MAKING THE RUSSIAN BOMB
FROM STALIN TO YELTSIN

by

Thomas B. Cochran

Robert S. Norris

and

Oleg A. Bukharin

A book by the
Natural Resources Defense Council, Inc.

Westview Press
Boulder, San Francisco, Oxford
Copyright Natural Resources Defense Council © 1995

Table of Contents

CHAPTER ONE
A BRIEF HISTORY OF THE SOVIET BOMB

CHAPTER TWO
AN OVERVIEW OF THE STOCKPILE AND COMPLEX

CHAPTER THREE
CHELYABINSK-65/MAYAK CHEMICAL COMBINE

CHAPTER FIVE
NUCLEAR FUEL CYCLE ACTIVITIES

CHAPTER SIX
RADIOACTIVE CONTAMINATION FROM NUCLEAR-POWERED VESSELS

List of Figures

List of Tables

About the Authors
Thomas B. Cochran

Dr. Thomas B. Cochran is Senior Staff Scientist with the Natural Resources Defense Council, and Director of NRDC's Nuclear Program. He initiated NRDC's Nuclear Weapons Databook Project. He also initiated a series of joint nuclear weapons verification projects with the Soviet Academy of Sciences. These include the Nuclear Test Ban Verification Project, which demonstrated the feasibility of utilizing seismic monitoring to verify a low-threshold test ban, and the Black Sea Experiment, which examined the utility of passive radiation detectors for verifying limits on sea-launched cruise missiles. He has served as a consultant to numerous government and non-government agencies on energy, nuclear nonproliferation and nuclear reactor matters. He is currently a member of the Department of Energy's Fusion Energy Advisory Board and Environmental Management Advisory Board. Previously he served as a member of DOE's Energy Research Advisory Board, the Nuclear Regulatory Commission's Advisory Committee on the Clean Up of Three Mile Island and the TMI Public Health Advisory Board.

Dr. Cochran is the author of *The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique* (Washington, DC: Resources for the Future, 1974); and co-editor/author of the *Nuclear Weapons Databook, Volume I: U.S. Nuclear Forces and Capabilities* (Cambridge, MA: Ballinger Press, 1984); *Volume II: U.S. Nuclear Warhead Production* (1987); *Volume III: U.S. Nuclear Warhead Facility Profiles* (1987); and *Volume IV: Soviet Nuclear Weapons* (1989). In addition, he has published numerous articles and working papers, including those in *SIPRI Yearbook* chapters, *Arms Control Today,* and the *Bulletin of the Atomic Scientists.* He has co-authored (with Dr. Norris) the article on ``Nuclear Weapons'' in the 1990 printing of *The New Encyclopedia Britannica* (15th edition).

Dr. Cochran received his Ph.D. in Physics from Vanderbilt University in 1967. He was assistant Professor of Physics at the Naval Postgraduate School, Monterey, California, from 1969 to 1971, and from 1971 to 1973, he was a Senior Research Associate at Resources for the Future. Dr. Cochran has been with NRDC since 1973. He is the recipient of the American Physical Society's Szilard Award and the Federation of American Scientists' Public Service Award, both in 1987. As a consequence of his work, NRDC received the 1989 Scientific Freedom and Responsibility Award by the American Association for the Advancement of Science.

Robert S. Norris

Dr. Robert S. Norris is Senior Staff Analyst with the Natural Resources Defense Council and Director of the Nuclear Weapons Databook Project. His principal areas of expertise include writing and research in the areas of nuclear weapons research and production, arms control, and nuclear weapons testing. He is co-editor of NRDC's *Nuclear Weapons Databook* series and is a co-author of *U.S. Nuclear Warhead Production,* Vol. II (1987); *U.S. Nuclear Warhead Facility Profiles,* Vol. III (1987); *Soviet Nuclear Weapons,* Vol. IV (1989); and *British, French and Chinese Nuclear Weapons*, Vol. V (1994). He has co-authored (with Dr. Cochran) the chapter on nuclear weapons in the 1985, 1986, 1987, 1988, 1989, 1990, 1991 and 1992 editions of the *SIPRI Yearbook.* Dr. Norris is an author of six recent NRDC Working Papers. He has written articles for *Arms Control Today,* and contributes a column for each issue of the *Bulletin of the Atomic Scientists.* He has co-authored (with Dr. Cochran) the article on ``Nuclear Weapons'' in the 1990 printing of *The New Encyclopedia Britannica* (15th edition).

Dr. Norris received his Ph.D. in Political Science from New York University in 1976, and taught at New York University, Miami University in Ohio, Miami University, Luxembourg, and American University. He was a senior research analyst for the Center for Defense Information before coming to the Natural Resources Defense Council in September 1984.

Oleg A. Bukharin

Dr. Oleg A. Bukharin is a Visiting Research Fellow at the Center for Energy and Environmental Studies of princeton University.

In 1991 Dr. Bukharin joined the Center for Arms Control, Energy and Environmental Studies at the Moscow Institute of Physics and Technology (MPTI). From October 1992 to october 1994 he was a SSRC-MacArthur Foundation Fellow. In October 1992 he assumed his current position at Princeton University. Dr. Bukharin continues his collaboration with the Center at MPTI as well. Dr. Bukharin studies problems involving nuclear power and nuclear proliferation.

Dr. Bukharin has been trained as a physicist at the Moscow Institute of Physics and Technology. He graduated from MPTI in 1986 and received his Ph.D. in Physics from MPTI in 1992. In 1990-1991 he also studied international security affairs at the Woodrow Wilson School of Public and International Affairs of

Princeton University.

CHAPTER ONE
A BRIEF HISTORY OF THE SOVIET BOMB

Russian and Soviet Nuclear Physics

When the time came in August 1945 to seriously develop the atomic bomb, the Soviet program was able to draw upon many individuals who made prominent contributions to the twentieth century revolution in physics. The Soviet commitment to science in general, and to physics in particular, was built upon Tsarist traditions and institutions that predated the Bolshevik Revolution.[1] Brief mention of a few of these figures is necessary before examining the atomic bomb program in more detail.

Shortly after the discovery of X-rays by Wilhelm C. Roentgen in 1895, radioactivity in uranium was discovered in 1896 by the French physicist Henri Becquerel. Two years later the French physicists Pierre and Marie Curie discovered the strongly radioactive elements polonium and radium, which occur naturally in uranium ores.

The first Soviet work with radioactive minerals was begun by Professor I.A. Antipov, who worked on uranium deposits in Central Asia in the period 1900-1903.[2] In 1908 the private ``Society for the Extraction of Rare Metals'' was organized. The Society was connected with the laboratory of M. Sklodovski-Curie.[3] In 1909 Professor P.P. Orlov was researching Siberian radioactive minerals. In 1911 at the request of V.I. Vernadsky at the St. Petersburg Academy of Sciences, steps were taken to organize the study of radioactive minerals on a large scale.[4]

The first Russian physicist of world stature and creator of the first Russian school in physics was P.N. Lebedev (1866-1912). When he was forced to leave Moscow University in 1911 due to conflicts with the Tsarist government, some Russian businessmen funded a laboratory for him. This eventually became the Lebedev Physics Institute of the Academy of Sciences (FIAN), and in this building, some three decades later, the first Soviet H-bomb would be invented.

In the years following the 1917 revolution, Soviet physicists established more than 10 major physics institutes in Petrograd (St. Petersburg),[5] Moscow, Kharkov, Kiev, and several provincial towns.[6] On 24 September 1918, the State Institute on Radiology, later transformed into the

---

[1] David Holloway, *Stalin and the Bomb: The Soviet Union and Atomic Energy, 1939-1956* (New Haven: Yale University Press, 1994), pp. 8-71; Loren R. Graham, *Science in Russia and the Soviet Union: A Short History* (Cambridge: Cambridge University Press, 1993); Paul R. Josephson, *Physics and Politics in Revolutionary Russia* (Berkeley: University of California Press, 1991); Arnold Kramish, *Atomic Energy in the Soviet Union* (Stanford, CA: Stanford University Press, 1959), pp. 3-30.

[2] Vasili S. Yemelyanov, *S Chego Nachinalos* (``How it Began'') (Moscow: Sovetskaia Rossiia, 1979), p. 166.

[3] Ibid.

[4] Ibid., p. 167. In 1912 the Physics Laboratory and the Physico-Mathematics Institute were established in the St. Petersburg Academy of Sciences.

[5] Prior to 31 August 1914, Petrograd was called St. Petersburg. The city was renamed Leningrad on 26 November 1924. In the fall of 1991 its historical name, St. Petersburg, was restored.

[6] Paul R. Josephson, ``Early Years of Soviet Nuclear Physics,'' *Bulletin of the Atomic Scientists*, December 1987, p. 36; Josephson,

Physico-Technical Institute, was created in Petrograd.[7] In 1919 Lebedev's pupil, P.P. Lazarev, created the Institute for Biological Physics in Moscow. During this same period two journals appeared: *Uspekhi Fizicheskikh Nauk* (Successes of Physical Science) and *Trudy Opticheskogo Instituta* (The Works of the Optical Institute).[8]

In 1919, the artificial transmutation of one element into another, the dream of alchemists for centuries, was first accomplished by Ernest Rutherford in England. In 1921, an exploration of the Soviet Union's natural resources was initiated at Lenin's direction, under the supervision of Professor Vernadsky. The search ultimately revealed ample deposits of uranium.[9] In January 1922, the Radium Institute was created in Petrograd under the direction of Vernadsky, with V.G. Khlopin as deputy director and head of the chemistry department.[10] Here, throughout the 1920s and 1930s, work was carried out on the study of radioactivity, radioactive minerals, radioactive disintegration, and the technical extraction of radioactive elements from natural sources. Here also, Vernadsky founded a school of radiochemistry and analytical chemistry. Some of their work concerned the uses of uranium, thorium, and other radioactive elements.[11] By the early 1930s, there were several scientific centers for research on the atomic nucleus and radioactivity, mainly in Leningrad and Kharkov.[12]

In 1923, Dimitri V. Skobeltsyn had begun advanced research on the measurement and detection of radioactivity.[13] In the late 1920s and early 1930s, Georgi Gamov, Peter L. Kapitsa, and Kirill Sinelnikov worked in Rutherford's Cavendish Laboratory in Cambridge, England, where many of the major early discoveries of nuclear physics occurred.[14] Yuli B. Khariton, the future

---

Physics and Politics in Revolutionary Russia.

[7] The Physico-Technical Institute is subsequently referred to as the Leningrad Physico-Technical Institute (LFTI).

[8] Yemelyanov, *S Chego Nachinalos*, p. 169.

[9] Joseph I. Lieberman, *The Scorpion and the Tarantula* (Boston: Houghton Mifflin Company, 1970), p. 191.

[10] Yemelyanov, *S Chego Nachinalos*, p. 169. Vernadsky was director of the Radium Institute until 1939, after which Khlopin served as director until 1950. The institute was subsequently named after Khlopin, who as a radiochemist directed the establishment of the Soviet Union's first radium plant at Berezniki and later developed the industrial processes for chemically separating plutonium from the irradiated uranium reactor fuel and fission products.

[11] Ibid., p. 170.

[12] Yemelyanov, *S Chego Nachinalos*, p. 170.

[13] Lieberman, *Scorpion and the Tarantula*, p. 191.

[14] Josephson, ``Early Years of Soviet Nuclear Physics,'' p. 36. Gamov brought advances in physics of the atomic nucleus to the attention of his Soviet colleagues by publishing his pioneer paper on the theory of alpha-decay in 1928 and a series of articles between 1930 and 1934 based on his work in Goetingen, Copenhagen, and Rutherford's laboratory. Kapitsa spent 14 years in Cambridge, beginning in 1921 at Cavendish Laboratory, later becoming director of Mond Laboratory at Cambridge University. He received the Nobel Prize in physics in 1978 for his work in low-temperature physics, and was known for his achievements in liquefying helium and superfluidity, as well as the development of intense magnetic fields and investigations into plasma physics and thermonuclear physics. Sinel'nikov worked on the development of a high-voltage apparatus for the acceleration of protons before returning to the Soviet Union in 1931. Many other Russians did research abroad as well. Yu. B. Khariton and Alexander I. Leipunskii also did research at the Cavendish Laboratory; V.I. Vernadsky and D.V. Skobel'tsyn worked in Marie Curie's Radium Institute in Paris; Lev Davidovich Landau did research in Niels Bohr's Institute in Copenhagen; and I.K. Kikoin worked in Munich with Walter Garlach. David Holloway, ``Entering the Nuclear Arms Race: The Soviet Decision to Build the Atomic Bomb, 1939-45,'' Wilson

scientific director of Arzamas-16, the laboratory where the first atomic bomb was designed and built, received his Ph.D. there in 1928.

In early 1931 Sinelnikov returned from Cambridge to organize a nuclear group in Kharkov at the Ukrainian Physico-Technical Institute (UkFTI), which had been set up by a group of scientists from the Leningrad Physico-Technical Institute (LFTI) in 1928.[15] At LFTI, the director Academician Abram F. Ioffe gathered a group of talented scientists for research on the atomic nucleus.[16] A nuclear group, headed by Ioffe and including Igor V. Kurchatov, Gamov, Skobeltsyn, and other physicists from institutes around Leningrad, met frequently, beginning in 1932.[17] In the first six months they discussed current experimental and theoretical literature, relativistic quantum mechanics, and cosmic rays.[18] This was the year in which the neutron was first postulated by James Chadwick of England.[19] D.D. Ivanenko was the first who suggested that the neutron be treated as an elementary particle. In December 1932, Ioffe organized at LFTI an atomic nucleus laboratory under his direction; and a year later the nuclear group became the Department of Nuclear Physics at LFTI under Kurchatov's direction.[20] In September 1933 the First All-Union Nuclear Conference (with serious international participation including Paul Dirac, Victor Weisskopf and Federic Joliot) took place at LFTI and stimulated interest about nuclear physics in the Russian attendees. By 1934 LFTI had four laboratories working in nuclear physics, under the direction of Kurchatov, Abram I. Alikhanov, Lev A. Artsimovich, and Skobeltsyn.[21] Kurchatov had invited others to work in nuclear physics there, including several from the Radium Institute. At this institute, due to Kurchatov's efforts the first European cyclotron was constructed and put into operation. One of the talented scientists was L.M. Mysovskii, who worked on the methods and instruments for the measurement of cosmic radiation and had headed the physics department of the Radium Institute when it was founded. Kurchatov and Ivanenko began intensive research into the effect of neutron irradiation on different elements.[22] It was the cyclotron at the Radium Institute that produced the first microscopic portions of irradiated uranium which were used to understand the technology of producing plutonium for the atomic bomb.

