms (kg) of tritium, and about 500 MT of highly enriched uranium in nuclear weapons,[79] with the amount of inventory of these materials available for, but not in, weapons a small fraction of the total.

The Soviet Union followed a pattern of nuclear weapons materials production similar to that of the United States. Each began with construction

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[78] At the U.S. Pantex plant, the time, manpower, and facility space required to assemble a nuclear warhead is about the same as that required for disassembly. The situation is presumed to be the same in Russia.

[79] According to Academician Yuri Trutnev, discussing an Arzamas-16 proposal to destroy plutonium pits with underground nuclear explosives, there are about 62 MT of plutonium in 20,000 pits. this implies 3.1 kg per warhead, or about 100 MT of plutonium in the 33,000 warheads stockpile. "Report of the Third International Workshop on Verified Storage and Destruction of Nuclear Warheads," held in Moscow and Kiev, December 16-20, 1991, Natural Resources Defense Council, p. 22.

of natural-uranium-fueled, graphite-moderated thermal reactors for plutonium production and development of gaseous diffusion technology for the enrichment of uranium. Today, Russia relies on graphite reactors for plutonium and tritium production, and primarily on gas centrifuge technology for uranium enrichment.

The Soviet government announced in October 1989 that "this year it is ceasing the production of highly enriched uranium," and that they had adopted a program to close down all plutonium-producing reactors by the year 2000, three by 1996 and the last three by 2000.[80] This policy was affirmed by President Boris N. Yeltsin, who said in his January 29, 1992 disarmament address, "Russia intends to proceed with the program for the cut-off of weapon-grade plutonium production. Reactors for weapon-grade plutonium production are to be shut down by the year 2000, and some of them even as early as in 1993. We confirm our proposal to reach agreement with the USA concerning the cut-off of fissionable materials production for weapons."

As of the beginning of 1992, six of 14 production reactors remained operational. Three of these are scheduled to be shut down in the last half of 1992, leaving three operational. These last three are dual purpose reactors producing heat and/or electricity. The year 2000 production cut-off apparently was chosen as the date by which a new power plant could brought on line to replace the dual purpose reactor at Krasnoyarsk-26, the last production reactor to be shut down. A MAPI official stated in 1989, that the Soviets would have a continuing requirement for "two to three tritium production reactors."[81] With commitments by Presidents Gorbachev and Yeltsin to retire 15,000 to 20,000 warheads over the next decade, requirements for new tritium production could be postponed for more than a decade, and at most only a single small reactor would be needed.

Several tens of tons of weapon-grade plutonium (perhaps as much as 60 MT) and several hundreds of tons of HEU (perhaps as much as 300 MT) will be removed from warheads committed to be eliminated by Presidents

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[80] V.F. Petrovsky, Deputy head of the USSR Delegation to the 44th UN General Assembly, in "Statement On the Item Entitled 'Report of the International Atomic Energy Agency,'" October 25, 1989. This initial schedule for retirement of the production reactors may have been driven , in part, by the need for fresh plutonium. When recycling plutonium recovered from retired warheads for reuse in new warheads, the Russian program does not chemically remove the americium-241, a contaminant that slowly builds up as a result of the radioactive decay of the plutonium-241 impurity in the weapon-grade plutonium. Instead the recycled plutonium is blended with freshly produced plutonium to meet impurity specifications. In the U.S. weapons program the plutonium recovered from retired warheads used to be sent to the Rocky Flats plant, where a pyrochemical process was used to remove the americium-241. The Rocky Flats plant is now closed.

[81] Statement by Evgeny Mikerin to members of an American delegation at Chelyabinsk-40, July 7-8, 1989; Christopher Paine, "Military Reactors Go on Show to American Visitors," *New Scientist*, July 22, 1989, p. 22.

Gorbachev and Yeltsin. Current government policy is to store all the fissile material from dismantled warheads for at least a decade, most likely at Tomsk-7. How Russia will ultimately dispose of the plutonium may not be decided for several years. Senior MAE officials want to complete the construction of the mixed-oxide (MOX) fuel plant at Chelyabinsk-65, and use the plutonium as MOX fuel in civil reactors.[82] In this case the plutonium fuel would be used in 16 VVER-1000 light water reactors at a concentration of 0.3 MT per reactor, with an annual consumption of seven MT for all 16 reactors. Experts from Arzamas-16 propose that the plutonium pits be destroyed by underground PNEs.[83] Experts from Chelyabinsk-70 propose to store the plutonium indefinitely, or at least until its final disposition is decided.

There is general agreement that the HEU ultimately should be diluted with natural of depleted uranium and used to fuel power reactors, but its use in this manner may be delayed until 2010-2015. Senior ministry officials would prefer to store the HEU, and continue to supply power reactor fuel by continuing to enrich natural uranium (or depleted tails). Russia has a surplus of enrichment capacity. The Ministry wants to maintain the work force at the enrichment plants.

As noted above and in Table 2, MAE (formerly the Ministry of Atomic Power and Industry (MAPI), and before that the Ministry of Medium Machine Building) is responsible for all nuclear materials production, i.e., the fuel cycle, for both military and civil purposes.

Plutonium and Tritium Production Sites

Plutonium production for weapons in Russia has taken place at three locations: Chelyabinsk-65 (previously Chelyabinsk-40, and for many years known in the West as the "Kyshtym Complex"), near Kyshtym in Chelyabinsk Oblast; at the Siberian Atomic Power Station, located at the Siberian Chemical Combine (Tomsk-7) on the Tom River 15 km northwest of Tomsk; and at The Mining and Chemical Combine (Krasnoyarsk-26) on the Yenisey River, 10 km north of Dodonovo, and 64 km northeast of Krasnoyarsk in Siberia. Prior to 1987, there were as many as fourteen production reactors at these three sites — six at Chelyabinsk-65, five at Tomsk-7, and three at

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[82] MOX fuel is a blend of plutonium oxide (PuO_2) and uranium oxide (UO_2).

[83] According to Arzamas-16 experts, as a rule of thumb, each kiloton of nuclear explosive yield could produce about 1000 MT of "melted substance." Thus, a 100 kiloton explosion would melt 100,000 MT of plutonium and rock. If 62 MT of plutonium from 20,000 warhead pits were eliminated in this manner the resulting plutonium would be uniformly distributed in vitrified rock at a concentration of $6x10^{-4}$ grams of plutonium in each gram of vitrified rock.

Krasnoyarsk-26.[84] This total excludes a small reactor currently operating at Chelyabinsk-65 for the production of special isotopes, e.g. Pu-238. At Chelyabinsk-65 a heavy water reactor, which we have counted as one of the production reactors, was shut down about a decade ago, and between 1987 and December 31, 1990, the five graphite production reactors were shut down. At Tomsk-7 two of the five graphite reactors were also shut down between 1987-1991, and one additional reactor will be shut down in the last half of 1992. At Krasnoyarsk-26 two of the three reactors will be shut down in the last half of 1992. Thus, there were six production reactors operating at the end of 1991, and by the end of 1992, only three will be operating - two graphite reactors at Tomsk-7 and one at Krasnoyarsk-26.

No tritium production takes place ar Krasnoyarsk-26. It is assumed that there are tritium separation facilities at the Chelyabinsk-65 and Tomsk-7 sites.

Mayak Chemical Combine (Chelyabinsk-65, formerly Chelyabinsk-40, "Kyshtym Complex")

A closed city until 1989, Chelyabinsk-65 is not on maps of the former Soviet Union. Prior to about 1990, it was called Chelyabinsk-40. It is about 15 km east of the city of Kyshtym on the east side of the southern Urals in Chelyabinsk Oblast.[85] It is located in the area around Lake Kyzyltash, in the upper Techa River drainage basin among numerous other lakes with interconnecting watercourses. Chelyabinsk-65 is run by the production association Mayak[86] (translated "Lighthouse" or "Beacon"), and the defense enterprise is referred to as the Mayak Chemical Combine. Between Lake Kyzyltash and Lake Irtyash, about 10 km from the reactor area, is Ozhorsk, the military-industrial city built to house the Chelyabinsk-65 work force, and whose population is 83,500.[87] Once the city bore the name of Beria. Today, local inhabitants call it Sorokovka ("Forties Town").[88]

Probably fashioned after the U.S. Hanford Reservation, Chelyabinsk-65 was the Soviet Union's first plutonium production complex. Construction was started on the first buildings of the new city in November 1945 and in June

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[84] The U.S. too had 14 production reactors, nine at the Hanford Reservation in Washington and five at the Savannah River Plant in South Carolina. During 1964, all 14 were operating at once. Eight were shut down in the mid- to late-1960s.

[85] Chelyabinsk-65 is located at 55° 44'N 060° 54'E, near the cities of Kyshtym (population about 40,000) and Kasli (population about 20,000), and about 70 km north of Chelyabinsk (population 1.1 million), the capital of Chelyabinsk Oblast which covers 88,000 km^2, an area about the size of Indiana.

[86] Ann MacLachlan, *Nucleonics Week*, July 26, 1990, p. 12.

[87] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, November 17, 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, November 21, 1991, p. 3).

[88] B.V. Nikipelov and Ye.G. Drozhko, "An Explosion in the Southern Urals," *Priroda*, May 1990, p. 48.

1948 the first production reactor was brought on line.[89] To construct the complex reportedly some 70,000 inmates of 12 labor camps were used.[90] At least in the 1950s, the complex covered a restricted area approximately 60 km north-south and 45 km east-west.[91] Today the site occupies an area on the order of 200 km^2.[92] The industrial area bordering the southeast shore of Lake Kyzyltash, where the reactors and chemical separation plant are located, is about 90 square kilometers (km^2).[93] In 1989, an American delegation was told that there were some 10,000 employees and 40,000 dependents at Chelyabinsk-65.

It was at this site that Kurchatov, working under Beria, built the Soviet Union's first plutonium production reactor.[94] Fursov, who with Kurchatov had designed the F-1 pile at Laboratory No. 2, oversaw Chelyabinsk-65 as Kurchatov's main representative.[95] Academician Khlopin was the first scientific director of Chelyabinsk-40. Khlopin and workers from the Radium Institute completed the first chemical plant for the separation of plutonium from irradiated uranium. Boris A. Nikitin was the engineer responsible for developing the technology for extracting the plutonium from the uranium and fission products.[96] A. Bochvar was responsible for processing the plutonium

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[89] Colonel L. Nechayuk, "In the City Without a Name,"*Krasnaya Zvezda*, October 19, 1990, First Edition (translated into English). According to posters on the wall in the A-Reactor building, the development stages before startup included: from 1943 - scientific research carried out; October 1945 - government commission inspected the construction site; November 1945 - geological prospecting began; February 1946 - design completed; April 1946 - government decree on beginning of construction issued. The construction area was assimilated August 4, 1946 and the first 40 specialists arrived on October 9, 1946.

[90] Diane M. Soran and Danny B. Stillman, "An Analysis of the Alleged Kyshtym Disaster," Los Alamos National Laboratory (LANL), LA-9217-MS, January 1982. The city of Kyshtym is located on the railroad linking the industrial cities of Chelyabinsk and Yekaterinburg. The area has a long history of munitions production, dating back to the time of the tsars.

[91] G.F. Wilson, CIA, enclosure 14 attached to November 11, 1977 reply to FOIA request by Richard B. Pollock for information relating to a nuclear disaster alleged to have occurred in the Ural Mountains in the Soviet Union in 1958.

[92] V.N. Chykanov, Y.G. Drozhko, A.P. Kuligin, G.A. Mesyats, A.N. Penyagin, A.V. Trapeznikov, and Bolbuev, "Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym," paper presented at the Conference on the Environmental Consequences of Nuclear Weapons Development, University of California, Irvine, April 11-14, 1991.

[93] B.V. Nikipelov, A.S. Nikiforov, O.L. Kedrovsky, M.V. Strakhov, and E.G. Drozhko, "Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes," (undated English translation ca. 1990; not known whether it has been published).

[94] "Special Purpose Facility: Report from a Nuclear Fuel Reprocessing and Storage Factory," *Pravda*, March 4, 1989.

[95] Steven J. Zaloga, "The Soviet Nuclear Bomb Programme -- The First Decade," *Jane's Soviet Intelligence Review*, April 1991, p. 178.

[96] Ibid.

and fabricating the two sub-critical fissile masses for the bomb.[97]

From 1948 until November 1, 1990, the combine produced plutonium for nuclear weapons. Chelyabinsk-65 now produces special isotopes and reprocesses naval and civil power reactor fuel for plutonium and uranium recovery. The combine also produces special (read "military") instruments.[98] No longer producing weapon-grade plutonium, the complex in recent years has begun to produce a variety of equipment for civilian use.[99]

The known facilities at Chelyabinsk-65 are listed in Table 3. At Chelyabinsk-65 there are five graphite-moderated water-cooled production reactors and a heavy water-moderated reactor (all of which have now been shut down). The five graphite-moderated production reactors had a reported total capacity of 6000 megawatts thermal (Mw_t).[100] The size of the heavy water reactor is not known. Mayak has advertized its capability to produce isotopes for special applications, e.g. plutonium-238 for thermo-electric power sources. Apparently, as evidenced from LANDSAT images of continued thermal discharges into Lake Kyzyltash, there is a small operating reactor used for this purpose. There is also a 500 metric ton of heavy metal per year (MTHM/y) chemical separation plant, called RT-1, which was formerly used to recover plutonium for weapons, but is now used to reprocess civil reactor (VVER) fuel; and a MOX fuel fabrication plant whose construction is suspended after being 65-70 percent completed.[101] A separate chemical separation facility is apparently used for special isotope production. The South Urals Project is the site for three BN-800 liquid metal fast breeder reactors (LMFBRs). Foundation construction on the first two reactors was suspended in the 1987. Whether construction of even one of the reactors is resumed seems doubtful. There are also some 60 tanks of high-level radioactive waste, a pilot vitrification plant and various other production related facilities. The history and status of these facilities is discussed separately below.