Center, Research Paper No. 9, 25 July 1979.

[15] Holloway, ``Entering the Nuclear Arms Race''; Josephson, ``Early Years of Soviet Nuclear Physics,'' p. 36. UkFTI had a group of very able physicists--among them Landau, Sinelnikov, Leipunskii, Ivan Obreimov, Lev Rosenkevitch, Lev Shubnikov, Abram Slutskin, and Vadim Gorsky. Alexander I. Akhiezer, ``Recollections of Lev Davidovich Landau,'' *Physics Today*, June 1994, pp. 35-42.

[16] Yemelyanov, *S Chego Nachinalos*, p. 170. The Leningrad Physico-Technical Institute was subsequently named after Abram F. Ioffe. It remained in the industrial sector until June 1939 when it was transferred to the Academy, although remaining in Leningrad.

[17] Josephson, ``Early Years of Soviet Nuclear Physics,'' p. 37.

[18] Ibid.

[19] For which he won the Nobel Prize for physics in 1935.

[20] Josephson, ``Early Years of Soviet Nuclear Physics,'' p. 37.

[21] Holloway, ``Entering the Nuclear Arms Race.''

[22] Yemelyanov, *S Chego Nachinalos*, p. 171.

In 1934 the Academy of Sciences and its Physico-Mathematics Institute moved from Leningrad to Moscow. The Physico-Mathematics Institute was then split in 1934, resulting in the creation of the Lebedev Institute of Physics of the Academy of Sciences, the principal center of physics research in Moscow. Sergei I. Vavilov (1891-1951), the director of the Institute, was anxious to make it the leading center for Soviet nuclear physics. The Institute had already made an important discovery that would become known as the Cherenkov effect--the radiation emitted by a rapidly moving electron.[23] Vavilov tried unsuccessfully to concentrate nuclear physics at a single place within the Academy, specifically at his institute. Before the end of the decade the rivalry between Moscow and Leningrad was to affect the organization of Soviet nuclear physics and delay the construction of a large cyclotron in Leningrad.[24]

During the 1930s, Soviet scientists were able to follow and confirm the exciting breakthroughs in atomic energy that were occurring throughout the world.[25] Soviet physicists Leonid Isaakovich Mandelstam (1879-1944) and M.A. Leontovich worked on the theory of radioactive disintegration. Igor Ye. Tamm and Ivanenko worked on the theory of nuclear forces. Kurchatov and his scientists studied the interaction of neutrons with matter.[26]

Experimental research in nuclear physics prior to 1932 was performed with alpha particles from naturally radioactive elements. The first successful experiments with artificially accelerated ions were performed at Cambridge University, England, by John D. Cockcroft and E.T.S. Walton in 1932.[27] The Cockcroft-Walton method was one of several promising high voltage accelerators. Others included the Van de Graaff electrostatic generators, impulse generators, and ``Tesla'' coils (resonance transformers). The low-voltage magnetic resonance accelerator, or cyclotron, was conceived by Ernest O. Lawrence and M. Stanley Livingston and demonstrated in 1931 at the University of California at Berkeley. In order to explore the physics of the nucleus, Soviet physicists constructed a variety of accelerators based on these designs.[28]

UkFTI took the lead at first, building high-voltage discharge tubes and Tesla transformers at 1.7 megavolts by the end of 1932, and was the first Institute to repeat Cockroft and Walton's experiment of splitting the atom by artificial means. The following year Kurchatov and Alikhanov began work on a small cyclotron in Leningrad. In 1934, it was the only functioning cyclotron outside of Lawrence's laboratory. It did not operate for long, however, and few experiments were conducted on it. In 1936, a larger but still low-power cyclotron went into operation at the nearby Radium Institute. In addition a linear accelerator of the Cockcroft-Walton type had already begun to operate in Kurchatov's laboratory. In September 1936, LFTI initiated plans for a large cyclotron. After several bureaucratic delays, including opposition from Moscow physicists who were

---

[23] For which Pavel A. Cherenkov, Ilya M. Frank, and Igor Ye. Tamm shared the Nobel Prize for physics in 1958.

[24] Holloway, ``Entering the Nuclear Arms Race.'' Skobeltsyn, in 1938, moved from LFTI to the Lebedev Institute of Physics.

[25] Lieberman, *Scorpion and the Tarantula*, p. 192.

[26] Yemelyanov, *S Chego Nachinalos*, p. 170.

[27] For which they won the Nobel Prize for physics in 1951.

[28] Josephson, ``Early Years of Soviet Nuclear Physics,'' p. 38.

advancing their own program, construction began in earnest on 22 September 1939, but was not completed until after the war.[29]

Towards the Atomic Bomb

After the discovery of nuclear fission by Otto Hahn and Fritz Strassman in Berlin in December 1938, Leningrad became a leading center for nuclear fission research with Kurchatov at LFTI a prime mover.[30] Kurchatov coordinated the research not only at his own laboratory, but also of scientists working at the Radium Institute and the Institute of Chemical Physics, directed by Nikolai N. Semenov,[31] among other institutes.[32] In 1938 half of UkFTI's leading scientists were arrested in a purge. Though many were released within a year and took part in discussions about nuclear fission throughout 1939-1941, the experience weakened the institute at a critical stage of the development of nuclear physics.[33]

A public congress dealing exclusively with problems of nuclear physics was held in Moscow in 1939.[34] In that same year, A.I. Brodsky published an article on the separation of uranium isotopes, while Kurchatov and Iakov Frenkel offered theoretical explanations of the fission process in the uranium atom at the same time as did Niels Bohr and John A. Wheeler in the United States and Otto Frisch in England.[35]

On 16 and 17 April 1940, an All Union Conference on Isotopes was held in Moscow and heard a paper on industrial production of heavy water.[36] In early 1940, two of Kurchatov's junior colleagues, Georgi N. Flerov and Lev 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 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.[37] In the same year, Flerov and Konstantin A. Petrzhak, working under Kurchatov's close direction, discovered

---

[29] Ibid. Work was near completion when it was interrupted by the German invasion on 22 June 1941, and the subsequent blockade and evacuation of Leningrad. Work on the cyclotron resumed in 1945, and it went into operation on 18 June 1945.

[30] David Holloway, *The Soviet Union and the Arms Race* (New Haven: Yale University Press, 1983), p. 16.

[31] Semenov shared the Nobel Prize for chemistry in 1956 for his work on chain reactions.

[32] Other institutions that were involved included the Ukrainian and Tomsk Physico-Technical Institutes, and the Leningrad Pedagogical Institute.

[33] Holloway, ``Entering the Nuclear Arms Race;'' Akhiezer, ``Recollections of Lev Davidovich Landau,'' *Physics Today*, June 1994, pp. 40-41.

[34] Lieberman, *Scorpion and the Tarantula*, p. 192.

[35] Ibid.

[36] Ibid.

[37] Ya. B. Zeldovich and Yu. B. Khariton, ``The Mechanism of Nuclear Fission,'' (Part I), *Usp. Fiz. Nauk* 25 (4) (September 1941), pp. 381-405, translated in *Soviet Physics Uspekhi* 26 (3) (March 1983), pp. 266-278.

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.

Other steps were taken to alert senior government officials about fission. On 12 July 1940 Vernadsky and Khlopin sent a letter to Nikolai Bulganin, a member of the Central Committee. Vernadsky had been alerted of the growing interest in nuclear fission in the West by reading a 5 May 1940 *New York Times* article by science correspondent William Laurence, sent to him by his son who was teaching history at Yale.[38]

On 30 July 1940, the Presidium of the Academy of Sciences established a Commission on the Uranium Problem, with Khlopin as chairman, to direct research.[39] The Academy also established a State Fund for Uranium Metal during the spring of 1940 to finance a study of ``the more important deposits of uranium in Central Asia."[40]

From 20-26 November 1940 the Fifth All-Union Conference on the Physics of Atomic Nuclei was convened in Moscow and attended by 200 scientists. On the last day of the year, an article in *Izvestiia*, entitled ``Uranium 235," predicted that ``mankind will acquire a new source of energy surpassing a million times everything that has hitherto been known . . . Human might is entering a new era . . . man will be able to acquire any quantity of energy he pleases and apply it to any ends he chooses."[41] The military significance of nuclear fission was becoming evident to some Soviet scientists, but the work of the Uranium Commission remained limited.

With the German invasion on 22 June 1941, Soviet scientists, like the rest of Soviet society, turned their energies to the immediate problems of the war. As a consequence, research on nuclear fission was brought virtually to a halt for the rest of the year. Institutes, laboratories, and scientists were evacuated eastward as the immediate war effort commanded first priority.[42] Many nuclear scientists were pressed into other tasks. For example, Kurchatov worked on degaussing techniques to protect ships against magnetic mines until April 1942, and later took over the armor laboratory of the Physico-Technical Institute.[43]

Diverted by War

---

[38] M.G. Meshcheryakov, ``O roli V.I. Vernadskogo i V.G. Khlopina v stanovlenii atomnoi problemy v Rossii,"in G.E. Gorelik, ``Iz dnevika V.I. Vernadskogo," *Voprosy Istorii Estestvoznaniya i Tekniki* (1993) No. 4; Holloway, *Stalin and the Bomb*, p. 61.

[39] Lieberman, *Scorpion and the Tarantula*, p. 192. The Commission included Vernadsky and Ioffe as deputies and Aleksandr Ye. Fersman (a leading Soviet geologist), Vavilov, Kapitsa, Kurchatov, and Khariton as members.

[40] Lieberman, *Scorpion and the Tarantula*, p. 192.

[41] Ibid.

[42] ``On 24 June 1941--only two days after the attack-- the Council of Evacuation was organized and started to work. From July through November 1941, 1,523 industrial enterprises were relocated, of which 1,360 were the largest in the nation. All were engaged in military production of one type or another. . . Ten million persons were evacuated with these plants. By the end of 1941 some of the relocated plants were already in production." Harriet Fast Scott and William F. Scott, *The Armed Forces of the USSR* (2d rev. ed.; Boulder, CO: Westview Press, 1981), p. 23.

[43] Holloway, *Stalin and the Bomb*, p. 75.

In response to the German invasion a State Defense Committee (Gosudarstvenny Komitet Oborony, GKO) was created on 30 June 1941 with Stalin as chairman and Viacheslav M. Molotov as deputy chairman. Lavrenti P. Beria, Georgi M. Malenkov, and Marshall Kliment Ye. Voroshilov were also members. The purpose of the GKO was to mobilize the resources of the Soviet Union to wage and win the war. On 10 July a Scientific-Technical Council was established with Sergei V. Kaftanov as chairman.

In the first months of 1942, the possibility of an atomic bomb was becoming a more serious issue for the Soviet leadership, as a result of recent information obtained about British, American, and German work on the bomb.[44] Originally, Stalin was skeptical of the information collected by Beria, the head of the Soviet secret police and the second most powerful man in the Soviet Union. When Beria discussed an atomic bomb with Stalin in late 1941, Stalin suggested the reports were ``propaganda,'' and that ``we are not about to develop this kind of superbomb, but keep tabs on it."[45] But as evidence of foreign progress on atomic weapons mounted through the espionage channel, it was complemented by the information and pressure of Soviet scientists.

In early 1942, Georgi Flerov, now an air force lieutenant based in Voronezh, noticed in the university library that articles on nuclear fission were no longer being published in Western journals, a sign to him that secret work was under way on an atomic bomb.[46] At this point Flerov wrote to Kaftanov notifying him of his concerns. There was no reply. In April he wrote to Stalin saying that ``we must build the uranium bomb without delay."[47]

As material began to flow in from intelligence operations abroad (see below) Beria sent a five page memo to Stalin and the GKO in March 1942 recommending that it be evaluated.[48]

Another suspicious event occurred that indicated possible German interest in a bomb. In April 1942 NKVD Colonel Ilya G. Starinov visited Kaftanov's senior assistant, S.A. Balezin. Starinov brought a notebook that had been captured from a German officer, a notebook that contained a list of materials needed for a bomb.[49]

---

[44] Ibid., pp. 76-86. 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*, 22 April 1990. See also, Robert Chadwell Williams, *Klaus Fuchs, Atom Spy*, (Cambridge, MA: Harvard University Press, 1987), pp. 60-61.

[45] See the excerpts from Vladimir Chikov, *Ot Los-Alamosa do Moskvy*, published in *Soyuz*, No. 21 (May 1991), p. 18, No. 22 (May 1991), p. 18, and No. 23 (June 1991), p. 18, translated ``Espionage Role in World War II Atom Bomb Program'' in JPRS-UMA-91-023, 10 September 1991, pp. 42-50. The quote is at p. 43.

[46] Flerov had noticed this earlier and spoke to a group of scientists in mid-December 1941 at Kazan about his concerns. He also wrote to Kurchatov about it. Holloway, *Stalin and the Bomb*, p. 76.

[47] The full text of the actual letter has not come to light. A draft of the letter was first published in the *Moscow News,* 17 April 1988, p. 16, and is reproduced in Appendix 2. It is not clear if Stalin saw it. Holloway, *Stalin and the Bomb*, p. 77. According to Chikov, this was actually Flerov's second letter to Stalin, the first sent before the war began. Chikov, JPRS-UMA-91-023, pp. 43-44.

[48] ``U istokov sovetskogo atomnogo proekta: rol` razvedki, 1941-1946gg," [Roots of the Soviet Atomic Project: Role of Intelligence, 1941-1946], *VIET [Voprosy Istorii Estestvoznaniya i Tekniki] Issues in the History and Methods of Natural Science*, 1992, No. 3, pp. 109-111.

[49] Holloway, *Stalin and the Bomb*, p. 85; ``Red Bomb," Discovery Channel, 12 September 1994.