Boris V. Brokhovich, an electrical engineer, was among the first 300 arrivals at the site in 1946. He became director of Chelyabinsk-65 in 1971, and was serving in that capacity at the time of the first American visit in July 7-8, 1989.[102] Viktor Ilich Fetisov was the director of the Mayak Production

[97] Ibid.

[98] Colonel L. Nechayuk, "In the City Without a Name,"*Krasnaya Zvezda*, October 19, 1990, First Edition (Translated in *FBIS*-SOV-90-208, October 26, 1990, p. 56).

[99] "Conversion at Chelyabinsk Plant Viewed," *Vremya* newscast, January 27, 1991, 1530 GMT, in Russian (Translated in *Foreign Broadcast Information Service-SOV-91-029*, February 12, 1991, p. 58.)

[100] *Nucleonics Week*, July 26, 1990, p. 12.

[101] Mixed-oxide (MOX) fuel is a blend of plutonium oxide (PuO_2) and uranium oxide (UO_2).

[102] Brokhovich, a Hero of Socialist Labor, was awarded the State Prize in 1954, the Lenin Prize in 1960.

Association in 1990; Aleksandr I. Pishchepov was the deputy director for procedures.[103]

Graphite Reactors: The five water-cooled graphite-moderated production reactors, all now decommissioned, are located in separate buildings in two separate production areas. The A-Reactor, IR-Reactor and the AV-3 Reactor are located in the a complex of buildings called Plant 156. The AV-2 and AV-3 Reactors are located in a separate area of the complex.

A-Reactor: The first reactor, "A" reactor, was graphite-moderated with 1,168 channels. It was originally designed to operate at 100 megawatts thermal (Mw_t), but was later upgraded to 500 Mw_t.[104] Called "Anotchka" ("Little Anna" in English), A-Reactor was designed by Nikolai Dollezhal, and constructed in only 18 months.[105] It is located in Building 1 in the Plant 156 area. A-Reactor was loaded with all the uranium then available in the country, and began operation on June 19, 1948. It was shut down 39 years later in 1987. Its plutonium was used to fabricate a ball almost 10 cm in diameter which was used in the first Soviet atomic bomb tested August 29, 1949.[106]

It used aluminum-clad natural uranium fuel in vertical fuel tubes and gravity fuel discharge. The core diameter was 9.4 meters (m) and height was 9.2 m. The top of the reactor was 9.3 m below grade. The core was located within a concrete well with walls 3 m thick. Outside the walls were large tanks of water.

A confinement system was used to control radioactive releases in the event of an accident. Accidental fission product releases were vented into a 100 cubic meter (m^3) tank. Gas and particulates would enter from one side and travel through a "labyrinth," gas holdup allowing short-lived activity to decay. Filters made from special textiles were designed to capture cesium and

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[103] Colonel L. Nechayuk, "In the City Without a Name,"*Krasnaya Zvezda*, October 19, 1990, First Edition, p. 2 (Translated in *FBIS*-SOV-90-208, October 26, 1990, p. 56).

[104] "Kyshtym and Soviet Nuclear Materials Production," *Science and Global Security*, Vol. 1, Nos. 1-2 (1989), p. 171 [a fact sheet containing technical information collected during a visit to Chelyabinsk-40 by an NRDC/Soviet Academy of Sciences delegation July 7-8, 1989]. By comparison, the first U.S. plutonium production reactor, B-Reactor at Hanford, has 2,004 channels; an original design power level of 250 Mw_t; and was eventually upgraded to 2090 Mw_t.

[105] At the beginning of 1946, Kurchatov invited Nikolai Dollezhal' to participate as chief designer of the first "industrial" reactor (as it is known in Soviet literature) for the production of plutonium. For his contribution, Dollezhal' was made a Hero of Socialist Labor and received a Stalin Prize. In 1953 Academician Dollezhal' became director of the Scientific Research and Design Institute of Power Technology (NIKIET) in Moscow; Julian Cooper, lecturer in Soviet technology and industry, University of Birmingham, July 10, 1986 letter to Thomas B. Cochran.

[106] Interview of Igor Golovin by Leonard Nikishin, "They Awakened the Genie," *Moscow News*, October 15-22,1989, p.1; see also, Abraham Pais, "Stalin, Fuchs, and the Soviet Bomb," *Physics Today*, "Letters," August 1990, pp. 13 and 15.

strontium isotopes. For iodine-131 there were absorber columns of activated carbon.

All of the production reactors are located near the southeast shore of Lake Kyzyltash and rely on open cycle cooling with water from the lake pumped directly through the core. The average temperature of the discharged water from A-Reactor was 70° C; and a high of 80-85° C. A thermal plume from reactor discharges into Lake Kyzyltash is clearly visible in LANDSAT images.

The A-Reactor is being dismantled in three stages. The first stage was shutdown and fuel unloading. The second stage, in progress, will take up to five years and involves dismantling of the control and operating system and filling the empty spaces with concrete. During the third stage, which will last 20 to 25 years, there will be no activity, after which a decision will be made to bury the reactor on site or remove it.

IR-Reactor: Housed in Building 701, a separate building adjacent to the A-Reactor, is a small 65 Mw_t dual-purpose graphite-moderated reactor with 248 channels, used for plutonium production and (1) fuel rod research, (including strengthening fuel elements for the A-Reactor, permitting an increase in its power level to 500 Mw_t), and (2) testing the fuel assemblies for the RBMK power reactors. The IR-Reactor was the third production reactor (the second graphite-moderated reactor) constructed at Chelyabinsk-65. Construction began on August 18, 1950, and the plant was brought on line 16 months later, on December 22, 1951. After 35 years of operation it was shut down on May 24, 1987, in the same year as the A-Reactor.

AV-1 Reactor: There are three large reactors, AV-1, AV-2 and AV-3, that appear to be of similar, if not the same design. Each has 2001 channels. Characteristics of the AV-2, the only one of the three which has been described in the open literature, are given below. The AV-1 was decommissioned on August 12, 1989.

AV-2 Reactor: A sign on the wall at the entrance to the AV-2 reactor describes it as the "Second series-produced energy installation in the USSR brought on line April 1951, Shut down July [14,] 1990."[107] This graphite reactor has the shape of a vertical cylinder. The 2001 channels, each 60 millimeters (mm) in diameter and evenly spaced 200 mm apart, make the AV-2 larger than the A-Reactor, and comparable in size to the C-Reactor at the Hanford Reservation in the United States which had an initial power level of 650 Mw_t and was upgraded to 2310 Mw_t. The core sits below grade in a concrete cylinder 11.8 m in diameter and 7.6 m high with equipment reaching a depth of 53.3 m into the ground. To provide radiological shielding "the

[107] Colonel L. Nechayuk, "In the City Without a Name," *Krasnaya Zvezda*, October 19, 1990, First Edition, p. 2 (Translated in *FBIS*-SOV-90-208, October 26, 1990, p. 56).

active zone and its sides were protected by three layers: water and sand, each to a thickness of 1.5 m, and a 2 m thick concrete wall. Above there was a layer of sand and bathite ore (batitovaya ruda) 1.5 m thick and then a 3 m thick layer of concrete, and finally a pool of water 1.5 m deep."[108] Above the core is a huge central hall with the reactor building equivalent in height to a ten story apartment. Prior to shut down the size of the AV-2 reactor staff was about 140 people, divided among five shifts per day with 28 people per shift.[109]

AV-3 Reactor: Housed in Building 501 in the same reactor complex (Plant 156) as the A- and IR-Reactors is the fifth graphite-moderated reactor at Chelyabinsk-40. Construction of the AV-3 took place between January 1951 and September 1952. It was brought on line on September 15, 1952, and was decommissioned November 1, 1990, the last of the five to be decommissioned.[110]

Heavy Water Reactor: The second reactor at Chelyabinsk-40 was heavy water moderated. It was designed by Academician Abram Alikhanov. Shortly after it began operation (between late-1948 and late-1951), the heavy water in the two heat exchangers froze. Yefrim P. Slavskiy, then complex chief engineer and later Minister of Medium Machine Building, claims he had to enter the radiation area and place his hand on one of the heat exchangers to convince the designers that the heavy water had frozen.[111] Whether this reactor was used for isotope production (including tritium), prior to its shutdown about a decade ago (circa 1980), is not known.

There is a small reactor currently in use for special isotope production, e.g. production of Pu-238. Although its type is not known, it is presumed to be a heavy water reactor.

Chemical Separation Facilities: Chemical separation (radiochemical, or reprocessing) plants are used to chemically separate the plutonium and uranium from the highly radioactive fission products contained in the irradiated reactor fuel elements. There have been at least two such plants at Chelyabinsk-65. The first chemical separation plant went into operation in December 1948, six months after the startup of the A-Reactor, and is now

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[108] Ibid.

[109] Ibid.

[110] Yevgeniy Tkachenko, "Southern Urals Plutonium Plant Decommissioned," *Moscow Tass*, in English 1710 GMT, November 1, 1990 (reproduced in *FBIS*-SOV-90-213, November 2, 1990, p. 70).

[111] "Annals of the Fatherland: A Reactor for Submarines," Discussion recorded by Captain 1st Rank S. Bystrov, *Krasnaya Zvezda*, October 21, 1989, 1st Edition, p. 3.

apparently shut down.[112] The initial chemical separation technology used at Chelyabinsk-65 was based on a precipitation processes developed at Radium Institute (Leningrad) under the guidance of Academician V.G. Khlopin. During the 40 year period of radiochemical plant operation the chemical separation and waste management technologies have changed substantially several times.[113]

The initial technology was based on slightly soluble sodium uranyl acetate ($NaUO_2(CH_3COO)_3$) precipitation from nitric acid solutions of irradiated uranium. Plutonium, when in the six valence state in the form of sodium plutonyl acetate, coprecipitates isomorphically with $NaUO_2(CH_3COO)_3$, or it remains in the solution when it is reduced to plutonium (4) or plutonium (3). In the first case the uranium and plutonium is separated from the fission products and in the second case the two are separated from each other. The resulting high level waste had a sodium nitrate concentration exceeding 100 grams per liter (g/l) and sodium acetate concentration of 60-80 g/l.[114]

In order to concentrate the high level waste and recover and reuse the acetic acid and sodium nitrate, the Physical Chemistry Institute of the Soviet Academy of Sciences, under the guidance of Academician V.I. Spitzin, developed a precipitation-crystallization-sorption technology. This waste processing technology may have been put into use about 1953, when the intermediate waste storage facility was placed into operation. It was impossible to achieve high concentration of the waste due to its high salinity. Moreover, the solutions contained a large quantity of deficient reagent - sodium acetate. Consequently, radionuclides were concentrated by coprecipitation with low soluble compounds including iron and chromium hydroxides, iron and nickel sulfides, and nickel ferrocyanide. The fission products, in the form of a suspension, were concentrated into a volume approximately 100 times smaller than the initial solution and were retained for long-term storage. The clarified solution after acidification by nitric acid was concentrated by evaporation. Simultaneously, acetic acid was distilled and caught in a plate column, sprayed with alkali. From distillation residue containing 1100-1150 g/l of sodium nitrate, its crystallization and even recrystallization were realized.[115]

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[112] Boris V. Nikipelov, Andri F. Lizlov, and Nina A. Koshurnikova, "Experience with the first Soviet Nuclear Installation," *Priroda*, February 1990 (English translation by Alexander Shlyakhter), p. 1.

[113] E.G. Drozhko, B.V. Nikipelov, A.S. Nikiforov, A.P. Suslov, and A.F. Tsarenko, "Experience in Radioactive Waste Management at the Soviet Radiochemical Plant and the Main Approaches to Waste Reliable Confinement Development," Ministry of Nuclear Power Engineering and Industry, (undated English translation ca. 1990).

[114] Ibid.

[115] Ibid.

RT-1 Radiochemical Plant: The combine's currently operating chemical separation plant (designated RT-1) started processing spent fuel from the production reactors in 1956. In 1976 it was modified to process spent fuel from naval propulsion reactors, and in 1977, shifted from processing military production reactor fuel, to processing spent fuel from naval (both submarine and civil icebreaker) reactors (which apparently occurred first), test reactors, and 210 Mw_e and 440 Mw_e light-water moderated and cooled power reactors (VVER-210s and VVER-440s).[116] It is the only facility for power and naval reactor fuel reprocessing. The RT-1 reprocessing plant capacity is 500 MTHM/y, or 300-900 fuel assemblies/y, comparable to the UP-400 plant operated by Cogema at La hague in France.[117] In 1989 it was reported that over the plants 10-year "civilian" lifetime, throughput has averaged 200 MTHM/y.[118] In 1992 ministry officials said, "Currently, it reprocesses 200-250 tones/year."[119]

The RT-1 reprocessing technology is based on the continuous multistage process of extraction by tributilphosphate. It currently provides recovery of 99 percent of the uranium and plutonium, and 85 percent of the neptunium. From one MT of spent fuel with a burnup of 28,000 Mwd/MT (corresponding to a reduction in the uranium enrichment from 3.6 to 1.4 percent) one extracts:[120]

-- about one MT of uranium
-- 8 kg of plutonium (as PuO_2)
-- 460-480 g of neptunium (as concentrated acid).