These events finally got Kaftanov's attention, and with Ioffe they sent a short letter to the GKO recommending that a research center be created. Though the precise date cannot be pinpointed, probably sometime before mid-July Stalin approved the recommendation.[50] Throughout the summer and fall scientists were consulted about the prospects of atomic energy, but they were not shown the intelligence data gathered abroad. An offer was made to Ioffe to lead the research effort. He declined and suggested either Kurchatov or A.I. Alikhanov. Both came to Moscow and met with Kaftanov and Balezin on 22 October 1942. They recommended Kurchatov and asked him to draw up a list of who he would want on his team. Kurchatov visited some of these scientists in November as he made his way back to Kazan. On 9 January 1943 Kurchatov returned to Moscow and met with Pervukhin, Kikoin, and Alikhanov. Pervukhin asked Kurchatov to write a memo on how he would organize the atomic research program. Kurchatov produced it quickly. It was passed on to Molotov, who was impressed with the scientist during a meeting in January.

On 11 February the GKO established a scientific and technical research program on the use of atomic energy.[51] Mikhail G. Pervukhin (a former commissar of the Soviet electrical and chemical industries and deputy chairman of the Council of People's Commissars) and Kaftanov were charged with supervision. On 10 March Kurchatov was confirmed as the scientific director of what would become Laboratory No. 2 in Moscow.[52] On April 12 the Academy of Sciences adopted a resolution establishing Laboratory No. 2.[53] It was first housed in the Seismological Institute on Pyzhevskii Lane. Eventually a site in Pokrovskoe-Streshnevo in the northwestern part of Moscow was found and a move was made in April 1944.[54] Kurchatov, at the time of his appointment was not a member of the Academy of Sciences, which reduced his influence among the more senior physicists.[55]

On the Politburo level, Vyacheslav Molotov, then People's Commissar of Foreign Affairs and deputy director of the GKO, was charged with overseeing the bomb program.[56] The selection of Molotov for the supervisory role is unexplained, although he had other defense industry connections such as managing the critical tank production program in his role as senior member of the GKO.[57] (Many tank officials would subsequently be involved in the nuclear weapons program.)

[50] Holloway, *Stalin and the Bomb*, p. 86.

[51] Khariton says February 11. Holloway says that Golovin says the 11th while V.V. Goncharov says it is the 15th. The decree has not been published as yet. Yuli Khariton and Yuri Smirnov, ``The Khariton Version,'' *The Bulletin of the Atomic Scientists (BAS)* , May 1993, p. 24; Holloway, *Stalin and the Bomb*, p. 392, fn 97.

[52] A.P. Aleksandrov, ed., *Vospominaniya ob Igore Vasilyevich Kurchatov* (Moscow: Nauka, 1988), p. 461; Andrei Sakharov, *Memoirs* (New York: Alfred A. Knopf, 1990), p. 159; Holloway, *Stalin and the Bomb*, p. 90.

[53] ``U istokov sovetskogo atomnogo proekta,'' *VIET*, 1992, No. 3, p. 100.

[54] Holloway, *Stalin and the Bomb*, p. 99. By 1947, Laboratory No. 2 had been renamed ``Laboratory for Measuring Instruments''- (LIPAN). Subsequently it was renamed I.V. Kurchatov Institute of Atomic Energy (*Institut atomnoy energii imeni I.V. Kurchatov,* or IAE). In April 1992 IAE was reorganized as the Russian Scientific Center (RSC), but is still referred to as the ``Kurchatov Institute.''

[55] To rectify this problem, Kurchatov was elected a full member on 29 September 1943, taking the unusual step of not becoming a corresponding member first.

[56] ``Atomic Energy--The Bomb,'' *USSR Technology Update,* 19 April 1990, p. 1.

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

The secret police under Beria's direction, like much else in Stalin's Soviet Union, had a paramount role in the bomb program. On 14 April 1943 the NKVD (Narodnyy Kommissariat Vnutrennikh Del--People's Commissariat of Internal Affairs) was split into the NKVD, and the People's Commissariat for State Security or NKGB (Narodnyy Komissariat Gosudarstvennoy Bezopasnosti. Beria headed the NKVD and his trusted subordinate Vsevolod Merkulov headed the NKGB.[58] Andrei Sakharov tells us that at the beginning of 1943, on orders from Beria, Nikolai I. 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 (see below). He was responsible for overseeing the nuclear weapons program, and rose rapidly through the ranks to become an exceptional administrator.

Sometime after 2 February 1943 Kurchatov began to be shown the foreign intelligence reports that went back fifteen months to September 1941.[59] We know from a 14-page memo he wrote to Pervukhin on March 7 that he considered the material ``of enormous, inestimable importance for our country and science."[60] He saw immediately the seriousness with which the British were pursuing their research. He also saw how the their program could guide Soviet research by allowing them to skip labor-intensive phases in the solution of problems. He concluded by proposing three research areas to investigate: isotope separation of U^{235} by diffusion, the achievement of a chain reaction in an experimental reactor using natural uranium; and a study of the properties of plutonium.

In a second eight-page memo to Pervukhin on March 22, Kurchatov further speculates on two problems before him, building a reactor and the properties of plutonium. Intrigued by the prospect that plutonium might be the answer--and that the difficult problem of isotope separation of uranium might be avoided--Kurchatov requested the intelligence agencies to find out what was being done at seven laboratories and universities in America.[61]

The research tasks facing Kurchatov were formidable, but at this preliminary stage the projects were to build experimental prototypes rather than the full-scale facilities that would be needed later. Kurchatov first needed to recruit a team of scientists and engineers that would staff his laboratory. Before he chose them he had visited many of his colleagues in November 1942. Recruitment went on through 1943 and, by 25 April 1944, 25 of the 74 people working at Laboratory No. 2 were scientists.[62]

---

[58] Soviet State Security was reorganized and renamed numerous times from the late 1930s to early 1954, when it became the KGB. See John J. Dziak, *Chekisty: A History of the KGB* (Lexington, MA: Lexington Books, 1987).

[59] Molotov says that after meeting with Kurchatov and being impressed by him he decided to provide him with the intelligence data. Kurchatov spent several days in Molotov's Kremlin office looking through the data. Sometime after the Battle of Stalingrad, Molotov asked Kurchatov, ```So what do you think of this?' He said `The materials are magnificent. They add exactly what we have been missing."' Albert Resis, ed., *Molotov Remembers: Inside Kremlin Politics* (Chicago: Ivan R. Dee, 1993), p. 56.

[60] ``U istokov sovetskogo atomnogo proekta," *VIET*, 1992, No. 3, pp. 111-116.

[61] Ibid., pp. 116-118.

[62] Holloway, *Stalin and the Bomb*, p. 99.

Among the highest priorities was to obtain enough uranium for an experimental reactor or pile. Fifty or 100 tons might be needed. A search for uranium had started under the Uranium Commission in 1940, and had received added impetus in 1942 at the urging and involvement of Academician Vernadsky and other Soviet geologists.[63] Small scale mining operations for uranium were initiated at old radium mines in the Fergan valley area near Leninabad, Tadzhik SSR, but by late 1944 Kurchatov wrote to Beria complaining of Molotov's incompetence and the desperate need for uranium. Kurchatov noted that after over a year, the surveys of the Leninabad deposits had not even been completed.[64] 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. A commission led by Zaveniagin was sent to Germany in 1945 to search for uranium and 100 metric tons were brought back.[65]

The best method of isotope separation also had to be decided upon. Kurchatov divided the task into three sections with Anatoli P. Aleksandrov investigating the thermal diffusion method; Isaak K. Kikoin overseeing the gaseous diffusion method, and Lev A. Artsimovich exploring the electromagnetic process.[66]

Also important would be to decide what kind of reactor to build. At Laboratory No. 2 three types of reactors were under consideration: heavy-water, gas-cooled graphite moderated, and water-cooled graphite moderated. Kurchatov undertook direct charge of investigating an atomic pile using graphite as the moderator. Abram I. Alikhanov explored building a pile using heavy water as the moderator.[67]

If the plutonium bomb was the path that might be taken, it was necessary to begin studying its properties as soon as possible. In 1945, Kurchatov obtained the first nanogram quantities (10^{12} atoms) by irradiating for a period of three months uranium hexafluoride targets with neutrons from a radium-beryllium source. Practically at the same time Khlopin's Radium Institute began radio-chemical analysis of sub-microgram quantities of neptunium and plutonium obtained using a cyclotron that had been returned and restored after its evacuation during the war. ``Weighable'' (microgram) quantities of plutonium became available a short time later from a more powerful cyclotron at Laboratory No. 2.[68]

The actual design of the bomb was also of crucial interest. After some urging Kurchatov got Khariton to work on bomb design.

---

[63] F.I. Volfson, N.S. Zontov, and G.R. Shushaniya, *Petr Yakovlevich Antropov, 1905-1979* (Moscow: Nauka, 1986) pp. 30-31.

[64] Igor Golovin, ``They Awakened the Genie,'' *Moscow News*, No. 41, 15-22 October 1989, pp. 8-9.

[65] A.K. Kruglov, ``On the History of Atomic Science and Industry,'' *The Bulletin of the Center of Public Information on Atomic Energy (Biulleten tsentra obshchestvennoi informatsii po atomnoi energi)*, No. 8, 1993, p. 63.

[66] Zaloga, ``Soviet Nuclear Bomb Programme,'' p. 175.

[67] Holloway, *Stalin and the Bomb*, p. 97.

[68] Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, p. 40.

To summarize, the Soviet bomb program basically remained small-scale from July 1940 to July 1945. The first phase, from establishment of the Academy of Science's Uranium Commission in July 1940 to the German invasion of June 1941, saw a limited investigation of the possibilities of atomic energy. With the outbreak of war even that small effort dissipated. Over the next eighteen months, through the darkest days of the war for the Soviet Union, several scientists kept agitating for a program. Also some troubling intelligence reports about western efforts led to government officials to form a modest research effort in February 1943. This phase was still quite modest and would last until August 1945, when everything would change dramatically.

Full Speed Ahead

As we have seen, by the time of the Potsdam Conference, which began on 17 July 1945 (the day after the *Trinity* test), the Soviet Union had a serious, albeit small atomic bomb project underway. On 24 July President Truman casually mentioned to Stalin after one conference session that the United States had a ``new weapon of unusual destructive force.'' Stalin told Truman he hoped the U.S. would make ``good use of it against the Japanese.''

The Kurchatov team at Laboratory No. 2 learned of the successful test of the first American atomic bomb in July 1945, but this still did not push the program into high gear. Rather remarkably, in retrospect, the full implications of the successful test, and all that occurred in the preceding four years of activity by the Americans and British, did not dramatize to the top leadership of the Soviet Union, most notably Stalin and Beria, the importance of the atomic bomb and the potential impact it could play in post-war politics.

The full measure of the impact finally began to manifest itself to Stalin in August 1945 when the United States dropped two atomic bombs on Hiroshima and Nagasaki, Japan. We do not have a record of Stalin's immediate reaction or how he might have suddenly realized that his past efforts had been inadequate. But we do know that he was now convinced. On either the 17th or the 18th of August, Stalin summoned Boris L. Vannikov, the People's Commissar of Munitions, and his deputies to the Kremlin.[69] There they were met by Kurchatov. ``A single demand of you, comrades,'' said Stalin. ``Provide us with atomic weapons in the shortest possible time! You know that Hiroshima has shaken the whole world. The balance [of power] has been destroyed! Provide the bomb--it will remove a great danger from us''[70] In a stroke the four-year long war effort seemed wasted and the fleeting sense of victory in jeopardy as a major new factor in world politics presented itself.[71] A crash program would be necessary to end an intolerable situation where only the United States had the bomb.

---

[69] Mikhail Rebrov, ``Atomic Bomb--How the Countdown Began,'' *Krasnaya Zvezda*, 20 August 1994, p. 7

[70] Christopher Andrew and Oleg Gordievsky, *KGB: The Inside Story* (New York: HarperCollins, 1990), p. 376; Holloway, *Stalin and the Bomb*, p. 132; Amy Knight, *Beria: Stalin's First Lieutenant* (Princeton, NJ: Princeton University Press, 1993), p. 261, fn 12.

[71] Alexander Werth, *London Sunday Times* correspondent, reported on the immediate significance of Hiroshima on the Russian people. ``The news had an acutely depressing effect on everybody. It was clearly realised that this was a New Fact in the world's power politics, that the bomb constituted a threat to Russia, and some Russian pessimists I talked to that day dismally remarked that Russia's desperately hard victory over Germany was now `as good as wasted.''' *Russia at War 1941-1945* (New York: E.P. Dutton & Co., Inc., 1964), p. 1037.

On 20 August 1945 the GKO adopted decision No. 9887 to establish a Special Committee (*Spetskom*) to solve the nuclear problem. The Special Committee was chaired by Beria, usurping control of the previous effort from Molotov. Beria's role in the program would be critical. Due to his control over the GULAG, Beria provided unlimited amounts of prison labor for large scale construction of the sites of the complex.[72] The other eight members of the Special Committee were: M.G. Pervukhin, G.M. Malenkov, V.A. Makhnev, P. Kapitsa, Kurchatov, Nikolai Voznesensky (head of State Planning Committee-Gosplan), B.L. Vannikov, and A.P. Zaveniagin. The Special Committee had a Technical Council, established 27 August 1945, and an Engineering-Technical Council, established 10 December 1945.

Administration and coordination of the atomic program was undertaken by a new interdepartmental ``semi-ministry,'' known as the First Main Directorate (PGU) of the USSR Council of Ministers, established on 29 August 1945[73] and chaired by former Minister of Armaments Vannikov, who was, in turn, overseen by Beria. The First Main Directorate would administer the bomb program from 1945 until 1953. In a 9 April 1946 decree of the Council of Ministers the PGU was given rights comparable to those of the Ministry of Defense in obtaining materials and coordinating activities between branches. Seven deputy ministers were appointed, including Zaveniagin, P.Y. Antropov, Ye.P. Slavsky, N.A. Borisov, V.S. Yemelyanov, and A.N. Komarovsky. At the end of 1947, Pervukhin was appointed First Deputy Head of the PGU until 1949, when Slavsky was appointed to the post. In April 1946, the Special Committee's Engineering-Technical Council was transformed into the Scientific-Technical Council (NTS) of the First Main Directorate. The NTS played an important role in providing scientific advice and was led in the 1940s by Vannikov (1946), Pervukhin (1947-1949), and Kurchatov (1949-?).