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[116] Christopher Paine, "Military Reactors Go on Show to American Visitors," *New Scientist*, July 22, 1989, p. 22; Oleg Bukharin, "Soviet reprocessing and waste-management strategies," DRAFT, November 5, 1991. Production reactor fuel is uranium metal. Because VVER fuel, and presumably naval fuel, is in the form of uranium oxide pellets in zirconium alloy (or stainless steel) fuel rods, a second "head-end" was added to the plant to chop the rods and dissolve the UO_2 fuel.

[117] Oleg Bukharin, notes taken at meeting with Evgeny Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992. "Soviet Union Postpones Completion of Siberian Reprocessing Plant," *Nuclear Fuel*, October 16, 1989, pp. 1-2, reports RT-1 capacity as 400 MTHM/y. Oleg Bukharin, "Soviet reprocessing and waste-management strategies,"DRAFT, November 5, 1991, reports the capacity as 600 MTHM/y, or 300-900 fuel assemblies/y.

[118] "Soviet Union Postpones Completion of Siberian Reprocessing Plant," *Nuclear Fuel*, October 16, 1989, pp. 1-2.

[119] Oleg Bukharin, notes taken at meeting with Evgeny Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992.

[120] Oleg Bukharin, "Soviet reprocessing and waste-management strategies,"DRAFT, November 5, 1991.

Americium and curium are not extracted at present and remain with the fission products.[121]

Following the modification of RT-1 to process civil fuel in 1976, the irradiated fuel elements from the production reactors at Chelyabinsk-65 were shipped by rail to Tomsk-7 for processing (see discussion under "Tomsk-7" below).

According to Evgeniy Mikerin, the Soviet stockpile of plutonium recovered from civil reactors was originally destined for the cores of the Ministry's ambitious breeder reactor program, and in 1989 amounted to "around 20 tons."[122] By the end of 1991 the stockpile of separated civil plutonium at Chelyabinsk-65 was reported to be about 25 MT.[123]

MOX Fabrication Plant: Construction of a MOX fuel fabrication plant has been suspended after being 65-70 percent completed. It was designed to produce three cores of for the BN-800 reactors that were to have been built at Chelyabinsk-65 (see South Urals Project below) - about 10 MT of plutonium annually. While there is a research and development program in Russia on use of MOX fuel in VVERs, there are currently no production lines for fabricating MOX fuel for VVERs at this plant.

South Urals Project: Construction of the South Urals Nuclear Power Station, which originally was intended to consist of three 800 Mw_e liquid metal fast breeder reactors, was begun in 1984 by the Ministry of Medium Machine Building.[124] Only the concrete footings for the first two reactors were put in place before construction was suspended in 1987.[125] The third reactor did not advance beyond the planning stage.

The reactor complex is clearly shown in French SPOT (Satellite Pour l'Observation de la Terre) satellite photographs of the Kyshtym area taken in 1987 (See Figure 1 and *Nuclear Weapons Databook, Vol. IV, Soviet Nuclear Weapons*, pp. 82-83). It is located on the northwestern edge of Reservoir No. 10. This 19 km^2, 76 million m^3, artificial lake was constructed on the Techa River (immediately downstream from Lake Kyzyltash), to control radioactivity

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[121] Ibid; Based on "Report by the Commission for Investigation of Environmental Situation in Chelyabinsk Region." (Decree by the President of the USSR, #RP 1283, January 3, 1991). Bukharin reports that in a June 27, 1991, Evgeniy Mikerin, then head of the Department of Isotope Separation, Reprocessing and Production Technology, MAPI, told him that 99.9 percent of the plutonium is recovered and americium and curium are also extracted for further utilization.

[122] Christopher Paine, "Military Reactors Go on Show to American Visitors," *New Scientist*, July 22, 1989, p. 22.

[123] Oleg Bukharin, "Soviet reprocessing and waste-management strategies,"DRAFT, November 5, 1991.

[124] *Nucleonics Week*, July 26, 1990, p. 11.

[125] Ibid.

dumped into the river, mostly in the 1949-1951 period (see discussion below). The site, in the words of *Selskaya Zhizin*, is "in a bright birch grove, which guards the secret of the Ural (radioactive) trace."[126] At the construction site the soil contamination ranges from 1.0-1.5 Curies/square kilometer (Ci/km^2) for strontium-90 (Sr-90) and 4.0-4.5 Ci/km^2 for cesium-157 (Cs-137).[127]

Construction of the South Urals project was halted after public protests and questions raised by Oblast officials, although some critics claim that the real reason construction was stopped was because the ministry ran out of funds. Some 1.5 billion rubles were authorized for the entire South Urals project, and 270 million rubles were spent before construction was suspended, including for the construction of some reactor parts at the Atommash plant at Volgodonsk beginning in 1988.[128]

Minatom would like to complete construction of one of the reactors and has invited international institutions to participate in the project. The Japanese have expressed an interest in funding the project. Whether construction of a single BN-800 unit is renewed will depend not only on the availability of outside financing, but also on the outcome of the political struggle between Minatom which supports the project and local public opposition. At various times the ministry has argued that the facility is needed to provide employment for the skilled workers who have lost or will lose their jobs as a result of the shut down of the production reactors, and that operation of the reactor would increase the rate of evaporation in Reservoir 10, thus preventing the overflow of Reservoir 11. Both of these arguments have been challenged, and neither supports the construction of a breeder over a VVER. For an extensive critique of the South Urals project, which cites numerous examples where the project justification or supporting data is incorrect or incomplete, see "Resonance," Chelyabinsk, 1991.

The breeder program is plagued by safety concerns — leaks in the sodium-water heat exchangers and the possibility of a runaway chain reaction during an overheating accident — and by problems encountered in the development of "mixed-oxide" (MOX) plutonium fuel. The BN-600 breeder at Beloyarskiy continues to operate at half power, and until recently operated with highly-enriched uranium rather than plutonium. The Soviet breeder is increasingly vulnerable to charges that it is uneconomical. Even its backers cheerfully admit that breeder generated electricity is "2.5 times more

[126] "The Ural Trace," *Selskaya Zhizn*, November 1, 1989.

[127] "Resonance," Chelyabinsk, 1991.

[128] Ibid.

expensive" than power from conventional power plants.[129] Scientists at Chelyabinsk-70 are seeking funding support to develop and test a lead cooled fast breeder that is said to be much safer than the sodium cooled fast breeders. Such claims could further erode support for the BN-800.

Radiation Exposure to Workers: Nikipelov, et al., recently published an analysis of the radiation doses to workers at A-Reactor and the chemical separation plant at Chelyabinsk-40.[130] The distributions of worker exposures at these two facilities are reproduced in Table 4. The period 1948-1952 is characterized by exceedingly high exposures. At A-Reactor the *average* annual worker dose peaked at 93.6 rem in 1949, the first full year of operation; and at the chemical separation plant the average annual dose peaked at 113.3 rem in 1951. From 1949 to 1951, 0.5 or 1.8 percent of the workers at either A-Reactor or the chemical separation plant were receiving doses in excess of 400 rem annually, more than 80 times the current occupational exposure standard. Because plutonium production was a higher priority than worker safety many workers received doses exceeding the administrative limits established by the Ministry of Medium Machine Building, which were:

1948: 0.1 rem for 6 hours (about 30 rem/year).

1952: 0.05 rem for 6 hours (about 15 rem/year); and a single emergency irradiation not exceeding 25 rem during a time not less than 15 minutes.

1954: some employees allowed to get doses up to 100 rem provided afterwards they would be transferred to other "clean" (no radiation exposure) jobs.

1954-55: employees to be transferred to "clean" conditions for 6 months after the total radiation dose exceeded 45 rem for the last year or 75 rem for the last two years.

1960: 0.1 rem/week; 5 rem/year for workers under the age of 30 years and 12 rem/year for workers 30 years and older.

1970: 5 rem/year.

The sum of the average annual dose for the first decade of operation was 226 rem at A-Reactor, and 438 rem at the chemical separation plant. Assuming a risk of 0.6×10^{-3} cancer fatalities/man-rem,[131] the average excess

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[129] "Kyshtym and Soviet Nuclear Materials Production," *Science and Global Security*, Vol. 1, Nos. 1-2 (1989), p. 174 [a fact sheet containing technical information collected during a visit to Chelyabinsk-40 by an NRDC/Soviet Academy of Sciences delegation July 7-8, 1989].

[130] Boris V. Nikipelov, Andri F. Lizlov, and Nina A. Koshurnikova, "Experience with the first Soviet Nuclear Installation," *Priroda*, February 1990 (English translation by Alexander Shlyakhter).

[131] National Research Council, *Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V)*, (Washington, D.C.: National Academy Press, 1990), p. 173 gives the excess cancer mortality estimate for male workers as 2,880/100,000 for continuous exposure to 1 rem/y from age 18 to age 65.

risk of cancer to a hypothetical worker receiving the average exposure each year during this ten year period is estimated to be 14 percent for a worker at A-Reactor, and 26 percent for a worker at the chemical separation plant.

Waste Management Activities: Some 600 million curies (MCi) of the long-lived fission products, Sr-90 and Cs-137, are estimated to have been produced through mid-1992, of which, following radioactive decay, some 460 MCi remain as of mid-1992.[132] When the activity of the daughter products, Y-90m and Ba-137m, are included these figures are doubled, i.e, some 1200 MCi having been produced and some 460 MCi remaining in mid-1992. By including other fission products and actinides it is reasonable to assume that there is on the order of 1000 MCi of radioactivity in storage and in the environment at Chelyabinsk-65. There is no accurate accounting of how much activity is in some storage locations even where figures are reported, because some reports fail to clarify what constituents are included in the totals, e.g. whether the inventories represent (Sr-90 + Cs-137), (Sr-90 + Y-90m + Cs-137 + Ba-137m), or total fission products.

In the first three years of operations, radioactive waste management at Chelyabinsk-65 was practically nonexistent. From 1949-1951, high-level waste from the chemical separation facility was discharged directly into the Techa River. By late-1951, after it was apparent that this was causing massive environmental contamination, the high-level waste was diverted into Lake Karachay. By 1953, a program was implemented whereby the solid fission products were precipitate out and stored in stainless steel waste tanks. Medium-level waste, containing Cs-137 and other fission products that remained in solution, continued to be discharged into Lake Karachay. One of the high-level waste tanks exploded in 1957, causing extensive off-site contamination. As a consequence the precipitation process was changed. Additional off-site contamination occurred in 1967, due to strong winds blowing radioactivity from the shore of Lake Karachay. In 1987, a small pilot plant began vitrifying high-level wastes. These highlights are discussed in more detail below.

Discharge of Waste into the Techa River: According to an official report, "During the first five years of the operation of the enterprise in this branch of industry there was no experience or scientific development of questions of protecting the health of the personnel or the environment. Therefore, during the fifties there was pollution of individual parts of the territory and around

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[132] This estimate is based on our estimate of the production reactor operating histories and the quantity of plutonium reported to have been recovered from reprocessing VVER and naval reactor fuel. We have 3 Ci Sr-90, and 3 Ci of Cs-137, per gram of Pu produced in production reactors; and 8 Ci Sr-90, and 8 Ci of Cs-137, per gram of Pu produced in VVERs (and naval reactors) (for an assumed VVER burnup = 20,000 Mwd/MT).

the enterprise."[133] These bland words actually mean that from its beginning in 1948 through September 1951, 76 million m^3 of high-level nuclear waste containing 2.75 MCi of beta activity from the radiochemical plant, was discharged directly into the Techa River 6 km below its source.[134] The Techa River is 240 km long, flowing into the Iset' River, which flows into the Tobol River. The extent of this river system is about 1000 km. The Tobol flows into the Irtysh which flows into the Arctic Ocean. As shown in Figure 2 the discharges into the Techa continued through 1956, although at a much reduced rate.[135] The composition of the radioactivity discharged into the Techa is also shown in Figure 2.[136]

A radiation survey, taken in the summer of 1951, revealed extensive contamination of the floodplain and bed of the Techa River and excessive exposure to the inhabitants if the region. Radioactivity was found as far away as the Arctic Ocean. A new solution was adopted in September 1951. Instead of discharging the radioactive waste into the Techa River, the wastes were diverted into Karachay Lake (see below), and a series of artificial reservoirs was created along the Techa to retain most of the activity already discharged.

Some 124 thousand people along the Techa-Iset'-Tobol River system were exposed to radioactivity, none having been warned about the danger.[137]

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[133] B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, N.S. Babaev, Yu.B. Kholina, and E.I. Mikerin, "Accident in the Southern Urals on 29 September 1957," International Atomic Energy Agency Information Circular, May 28, 1989, p. 1.

[134] N. I. Dubenyok, A.Sh. Liberman, and N.I. Mironova, "The Necessity for Independent Retrospective Ecological Expertise for the Zone of Radioactive Influence of the Military Industrial complex in the Chelyabinsk Region," paper presented at the First Soviet-American Conference for Ecological Non-Governmental Organizations, March 12-20, 1991, Moscow; and "Supreme Soviet Committees, Commissions Meet 5 Oct; Committee Views on Nuclear Pollution," *Moscow Domestic Service*, in Russian, at 1130 GMT, October 5, 1990 (translated in FBIS-SOV-90-195, October 9, 1990, pp. 35-36).

[135] M.M. Kosenko, M.O. Degteva, and M.A. Petrushova, "Leukemia Risk Estimate on the Base of Nuclear Incidents in Southern Urals," Chelyabinsk Branch Office of the Institute of Biophysics of the USSR Ministry of Health, Chelyabinsk, USSR (undated, ca. 1991), submitted to *PSR Quarterly* for publication.

The total release estimated from the figure is 2.6 MCi; approximately 98.7 percent released in the period 1949-1951, and 1.3 percent of the discharge (34 thousand Ci) occurred during the period 1952-1956.

[136] Strontium-90 (Sr-90) and cesium-137 (Cs-137) are produced in roughly equal amounts, 3 Ci of Sr-90 and 3 Ci of Cs-137 per gram of plutonium-239 (Pu-239) produced. Had there been any effort to concentrate the solid fission products in tanks during this period, the discharge into the Techa would have contained a much higher concentration of Cs-137, relative to Sr-90, which is not the case. The total Sr-90 and Cs-137 discharged through 1951, about 300 thousand Ci each, implies that 100 kg of plutonium were recovered during that period. This is consistent with the estimate of plutonium production at Chelyabinsk-65 during this period based on the reactor operation data (see Table 8).

[137] N. I. Dubenyok, A.Sh. Liberman, and N.I. Mironova, "The Necessity for Independent Retrospective Ecological Expertise for the Zone of Radioactive Influence of the Military Industrial complex in the Chelyabinsk Region," paper presented at the First Soviet-American Conference for Ecological Non-Governmental Organizations, March 12-20, 1991, Moscow.

Ninety-nine percent of the radioactivity that was dumped into the Techa was deposited within the first 35 km - downstream (Figure 3). Prior to the contamination there were 38 villages with 28 thousand people along the Techa riverside.[138] For many of the 28 thousand the river was the main source of drinking water. Some years later 7500 people in the upper reaches of the Techa were relocated. The others were transferred to underground sources of water supply, and radioactive floodplain was fenced off.[139] An epidemiological study of the 28,100 exposed individuals who received substantial external and internal radiation dose confirmed a statistically significant increase in leukemia morbidity and mortality.[140] The greatest exposure, estimated to be 1.64 Gray (164 rads) to the red bone marrow, was received by the 1200 inhabitants of the town of Metlino, 7 km downstream from the release point (Table 5).[141] Seventy-five hundred people from 20 other population centers received doses averaging from 3.5 to 170 rem.[142] Ten thousand people were evacuated,[143] and in other affected settlements people were supplied with water from other sources. The Techa River and all its floodlands (8000 hectares (ha)[144]) were excluded from use by people.

A cascade of five reservoirs (Lake Kyzyltash, or Numbers 2, and the artificial reservoirs 3, 4, 10, and 11, shown in Figure 1) were created along the Techa to isolate water from the most contaminated areas. The first dam was erected in 1951, the second in 1956, the third in 1963, and the fourth in 1964. The reservoirs, with a combined area of 84 km^2 and volume of 394 million m^3,

[138] M.M. Kosenko, M.O. Degteva, and M.A. Petrushova, "Leukemia Risk Estimate on the Base of Nuclear Incidents in Southern Urals," Chelyabinsk Branch Office of the Institute of Biophysics of the USSR Ministry of Health, Chelyabinsk, USSR (undated, ca. 1991), submitted to *PSR Quarterly* for publication.

[139] M.M. Kosenko, M.O. Degteva, and M.A. Petrushova, "Leukemia Risk Estimate on the Base of Nuclear Incidents in Southern Urals," Chelyabinsk Branch Office of the Institute of Biophysics of the USSR Ministry of Health, Chelyabinsk, USSR (undated, ca. 1991), submitted to *PSR Quarterly* for publication.

[140] Ibid.

[141] Ibid; and N. I. Dubenyok, A.Sh. Liberman, and N.I. Mironova, "The Necessity for Independent Retrospective Ecological Expertise for the Zone of Radioactive Influence of the Military Industrial complex in the Chelyabinsk Region," paper presented at the First Soviet-American Conference for Ecological Non-Governmental Organizations, March 12-20, 1991, Moscow.

[142] Ibid.

[143] Ibid.

[144] One hectare = 0.01 km^2 = 2.471 acres. Therefore, 8000 hectares = 80 km^2 = 20,000 acres = 30 mi^2.

now contain about 193 thousand Ci of Sr-90 and Cs-137 activity (Table 6). They reportedly "isolated about 98 percent of the radionuclides deposited in the flood-lands from the open hydrographic network."[145] The Asanovski marshes (or swamps), an area of 30 km^2 through which the Techa flows just below the last reservoir (No. 11), contains some 6000 Ci of Sr-90 and Cs-137.[146] These marshes are a constant open source of radioactivity, flowing into the Techa.[147]

Lake Karachay (Reservoir 9): As noted above, in September 1951, the Soviets curtailed the discharging the high-level or intermediate-level wastes directly into the Techa, and instead diverted it into Lake Karachay - at the time, a natural 45 ha (110 acres) lake with no outlet, and therefore, isolated from the Techa river hydrographic system.[148] The intermediate waste storage facility (discussed below) was not put into operation until 1953. Consequently, this practice must have continued for more than a year.

Since 1953, the Soviets have continued to discharge "medium-level waste" into Lake Karachay. Comparing the concentrations of cesium and strontium in the lake and the intermediate waste storage tanks, it appears that the precipated sludge, which included most of the strontium, was retained in the waste tanks, and the excess supernatant, which contained most of the cesium, was discharged from the waste tanks into the lake.[149] This is apparently still the practice in that today medium-level waste is still being added to the lake.[150]

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[145] B.V. Nikipelov, A.S. Nikiforov, O.L. Kedrovsky, M.V. Strakhov, and E.G. Drozhko, "Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes," (undated English translation ca. 1990).

[146] V.N. Chykanov, Y.G. Drozhko, A.P. Kuligin, G.A. Mesyats, A.N. Penyagin, A.V. Trapeznikov, and P.V. Bolbuev, "Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym," paper presented at the Conference on the Environmental Consequences of Nuclear Weapons Development, University of California, Irvine, April 11-14, 1991.

[147] "Resonance," Chelyabinsk, 1991.

[148] The lake was originally one-half mile long by one-fourth mile wide by 8 feet deep; Frank P. Falci, "Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, June 15-28, 1990," Office of Technology Development, DOE.

[149] The Soviets now classify liquid radioactive wastes as: low level - $<10^{-5}$ Ci/l; intermediate level - $>10^{-5}$ Ci/l and <1 Ci/l; and high level - >1 Ci/l. Solid wastes are classified as: low level - <0.3 mr/h; intermediate level - 0.3 to 10 mr/h; and high level - >10 mr/h, with the measurements in each case taken 10 cm from the surface.

[150] V.N. Chykanov, Y.G. Drozhko, A.P. Kuligin, G.A. Mesyats, A.N. Penyagin, A.V. Trapeznikov, and P.V. Bolbuev, "Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym," paper presented at the Conference on the Environmental Consequences of Nuclear Weapons Development, University of California, Irvine, April 11-14, 1991.

In the 1960s it was discovered that radioactivity from the lake was entering the ground water. Efforts to eliminate the reservoir began in 1967. The lake is now slowly being filled to reduce the dispersion of radioactivity. Hollow concrete blocks, one meter on a side with one side open, are first placed in the lake, then rock and soil are placed on top. The blocks keep the sediment from being pushed up to the surface. The three point program is to: (1) fill in the lake, (2) cover over the lake, and (3) pump and treat the water.[151] As of mid-October 1991, about 5000 blocks had been placed in into the lake. In June 1990, it was reported that the size of the lake still had shrunk to 25 ha (62 acres) and its volume to 400,000 m^3.[152] In October 1991 it was reported that the lake had been reduced in size to about 20 ha, down from its original size of 45 ha.[153] The plan is to completely fill the reservoir by 1995.

To date the lake has accumulated 120 MCi of the long-lived radionuclides Cs-137 (98 MCi) and Sr-90 (20 MCi).[154] This compares with 1 MCi of Cs-137 and 0.22 MCi of Sr-90 released from Chernobyl.[155] As shown in Table 6, under the entry Reservoir No. 9, 110 MCi (93 percent) of the accumulated activity is in ground deposits (about 35 percent in the loam screen of the reservoir bed (up to 4 m), and 60 percent in mobile deposits), with the remaining 8.4 MCi (7 percent) in the water.[156] The lake currently has a surface radiation exposure level of 3-4 rad/h.[157] When a visiting delegation approached within a few hundred feet of the water, the radiation

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[151] Frank P. Falci, "Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, June 15-28, 1990," Office of Technology Development, DOE.

[152] One m^3 = 264.1721 gallons (U.S.) and 1 acre-foot = 1233.482 m^3; therefore, 400,000 m^3 = 100 million gal. = 300 acre-feet.

[153] "Foreign Travel Report, Travel to Russia to Conduct Technology Exchange Workshops as part of the DOE U.S./U.S.S.R. Joint Coordinating Committee on Environmental Restoration and Waste Management," October 16-27, 1991, Trip Report For: Don J. Bradley, November 11, 1991.

[154] B.V. Nikipelov, A.S. Nikiforov, O.L. Kedrovsky, M.V. Strakhov, and E.G. Drozhko, "Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes," (undated English translation ca. 1990).

[155] State Committee for the Use of Atomic Energy of USSR, "The Accident at the Chernobyl AES and its Consequences," Prepared for the International Atomic Energy Agency Expert Conference, August 25-29, 1986, Vienna, (Translated by the U.S. Department of Energy, NE-40, August 17, 1986), Appendix 4, p. 21.

[156] B.V. Nikipelov, A.S. Nikiforov, O.L. Kedrovsky, M.V. Strakhov, and E.G. Drozhko, "Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes," (undated English translation ca. 1990).

[157] Frank P. Falci, "Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, June 15-28, 1990," Office of Technology Development, DOE.

reading in the bus reached 80 millirem/hour (mr/h).[158] A second delegation received 300-600 mr/h at a point about 10-12 m from the edge of the lake.[159] On the lake shore in winter the radiation dose is about 20 rems per hour, and summer about 18 rems per hour.[160] In the region near the discharge line, the radiation exposure rate is about 600 Roentgens per hour (R/h), sufficient to provide a lethal dose within an hour.[161]

In 1967, a hot summer followed a dry winter. The water evaporated and dust from the lake bed was blown over a vast area, up to 75 km long, affecting 41,000 people.[162] Some 600 Ci of Cs-137 and Sr-90 from the shores of Lake Karachay contaminated about 1800 to 2700 km^2, including the reactor site and portions under the radioactive plume from the 1957 accident at Kyshtym (discussed below).[163] The reactor site was contaminated with Cs-137 and Sr-90 in the ratio of 3:1 with Sr-90 contamination up to 10 Ci/km^2.[164]

As a result of over 40 years of dumping into Lake Karachay, radioactivity has seeped into the groundwater and migrated 2.5 to 3 km from the lake reaching the Mishelyak River. Radioactive groundwater flows under the river bed at a depth of 15 m. The total volume of groundwater is estimated to be

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158 Ibid.

159 "Foreign Travel Report, Travel to Russia to Conduct Technology Exchange Workshops as part of the DOE U.S./U.S.S.R. Joint Coordinating Committee on Environmental Restoration and Waste Management," October 16-27, 1991, Trip Report For: Don J. Bradley, November 11, 1991.

160 Gerard Sevestre, "USSR Nuke Testing Site Legacy," September 27, 1990, *The Greenbase*, 20:51:50 GMT.

161 B.V. Nikipelov, A.S. Nikiforov, O.L. Kedrovsky, M.V. Strakhov, and E.G. Drozhko, "Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes," (undated English translation ca. 1990). The radiation dose at which half the population would be expected to die (LD_{50}) depends upon a number of factors, including type of exposure, whether whole body or specific organ, the length of time of the exposure, the medical attention received after the exposure, etc. For whole body (or bone marrow) exposure, estimates of the LD_{50} range from 250 rem to 650 rem; see Rosalie Bertell, *Handbook for Estimating Health Effects from Exposure to Ionizing Radiation*, 2nd Edition, Revised, October 1986, p. 2; and J.S. Evans, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis," January 1990, NUREG/CR-4214, SAND85-7185, Rev. 1, Part 1, Table 2.3, p. I-17.

162 "Supreme Soviet Committees, Commissions Meet 5 Oct; Committee Views on Nuclear Pollution," Moscow Domestic Service in Russian at 1130 GMT, October 5, 1990 (English translation in FBIS-SOV-90-195, October 9, 1990, pp. 35-36).

163 B.V. Nikipelov, A.S. Nikiforov, O.L. Kedrovsky, M.V. Strakhov, and E.G. Drozhko, "Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes," (undated English translation ca. 1990) reports a contaminated area of 1800 km^2. "Resonance," Chelyabinsk, 1991, reports an area of 2700 km^2 contaminated in excess of 0.1 Ci/km^2 Sr-90 and in excess of 0.3 Ci/km^2 Cs-137.

164 B.V. Nikipelov, A.S. Nikiforov, O.L. Kedrovsky, M.V. Strakhov, and E.G. Drozhko, "Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes," (undated English translation ca. 1990).

over 4 million m^3, with a halo area of 10 km^2 and a depth to 100 m, containing in excess of 6,000 Ci of long-lived fission products.[165] The discharge of contaminated groundwater is 65 m^3/day (d), and the flow speed is 0.84 m/d.[166] The speed at which the contaminants move is:[167]

0.23 m/d (84 m/y) for Sr-90 and NO
0.14 m/d (51 m/y) for Co-60.