At the Politburo level ultimate control of the nuclear program remained with Beria and the First Main Directorate reported directly to the Politburo.[74] Beria's main aide in supervising the program was NKVD Colonel General Avraami Zaveniagin, who served simultaneously as deputy to both Beria and Vannikov and whose official title was chief representative of the USSR Council of Ministers. Zaveniagin was a metallurgist by training, and his role in the Soviet programme was in some respects similar to General Leslie R Groves' in the American Manhattan Project. Sakharov calls him, ``a tough, decisive, exceptionally enterprising chief . . . a man of great intelligence--and an uncompromising Stalinist.''[75]

Yefim P. Slavsky, who later was to head the Soviet nuclear program at the ministerial level from 1957 to 1986, was brought in to supervise the production of very pure graphite needed for Kurchatov's nuclear pile experiments. Slavsky had been a classmate of Zaveniagin in the mining academy and at the time he was deputy chief of the Aluminum, Magnesium and Electronics

---

[72] Knight, *Beria*, p. 135. GULAG is the acronym for the Main Directorate of Corrective Labor Camps. Beria also took over many other high technology programs, including the ballistic missile effort.

[73] *International Affairs* (Moscow), No. 9, 1994, p. 15.

[74] ``Atomic Energy--The Bomb,'' *USSR Technology Update,* 19 April 1990, pp. 1-2.

[75] Sakharov, *Memoirs*, p. 136.

Industry. Slavsky eventually was placed in charge of the metallurgical extraction and processing aspects of the early bomb program.

Pyotr Ya. Antropov, a geologist and metallurgist and a deputy to a member of the GKO during the war, was Vannikov's deputy with responsibility for locating and mining uranium.

By the summer of 1945, Kurchatov had sufficient confidence in the directions being pursued that he began to design the first ``industrial'' reactor, that is, the first large plutonium production reactor. The reactor site (discussed in more detail in Chapter Three) was first known as the Plutonium Integrated Works (later Mayak Integrated Works, then Mayak Chemical Combine), also code named Chelyabinsk-40 (now Chelyabinsk-65).

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.

Also during 1946 an experimental radiochemical shop was built at Laboratory No. 2.[76] The shop was subsequently named Installation No. 5 (within NII-9).[77] Tests to isolate plutonium based on procedures created by the Radium Institute were conducted using slugs irradiated in the F-1 reactor, all with the purpose of perfecting Plant B at Chelyabinsk-40 which was still under construction.

Establishment of the Test Site and the First Test[78]

A place to test the bomb once it was finished was needed. On 21 August 1947 a special resolution was adopted calling for the creation of a site to test the atomic bomb. Kurchatov selected an isolated spot 160 kilometers west of the city of Semipalatinsk, in Kazakhstan. In the early days it was known as ``Test Site Number 2,'' or just ``N 2.'' In late 1947 military units began to arrive in order to build the facilities for the test. This garrison was called Moscow-400, and was established on the banks of the Irtysh river, some 60 kilometers east of the center of the test site. Many buildings were constructed to house the personnel and to accommodate all of the scientific and technical support that was needed. The military engineers were under the command of Lieutenant-General Nikolai I. Timofeev, a brilliant organizer whose experience went back to the times of the Tsarist army.

At the center of the test site a 100-foot metal tower was constructed on which to place the nuclear device. At various distances from the tower, buildings were erected to house the instrumentation and photographic equipment that would record the test. Since the test was also

---

[76] Khlopin on 20 May 1946 provided a report to the PGU NTS based on the study of radiochemistry that was instrumental in the leadership's decision to begin construction of what became known as Plant B at Chelyabinsk-40 that summer and the experimental shop at Laboratory No. 2.

[77] Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, pp. 40-41. Scientific Research Institute No. 9 (NII-9) is an early designation of the All-Russian Scientific Research Institute of Inorganic Materials (VNIINM), imeni Bochvar.

[78] The following section is derived from a draft of the memoirs of Viktor Ivanovich Zhuchikhin, *History of the Creation of the First Atomic Bomb in the USSR* (unpublished); Kruglov, ``On the History,'' *Bulletin*, No. 11, 1993, pp. 59-68; Holloway, *Stalin and the Bomb*, pp. 213-219.

intended to examine the effects of the explosion on military and civilian equipment, many experiments were prepared and structures built, including: at 800 meters from ground zero, two three-story houses; at 1000 meters a section of railroad, complete with metal bridge and two rail cars; at 1200 meters a section of highway with reinforced concrete bridge, and trucks and automobiles placed on it; at 1500 meters an electric power station, with two diesel generators; at 200-300 meters, to a depth of 15-30 meters, a metro tunnel that had been carved out. A wide variety of military equipment was arrayed at various distances, including tanks, artillery, ship superstructures, and aircraft. Two Petlyakov-2 bombers were placed at a distance of nine kilometers from the tower, one as if taking off, the other as if in a steep turn. In the open, animals were shackled including dogs, swine, rats, mice, and two camels. All of this vast construction and preparation took almost two years of round-the-clock work to complete. By 10 August 1949 everything was ready.

Back at KB-11/Arzamas-16, preparations proceeded throughout the first half of 1949. In early June a state commission headed by Vannikov arrived at KB-11 to determine the progress. They were given the go-ahead, and Khariton was appointed test leader with Kirill Shchelkin as his deputy.[79] The working groups and teams were finalized, and in July Kurchatov approved the final design. We now know that this first test used a device that was almost a carbon copy of the American Trinity/Nagasaki design. After numerous railway shipments, and some by air, almost all of the equipment had been delivered by late July.

In early August four aircraft were used to transport parts of the device itself. The scientific and administrative leaders began to arrive in force from KB-11 and Moscow. Several days were spent checking equipment and instruments, and three full-scale dry runs were executed on 14, 18, and 22 August, each with a detonation time of 7:00 am (local). With three successful dry runs the decision was made to conduct the test on 29 August at 7:00 am.

On August 26th, 27th and 28th final arrangements were made in preparing the device. Throughout the evening of the 28th and into the early morning of the 29th, Dukhov, Khariton, Davidenko, Alferov, and others assembled the bomb. With all but a few final procedures completed, the device was hoisted up to the top of the tower. There G.G. Lominskii, Flerov, Davidenko and Shchelkin made the last connections. The final wires were connected and the last person to leave the tower was Shchelkin at 5:40 am.

Kurchatov, Khariton, Shchelkin, Pervukhin, Boliatko, Flerov, Beria and Zaveniagin convened at Building 12, the two-room command post, 10 kilometers from the tower. There were also two observation posts, one 15 kilometers south of the tower for the military, and the other 15 kilometers north of the tower for the scientists.

Kurchatov gave the order to fire and Anatoly Malsky announced the countdown: ``minus 30

---

[79] According to Khariton, there is no truth to the story that Kurchatov, Khariton, and General Pavel M. Zernov presented Stalin with a sphere of plutonium in the spring of 1949 and asked permission to test the first atomic bomb. Khariton and Smirnov, ``Khariton Version,'' *BAS*, p. 28. The story is recounted by Steven J. Zaloga, *Target America* (Novato, CA: Presidio Press, 1993), p. 58. Sometime later, possibly in July, Kurchatov, Khariton and others were summoned to Moscow and made reports to Stalin in person about the preparations for the test. Stalin asked if there was enough plutonium for two less powerful bombs, and Khariton responded that it would not be possible. Holloway, *Stalin and the Bomb*, pp. 200-201.

minutes . . . minus 15 minutes . . . 30 seconds . . . ten seconds . . . five, four, three, two, one, zero." Approximately 30 seconds elapsed before a huge roar swept over the command post. After the shock wave subsided they left the building to witness the rising mushroom cloud and the destruction that the 20 kiloton explosion wreaked. Less than ten minutes after the explosion one of the tanks designed to study the effects of radiation was at ground zero taking measurements and soil samples.

Beria, happy about the successful test,[80] proposed to Kurchatov that a name be given to the device. Kurchatov replied that a name had already been chosen, by Shchelkin. It was RDS-1, the first letters of *Rossiya delaet sama* (Russia makes (or does) it by itself), a misnomer perhaps, now knowing the bomb's original provenance. When Stalin was told, he liked the ring of it, and over the next several years RDS-2, RDS-3, and so on would be used for successive variants and models.[81]

RDS-1 was not put into service. As we now know it was more of a ``political bomb'' than a military one. The first bomb put into production did not enter service until 1953. According to Khariton these Soviet-designed bombs were more than twice as powerful and much lighter that the first ``American-type'' design. These bombs were based on the two tests conducted on 24 September and 18 October 1951.[82]

In the aftermath of the first test it was time for the granting of awards. Beria was in charge of deciding who would receive them. It is said that he adopted the simple principle that those who would have been shot in case of failure would now become Heroes of Socialist Labor, those who would have received maximum prison sentences would receive the Order of Lenin, and so on.[83]

Following the first atomic test there was an enormous effort to achieve the next milestone, developing and testing a hydrogen bomb. Work on the fusion bomb was already proceeding parallel with work on the fission bomb. Unlike the U.S., where an elaborate, largely secret, debate arose over the question of undertaking an all out effort to build a hydrogen bomb, in the Soviet Union no such debate ensued. It is not known precisely when such a governmental decision was taken by Stalin, Beria, and the PGU.

The Role of Espionage

Questions about the role of espionage in the making of the Soviet bomb have been deliberated about in the West for more than forty-five years. They began soon after the first spies

---

[80] The consequences of failure would have been severe, up to and including some being shot. After the successful test Lev Artsimovich was heard to say, ``Imagine how bloody this test would have been if the bomb hadn't gone off.'' Roald Z. Sagdeev, *The Making of a Soviet Scientist* (New York: John Wiley & Sons, 1994), p. 56. See also Holloway, *Stalin and the Bomb*, p. 215.

[81] There are two other interpretations as to what RDS means. Khariton, who would be likely to know, says it stands for *Reaktivnyi dvigatel Stalina* (Stalin's rocket engine) and was coined by Gen. V.A. Makhnev. Khariton and Smirnov, ``Khariton Version,'' *BAS*, p. 20. There is also *Reaktivny dvigatel spetsialny* (Special jet engine). According to a forthcoming official history it had more than one official name--Article 501 and 1-200, as well as RDS. ``How It All Began,'' *International Affairs* (Moscow), No. 9, 1993, p. 140.

[82] The October test was the first airdrop of an atomic bomb in the Soviet Union. The air crew was commanded by Lt.-Col. K.I. Urzhuntsev. Khariton and Smirnov, ``Khariton Version,'' *BAS*, p. 30. Others involved in the bomb design were Zeldovich, Zababakhin, Altshuler, K.K. Krupnikov, and V.M. Nekrutkin. Holloway, *Stalin and the Bomb*, p. 219.

[83] Holloway lists nineteen who received the highest honor, Hero of Socialist Labor. *Stalin and the Bomb*, pp. 218-219.

were revealed in 1946 and intensified after the arrests of Klaus Fuchs and the Rosenbergs in 1950. As we revisit these questions today, what is different is that the Russians are involved in the debate and have provided new information that no doubt will revise western accounts. Who should take more credit for the bomb, the Soviet spies or the Soviet scientists? How much time was saved by Soviet scientists' reliance on the U.S. program?

For obvious reasons the line during the Cold War by Soviet commentators was to minimize the contribution of espionage to the development of the atomic bomb. Recently revealed documents confirm its crucial importance.[84] A second fact is that the scope of the effort was larger than previously thought. It is likely that many more atomic spies will be revealed over the coming years.

In addition to running the domestic bomb program, Beria also controlled the overseas espionage network. Throughout the war, and well afterwards, information came from several sources about the technical aspects of how to build a bomb and about key political decisions and developments made by the U.K. and the U.S.[85]

Through the Cambridge spy network in Britain, Stalin probably had knowledge of British and American plans at a very early date. According to recently published Soviet intelligence documents the first details about the British ``uranium problem'' came from Donald Maclean. The information was contained in reports--dated 25 September 1941 and 3 October 1941--transmitted to Moscow by Anatoli B. Gorski, the control agent of the Cambridge spies from 1940 to 1944.[86] Gorski reported that he obtained the information from Maclean (codename ``Leaf'').[87] Gorski reported a meeting of the British Uranium Committee on 16 September 1941 that concluded that a uranium bomb could be developed in the course of two years.

A second member of the Cambridge spy ring, whose precise role in atomic espionage has yet to be determined, is John Cairncross, who admitted in September 1991 that he was the ``fifth man'' of the group of British spies that included Maclean, Guy Burgess, H.A.R. ``Kim'' Philby, and Anthony Blunt.[88] Cairncross was the private secretary (from September 1940 until March 1942) to

---

[84] Other commentators maximize the espionage contribution. The upshot of this is a rather heated public quarrel between the scientists and the spies over who should be given proper credit. See ``Academy of Sciences Views Sudoplatov's Atom Spy Allegations,'' FBIS-USR-94-089, 16 August 1994, pp. 1-4; ``Physicist on Soviet Nuclear Espionage,'' FBIS-USR-94-105, 27 September 1994, pp. 4-6 (Interview with Arkadi Brish, originally published in *Literaturnaya Gazeta*, No. 36, 7 September 1994, p. 10); Roald Sagdeev, ``Russian Scientists Save American Secrets,'' *Bulletin of the Atomic Scientists*, May 1993, pp. 32-36; Sergei Leskov, ``Dividing the Glory of the Fathers,'' *Bulletin of the Atomic Scientists*, May 1993, pp. 37-39.

[85] ``U istokov sovetskogo atomnogo proekta, *VIET*, 1992, No. 3, pp. 97-134. The story of trying to suspend this publication is told by Gennady Gorelik, ``Yadernay istoiya i zloba dnya (O sud`be *VIET* No. 3, 1992),'' *VIET,* 1993, No. 2, pp. 159-161.

[86] Specifically, Documents No. 1 and 2, pp. 107-108 in VIET, 1992, No.3. Gorski, who was also known as Anatoli Gromov, and to his agents as ``Henry,'' took up his post at the Soviet Embassy in London in the autumn of 1940, and in August 1941 was promoted to Second Secretary. He would follow Maclean to Washington and in 1951 was deputy head of the First Directorate of the NKVD in Moscow.