Lake Staroe Boloto (Old Swamp; Reservoir 17): Located 5 km northeast of Lake Karachay this 17 ha (42 acre) drainless lake, which has a volume of 35 thousand m^3, has accumulated 3 MCi of radioactivity.[168] Medium-level waste, including tritium, continues to be added to Staroe Boloto today.[169] The bottom of Lake Staroe Boloto sorbs most of the radionuclides more readily than that than the bottom of Karachay. Consequently, the contaminated halo is considerably smaller.[170]

Waste explosion in 1957: The so-called "Kyshtym Disaster" was the subject of considerable analysis and speculation in the West prior to 1989, when details of the accident were first revealed by the Soviet officials.[171] As noted above, during the initial period of operation of the chemical separation

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[165] Alexander Bolsunovsky, "Russian Nuclear Weapons Production and Environmental Pollution," paper presented at the Conference on "The Nonproliferation Predicament in the Former Soviet Union," Monterey Institute of International Studies, Monterey, California, April 8, 1992.

[166] Ibid.

[167] Ibid. The speed at which the contaminants move depends on a number of factors, including the flow velocity, dispersion rate, and the physical and chemical interactions with the rock.

[168] V.N. Chykanov, Y.G. Drozhko, A.P. Kuligin, G.A. Mesyats, A.N. Penyagin, A.V. Trapeznikov, and P.V. Bolbuev, "Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym," paper presented at the Conference on the Environmental Consequences of Nuclear Weapons Development, University of California, Irvine, April 11-14, 1991.

[169] Ibid.

[170] Alexander Bolsunovsky, "Russian Nuclear Weapons Production and Environmental Pollution," paper presented at the Conference on "The Nonproliferation Predicament in the Former Soviet Union," Monterey Institute of International Studies, Monterey, California, April 8, 1992.

[171] The first published reports of a Soviet nuclear accident are attributable to Zhores Aleksandrovich Medvedev, *New Scientist,* 1976, p. 264; 1977, p. 761; 1977, p. 352 (see also, *New Scientist,* 1976, p. 692; and *Nuclear Disaster in the Urals* [New York: W.W. Norton, 1979] [paperback edition, New York: Vintage Books, 1980]). The most comprehensive Western analyses of the Kyshtym Disaster are by John R. Trabalka, L. Dean Eyman, and Stanley I. Auerbach, "Analysis of the 1957-58 Soviet Nuclear Accident," Oak Ridge National Laboratory, ORNL-5613, December 1979 (subsequently published in condensed form in *Science,* July 18, 1980, pp. 345-352); Soran and Stillman, "An Analysis of the Alleged Kyshtym Disaster;" W. Stratton, D. Stillman, S. Barr, and H. Agnew, "Are Portions of the Urals Really Contaminated," *Science,* October 26, 1979, pp. 423-425; and Frank L. Parker, "Search of the Russian Scientific Literature for the Descriptions of the Medical Consequences of the Kyshtym 'Accident,'" Vanderbilt University, Battelle Project Management Division, ONWI-424, March 1983. Additional references to the Kyshtym accident and its consequences are cited in these documents.

plant, the irradiated fuel elements were treated by an "all-acetate precipitation scheme,"[172] resulting in high-level radioactive waste solutions containing as much as 100 grams per liter (g/l) of sodium nitrate and 80 g/l of sodium acetate.[173] The solution was stored for a year in tanks (presumably at what is referred to below as the intermediate storage facility) in order to reduce the radioactivity and cool prior to further treatment for additional extraction of plutonium and uranium.[174] After treatment, a portion of the solutions was returned to the storage tanks and the less active part was dumped into a "storage reservoir," (presumably Lake Karachay).[175]

The intermediate storage facility was put into operation in 1953.[176] It consisted of a rectangular buried stainless steel clad concrete canyon with walls 1.5 m thick, designed for installation of 20 stainless steel tanks at a depth of 8.2 m.[177] Called "permanent storage containers,"each tank was 300 cubic meters (m^3) (80,000 gal. (U.S.)) in volume.[178] The tanks, entirely immersed in water, utilized an external cooling system with water flowing through an annular gap between the tank walls and the trench.[179] Some of the instruments for monitoring the tanks failed and could not be repaired due to the high radiation field in the canyon.[180] As the solution in the tanks evaporated, the tanks gradually rose, breaking the seals in the waste transfer lines and contaminating the cooling water. The cooling water was treated in the same part of the plant used to process the waste. Because of insufficient production capacity the tanks were switched to a "periodic cooling mode."[181] The cooling system in one of the unmonitored tanks failed, however, and the waste

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[172] B.V. Nikipelov and Ye.G. Drozhko, "An Explosion in the Southern Urals," *Priroda*, May 1990, pp. 48-49; the technology for chemically separating the plutonium from radioactive fission products changed several times over the 40 year history of the chemical separation plant.

[173] B.V. Nikipelov and Ye.G. Drozhko, "An Explosion in the Southern Urals," *Priroda*, May 1990, p. 48.

[174] Ibid.

[175] Ibid.

[176] Ibid.

[177] Ibid. *Nuclear News*, January 1990, p. 74 says "one of 16 steel tanks" exploded, rather than one of 20. Donald Wodrich, a member of the DOE delegation that traveled to Chelyabinsk-40 in June 1990, reported 16 tanks; "USSR 1957 Waste Tank Explosion at Kyshtym," viewgraphs from presentation by Don Wodrich, Westinghouse Hanford Company, to the Advisory Committee on Nuclear Safety, October 31, 1990.

[178] "Hearing in Committee on Preparation of Law on Nuclear Safety: 1957 Accident" *Moscow Home Service*, (SU/0519i), 1200 GMT, July 25, 1989.

[179] B.V. Nikipelov and Ye.G. Drozhko, "Explosion in the Southern Urals," *Priroda*, May 1990, pp. 48-49.

[180] Ibid.

[181] Ibid.

began to dry out. Nitrates and acetates in the waste precipitated, heated up to 350°C (660 °F), and on September 29, 1957 at 4:20 PM local time, exploded[182] with a force equivalent to 5 to 10 tons of TNT.[183] The meter-thick concrete lid was blown off and hurled 25 meters away, and 70-80 MT of waste containing some 20 MCi of radioactivity were ejected.[184]

The composition of the ejected waste is given in Table 7.[185] About 90 percent of the activity fell out in the immediate vicinity of the vessel. The remaining, approximately 2.1 mCi formed a kilometer-high radioactive cloud that was carried through Chelyabinsk, Sverdlovsk, and Tumensk Oblasts reaching the neighborhood of Kamensk-Uralskiy after 4 hours, and Tyman after 11 hours.[186] The Kaslinsky, Kunashaksky, and Argayashsky regions of the Chelyabinsk Oblast received the greatest off-site contamination. The contaminated territories were subsequently given the name, "East Ural Radioactive Trace (VURS)." Some 15,000-23,000 km^2, in a track 300 km in length and 10-15 km wide, were contaminated at a level greater than 0.1 Ci/km^2 (Sr-90);[187] 1000 km^2 in a track 105 km in length and 8-9 km wide were contaminated at a level greater than 2 Ci/km^2 (Sr-90); and 17 km^2 contaminated to 1000-4000 Ci/km^2 (Sr-90) (see Table 8 and Figure 2).[188]

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[182] B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, N.S. Babaev, Yu.B. Kholina, and E.I. Mikerin, "Accident in the Southern Urals on 29 September 1957," International Atomic Energy Agency Information Circular, May 28, 1989; B.V. Nikipelov and Ye.G. Drozhko, "An Explosion in the Southern Urals," *Priroda*, May 1990, p. 48.

[183] Frank P. Falci, "Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, June 15-28, 1990," Office of Technology Development, DOE. *Nuclear News*, January 1990, pp. 74-75, reported the explosion was equivalent to 70 to 100 tons of TNT.

[184] B.V. Nikipelov and Ye.G. Drozhko, "An Explosion in the Southern Urals," *Priroda*, May 1990, p. 48. Two adjacent tanks were also damaged; *Nuclear News*, January 1990, pp. 74-75.

[185] When the high-level waste is neutralized most of the fission products and actinides, except cesium, precipitate out as a sludge. The high ratio of strontium-90 to cesium-137 in the tank, equal to 75, suggests that the supernatant containing most of the cesium had been discharged, apparently discharged into Lake Karachay where the ratio of cesium-137 to strontium-90 is 5 (see Table 2).

[186] G.N. Romanov and A.S. Vorovov, "The Radiation Situation After the Explosion," *Priroda*, May 1990, p. 50; B.V. Nikipelov and Ye.G. Drozhko, "An Explosion in the Southern Urals," *Priroda*, May 1990, p. 48; B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, N.S. Babaev, Yu.B. Kholina, and E.I. Mikerin, "Accident in the Southern Urals on 29 September 1957," International Atomic Energy Agency Information Circular, May 28, 1989; "Hearing in Committee on Preparation of Law on Nuclear Safety: 1957 Accident" *Moscow Home Service*, (SU/0519i), 1200 GMT, July 25, 1989; "A Nuclear Deadlock: Can a Nuclear Power Plant Save Us from Radioactive Contamination," *Sovietskaya Rossiya*, November 21, 1989, 2nd Edition.

[187] The 0.1 Ci/km^2 (Sr-90) level is about twice the Sr-90 level from fallout from atmospheric weapons testing before the accident.

[188] G.N. Romanov and A.S. Vorovov, "The Radiation Situation After the Explosion," *Priroda*, May 1990, p. 50.

(The Sr-90 integrated deposition density from all atmospheric nuclear weapons testing is 0.08 Ci/km^2 at this latitude.[189]) Since Sr-90 (beta activity) comprised only 2.7 percent of the total (beta and gamma) activity initially, the total activity levels were 40 times higher immediately after the accident, and four times higher after three years, than they are today (33.5 years later). The highest contamination level, 4000 Ci/km (Sr-90) at the head of the trace immediately after the accident, correspond to 150,000 Ci/km^2 (all activity). Radiation levels within 100 m of the crater exceeded 400 R/h. At a kilometer the levels were 20 R/h, and at 3 km the levels were 3 R/h.[190] Guards received the largest reported dose, about 100 R. During the initial period the external gamma dose rate was about 150 microroentgens per hour ($\mu R/h$) (equivalent to 1.3 R/year) in open areas where the Sr-90 contamination was 1 Ci/km^2.[191] The external gamma dose levels were two to three times higher in forests where up to 90 percent of activity was initially held up in the crowns of the trees.[192] After about 3 years of radioactive decay, Sr-90 was the dominant isotope with respect to contamination and exposure. Today, Sr-90 comprises 99.3 percent of the residual radioactivity from the accident, and Cs-137 comprises 0.7 percent.

In a 20 km^2 area where the contamination exceeded 180 Ci/km^2 the pine needles received 3000-4000 rads in the first year, and all the pine trees perished by the autumn or 1959.[193]

There were 217 towns and villages with a combined population of 270,000 inside the 15,000-23,000 km^2 (6000-9000 mi^2) area contaminated to 0.1 Ci/km^2 (Sr-90) or greater; 10,000 people within 1000 km^2 contaminated to greater than 2 Ci/km^2 (Sr-90); and 2100 people in within 120 km^2 contaminat-

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[189] United Nations Scientific Committee on the Effects of Atomic Radiation, "Ionizing Radiation: Sources and Biological Effects," 1982 Report to the General Assembly, with annexes, United Nations, New York, Table 6, p. 230. Strontium-90 decays by beta emission with a half-life of 28.6 years. Strontium has chemical properties similar to calcium.

[190] B.V. Nikipelov, A.S. Nikiforov, O.L. Kedrovsky, M.V. Strakhov, and E.G. Drozhko, "Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes," (undated English translation ca. 1990).

[191] G.N. Romanov and A.S. Vorovov, "The Radiation Situation After the Explosion," *Priroda*, May 1990, p. 50; B.V. Nikipelov and Ye.G. Drozhko, "An Explosion in the Southern Urals," *Priroda*, May 1990, p. 48; B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, N.S. Babaev, Yu.B. Kholina, and E.I. Mikerin, "Accident in the Southern Urals on 29 September 1957," International Atomic Energy Agency Information Circular, May 28, 1989.

[192] G.N. Romanov and A.S. Vorovov, "The Radiation Situation After the Explosion," *Priroda*, May 1990, p. 50.

[193] D.A. Spirin, E.G. Smirnov, L.I. Suvornova, and F.A. Tikhomirov, "Radioactive Impact on Living Nature," *Priroda*, May 1990, p. 59.

ed to greater than 100 Ci/km^2 (Sr-90).[194] Virtually all water supply sources were contaminated. Calculations indicated that the cumulative dose over the first month for the three most contaminated villages, Berdyanish, Saltikovka, and Galikaeva, would range from 150 rads to about 300 rads.[195] These three villages, in which 1054 people lived, were evacuated, but not until 7-10 days after the accident.[196] The average dose received before evacuation reached 17 rems from external radiation and 52 rems of equivalent effective dose (150 rem to the gastrointestinal tract).[197]

The next wave of evacuations began about eight months after the accident, involved 6500 people from areas where the Sr-90 contamination exceeded 4 Ci/km^2.[198] These people consumed contaminated foods for three to six months without restriction and continued to consume some contaminated food until their evacuation. Some 280 people in areas with average contamination of 65 Ci/km^2 (Sr-90) received (before evacuation was completed 250 days after the accident) 14 rems from external radiation and 44 rems of

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[194] G.N. Romanov and A.S. Vorovov, "The Radiation Situation After the Explosion," *Priroda*, May 1990, p. 50; B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, N.S. Babaev, Yu.B. Kholina, and E.I. Mikerin, "Accident in the Southern Urals on 29 September 1957," International Atomic Energy Agency Information Circular, May 28, 1989, p. 10; A.I. Burnazyana, editor, "Results of Study and Experience in the Elimination of the Consequences of Accidental Contamination by Fission Products," *Energiya: Ekonomika, Teknika, Ekologiya*, No. 1, January 1990, p. 51.

[195] A.I. Burnazyana, editor, "Results of Study and Experience in the Elimination of the Consequences of Accidental Contamination by Fission Products," *Energiya: Ekonomika, Teknika, Ekologiya*, No. 1, February 1990, p. 14. The names of the villages are from N. I. Dubenyok, A.Sh. Liberman, and N.I. Mironova, "The Necessity for Independent Retrospective Ecological Expertise for the Zone of Radioactive Influence of the Military Industrial complex in the Chelyabinsk Region," paper presented at the First Soviet-American Conference for Ecological Non-Governmental Organizations, March 12-20, 1991, Moscow.

[196] V.N. Chykanov, Y.G. Drozhko, A.P. Kuligin, G.A. Mesyats, A.N. Penyagin, A.V. Trapeznikov, and P.V. Bolbuev, "Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym," paper presented at the Conference on the Environmental Consequences of Nuclear Weapons Development, University of California, Irvine, April 11-14, 1991. G.N. Romanov, L.A. Buldakov and V.L. Shvedov, "Irradiation of the Population and the Medical Consequences of the Explosion," *Priroda*, May 1990, p. 64 gives the size of the population evacuated in 7-10 days as 1150 people and the average contamination density as 500 Ci/km^2. B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, N.S. Babaev, Yu.B. Kholina, and E.I. Mikerin, "Accident in the Southern Urals on 29 September 1957," International Atomic Energy Agency Information Circular, May 28, 1989, in Table 4, gives the size of the population evacuated in 7-10 days as 600 people and the average contamination density as 500 Ci/km^2 (Sr-90). N. I. Dubenyok, et al., *op. cit.*, gives 1055 people in the three villages; A.I. Burnazyana, *Energiya: Ekonomika, Teknika, Ekologiya*, January 1990, p. 52, reports 1500 inhabitants in the area, and in February 1990, p. 14, reports 1100 inhabitants evacuated in 7-10 days.

[197] G.N. Romanov, L.A. Buldakov and V.L. Shvedov, "Irradiation of the Population and the Medical Consequences of the Explosion," *Priroda*, May 1990, p. 64; B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, N.S. Babaev, Yu.B. Kholina, and E.I. Mikerin, "Accident in the Southern Urals on 29 September 1957," International Atomic Energy Agency Information Circular, May 28, 1989, Table 4.

[198] Ibid.

equivalent effective dose; an additional 2000 people in areas .[199] In all, inhabitants of 23 villages,[200] about 10,700 people, were evacuated from areas having contamination levels greater than 2 Ci/km^2 (Sr-90).[201]

The 1957 harvest, contaminated with radionuclides, was eaten by the population.[202] By 1959 all areas contaminated in excess of 2 Ci/km^2 were subject to special sanitary protection regulations.[203] In 1962, this "sanitary alienation zone" was reduced in size to 220 km^2.[204] In 1958-1959, about 20,000 ha (80 mi^2) of agricultural land at the head of the cloud track were ploughed under, and in 1960-1961 an additional 6200 ha (25 mi^2).[205] In 1958, 106,000 ha (410 mi^2) of land were removed from agricultural use in Chelyabinsk and Sverdlovsk Oblasts.[206] By 1961, all the land in Sverdlovsk, 47,000 ha (180 mi^2) were returned to agriculture; and by 1978, 40,000 ha (150 mi^2) out of 59,000 ha (230 mi^2) in Chelyabinsk were returned to use.[207]

In experimental study areas where the ground was not ploughed under, in the first two years 90 percent of the Sr-90 was concentrated in the upper 2 cm of soil. By 1988, 84-94 percent of the Sr-90 was concentrated in the upper 10 cm of soil. Transport by wind and water runoff have reduced the Sr-

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[199] Ibid; an additional 2000 people where the average contamination density was 18 Ci (Sr-90)/km^2 received 3.9 rem external dose, and 12 rem effective dose equivalent, before evacuation was completed 250 days after the accident; 4200 people where the average contamination density was 8.9 Ci (Sr-90)/km^2 received 1.9 rem external dose, and 5.6 rem effective dose equivalent, before evacuation was completed 330 days after the accident; and 3100 people where the average contamination density was 3.3 Ci (Sr-90)/km^2 received 0.68 rem external dose, and 2.3 rem effective dose equivalent, before evacuation was completed 670 days after the accident.

[200] "Hearing in Committee on Preparation of Law on Nuclear Safety: 1957 Accident" *Moscow Home Service*, (SU/0519i), 1200 GMT, July 25, 1989.

[201] Ibid.

[202] N. I. Dubenyok, A.Sh. Liberman, and N.I. Mironova, "The Necessity for Independent Retrospective Ecological Expertise for the Zone of Radioactive Influence of the Military Industrial complex in the Chelyabinsk Region," paper presented at the First Soviet-American Conference for Ecological Non-Governmental Organizations, March 12-20, 1991, Moscow.

[203] G.N. Romanov, L.A. Buldakov and V.L. Shvedov, "Irradiation of the Population and the Medical Consequences of the Explosion," *Priroda*, May 1990, pp. 64-67; B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, N.S. Babaev, Yu.B. Kholina, and E.I. Mikerin, "Accident in the Southern Urals on 29 September 1957," International Atomic Energy Agency Information Circular, May 28, 1989.

[204] Ibid.

[205] Ibid.

[206] Ibid.

[207] Ibid.

90 exponentially with a half-life of 4-5 years.[208]

One-fifth of the people living in the areas with a contamination greater than 2 Ci/km^2 showed reduced leukocytes in the blood, and, in rare cases, thrombocyte levels also were reduced. No deviations in the incidence of diseases of the blood and in the incidence of malignant tumors have been registered according to Soviet investigators.[209] The combined collective effective dose commitment of the evacuated population prior to evacuation was approximately 130,000 person-rem; and the collective effective dose commitment of those persons that were not evacuated was 450,000 person-rem.[210] Over their lifetimes the collective radiation exposure from this accidental release could result in as many as 1000 additional cancers in the population.[211]

High-Level Waste Tanks: In the early years the practice of managing high-level waste involved the production of nitrate acetate solutions, which upon drying yielded an explosive similar to gun powder; and, as noted above, one of the waste tanks in fact exploded in 1957. The current procedure for handling high-level waste involves first evaporation and then fixation in sparingly soluble compounds, i.e. hydroxide and ferrocyanide compounds. The concentrated waste are stored in instrumented single shell stainless steel storage tanks housed in metal-lined reinforced concrete canyons. It was reported in 1991 that not less than 976 MCi of radioactive waste is kept in storage in solutions. Elsewhere it has been reported that a 1990 inventory indicated that there are 546 m Ci of "radioactive solutions and deposits," including (note sum is 528 m Ci):[212]

374 m Ci	sodium nitrate solution
149 m Ci	hydroxide and ferrocynide
4.9 m Ci	sediments (pulp).

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[208] G.N. Romanov, D.A. Spirin, and R.M. Alexahin, "Sr-90 Migration Peculiarities in the Environment," 1991. Paper presented to the US DOE Delegation, October 21, 1991.

[209] Ibid.

[210] V.N. Chykanov, Y.G. Drozhko, A.P. Kuligin, G.A. Mesyats, A.N. Penyagin, A.V. Trapeznikov, and Bolbuev, "Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym," paper presented at the Conference on the Environmental Consequences of Nuclear Weapons Development, University of California, Irvine, April 11-14, 1991.

[211] This assumes one cancer fatality per 1000 person-rem, and two cancers incurred per cancer fatality.

[212] "Material of the Commission to Investigate the Ecological Situation of the Chelyabinsk Region," Commission formed President Gorbachev's order RP-1283, January 3, 1991; cited by Alexander Bolsunovsky, "Russian Nuclear Weapons Production and Environmental Pollution," paper presented at the Conference on "The Nonproliferation Predicament in the Former Soviet Union," Monterey Institute of International Studies, Monterey, California, April 8, 1992.

At the time of this survey a small portion of the wastes (4 m Ci) has been vitrified. These data are consistent with other sources that indicate that there are some 150 million curies (MCi) (a volume of 20,000 m^3) of high-level radioactive waste sediments stored in approximately 60 single-walled steel tanks.[213] Alexander Penyagin is reported to have said there are a total of 99 waste tanks at Mayak.

Waste Vitrification: In the mid-1950s the Soviets began to develop techniques for transforming liquid radioactive wastes into a solids with radionuclide fixation in stable matrixes suitable for long-term safe storage. Preference was given to vitrification (i.e., preparation of glass-like materials), and development proceeded in two directions: (a) two-stage vitrification with waste calcination at the first stage; and (b) a large development effort, the so-called single-stage method of preparing phosphate and borosilicate glass-like materials in a ceramic melter without preliminary calcination. In the latter case dehydration, calcination of wastes, and their melting with fluxing additions are conducted in one apparatus, where (the zone of glass-like melt) liquid high-level wastes and fluxing agents are added directly. For obtaining phosphate glass the orthophosphoric acid is added as a fluxing agent and for borosilicate glass the boron-containing mineral-datolite is added. The heating of glass-like melt is carried out by conducting alternating current through the glass melt. Despite the bulky technological flowsheet, the technique of single-stage vitrification is characterized by high capacity and allows the high alkali metal salt-containing wastes to be processed.[214]

The Soviets developed a process for extracting Sr-90 from acidic high level waste using a crown-ether based extractant, and 1.5 million curies have been extracted.[215]

The Chelyabinsk-65 vitrification program began in 1967. After almost 10 years of testings carried out in a 100 l/h facility using model solutions, in 1986 a 500 liter/hour (l/h) vitrification facility for liquid high-active solutions was put into operation at Chelyabinsk-65. The process, still in use, is based on

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[213] V.N. Chykanov, Y.G. Drozhko, A.P. Kuligin, G.A. Mesyats, A.N. Penyagin, A.V. Trapeznikov, and P.V. Bolbuev, "Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym," paper presented at the Conference on the Environmental Consequences of Nuclear Weapons Development, University of California, Irvine, April 11-14, 1991; and Falci, Frank P., "Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, June 15-28, 1990," Office of Technology Development, DOE.

[214] E.G. Drozhko, B.V. Nikipelov, A.S. Nikiforov, A.P. Suslov, and A.F. Tsarenko, "Experience in Radioactive Waste Management at the Soviet Radiochemical Plant and the Main Approaches to Waste Reliable Confinement Development," Ministry of Nuclear Power Engineering and Industry, (undated English translation ca. 1990).

[215] Frank P. Falci, "Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, June 15-28, 1990," Office of Technology Development, DOE.

radionuclide introduction into phosphate glass, prepared in a ceramic melter made of high-alumina zirconium refractory material with molybdenum electrodes. Orthophosphoric acid is used as a fluxing addition. Vitrified wastes are poured through special drains into 0.2 m^3 vessels. After cooling three such vessels are placed into metal containers (0.63 m diameter, 3.4 m height).[216] The first liquid-fed, ceramic melter, which was placed in operation in 1986, ran for 13 months before the electrode failed due to a very high current load (2000 amperes). Contents of the melter were spilled onto the building floor. The furnace was decommissioned in February 1987. Maximum output was 90 kg/hr of glass. About 162 MT of phosphate glass (998 m^3) containing 3.97 million Ci was poured into 366 canisters.[217] The aluminum-carrying waste were from reprocessing highly enriched fuel elements of the BM type.[218] The furnace was too large (30' long x 13' wide x 10' high) to be removed. A second similar furnace was constructed in the same building. Testing began in December of 1990, and after six months vitrification was resumed on June 25, 1991. As of October 1, 1991, 440 m^3 of high-level waste solution was processed, producing 88 MT of glass containing 13 MCi of activity. Initially, the waste solution was from reprocessing high-enriched BN type fuel, and then a mixture of waste from processing BN and VVER fuel.

In May 1992 it was reported that 60 MCi had been vitrified. The production capacity of the plant is now 1 MT/d. Originally, the concentration of radioactivity was 100 Ci/l (50 Ci/kg); currently 400 Ci/l is achieved.[219]

The glass blocks, after being placed into metal containers, are put into surface storage, equipped with a forced system of air cooling and with a powerful gas-purification system. Permanent temperature and gas control of the containers will be carried out by air cooling the canisters for 20-30 years,

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[216] E.G. Drozhko, B.V. Nikipelov, A.S. Nikiforov, A.P. Suslov, and A.F. Tsarenko, "Experience in Radioactive Waste Management at the Soviet Radiochemical Plant and the Main Approaches to Waste Reliable Confinement Development," Ministry of Nuclear Power Engineering and Industry, (undated English translation ca. 1990).

[217] Frank P. Falci, "Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, June 15-28, 1990," Office of Technology Development, DOE. According to E.G. Drozhko, B.V. Nikipelov, A.S. Nikiforov, A.P. Suslov, and A.F. Tsarenko, "Experience in Radioactive Waste Management at the Soviet Radiochemical Plant and the Main Approaches to Waste Reliable Confinement Development," Ministry of Nuclear Power Engineering and Industry, (undated English translation ca. 1990), "About 1000 m^3 high active solutions, containing $3.9x10^6$ Ci of total activity, was vitrified during 1987-1988. The total weight of the obtained glass blocks has constituted 160 metric tons."

[218] "Foreign Travel Report, Travel to Russia to Conduct Technology Exchange Workshops as part of the DOE U.S./U.S.S.R. Joint Coordinating Committee on Environmental Restoration and Waste Management," October 16-27, 1991, Trip Report For: Don J. Bradley, November 11, 1991.

[219] Oleg Bukharin, notes taken at meeting with Evgeny Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992.

after which the Soviet plan is to bury the waste in a granite or salt formation. The government has been looking in the region of the Urals for a possible granite site, and are experiencing public opposition.