[87] It is unclear how Maclean obtained it. In August and September 1941 he was working in the newly created General Department of the Foreign Office and would not have had easy access to the MAUD report. It is possible that he received it from John Cairncross.

[88] ``A Briton Admits Spying for Soviets,'' *New York Times*, 23 September 1991, p. A8. For recent accounts of the others see, Verne W. Newton, *The Cambridge Spies: The Untold Story of Maclean, Philby, and Burgess in America* (Lanham, MD: Madison Books, 1984), esp. pp. 145-185; Robert Cecil, *A Divided Life: A Personal Portrait of the Spy Donald Maclean* (New York: William Morrow and Company, Inc., 1989); Anthony Cave Brown, *Treason in the Blood: H.St. John Philby, Kim Philby, and the Spy Case of the Century* (New York: Houghton Mifflin, 1994). A second spy ring at Oxford could bring more surprises. Martin Walker, ``The Cloud

Lord Hankey, the first Chairman of the Scientific Advisory Committee of the Cabinet and a reader of the MAUD Report at the end of August 1941. The famous MAUD Report concluded that a bomb was possible and that it would take two and one-half years to develop. As Hankey's secretary the report was likely to be first handled by Cairncross, but if indeed the MAUD report did come across his desk it is not clear what he did with the information.[89]

Maclean was a very important figure in supplying information to the Soviet Union about the atomic bomb. This was particularly the case during his four year tour at the British Embassy in Washington, DC, from 6 May 1944 until 1 September 1948.[90] His first position was as Second Secretary, and on 11 April 1945 was promoted to First Secretary. Soon thereafter he became Head of Chancery, the third ranking position at the Embassy, a post he held until December 1946.

From February 1947 to September 1948 Maclean was the British secretary to the Combined Policy Committee (CPC). The year before a special security zone has been established at the Embassy at 3100 Massachusetts Avenue to house files about the atomic bomb to which only Maclean, Sir Roger Makins (Lord Sherfield) and their secretaries had access.[91] The CPC had been established by Roosevelt and Churchill during the war to coordinate atomic energy plans of the U.S., U.K. and Canada and to provide a forum to discuss sensitive matters. On 22 September 1947 President Truman named the Secretary of State, Secretary of Defense, and the Chairman of the Atomic Energy Commission as the American members.[92] A second organization, the Combined Development Trust handled matters related to uranium and sought to buy up what was then thought to be limited amounts of high-grade uranium. Maclean represented British interests on this body as well.[93]

Maclean passed along atomic energy information in several other ways. Between August 1947 and June 1948 Maclean made over twenty-five visits to AEC headquarters and from November 1947 had a ``no escort'' pass to wander through the building.

Though Klaus Fuch's role has always been known to be important, new details have emerged. According to Khariton, the first Soviet test device (fired on 29 August 1949) was a copy of the bomb the Americans dropped on Nagasaki, based on full plans received through espionage.[94]

of Treason Descends Upon Another Bastion of British Respectability,'' *Los Angeles Times*, 12 July 1992, p. M2.

[89] Cairncross was first named as the ``fifth man'' in 1990 by Soviet double agent Oleg Gordievsky, who defected to Britain in 1985. Christopher Andrew and Oleg Gordievsky, *KGB: The Inside Story* (New York: HarperCollins, 1990), pp. 216-217, 261-262, 279.

[90] On 1 September 1948 Maclean was posted to Cairo as Head of Chancery. On 12 May 1950 he was sent back to London and placed on sick leave. On 1 November 1950 he was made head of the American Department of the Foreign Office. On 25 May 1951 he fled to Moscow and died there in March 1983.

[91] Cecil, *A Divided Life*, p. 70; George A. Carver, Jr., ``A Fresh Look at the Cambridge Comintern,'' *International Journal of Intelligence and Counterintelligence*, Vol. 5, No. 1, pp. 109-122.

[92] Richard G. Hewlett and Francis Duncan, *Atomic Shield, 1947-1952* (Berkeley, CA: University of California Press, 1990), originally published 1969, p. 273.

[93] Newton, *Cambridge Spies*, p. 148.

[94] Khariton and Smirnov, ``Khariton Version,'' *BAS*, May 1993, pp. 22-23. Yuli Khariton and Yuri Smirnov, ``USSR Nuclear Arms: From America or Developed Independently?'' *Izvestiia*, 9 December 1992, p. 3. According to Khariton, even some Soviet scientists who worked on the bomb itself were not aware it was a copy of the American bomb and were apparently shocked to recently

The purpose of using the Western design was to save time and avoid a ``misfire.'' It was thought that it would be more dependable and less risky to use a proven design for a first detonation. In those early days of the Cold War, Stalin's goal was to announce, as quickly as possible, that the Soviets too had the bomb.

The design was supplied by Fuchs, and perhaps by another spy at Los Alamos during the War, identified by the Russians only as ``Perseus.''[95] The fact that there was a second spy at Los Alamos is a most significant revelation, one that is bound to alter an extensive historical literature about the Rosenbergs, Harry Gold, and David Greenglass. According to Anatoly Yatskov, the NKGB officer based at the Soviet consulate in New York, who was the control agent, Perseus joined the Manhattan Project in 1942, well before Fuchs arrived in America.[96]

The key figures associated with Perseus appear to be an American couple, Morris and Lona Cohen. Cohen was born in 1910, grew up in New York City, went to study in Mississippi on a football scholarship and then graduated from the University of Illinois. It was there that he joined the Communist Party and afterwards worked for the Young Communist League in New York. Cohen went to Spain to fight with the International Brigade for the republicans in the Spanish Civil War in July 1937 under the name Israel Altman. On the Aragon front Cohen was wounded in both legs by a rifle round and while recuperating in a hospital in Barcelona was recruited to work for the Soviets. Upon returning to the U.S., he worked as a guard at the Soviet pavilion at the New York World's Fair in 1939, where he met and recruited Leontina Vladislavovna Petka (born 11 July 1913), whom he married in 1941.[97] Yatskov claims Cohen was approached in New York by an ``acquaintance,'' a physicist who had been invited to be part of the atomic bomb project. This physicist was to become Perseus.[98] When Morris was drafted into the Army in July 1942 and went

---

discover this fact. For accounts of Fuchs, see, Williams, *Klaus Fuchs, Atom Spy*; Norman Moss, *Klaus Fuchs: The Man Who Stole the Atom Bomb* (London: Grafton Books, 1987); Rudolf Peierls, *Bird of Passage: Recollections of a Physicist* (Princeton, NJ: Princeton University Press, 1985), esp. pp. 223-225.

[95] Perseus was first mentioned by Vladimir Chikov, a KGB Colonel, who published an excerpt from his book, *From Los Alamos to Moscow*, in May and June 1991 issues No. 21, 22 and 22 of *Soyuz*. They are translated in *Soviet Union Military Affairs*, JPRS-UMA-91-023, 10 September 1991, pp. 42-50. See also Ronald Radosh and Eric Briendel, ``Bombshell,'' *New Republic*, 10 June 1991, pp. 10-12; Michael Dobbs, ``How Soviets Stole U.S. Atom Secrets,'' *Washington Post*, 4 October 1992, p. A1.

[96] Dobbs, ``How Soviets Stole U.S. Atom Secrets,'' *Washington Post*, p. A1. Yatskov is better known as Yakovlev. The Itar-Tass news agency announced his death in March 1993 at the age of 79, though the exact date when he died was not given. *New York Times*, 1 April 1993, p. D24. The Manhattan Engineer District (MED), or Manhattan Project, was established 13 August 1942, and Colonel Leslie R. Groves was appointed to head it on 17 September 1942. Only in mid-March 1943 did the scientists begin to arrive at Los Alamos. Much work was underway on the bomb at various places throughout the U.S. before creation of the MED. Klaus Fuchs arrived in the United States on 3 December 1943 and worked in New York City at the British Department of Scientific and Industrial Research, assisting the Kellex Corporation in exploring the gaseous diffusion method of uranium isotope separation. He arrived at Los Alamos on 14 August 1944 and left on 15 June 1946, returning to Britain.

[97] Vladimir Chikov, ``How the Soviet Intelligence Service `Split' the American Atom,'' *New Times*, Issue 16, 1991, pp. 37-40; *New Times,* Issue 17, 1991, pp. 36-39; Robert J. Lamphere and Tom Shachtman, *The FBI-KGB War* (New York: Random House, 1986), pp. 276-278; Peter N. Carroll, *The Odyssey of the Abraham Lincoln Brigade: Americans in the Spanish Civil War* (Stanford, CA: Stanford University Press, 1994), p. 243. Chikov has them meeting before Cohen goes to Spain.

[98] Dobbs, ``How Soviets Stole U.S. Atom Secrets,'' *Washington Post*, p. A1, surmises that the recruitment must have taken place between September 1941 and July 1942 when Cohen left New York and joined the Army. This of course is very early. The U.S. did not firmly commit to building the bomb until mid-1942, Groves was appointed to head the Manhattan Project on 17 September 1942, and Los Alamos was only established in March/April 1943. Many of the ``facts'' surrounding Perseus, especially those recounted by Yatskov in the *Washington Post* article, do not accord with the historical record and chronology and have the strong aroma of being

off to serve in the quartermaster corps in Europe, Lona became the courier. According to Yatskov, Lona Cohen undertook two missions to Albuquerque to meet Perseus, one of which was in August 1945 after the bombing of Hiroshima.

After discharge from the army Morris took courses at Columbia and taught elementary school while his wife worked in a public library. After the Rosenberg's arrest the Cohens apparently fled to Britain, where they took new names, Peter and Helen Kroger, used KGB supplied New Zealand passports, and became antiquarian booksellers. In 1961 a spy named Gordon Lonsdale was arrested in Great Britain along with the Krogers, in a case known as the Portland Naval Secrets case. They were sentenced to 20 years in jail but were exchanged for Gerald Brooke in 1969. After a brief stay in Warsaw they went to Moscow in 1972. Lona Cohen died in Moscow in late December 1992 at age 79. Her husband Morris is still alive. Though Perseus's identity is not publicly known, according to Yatskov he was still alive in 1992.

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 a prison lab at Sukhumi on the Black Sea.[99] He was later joined by other German engineers, including Dr. Max Steenbeck, who was primarily involved in gas centrifuge techniques.[100] Given the low level of effort by the German scientists in developing their own bomb during the War,[101] their contribution to the Soviet program must be assessed as extremely limited.[102]

Thermonuclear Weapons Developments

The initiative to create a Soviet hydrogen bomb project began in 1946 with a short report to the government by Isai I. Gurevich, Yakov B. Zeldovich, Isaak Y. Pomeranchuk, and Yuli B. Khariton, entitled, *Utilization of the Nuclear Energy of Light Elements*.[103]

---

disinformation to continue to shield Perseus. In another account the sequence is equally confusing and suspect. V. Chikov claims to quote from intelligence File No. 13676, which is Cohen's account of a meeting with Perseus. Though the time or place is unclear, it is after Perseus has begun work at Los Alamos. *New Times*, Issue 17, 1991, p. 38.

[99] 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.

[100] Ibid.

[101] Thomas Powers, *Heisenberg's War: The Secret History of the German Bomb* (New York: Alfred A. Knopf, 1993).

[102] Khariton says that, ``German specialists were not directly involved in the design and development of the weapon.'' Their work in developing methods for separating isotopes and producing metallic uranium was ``subsidiary.'' Khariton and Smirnov, ``Khariton Version,'' *BAS*, p. 23. Holloway cites Nikolaus Riehl and his group, which produced uranium metal at a crucial stage. He was awarded the Hero of Socialist Labor in 1949. *Stalin and the Bomb*, pp. 218-219, 221.

[103] A. Romanov, ``Father of the Soviet Hydrogen Bomb,'' *Priroda*, August 1990, p. 20. The report has been published in *Usp. Fiz. Nauk* 161 (May 1991), pp. 170-171, and translated in American Institute of Physics, *Soviet Physics Uspekhi*, 34 (5) May 1991, pp. 445-446.

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.[104] Tamm's group included Andrei D. Sakharov (a graduate student under Tamm at FIAN from January 1945 until 1947, when he received his degree), Semyon Belenky, Vitali Ginzburg, and Yuri Romanov.[105] The group's task was to investigate the possibility of building a hydrogen bomb, and specifically, to verify and refine the calculations of Zeldovich's theoretical group at the Institute of Chemical Physics.[106] Sakharov was a member of Tamm's group at FIAN until he was assigned to the ``Installation'' (Arzamas-16) in March 1950, where he was employed until his clearance was revoked in July 1968.[107] Sakharov left Arzamas on 14 September 1969.[108]

Soviet progress on the hydrogen bomb closely parallels developments in the United States; indeed, Soviet efforts may have been misdirected by espionage reports of U.S. designs that ultimately proved unsuccessful.[109] It was clear that to generate a thermonuclear reaction, a temperature of several tens of millions of degrees was required. 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 sur-rounding chemical high explosive.[110] It was noted, however, that the lack of heat and compression of the deuterium resulted in practically no thermonuclear reaction in the deuterium.[111] To increase the reaction rate, two improvements in the design were proposed in 1948, one by Sakharov and the second by Vitali Ginzburg.[112] 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.[113] 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

---

[104] Sakharov, *Memoirs,* p. 94; Romanov, ``Father of the Soviet Hydrogen Bomb,'' p. 20.

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

[106] Ibid., p. 94.

[107] Ibid., p. 101.

[108] *Andrei Sakharov, Facets of a Life*, P.N. Lebedev Physics Institute (Gif-sur-Yvette Cedex, France: Editions Frontieres, 1991), p. 50.

[109] See Daniel Hirsch and William G. Matthews, ``The H-Bomb: Who Really Gave Away the Secret?'' *The Bulletin of the Atomic Scientists*, January/February 1990, pp. 22-30; and Sakharov, *Memoirs*, p. 94.

[110] V.I. Ritus, ``If Not Me Then Who?,'' *Piroda*, August 1990, p. 12; Romanov, ``Father of the Soviet Hydrogen Bomb,'' p. 20.

[111] 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 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.

[112] Ritus, ``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.''