Solid Waste Burial:[220] There are 227 solid waste burial sites (about 25 still functional) comprising total area of about 30 ha, with the burials themselves occupying 21.3 ha (Table 9). The sites contain some 500 thousand MT of waste with 12 MCi of activity.[221] The burial sites for low-level and medium-level solid radioactive waste are trenches dug in the soil. As soon as the trenches are filled with wastes they are covered with waterproof soil. Burials sites usually are located where the water table is greater than four metres below the bottom of the burial. The bottom and the walls are made "waterproof" with a layer of clay. Radionuclides can migrate from burial sites due to infiltrating atmospheric precipitation (while filling the burial before the waste is covered); and can also migrate in the water-bearing horizon, and diffuse in moist soil.

High-level solid radioactive wastes are placed in reinforced concrete structures with multiple waterproofing -- with bitumen, stainless steel, concrete. Radionuclide migration is also prevented by the clay soil coating the bottom and the walls of the container. Only these high-level radioactive waste structures are equipped with instrumentation and a signalling system. The trench-like burials have no instrumentation.

Nearly all of solid production wastes are dumped without being processed due to the lack of well-developed installations for burning, compaction, deactivation, melting. The large number of burial sites is explained by the fact that originally every plant had, and still has, its own burial sites for each kind of waste. The dumping was organized according to the following principle -- the distance between the production site and the burial site for solid waste must be reduced to the minimum.

Contamination Today: Since 1949 Mayak has discharged in excess of 154 MCi of long-lived radionuclides (Sr-90 and Cs-135) into the environment, contaminating in excess of 26,700 km^2, and exposing more than 437,000 people, making the Chelyabinsk-65 environs arguably the most polluted spot on the planet. Parts of the Chelyabinsk-65 site have a dose rate of up to 15 milliR/h. The average value for the remainder of the site is in the range of 10 to 30 μR/h. The Techa River is cordoned off with a wire fence and people are forbidden to catch fish, pick mushrooms or berries, or cut the hay. There are

[220] Alexander Bolsunovsky, "Russian Nuclear Weapons Production and Environmental Pollution," paper presented at the Conference on "The Nonproliferation Predicament in the Former Soviet Union," Monterey Institute of International Studies, Monterey, California, April 8, 1992.

[221] "Resonance,' Chelyabinsk, 1991.

340 million m^3 of radioactive water in open reservoirs. Fish in Reservoir No. 10 are reported to be "100 times more radioactive than normal."[222]

The production complex, by consuming contaminated water for its needs, regulates the water level in the lakes. With four reactors shut down and a fifth to close, a new danger has been identified — overfilling the reservoirs with natural water and possibly even failure of the dams, sending contaminated water into the rivers of the Ob basin. The South Urals nuclear power station was to avert this sort of catastrophe by using radioactive water to cool turbine condensers, thus increasing evaporation.[223] But, as noted above, the South Urals project may never be completed.

The Siberian Chemical Combine (Tomsk-7, Seversk)

The Siberian Chemical Combine (Sibkhimkombinat) at Tomsk-7 was founded in 1954 on the Tom River, 15 km northwest of Tomsk. The closed city of Seversk (population 107,700) is a satellite town of Tomsk.[224] Tomsk, itself has about 500,000 inhabitants. Tomsk-7 occupies an area greater than 20,000 hectares.[225] It is the site of the Siberian Atomic Power Station, a chemical separation plant, facilities for plutonium processing and blending and pit fabrication, an enrichment plant, and nuclear waste management facilities.[226] The Siberian Atomic Power Station houses five graphite-moderated dual-purpose reactors, two of which have been shut down as of the end-1991, and a third to be shut down in 1992.[227] Additional power is also provided by a fossil fueled plant.[228] The Ministry of Atomic Energy proposes to construct at Tomsk-7, a large facility for storage of fissile material recovered from retired warheads.

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[222] *Nucleonics Week*, July 26, 1990, p. 11.

[223] "Chain Reaction of Wastefulness - Do We Need the South Urals AES?," *Sovietskaya Rossiya*, December 24, 1989.

[224] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, November 17, 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, November 21, 1991, p.3.); *Izvestiya*, May 4, 1990, morning edition, p. 6 (Translated in *FBIS*, London UK, Serial: PM0405112290); Moscow Central Television First Program Network in Russian, in its Vremya Newscast at 1530 GMT, January 2, 1991 (Translated in *FBIS*, London UK, Serial: LD0201170891); and "Open Deal in a Closed City,"*Isvestiya*, January 25, 1991, Union Edition, p. 2 (Translated in *FBIS*, London UK, R 251109Z Jan 1991).

[225] V. Kostyukovskiy, et al., "Secrets of a Closed City," *Moscow Izvestiya*, Union Edition, August 2, 1991 (in Russian), (translated in JPRS-TEN-91-018, October 11, 1991, pp. 71-72).

[226] The reactor site near Tomsk is located at 56° 37'N 84° 47'E.

[227] The current (1990) head of the station is named Meshceryakov.

[228] The smoke plume from this plant can be seen in LANDSAT images.

The director of the Siberian Chemical Combine (in 1991) is G. Khandorin.

Siberian Atomic Power Station: The first of the five reactors is reported to have come on line in September 1958;[229] the second in December 1959; and subsequent ones spaced about a year apart. In 1955, at the Second International Conference on Peaceful Uses of Atomic Energy, the Soviets described the nuclear reactors at this station as being solely for electric power generation.[230] In 1981, A.M. Petrosyants, then Chairman of the State Committee for Utilization of Atomic Energy, admitted that these reactors served a dual purpose—plutonium production for warheads and power generation.[231] Not until May 4, 1990 did the Soviets reveal that the reactors were at Tomsk, supplying energy to the Siberian Chemical Combine and heat to agricultural complexes and housing.[232]

The reactors, as described in 1955 and 1958, are graphite-moderated. water-cooled, and have 2,101 channels. Thus, they are slightly larger than the reactor shut down in 1989 at the Chelyabinsk-65 complex. In 1964, it was reported that the station had exceeded its design capacity of 600 megawatts-electric (Mw_e), and in 1979 it was reported that "the capacity of this nuclear power station considerably exceeds 600,000 kw [kilowatts]."[233] Western sources always describe it as now consisting of six 100 Mw_e units, and this appears to have been the original intention. But there are only five units and according to Aleksandrov, the second unit was 200 Mw_e.[234] Subsequent units were probably even larger, and the power output of all units was probably increased significantly over time.[235] The reactors operate use once through cooling judging by the high concentration of neutron activation products in the

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[229] In September 1958, a brief announcement in *Pravda* revealed that the first stage of a second atomic power station (following the 5 megawatt-electric (Mw_e) experimental installation at Obninsk) had entered service, and that its eventual capacity would reach 600 Mw_e.

[230] A film of the new station was shown to delegates at the conference, then in session, and it was disclosed that its location was in Siberia.

[231] A.M. Petrosyants, *Nuclear Energy*, (Moscow: 1981), p. 13.

[232] *Izvestiya*, May 4, 1990, morning edition, p. 6 (Translated in *FBIS*, London UK, Serial: PM0405112290).

[233] A. M. Petrosy'ants, *Problems of Nuclear Science and Technology*, 4th ed., translated from the Russian by W. E. Jones (Oxford: Pergamon Press, 1981), p. 103.

[234] *Kommunist*, No. 1, 1976, p. 65.

[235] By comparison, in the U.S. program at Hanford the first four graphite reactors, B, D, F, and DR, which began operating between 1944 and 1950, had a design power level of 250 Mw_t; the next two, H and C, which came on line in 1948 and 1951, had design power levels of 400 and 600 Mw_t, respectively; and the last two, KE and KW, were initially rated at 1850 Mw_t at startup in 1952 and 1953. By 1964 the rating of these eight reactors had been increased to between 2090 and 4400 Mw_t; see Thomas B. Cochran, et al., *Nuclear Weapons Databook*, Vol. II, p. 61.

Tom River.

On August 21 and December 31, 1990, the first two of the five Tomsk-7 reactors was shut down, respectively.[236] In announcing the shut down of the first, *Tass* reported "The Siberian Atomic Station is working its last few months and soon another reactor will be shut down. As a result it is said that the amount of harmful effluent going into the Tom River will be halved."[237] The Collegium of Gosatomnadzor (GAN), Russia's atomic energy inspectorate, has directed that a third reactor at Tomsk-7 be shut down this year, in 1992.[238] In 1992 it was reported that the "reactors are producing 40% heat and electricity for Tomsk. There are proposals to construct AST reactors in Tomsk."[239]

Chemical Separation Plant: The chemical separation and fuel storage facilities probably date from the mid-1950s when the reactors went on line. The separation (or reprocessing) plant is used to chemically separate the plutonium from the highly radioactive fission products contained in the irradiated reactor fuel elements. As noted above, in 1978 the Soviets initiated an extensive program of civilian fuel reprocessing and shifted the Chelyabinsk-65 separation plant operations from military to civilian operations. As a result, the Tomsk separation plant began receiving by rail the military production reactor fuel from Chelyabinsk-65 for processing.[240] Presumably these shipments have ceased now that the production reactors at Chelyabinsk-65 are no longer operating. Current plans are to continue to process the fuel from the two remaining (after 1992) production reactors at Tomsk-7.[241]

Plutonium Processing: In the 1960s blending of plutonium of different isotopic concentrations took place at Plant 5 and was transferred to Plant 25, as evidenced by more recent criticisms of plant activities at these plants.[242] A former employee of Plant 25 has alleged that in 1967, management officials at Plant 25 falsified plutonium blending ratios, apparently creating a

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236 "Siberian Atomic Reactor Closes," *Moscow Tass*, International Service in Russian, August, 21, 1990, 1449 GMT.

237 Ibid.

238 Khots, Yuriy, "Plutonium-Producing Reactors in Krasnoyarsk to be Shut Down," *Moscow ITAR-Tass World Service*, in Russian, May 19, 1992, 1352 GMT.

239 Oleg Bukharin, notes taken at meeting with Evgeny Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992.

240 Christopher Paine, "Military Reactors Go on Show to American Visitors," *New Scientist*, July 22, 1989, p. 22.

241 Oleg Bukharin, notes taken at meeting with Evgeny Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992.

242 L.V. Stryapshin, "'We Need Independent Assessments," Tomsk-37, July 8, 1991.

"fictitious" inventory of plutonium. "[I]n a ten-month period, about 90 kg of 'fictitious' plutonium oxalate 'piled up' at the Shop 1 warehouse." According to the same source, management officials at Plants 25 and 15 decided cover up the problem by transferring the "fictitious" plutonium to Plant 15 for "purification." "In this operation only 50-60 kg of pure plutonium were manipulated, and several hundred kilograms of plutonium plus several tons of HEU were dumped by Plant 25 into its reservoir."[243]

Waste Management Activities: During the 30-year operation of the plant, about 127,000 tons of solid and about 33 million m^3 of liquid radioactive wastes have been collected in underground storage facilities.[244] "The Sibkhimkombinat (Siberian Chemical Combine) burial sites are located 10-20 km from the river Tom. At these sites radioactive wastes of unknown quantity and concentration have been pumped into sandy beds at a depth of 220-360 meters. In the immediate area of the burial sites the beds are covered with uniform, water-resistant clay strata; however, throughout the region as a whole these strata can thin out."[245]

Problems with defense waste at Tomsk date back to the 1970s. At that time, a senior engineer responsible for "monitoring stocktaking and storage of special output" discovered a "vast quantity of radioactive output" at the plant. *Izvestiya* claims that his letter to the Central Committee and L.I. Brezhnev only resulted in his reprimand and threatened expulsion from the party.[246] Not until April 18, 1990, when Tomsk-7 radio warned that people had been contaminated, did the public learn of this problem.[247]

Large quantities of radioactive have been dumped into open reservoirs on site. *Izvestiya* reported that the radioactive waste burial site is poorly fenced and contaminated water areas are not fenced at all. Elk, hare, duck, and fish are contaminated, and 38 people were found to have higher than permissible levels of radioactive substances in their body. Of these 38, four adults and three children have been hospitalized.[248]

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[243] Ibid.

[244] V. Kostyukovskiy, et al., "Secrets of a Closed City," *Moscow Izvestiya*, Union Edition, August 2, 1991 (in Russian), (translated in JPRS-TEN-91-018, October 11, 1991, pp. 71-72).

[245] Ibid; quoting from an article appearing "not long ago" in *Rossiyskaya Gazeta*, which in turn was quoting from an official document compiled by specialists from Tomskneftegasgeologiya.

[246] "Urgent Warning: Radioactive Waste Available to All," *Izvestiya*, May 4, 1990, morning edition, p. 6 (Translated in *FBIS*, London UK, Serial: PM0405112290).

[247] Ibid.

[248] "Urgent Warning: Radioactive Waste Available to All," *Izvestiya*, May 4, 1990, morning edition, p. 6 (Translated in *FBIS*, London UK, Serial: PM0405112290).

Wastes apparently are also discharged into a tributary of the Tom River, which has been dammed o form a system of settling ponds. The Tom also receives the direct discharge of reactor cooling water. In July 1990, French scientists took radiation measurements just outside the Tomsk-7 site.[249] At the bank of the cooling water discharge canal, where it flows into the Tom about 2.5 km downstream from the reactors, the gamma radiation levels were 300 microrad/h in air and 400 μrad/h in the water in the canal.[250] On the bank of the Tom, 2 km downstream from the canal, the gamma radiation level was 150 μrad/h in air. A sample of sediment, taken at 5 cm depth in the canal where it flows into the Tom, was found to contain 121 Becquerels/kilogram (Bq/kg) of Cs-137, 4036 Bq/kg of cobalt-58, 18,564 Bq/kg of chromium-51, and 2441 Bq/kg of zinc-65.[251] The high levels of activation products (Co-58, Ch-51, and Zn-65) are indicators of corrosion in one or more of the reactors.

Uranium Enrichment Plant: On January 25, 1991, *Isvestiya* reported a commercial deal whereby the Siberian Chemical Combine would enrich up to four percent uranium recovered from reprocessed French power reactor fuel.[252] Some 150 MT of uranium had been processed by January 1991.[253] The Russians would be paid around $50 million a year under the cooperative arrangement expected to last at least 10 years.[254] Later that year it was reported that these were precontract negotiations.[255] Apparently, the French want to avoid contaminating their own enrichment plants with uranium-232 and uranium-236 impurities in the uranium recovered from spent fuel, by enriching the recovered uranium in Russian enrichment plants.

Fissile Material Storage Facility: The Ministry of Atomic Energy studied two alternatives for the storage of plutonium and HEU removed from warheads dismantled under the Gorbachev and Yeltsin initiatives of 1991-92: construction of two 20,000 m^2 facilities, one each at Tomsk-7 and Chelyabinsk-

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[249] Max Lariviere and Jaqueline Denis-Lampereur, *Science & Vie*, February 1991, pp. 102-103.

[250] Normal background levels in the region are 10-20 microrad/h.

[251] Max Lariviere and Jaqueline Denis-Lampereur, *Science & Vie*, February 1991, p. 103. Subsequent gamma spectroscopy of the sample identified Mn-54, Co-60, Zn-65, Eu-152, and Pu-239,240 in concentrations above background levels.

[252] "Open Deal in a Closed City,"*Isvestiya*, January 25, 1991, Union Edition, p. 2 (Translated in *FBIS*, London UK, R 251109Z Jan 1991); and Moscow Russian Television Network, January 3, 1991, 1700 GMT (translated from Russian).

[253] Moscow Russian Television Network, January 3, 1991, 1700 GMT (translated from Russian).

[254] Ibid.

[255] V. Kostyukovskiy, et al., "Secrets of a Closed City," *Moscow Izvestiya*, Union Edition, August 2, 1991 (in Russian), (translated in JPRS-TEN-91-018, October 11, 1991, pp. 71-72).

65, or construction of one 50,000 m^2 facility at Tomsk-7. The population in the Chelyabinsk region, traumatized by the past accidents at Chelyabinsk-65, resisted siting another facility there. Consequently, the ministry chose the option of a single larger facility at Tomsk-7. The proposed facility consists of three blocks: a central part consisting of a loading area, radiation and safety control, etc.; a storage area for 45,000 containers (the first stage); and a storage area with a 65,000 container capacity (second stage). It is estimated to take eight years to complete construction of the first stage (the first two blocks) if only Russian resources are used. With U.S. assistance, construction could be completed in four years. No decision has been made with respect to the physical and chemical form of the fissile material to be stored, e.g., whether the plutonium will be stored as plutonium pits, plutonium metal buttons, or PuO_2. The construction phase will not delay the rate of dismantlement of nuclear warheads; temporary storage facilities will be used.[256]

Mining and Chemical Combine (Krasnoyarsk-26, Zhelenogorsk, "Devatka," "Atomgrad," Dodonovo)

In 1950, Stalin authorized the building of a "radiochemical enterprise" for producing plutonium on the mountainous east bank of the Yenisey River in the Siberian taiga not far from the Stolba National Preserve,[257] 10 km north of Dodonovo, and 50 km northeast of Krasnoyarsk.[258] Thus, in the same year was born, "Sibkhimstroy" (Siberian Chemical Complex), now known as the Mining and Chemical Combine, and along with it, the closed city Zkelenogorsk (population 90,000).[259] Code-named Krasnoyarsk-26, local inhabitants call it Devyatka. *Gorod i Gorozhanye*, a local newspaper, often calls it "Atomgrad." Unlike Chelyabinsk-65 and Tomsk-7, the plutonium production and separation at Krasnoyarsk-26 takes place entirely underground.

There are three plutonium production reactors located at the bottom of huge artificial caverns, a chemical separation plant that has operated since 1965, waste treatment and storage facilities, and "innumerable laboratories,"

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[256] Oleg Bukharin, notes taken at meeting with Evgeny Mikerin, Frank von Hippel, and others, Moscow, May 28, 1992.

[257] "The Nuclear City: A Trip to a Populated Area Which is Not on the Map," *Pravda*, June 26, 1989; Aleksky Tarasov and Dmitriy Khrupov, "Spy Satellites are Made Here: Report from a Closed Military City," *Moscow Izvestiia*, in Russian, January 11, 1992, Union Edition, pp. 1,8 (translated into English); and Steven Erlanger, "A Siberian Town: Not a Secret and Ready to Deal," *New York Times*, March 29, 1992, pp. 1,6.

[258] The Krasnoyarsk-26 reactor site is located at 56° 20'N 93° 36'E.

[259] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, November 17, 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, November 21, 1991, p.3.). "Sibkhimstroy" (Siberian Chemical Complex) should not be confused with "Sibkhimkombinat" (Siberian Chemical Combine), which is Tomsk-7 at Tomsk.

all some 200-250 m underground. "A concrete road that stretches along the shore of the Yenisey leads to a tunnel situated at the base of an enormous mountain."[260] Employees of the combine go to work by train along the five km long tunnel. Digging the multilevel system of underground tunnels and 3500 rooms took more than 65,000 prisoners and more than 100,000 soldiers. In the 1970s, the volume of excavation was compared to that of the Moscow metro.[261] The production facilities were placed underground to provide protection against potential enemy air raids; and, in fact, the tunnels have several widened areas designed to suppress the shock wave from a nuclear attack.[262] Nearby, aboveground, there is a fossil fueled plant that can be used to provide backup power. Also aboveground, construction of RT-2, a second chemical separation plant, was halted in 1989. A spent fuel storage facility was completed at the RT-2 site. Across the river, some 10 km away, is Site 27, where radioactive waste from RT-2 was to have been injected into the ground. The director of the Mining and Chemical Combine is Valeriy Lebedev.[263]

A second nuclear weapons related facility at Krasnoyarsk-26 is the Scientific Production Association of Applied Mechanics, established in 1959, employing 11,000 workers, and headed by Academician Mikhail F. Reshetnev, a colleague of S. Korolev.[264] This facility is part Krasmash, a larger defense industry enterprise with facilities in and around Krasnoyarsk. The START Treaty data exchange identifies the Krasnoyarsk Machine Building Plant (Krasmash) at Krasnoyarsk as a production facility for Submarine-Launched Ballistic Missiles (SLBMs).[265] Krasmash also designs, manufactures, and tests spy satellites, space vehicles, special communications, and satellites for the Academy of Sciences.[266] More than one-third of the Cosmos space vehicles were worked on here.[267] The firms output is represented by the Molniya,

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[260] Yu. Khots, "Underground AES [Nuclear Power Station] Will No Longer Produce Plutonium," *Moscow Izvestiya*, Union Edition (in Russian), November 14, 1991, p. 6.

[261] Aleksey Tarasov and Dmitriy Khrupov, "Spy Satellites are Made Here: Report from a Closed Military City," *Moscow Izvestiya*, Union Edition, in Russian, January 11, 1992, p. 1,8 (translated into English).

[262] Ibid.

[263] Aleksey Tarasov and Dmitriy Khrupov, "Spy Satellites are Made Here: Report from a Closed Military City," *Moscow Izvestiya*, Union Edition, in Russian, January 11, 1992, p. 1,8 (translated into English).

[264] Ibid; and Erlanger, *New York Times*, March 29, 1992, pp. 1,6.

[265] United States Arms Control and Disarmament Agency, *Arms Control and Disarmament Agreements: START, Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms*, 1991, p. 186.

[266] Aleksey Tarasov and Dmitriy Khrupov, "Spy Satellites are Made Here: Report from a Closed Military City," *Moscow Izvestiya*, Union Edition, in Russian, January 11, 1992, p. 1,8 (translated into English).

[267] Ibid.

Raduga, Gorizont, Ekran, Luch, and radio satellites, navigation (including the Tsikada and Glonass satellites), and Geodesy (Geoik and Etalon).[268]

Also about 90 km east of Krasnoyarsk is the Electrochemistry Plant, one of four uranium enrichment plants in Russia. It is also identified as Krasnoyarsk-45, with its closed city Zelnogorsk (population 63,300).[269]

Graphite Reactors: The three graphite-moderated production reactors, hidden 200-250 m underground, produce only plutonium.[270] Tritium is not produced at Krasnoyarsk-26. Judging by a photograph of the reactor fuel loading deck, the reactors are estimated to be comparable in size to the AV-1, AV-2, and AV-3 reactors at Chelyabinsk 65, each of which has 2001 channels.[271] The first reactor at Krasnoyarsk-26 was started up in 1958; the second in 1961; and the third in 1964. The oldest reactor will be shut down July 1, 1992, and the second no later than September 1, 1992.[272] Since the third reactor is dual purpose, producing plutonium and providing electricity for the closed city and the underground facility, it is not scheduled to be shut down until the Sosnovoborsk power and heating plant begins operating in the year 2000.[273] The capacity of the reactors had been reduced by 20 percent by the end of 1990.[274]

The first two reactors utilize once-through cooling. Since water from the Yenisey is pumped through these reactors and returned directly to the river, it is contaminated fission product leakage and neutron induced radioactivity. Radioactive contamination of the discharged cooling water "results in an increase in the radioactivity level of the dumped water to 3000 microroentgen per hour."[275] The dual purpose reactor has a closed cooling cycle. Two

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[268] Ibid.

[269] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, November 17, 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, November 21, 1991, p.3.).

[270] "Out from Under the Earth," *Pravda*, December 21, 1991. Photographs of the control room and the floor of one of the reactors accompany the article.

[271] Ibid.

[272] Yuriy Khots, "Plutonium-Producing Reactors in Krasnoyarsk to be Shut Down," *Moscow ITAR-Tass World Service*, in Russian, May 19, 1992, 1352 GMT; Yuriy Khots, "Underground AES [Nuclear Power Station] Will No Longer Produce Plutonium," *Moscow Izvestiya*, Union Edition (in Russian), November 14, 1991, p. 6; V. Yaroslavtsev, "The Yenisey's X-Rays" from "What Troubles our Conscience: A Polar Chernobyl Syndrome," *Vozdushnyy Transport*, October 4, 1990, p. 3; and *The Washington Post*, April 21, 1992, P. A15.

[273] Ibid.

[274] Ibid.

[275] "Nuclear Storage and weapon Plutonium Facilities at Krasnoyarsk," *1991 The British Broadcasting Corporation; Summary of World Broadcasts*, December 20, 1991, Postfactum in English 2147 GMT December 9, 1991.

streams of thermal effluents into the Yenisey River are visible on a composite of LANDSAT images, a day image from December 17, 1989 combined with a night image from September 5, 1989. The southern most, or upstream, discharge is the combined flow of water from the two reactors with open cycle cooling. The northern most, or downstream, discharge is from the secondary loop of the dual purpose reactor.

RT-2 Spent Fuel Storage and Chemical Separation Plants: In 1975, it was resolved to build an irradiated fuel-storage facility and a fuel reprocessing (i.e., chemical separation) plant to be used for recycling civil reactor spent fuel, namely, fuel from the new 1000 MW_e pressurized water reactors (VVER-1000) and "other" reactors. Construction of the facilities, called RT-2, was begun in 1976 or 1978, at a hill-top site overlooking the Yenisey River just north of the underground reactors. The spent fuel storage facility with auxiliary and service buildings was put into service in 1985. It comprises 1328 cylinders (6 m in length and 2 m in diameter), with the fuel is stored eight meters below ground under three meters of water.[276] In early-1992, it was reported to contain some 750 MT of spent fuel from VVER-1000 power reactors. The plant has a design capacity of 6000 MT, enough fuel assembly storage until to 2004.[277]

The second section of RT-2, the 1500 MTHM/y fuel reprocessing plant,[278] which is adjacent to and surrounds the spent fuel facility, was scheduled to be completed by 1997-98. There was a sharp reduction in funding for the project in 1985.[279] It was only about 30 percent complete when it was interrupted and then halted in 1989, as a result of public controversy.[280] In June 1989, *Komsomolskaya Pravda* reported that some 60,000 people in Krasnoyarsk signed a protest, in part, because they were angered by the revelation that the scientific study justifying the selection of the site was

[276] "Nuclear Storage and weapon Plutonium Facilities at Krasnoyarsk," *1991 The British Broadcasting Corporation; Summary of World Broadcasts*, December 20, 1991, Postfactum in English 2147 GMT December 9, 1991.

[277] Ibid.

[278] RT-1, the first reprocessing plant for civil reactor fuel, is located at Chelyabinsk-65.

[279] Aleksey Tarasov and Dmitriy Khrupov, "Spy Satellites are Made Here: Report from a Closed Military City," *Moscow Izvestiya*, Union Edition, in Russian, January 11, 1992, p. 1,8 (translated into English).

[280] "The Mystery of Site 27," *Sotsialisticheskaya Industriya*, July 29, 1989; and V. Yaroslavtsev, "The Yenisey's X-Rays,"from an article "What Troubles Our Conscience: A Polar Chernobyl Syndrome," *Vozdushnyy Transport*, October 4, 1990, p. 3; and "Soviet Union Postpones Completion of Siberian Reprocessing Plant," *Nuclear Fuel*, October 16, 1989, pp. 1-2.