[113] Ritus, ``If Not Me Then Who?,'' p. 12; Sakharov, *Memoirs*, p. 102.

layers of thermonuclear fuel, e.g., deuterium, tritium, or their chemical compounds, and a heavy substance, e.g., uranium-238.[114] Sakharov called it ``sloyka,'' (``layer cake'').[115] His colleagues referred to Sakharov's approach as ``sugarization'' (in English Sakharov means ``of sugar'').[116]

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.[117] 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

$$^6\text{Li} + n \rightarrow {}^4\text{He} + T + 4.8 \text{ MeV},$$
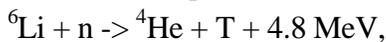
a process that is expensive. Moreover, tritium is radioactive, decaying with a 12.3 year half-life, and thus, it must be replenished on a regular basis. Soon after Sakharov proposed his ``First Idea,'' Ginzburg proposed in November 1948 substituting lithium-6 for some of the deuterium, as a means of generating tritium in the weapon itself.[118] Ultimately, perhaps by Ginzburg's suggestion, the lithium-6 was incorporated in the weapons as a chemical compound lithium deuteride (^{6}LiD).

Was Joe-4 a Hydrogen Bomb?

These two ideas, ^{6}LiD and ``sugarization,'' were incorporated into the first Soviet thermonuclear test on 12 August 1953.[119]  Identified as Joe-4 by the U.S., this test was, as described by Hans Bethe, a single-stage ``big boosted fission''[120] weapon with a yield of 400 kilotons.[121]

U.S. analysis of the fallout from Joe-4 revealed that the core was highly enriched uranium (HEU, no plutonium was used).[122] Ten percent of the yield (40 kt) was from the fission core; 15-20 percent of the yield (60-80 kt) was from thermonuclear reactions (from the ^{6}LiD); and the balance (280-300 kt) was from U-238 fissions in the uranium layers.[123]

---

[114] Romanov, ``Father of the Soviet Hydrogen Bomb,'' p. 21.

[115] Ibid.

[116] Ibid.

[117] Ibid., p. 20.

[118] Ritus, ``If Not Me Then Who?,'' p. 13.

[119] Ibid.

[120] Hans Bethe, "Sakharov's H-Bomb," *Bulletin of the Atomic Scientists*, October 1990, p. 9. The U.S. designated Soviet tests Joe-1, Joe-2, Joe-3, etc., for Joseph Stalin.

[121] This new yield estimate comes from a caption on an exhibit at a museum of nuclear weapons recently opened to special visitors at Arzamas-16. ``Mikhailov Comments on Nuclear Weapons Museum,'' *Rossiyskaya Gazeta*, 20 October 1992, p. 4, in JPRS-UMA-92-041, 18 November 1992, p. 6. An early U.S. estimate put the yield at 700 Kt. H.A. Bethe, *Analysis of Joe-4*, T-527, p. 3. Released to NRDC under the FOIA. This was later revised downward to 200-300 Kt with an upper limit of 400 Kt.

[122] Bethe, *Analysis of Joe-4*, p. 3.

[123] Khariton and Smirnov, ``Khariton Version,'' *BAS*, p. 30.

A caption at the weapon museum at Arzamas-16 for the model of Joe-4 on display describes it as the ``World's First Hydrogen Bomb.'' But whether Joe-4 was a genuine hydrogen bomb has been a matter of long-standing controversy and it has left a confusing legacy about the genealogy of the H-bomb.

It is worth quoting from the official history of the U.S. Atomic Energy Commission about Joe-4:

> It was apparent that the general statements made in 1953 and later years about Soviet superiority in thermonuclear weapon development were far from the whole truth. The Soviet scientists had *not* detonated a `true' hydrogen weapon within nine months after Mike. They had *not* developed an airborne thermonuclear weapon before the United States. And it was *not* true that the Americans had taken the wrong path in using deuterium while the Russians had struck out directly for the more practical lithium-deuteride approach.[124]

Khariton, not surprisingly, is very defensive in asserting that Joe-4 was a *real* hydrogen bomb.[125] He dismisses the 10 megaton Mike device, ``as a huge immobile 50-ton, land-based building the size of a two-story house. The nuclear fuel contained inside had to be cryogenically condensed.'' He acknowledges that Mike and Joe-4 were of different designs and claims that it would have been possible to create a hydrogen bomb on the order of one megaton based on the Joe-4 design. Without saying so explicitly Professor Khariton acknowledges that the design is inefficient and was dropped for that reason in favor of the more sophisticated Teller-Ulam/``Third Idea'' design which the Soviets would discover the following year and successfully test on 22 November 1955. The Joe-4 design concept was already known to the U.S. designers and was called the Alarm Clock. The United States never tested the design. Nine months before Joe-4 was tested, the United States did test a pure oralloy fission device. As a companion test to *Mike* Shot *King* was conducted on 15 November 1952. The device was contained in a Mark 6 (*Fat Man* type) casing and weighed 8600 pounds. It was dropped from a B-36 bomber and had a yield of 500 kilotons. The HEU requirement of Joe-4 was a fraction of that in the King device, but Joe-4's overall weight was greater than King to achieve a somewhat smaller yield.

There is no doubt that at the time Soviet officials and the scientists believed that they had successfully detonated a hydrogen bomb and ended the second monopoly. Four days before the test Premier Georgi Malenkov startled the west by announcing that the U.S. no longer had a monopoly on the hydrogen bomb. A Soviet announcement a week after the test made five references to a hydrogen bomb. Great honors were bestowed upon the scientists and managers who accomplished the feat.

Testing the Third Idea

---

[124] Richard G. Hewlett and Jack M. Holl, *Atoms for Peace and War, 1953-1961* (Berkeley: University of California Press, 1989), p. 59 (emphasis in original).

[125] Khariton and Smirnov, ``Khariton Version,'' *BAS*, p. 30.

Sakharov, Zeldovich, and Khariton are generally credited as the three principal developers of the Soviet hydrogen bomb, although the work of Arzamas-16 was supported, especially during the first years, by theoretical groups in FIAN (V. Ginzburg, E. Fradkin), in the Institute of Physical Problems (IFP) (Lvov Davidovich Landau, I.M. Khalatnikov),[126] and experimentalists at LIPAN and Dubna. Khariton was the scientific director of Arzamas-16 from its inception in 1946. Zeldovich was initially responsible for theoretical research at Arzamas-16, arriving there in 1946 with Khariton. When Tamm and Sakharov went to Arzamas in 1950, a second theory department was formed under Tamm. After Tamm left in 1953-1954, Sakharov took over Tamm's position. In 1955, Zeldovich and Sakharov were appointed deputies to Khariton.

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"[127]) and several of his colleagues in the two theoretical departments (Zeldovich's and Sakharov's) at Arzamas-16. In his *Memoirs*, Sakharov refers to it as the ``Third Idea," and claims that Zeldovich, Yuri Alekseyevich Trutnev, and others undoubtedly made significant contributions.[128] Something like the Third Idea had been the subject of earlier speculation, but this two-stage approach became a serious research option in 1954.[129]

Sakharov says that early in 1954 the ideas contained in a report he had submitted to Malyshev in November about the ``second-generation" device were not leading anywhere.[130] His projections to boost the power by only a negligible amount complicated its production and limited its deliverability. Throughout 1954 and 1955 work continued on the Joe-4 design as well, with a difference of opinion over whether it would be a viable path to pursue.

The first Soviet test of a device of this type occurred on 22 November 1955.[131] Sakharov said of this test that it ``crowned years of effort [and] opened the way for a whole range of devices with remarkable capabilities . . . it had essentially solved the problem of creating high-performance thermonuclear weapons."[132]

Stalin's Death and the Reorganization of the Bomb Program

With Stalin's death in March 1953, the nuclear weapon program underwent bureaucratic

---

[126] The process that produced deuterium for the first Soviet thermonuclear weapon was designed at IFP. Holloway, *Stalin and the Bomb*, p. 305.

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

[128] Ibid., p. 182. Khariton also gives credit to Trutnev. Khariton and Smirnov, ``Khariton Version," *BAS*, p. 29.

[129] Ibid.

[130] Sakharov, *Memoirs*, p. 182.

[131] The airplane crew was commanded by F.P. Golovashko. Khariton and Smirnov, ``Khariton Version," *BAS*, p. 30.

[132] Sakharov, *Memoirs*, pp. 192-193.

changes. On 26 June, Beria was arrested and was shot by the end of the year. With new political leaders came a reorganization of government ministries which led to the creation of the Ministry of Medium Machine Building (MMMB). Vannikov was demoted to First Deputy Minister, and another veteran of the defense industry, Vyacheslav A. Malyshev, was appointed Minister. One of Malyshev's accomplishments was to promote a number of his former colleagues in the heavy and tank industries to key positions: Zernov was moved from his post as director of Arzamas-16 to deputy minister, as were the former party organizer at the Uralmash plant (L.G. Mezentsev), and his economic deputy at the Ministry of Heavy Industry (A.M. Petrosyants). Another deputy minister, A.N. Komarovsky, was appointed with responsibility for site construction as the nuclear industry expanded.

Stalin's death and Beria's arrest left the nuclear weapons designers, in the words of one commentator, ``truly orphaned.'' Stalin's successor, Georgi M. Malenkov, was unaware of the hydrogen bomb or its upcoming test scheduled for August 1953. Malyshev and Kurchatov explained the project to Malenkov, and received approval to conduct the test, although it was clear the era of high-level management of the program was being replaced by one allowing for greater initiative and independence by the ministry.[133]

When Malenkov was ousted in 1955, so was Malyshev, who was replaced by A.P. Zaveniagin. Zaveniagin lived long enough to oversee establishment of a second nuclear weapons design laboratory, Chelyabinsk-70, in 1955. Zaveniagin died in December 1956. After a short stint in early 1957 by Boris Vannikov as acting minister, M.G. Pervukhin was appointed Minister in May 1957, only to be replaced two months later because of his alleged involvement with the so-called ``Anti-Party Group'' of Khrushchev opponents. Pervukhin's successor, Ye.P. Slavsky, ushered in an era of stability at the top, as he held the post for almost 30 years.

---

[133] Yaroslav Golovanov, *Korolev* (book chapter published in) *Poisk* No. 7 (February 1990), pp. 15-21; February, 1990, No. 8, pp. 22-28, translated as ``Secret Details of Early ICBM, Nuclear Warhead Development Revealed,'' in JPRS-UMA-90-006, 31 May 1990, pp. 87-91, at p. 88.

CHAPTER TWO
AN OVERVIEW OF THE STOCKPILE AND COMPLEX

The Nuclear Weapons Stockpile

According to Ministry of Atomic Energy Minister Viktor Mikhailov, the Soviet nuclear weapons stockpile grew rather steadily until it peaked in 1986 at 45,000 warheads;[134] and then declined more than 20 percent to 32,000 warheads by May 1993.[135] An official CIA estimate given in May 1992 placed the stockpile of the former Soviet Union at 30,000 nuclear weapons with an uncertainty of plus or minus 5,000.[136] The upper limit, of the CIA estimate is consistent with the Minatom figures. According to Minatom the stockpile was projected to decline to 40-50 percent of its mid-1992 level as a result of arms control initiatives through early-1992.[137] This implies a 17,500 to 21,000 warhead reduction, bringing the stockpile down to 14,000 to 17,500 warheads. The CIA, on the other hand, stated in May 1992 that:

> . . . the Russians have something on the order of 9,000 to 16,000 nuclear weapons slated for dismantling. They have not given us an official figure for how many weapons are slated for dismantling as a result of the Gorbachev-Yeltsin initiative. This is our estimate. We have a highly uncertain estimate of the size of their tactical nuclear weapon inventory. Their initiative included something on the order of 1,200 strategic weapons; 5,000 to 12,000 tactical nuclear weapons, and our estimate of 2,700 weapons remaining from the INF treaty.[138]

The CIA upper limit on the number of warheads slated for dismantlement is 1500 warheads less than the lower limit derived from the Minatom statements.

As a consequence of the Bush/Gorbachev initiatives of September and October 1991 and the Strategic Arms Reduction Treaty

---

[134] Private communication to authors concerning remarks by Viktor Mikhailov.

[135] ``According to Minister Viktor Mikhailov approximately 13,000 nuclear munitions have been dismantled in this time [the last eight to 10 years], 2,000 a year on average.'' Sergei Ovsiyenko, ``Weapons-Grade Plutonium Stocks Dwindling,'' *Rossiyskiye Vesti*, 19 May 1993, p. 7. Viktor Mikhailov and Evgeni Mikerin, in remarks at the International Symposium on Conversion of Nuclear Warheads for Peaceful Purposes, Rome, Italy, 15-17 June 1992, stated that the stockpile had declined by 20 percent since it peaked in 1986. In an interview with Evgeni Panov, *Moscow Rossiyskaya Gazeta*, in Russian, 11 December 1992, p. 7 (translated in the Foreign Broadcast Information Service series, FBIS-SOV-92-239, 11 December 1992, p. 3), Mikhailov is quoted as having said, ``. . . if destruction of nuclear weapons in our country is halted as a result of financial and technical difficulties, by the year 2000 the Americans will be scrapping their own weapons but we will be unable to. They will have 10,000 charges left, we will have 35,000.'' See also, Trip Report, Senate Armed Services Committee Delegation's Visit to Russia, Kazakhstan and Ukraine, 15-20 January 1992, p. 4. ``According to officials of the Ministry and other informed sources, some 8-10 thousand warheads have been disassembled in Russia since 1985.''

[136] Lawrence K. Gershwin, National Intelligence Officer for Strategic Programs, Central Intelligence Agency, Hearings before the House Committee on Appropriations, DOD Appropriations for 1993, Part 5, 6 May 1992, p. 499.

[137] Mikhailov and Mikerin, International Symposium, Rome, 15-17 June 1992.

[138] Gershwin in HAC, DOD FY 1993, Part 5, p. 499.

(START I), the Russian stockpile would be reduced to some 10,500 to 13,000 warheads by the year 2000. On 17 June 1992, Presidents Bush and Yeltsin announced that the U.S. and Russian strategic arsenals would each be reduced to 3000-3500 strategic warheads no later than 1 January 2003. This agreement was codified as the second Strategic Arms Reduction Treaty (START II), signed in Moscow by Yeltsin and Bush on 3 January 1993. Depending on many decisions about the future composition of Russian forces, especially the non-strategic weapons, the Russian active or operational stockpile at the turn of the century could be anywhere from 4000-5000 warheads,[139] to a much larger figure of 8000 to 10,000.[140]

Russian sources have estimated that some 55,000 nuclear warheads have been produced since 1949. If this is the case, and some 29,000 warheads remain as of the end of 1994, then some 26,000 warheads would have been retired since 1949.

Ministry of Atomic Energy

The Russian Ministry of Atomic Energy (in Russian, *Minatom*), whose counterpart in the United States is the Department of Energy (DOE),[141] is responsible for the research, development, testing, and production of nuclear warheads. Once produced, the warheads are delivered by Minatom to the Main Directorate for Nuclear Weapons (the Twelfth Main Directorate) of the Ministry of Defense.[142] By decree of President Yeltsin on 28 January 1992, the Russian Minatom 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''). Minatom, as did its predecessors

---

[139] This assumes 3500 strategic weapons plus a few spares, and a small non-strategic force.

[140] This assumes an additional reserve of 4000 to 5000 strategic and non-strategic warheads.

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

[142] Little is known about the history, organization, or responsibilities of the Twelfth Main Directorate (or Administration) of the Ministry of Defense. We are grateful to Peter Almquist for sharing his knowledge about the Twelfth Main Directorate with us. A recent article provides some new detail. Igor Sutiagin, ``Safety Problems of Russian Nuclear Weapons: Ensuring the Technical Safety of Nuclear Charges,'' *Voennyi Vestnik*, No.7, 1993, pp. 62-76. The Directorate is responsible for overseeing the development, testing, storage and transportation of nuclear weapons for the Ministry of Defense and thus works in close cooperation with the Ministry of Atomic Energy. Only a few names have emerged as being associated with it (see Appendix A for further details on some of the following individuals): V.A. Bolyatko, possible head from the late-1950s to 1965; N.P. Yegorov, probable head from 1965 to 1974; Ye.V. Boychuk, head from 1974-1985, V.I. Gerasimov, 1985-1992; Ye.P. Maslin, 1992-to date; General Sergei Zelentsov, Head Nuclear Engineer.

MAPI and MMMB, supervises the entire chain of production for nuclear weapons, from the mining of uranium ore through the fabrication of warheads. It is responsible for the production of all nuclear materials and for uranium enrichment, production reactors, nuclear waste management, and warhead research, development, testing, and production. Analogous to the U.S. DOE, Minatom 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.[143]

Abbreviated organizational tables of Minatom, adapted from various brochures and charts, are provided in Table 2.2 Viktor N. Mikhailov was appointed the first Minister of Atomic Energy in early March 1992, shortly after Minatom was formed. Under Mikhailov are two first deputy ministers, Vitali F. Konovalov (the former minister) and Lev Ryabev, and five deputy ministers.[144] Reporting directly to Mikhailov are two department heads responsible for central nuclear weapons activities: Boris V. Gorobets is Head of the Sixth Directorate,[145] responsible for nuclear weapons production; and Georgi P. Tsyrkov is Head of the Fifth Directorate,[146] responsible for nuclear warhead design and testing. Officially reporting through Deputy Minister Nikolai N. Yegorov, Evgeni I. Mikerin, Head of the Fourth Directorate,[147] is responsible for the production and separation of plutonium, tritium, and other isotopes, for uranium enrichment, and for uranium and plutonium metallurgy and component manufacture.

To summarize, the principal administrators (after Beria) of the nuclear weapons program after the creation of the MMMB were:

---

[143] 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. For a survey of its current fields of activity see, *Minatom of Russia*, Minatom brochure, 24/26, B. Ordynka ul., 101000 Moscow, Russian Federation, Tel: 239-4545; Fax: 230-2420.

[144] 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 Viktor 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.

[145] Other senior officials are Nikolai Petrovich Larin, Evgeni Konstantinovich Dudochkin, Vyacheslav Vasiliyevich Bakhchevnikov, and Akhat Sabitovich Tyatigachev. *Russian Government Today* (Washington, DC: Carroll Publishing Company, 1993), p. 184.

[146] Other senior officials are Boris Yuriyevich Lubovin, Vitali Mikhailovich Ivanov, Arkadi Alexandrovich Kolegov, Yelena Vladimirovna Ponomareva. *Russian Government Today*, p. 184.

[147] Other senior officials are Stanislav Vasileyevich Malyshev, Aleksandr Alexandrovich Samarkin, Viktor Nikitovich Khaprenko, Arkadi Antonovich Kuznetsov. *Russian Government Today*, p. 184.

Malyshev, V.A.- Minister, MMMB, June 1953-February 1955.
Zaveniagin, A.P. - Minister, MMMB, February 1955-31 December 1956.
Vannikov, B.L. - Acting minister, MMMB, January-May, 1957.
Pervukhin, M.G.- Minister, MMMB, May-24 July 1957.
Slavsky, 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 resigned following the attempted coup in August 1991.
Nikipelov, B.V. - Acting Minister MAPI/Minatom, September 1991-
March 1992.
Mikhailov, V.N. - Minister, Minatom, March 1992-to date

Overview of the Nuclear Weapons Complex

During the initial years of the Soviet nuclear program, Sverdlovsk-44 and Sverdlovsk-45 produced HEU, and Chelyabinsk-40 produced plutonium and tritium. Fissile materials were fabricated into warhead components at Chelyabinsk-40 and were transferred to Arzamas-16 for final assembly. Arzamas-16 also was the principal warhead design laboratory. Weapons production technologies (processing and machining of HEU and plutonium) were developed at the NII-9 in Moscow (presently, the Institute of Inorganic Materials), the principal technology development center of the First Main Directorate. Pilot production of uranium warhead components took place at Electrostal (the plant also produced lithium-6 hydrides for thermonuclear weapons).

The weapons production complex significantly expanded in the subsequent years. By the early 1980s, design, testing, and production of warheads took place at 13 principal sites. Arzamas-16 and Chelyabinsk-70 were responsible for design and scientific and engineering support of warheads at all stages of their life-cycle. Testing took place at Semipalatinsk and Novaya Zemlya. Production of fissile materials for weapons took place at five sites. Chelyabinsk-40, Krasnoyarsk-26, and Tomsk-7 produced plutonium. Sverdlovsk-44, Krasnoyarsk-45, and Tomsk-7 produced HEU. (The fourth enrichment facility at Angarsk has not produced HEU.) Other nuclear materials for weapons--lithium-6 and tritium--were reportedly produced at Novosibirsk and Chelyabinsk-40 respectively. Chelyabinsk-40, Tomsk-7, and Sverdlovsk-44 were involved in metallurgical processing of fissile materials and production of warhead components.[148] Warhead assembly took place

---

[148] Fissile material metallurgy also took place at Krasnoyarsk. See Russian Federal Nuclear Inspectorate [Gosatomnadzor], ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993, Parts I, II,'' Approved by Order of the Gosatomnadzor, No. 61 from 13 May 1994 (Moscow). It is not known, however, if it was directly related to warhead production.

at Arzamas-16, Sverdlovsk-45, Zlatoust-36, and Penza-19. Reportedly, only Arzamas-16 and Sverdlovsk-45 assembled nuclear materials packages.[149] At the assembly plants, when the warheads have been assembled the 12th Main Directorate of the Ministry of Defense (military unit 31600) assumed responsibility and distributed them to branches of the Armed Forces, each with their own analogous directorate. Every 3-6 years, warheads were returned to the Minatom's warhead assembly plants at Arzamas-16 and Sverdlovsk-45 for general maintenance and for replacement of tritium components.[150] In the end of the warhead life-cycle (approximately 8-10 years[151]), warheads were delivered by the 12th Main Directorate to the Minatom's assembly plants for disassembly and recycle.

This warhead production pipeline was supported by the two test sites at Semipalatinsk in Kazakhstan and Novaya Zemlya in Russia, and by many R&D institutes. For example, the Khlopin Institute developed reprocessing technologies: the Institute of Inorganic Materials, fissile materials processing technologies: the Institute of Impulse Technology, nuclear testing infrastructure and equipment: and the Institute of Automation, automatic and electronic systems for weapons.

The conversion effort initiated in the late 1980s and the changes the country has gone through sharply affected the activities of the warhead production complex. Production of HEU for weapons was terminated in 1988. Production of plutonium for weapons has been dramatically reduced and is expected to be ended soon. The Semipalatinsk nuclear test site was permanently shut down after the Soviet break up. Weapons-related activities at other facilities have been either cut or directed toward warhead dismantlement. In addition to dismantlement, the complex continues arsenal maintenance activities and probably limited production of new warheads for SS-25 strategic missiles.

Since the nuclear warhead production complex and most of the arsenal were concentrated in Russia, upon the break up 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, headquartered in Moscow.

Consistent with the traditional Soviet secrecy practices, ten

---

[149] Sutiagin ``Problems of Security,'' *Voenny Vestnik*, No. 7, 1993, pp. 62-76.
[150] Ibid.
[151] Ibid.

of these sites (and the closed cities that support them) were not found on any Soviet maps.[152] In addition to their primary names, these closed sites were code-named after cities 50 to 100 kilometers away followed by a postal zone number (e.g., Arzamas-16). Their precise locations were not always known. Beginning in 1989, several sites have been opened to limited visits by the Russian press and sometimes to foreigners, but other 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. Their total population is about 700,000.

The two weapon design laboratories, now called Federal Nuclear Centers, 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) at Snezhinsk, in the Urals region. Arzamas-16 and Chelyabinsk-70 are reported to have a capability to fabricate experimental and prototype warheads. Arzamas-16 (but not Chelyabinsk-70) has been identified as a site with a capability to assemble and disassemble warheads, suggesting a capability greater than prototype assembly. Specifically this refers to a co-located facility known as the Electromechanical Plant ``Avangard,'' which reports to the Sixth Main Directorate. The Director at the beginning of 1994 was Yu. K. Zavalishin.

Sverdlovsk-45 (with its closed city Lesnoy) at Nizhnyaya Tura in the Urals is the largest of the four nuclear warhead assembly (and disassembly) plants. Zlatoust-36 (with its closed city Trekhgorny), is in the town of Yuryuzan, 85 km southwest of

---

[152] Originally the towns were named by a top-secret resolution by the Presidium of RSFSR Supreme Soviet passed in 1954. Recently, the names were confirmed publicly by the Russian government in a resolution signed by O.Soskovets. Information Bulletin, Nuclear Society (Moscow), 1/1994-1995, p. 12.
   Initial disclosures were first revealed in a Japanese newspaper. Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, 17 November 1991, Morning Edition, p. 1 (translated in FBIS-SOV-91-225-A, 21 November 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)	6. Zelenogorsk (Krasnoyarsk-45, 63,300)
2. Snezhinsk (Chelyabinsk-70, 46,300)	7. Norouralsk (Sverdlovsk-44, 88,500)
3. Ozersk (Chelyabinsk-65, 83,500)	8. Lesnoy (Sverdlovsk-45, 54,700)
4. Seversk (Tomsk-7, 107,700)	9. Zarechnyy (Penza-19, 61,400)
5. Zheleznogorsk (Krasnoyarsk-26, 90,300)	10. Trekhgornyy (Zlatoust-36, 29,800)

In the original there were transliteration problems of translating the Russian first into Japanese and then into English. Since 1991 the secret cities have been mentioned in the press and the spellings above seem to be the correct ones. Apparently most of these once numbered cities have been given official names. Anatoli Safonov, ``Closed Cities Given New Names,'' *Pravda*, 16 March 1994, p. 8 (translated in FBIS-SOV-94-052, 17 March 1994, pp. 15-16). To avoid confusion we will retain the code-names in discussing the complex.

Zlatoust, and has also been identified as a warhead assembly and disassembly facility.[153] The third facility, Penza-19 (with its closed city Zarechnyy), in Kuznetsk (115 km east of Penza), has been identified as a warhead assembly and disassembly facility and separately as the site of an electronics plant, presumably similar to the Kansas City Plant in the United States.

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 used 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 against Gorbachev earlier that month.

Prior to 1987, there were 15 military production reactors operating at three sites: at Mayak Chemical Combine (Chelyabinsk-65, previously Chelyabinsk-40), near Kyshtym in Chelyabinsk Oblast; 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. Thirteen of the 15 were plutonium production reactors—five at Chelyabinsk-65, five at Tomsk-7, and three at Krasnoyarsk-26.[154] The five graphite production reactors at Chelyabinsk-65 were shut down between 1987 and 31 December 1990. At Tomsk-7 three of the five graphite reactors were also shut down between 21 August 1990 and 14 August 1992. At Krasnoyarsk-26 one of the three reactors was shut down about 30 June 1992, and a second was retired on 29 September of the same year. Thus, there have been only three plutonium production reactors operating since 14 August 1992--two graphite reactors at Tomsk-7 and one at Krasnoyarsk-26. All three of these are dual purpose, producing plutonium, and steam for district heating and electricity.

At Chelyabinsk-65 there are currently the two light water production reactors that are used for the production of tritium and special isotopes, e.g. Pu-238. One of these reactors was a heavy water type before being rebuilt in the late-1980s. No tritium production has taken place at Krasnoyarsk-26 and none is believed to take place at Tomsk-7. Whether tritium production ever took place at Tomsk-7 is not known. Warhead pit manufacture

[153] SASC, *Threat Assessment, Military Strategy, and Defense Planning*, Senate Hearing 102-755, pp. 55-56.
[154] The U.S. 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.

and uranium enrichment also take place at Tomsk-7, Chelyabinsk-65, and Sverdlovsk-44.

The four operating uranium enrichment plants are the Urals Electrochemical Plant[155] at Sverdlovsk-44 (with its closed city Novouralsk) near Verkh-Neyvinsk (formerly Kefirstadt), near Yekaterinburg (called Sverdlovsk prior to the break up 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. Production of HEU for weapons ceased in 1988.

Prior to the break up of the Soviet Union, there were thought to be some 29 nuclear weapons production/storage sites in the Soviet Union. As of the beginning of 1995, due to consolidation these storage sites are thought to number about 15.[156] The locations of most of these is are not publicly known. Tactical warheads are moved in truck convoys under heavy guard. The main volume of nuclear warhead transport is done by railroad. In the former Soviet Union, 120-160 railroad cars were used for this. This allowed transport of up to 800 warheads per month and in special circumstances up to 1500 per month.[157]

According to Mikhailov, nuclear weapons production employed slightly more than 100,000 people in early 1992, with 10,000 to 15,000 having ``really secret information,'' and 2000 to 3000 having information ``of paramount importance.''[158] 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.[159]

---

[155] It has also been referred to as the Urals Electrochemistry Combine and Urals Electrochemical Combine.

[156] Many of the storage sites are old and in need of repair. The necessity of removing nuclear weapons from storage sites in unstable areas has resulted in other sites having numbers in excess of the intended capacity. Sutiagin, ``Problems of Security,'' *Voenny Vestnik*, No.7, 1993, pp. 62-74.

[157] Ibid., p. 70.

[158] *Komsomolskaya Pravda*, 31 January 1992, p. 1 (translated in FBIS-SOV-92-022, 3 February 1992, pp. 5-6). ``At present, there are approximately 1 million employees working under the Russian Atomic Energy Ministry: at enterprises, in research institutes, design organizations, and production complexes. In the ministry itself, there are some 900 officers. (Incidentally, when the [MMMB] was formed in 1953 . . . the number of its employees was 3,031). Projects related to the nuclear arms complex constitute 15 percent. while the remaining 85 percent are civilian projects.'' Interview with Viktor Mikhailov in *Nezavisimaya Gazeta*, 18 August 1993, pp. 1,3 (translated in FBIS-SOV-93-159, 19 August 1993, p. 35); ``Russia's Chief Hawk,'' *Komsomolskaya Pravda*, 4 June 1994, p. 2 (translated in FBIS-SOV-94-109, 7 June 1994, pp. 27-31).

[159] Elaine Sciolino, ``U.S. Report Warns of Risk in Spread of Nuclear Skills,''*New York Times*, 1 January 1992.

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) and now Russian Scientific Center (RSC) in Moscow.[160] Here the first Soviet nuclear reactor, called F-1 (``Physics-1''), was constructed and began operating on 25 December 1946.[161] 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 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 work on military programs.[162] Upon his death in 1960, Kurchatov was succeeded as director of the institute by Academician Anatoli P. Aleksandrov. Thrice a Hero of the Soviet Union, Aleksandrov was also the President of the Soviet Academy of Sciences from 1975 until October 1986. Aleksandrov was succeeded as director of Kurchatov by Academician Evgeni P. Velikhov.

Arzamas-16

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 April 1946. One of its early designations was KB-11 (*konstruktorskoe biuro*--Design Bureau-11). According to another account, ``[i]ts very first name was `Obyekt No. 558' [Installation].  Then it was called `Volga Office [Privolzhskaya Kontora] No. . .' (112, it seems). For mail items it was called `Moscow Center 300.'  Somewhat later the city was named `Kremlev,' and then Arzamas-75. The number corresponds to the number of kilometers from the real Arzamas. However, it was pointed out to someone that the number discloses the location, and that is why they gave it a different number [Arzamas-16] at random.''[163] Another reference says Arzamas-16 was initially known as ``Military Installation `N,''' then ``Kremlev City.''[164] The

---

[160] There was no Laboratory No. 1.

[161] 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, *Izvestiia,* 23 July 1988, p. 3 (translated in the Joint Publications Research Service series, JPRS-UMA-88-029, 16 December 1988, pp. 55-60).

[162] ``Brains for Sale,'' *Poznan WPROST*, in Polish, 8 March 1992, pp. 38-39 (translated in FBIS-SOV-92-054, 19 March 1992, p. 8).

[163] Mikhail Rebrov, ``Three Generations of Bombs: Only Now Can We Talk About The City Where They Were Born,'' *Moscow Krasnaya Zvezda,* in Russian, 27 October 1992, p. 2 (translated in JPRS-UMA-92-042, 25 November 1992, p. 42). In his *Memoirs,* Sakharov referred to Arzamas-16 as the ``*obyekt*'' [installation], as this was the only word that could be used to refer to the facility for security reasons. Sagdeev, refers to it as ``Moscow 300'' and the ``Near Volga Office.'' *Making of a Soviet Scientist*, pp. 47-48.

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

mailbox numbers ``changed like the weather in early spring (49, 51, 214, 975), '' not due to confusion but to assure complete territorial anonymity.[165]

Prior to the dissolution of the Soviet Union Arzamas-16's formal name was the All-Union Scientific Research Institute of Experimental Physics. It is also known informally as ``Khariton's Institute,'' named after Academician Yuli B. Khariton, who was the institute's scientific director from its creation until he retired in 1992.[166]

The site for the secret installation was chosen by Khariton and General Pavel M. Zernov (who was appointed director of the institute) because it was no closer than 400 kilometers from Moscow (Stalin imposed this condition) yet not too far away; the wooded expanse where one could ``hide''and the small plant which produced shells for the Katyushas could become somewhat of a mechanical base.[167] In addition, the site was both isolated and protected. It is situated on lands of the former Sarovsky Hermitage (Sarov monastery), destroyed in 1927, at Sarova, in the Nizhni Novgorod oblast at the Mordvinian autonomous republic border, 75-80 kilometers southwest of Arzamas.[168]

The closed city, which as noted above, was at one time temporarily named Kremlev (and is now again), has a population of some 80,300.[169] It is here that the first Soviet nuclear bomb was designed and assembled.[170]

There are about 25,000 employees at the institute. In 1990, the institute reported having two academicians, two corresponding

---

recounts all these names and suggests their proliferation was partly due to the exceptional secrecy surrounding the program and the need for a ``pigeon language'' of code words. Yuli Khariton and Yuri Smirnov, ``The Khariton Version,'' *The Bulletin of the Atomic Scientists (BAS)* , May 1993, p. 20.

[165] *International Affairs* (Moscow), No. 9, 1994, p. 139 (excerpt from *The End of Nuclear Monopoly*).

[166] Khariton, who arrived at Arzamas on 2 April 1946, 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.

[167] Rebrov, ``Three Generations,'' p. 43. A recent article states that on 8 April 1946 a three man commission (one of whom was Khariton) arrived at Sarov. Aleksandr Nezhnyy, ``The Bomb,'' *Rossiyskaya Gazeta*, 8 February 1994, p. 7 (translated in FBIS-SOV-94-028, 10 February 1994, p. 25.

[168] ``Silent People Live Here,'' *Komsomolskaya Pravda,* 25 November 1990, p. 2. Sarova is located at 54$^o$ 55'N/43$^o$ 19'E; Arzamas at 55$^o$ 23'N/43$^o$ 50'E. According to Serge Schmemann, *New York Times,* 8 February 1991, p. A4, ``In the 1920's the monastery was used to house war orphans, and in the 1930's it became a special institution for young criminal boys without parents--juvenile delin- quents. Just before World War II there was a factory there that made artillery projectiles. 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.'' The monastery was named after Reverend Serafim Sarovsky, canonized by the Orthodox Church in 1903 during a visit to Sarov by Tsar Nikolai and his wife Aleksandra.

[169] Furumoto, *Tokyo Yomiuri Shimbun*, p. 1 (translated in FBIS-SOV-91-225-A, 21 November 1991, p. 3); in the translation the town is transliterated ``Kremryuv.''

[170] ``Silent People Live Here,'' *Komsomolskaya Pravda,* 25 November 1990, p. 2. See also, *Pravitelstvennyy Vestnik*, No. 49, Decem- ber 1990, p. 12. The nearby plant where this production took place is believed to have been called ``N 3.'' Khariton said the first laboratory was located in a wing of the monastery. ``Interviews With Arzamas-16 Nuclear Weapons Scientists,'' (translated in JPRS-TAC-93-006-L, 11 June 1993, p. 9).

members of the academy, 50 doctors, 500 candidate Ph.D.s, and 250 winners of Lenin and State prizes.[171]

The primary mission of Arzamas-16 has been to design nuclear warheads. The institute fabricates experimental and prototype warheads.[172] Some factory production probably took place at Arzamas-16 in the early years. *Komsomolskaya Pravda* described the work of an ``engineer-fitter'' that worked in a shop of about 30 people engaged in the final assembly of bomb and missile warheads.[173] He claimed to have assembled several thousand nuclear warheads over a fourteen-year period.[174] Minatom Minister Mikhailov in 1992 identified Arzamas-16 as one of four facilities for the assembly and disassembly of warheads. This suggests that the production capacity at Arzamas-16 may be as much as several hundred warheads per year. At one test stand, warheads are accelerated to escape velocities by a rocket driven sled along a three kilometer rail track (whose deviation from a straight line does not exceed three millimeters), after which they travel over a low angle trajectory to a target area pipe 100 meter in length and six meters in diameter.[175] The testing area for the explosions department is called Area No. 19.[176]

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 12-beam, 120-terawatt 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.

Today the city and ``industrial zone'' are separated. The

---

[171] All-Union Scientific Research Institute of Experimental Physics, *Prospectus*, 1990, p. 3. The figures are quoted in G. Lomanov, ``The City That is Not on the Map,'' *Pravitelstvennyy Vestnik* [Government Herald--the newspaper of the Council of Ministers], No. 49, December 1990, p. 12 (translated in JPRS-UMA-91-013, 20 May 1991, pp. 49-50).

[172] Viktor 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. Natural Resources Defense Council, ``Report of the Third International Workshop on Verified Storage and Destruction of Nuclear Warheads,'' held in Moscow and Kiev, 16-20 December 1991, p. 13.

[173] Jonathan Lyons, ``Bomb-Builder Gives Rare Look at Soviet Arms Industry,'' Reuter, 6 February 1992. See also Igor Stadnik, ``Survivors of the Soviet Atomic Bomb Programme,'' *Moscow News*, No. 26, 1992.

[174] Ibid.

[175] Rebrov,``Three Generations,'' p. 43.

[176] Ibid.

roads are scattered along the wooded areas for many kilometers. Work zones and experimental complexes are usually called ``areas.'' Each has its own fence, ``tracking zone,'' and guard towers. Crossings from zone to zone are restricted.[177]

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, who will be 91 on 27 February 1995, was the scientific director until he retired in the fall of 1992. Khariton's successor, Viktor Mikhailov, now wears two hats--scientific director of Arzamas-16 and minister of the Ministry of Atomic Energy. 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 and was instrumental in developing the hydrogen bomb.

The first director of Arzamas-16 (1946-1951) was General Pavel M. Zernov. The second director was General Anatoli S. Aleksandrov (1951-1955), followed by Boris G. Muzrukov (1955-1974), then Evgeni A. Negin (1974-1994). Negin was simultaneously chief designer. The institute's current (early 1995) director is Vladimir A. Belugin[178] (see Table 2.3).

Chelyabinsk-70

The second of the two existing principal nuclear weapons design laboratories, is the All-Russian (formerly All-Union) Scientific Research Institute of Technical Physics (VNIITF), more informally called Chelyabinsk-70. It is located between Lakes Sinara and Silach, just east of the Urals, in the town of Snezhinsk, 20 km north of Kasli and about 80 km south of Yekaterinburg.[179] Its creation in 1955 parallels that of the establishment of Lawrence Livermore National Laboratory (LLNL) in the United States.[180]

The institute started at Site 21, which is located on a peninsula between Lake Sungul and Lake Silach--about midway

---

[177] Ibid.

[178] Vladimir Gubarev, ``The Atom Bomb-Superstar,'' *Moscow VEK*, No. 15, 4 December 1992, p. 10, in Russian (translated in JPRS-UMA-93-001, 6 January 1993, pp. 2-6).

[179] ``Film Depicts Secret Nuclear Town: Chelyabinsk-70,'' Moscow Teleradiokompaniya Ostankino Television First Program Network, 1922 GMT on September 1992 (a partial account translated in JPRS-TND-92-035, 23 September 1992, pp. 27-29). 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 kilometers to the south. A small village is located at 56° 04'N/60° 46'E.

[180] Livermore was originally founded as a branch of the University of California Radiation Laboratory on 2 September 1952.

between Snezhinsk, 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. Timofeev-Resovsky, 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.[181] 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 scientists from Arzamas-16 moved 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 began conversion to non-weapons work, a computer assembly and repair facility, called the Sungul Science Engineering Center, was created at Site 21.[182] 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 six kilometers to the west of town, are enclosed by a rectangular fence. The enclosed area measures approximately six by thirteen kilometers and 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,[183] 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 used by Lawrence Livermore National Laboratory in the U.S.). The main test area is about five km to the northeast of Lake Itkul.[184]

Since 1988, Chelyabinsk-70 has been converting a portion of its military research to civilian applications. In early-1992, roughly 50 percent of its research was military and 50 percent

---

[181] 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,'' *Komsomolskaya Pravda*, 26 June 1991, pp. 1,4.

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

[183] Furumoto, *Tokyo Yomiuri Shimbun*, p. 1 (in FBIS-SOV-91-225-A, 21 November 1991, p. 3).

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

non-military, with further cuts on the military side expected.[185]
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.

Dmitri Ch. Vasilyev was the first director of Chelyabinsk-70
from 1955 until his death in early-1961. He was succeeded by
Boris N. Ledenyov, from 1961-1963; who was succeeded by Lt. Gen.
Georgi P. Lominsky, from 1963-1986; followed by Vladimir Z.
Nechai, who has been the director since 1986. Vladislav I.
Nikitin is currently the deputy director.

Kirill I. Shchelkin, who had been Khariton's deputy at
Arzamas-16, was the first scientific leader of Chelyabinsk-70,
occupying the position from 1955 until 1960. Academician Evgeni
I. Zababakhin was the scientific leader from 1960 until his
untimely death in December 1984. He was succeeded by Academician
Evgeni 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 (See Table 2.3).

Nuclear Warhead Test Sites

Various Russian, Kazakhstan, and American documents have
helped break down 715 Soviet tests by date, type, location, and
purpose.[186] Our current best estimate is that by type there have
been 204 nuclear tests in the atmosphere, 508 underground, and
three underwater. By location, 496 were conducted in Kazakhstan,
214 in Russia, and five in three other republics. Within
Kazakhstan, 470 tests were conducted at the Semipalatinsk test
site: 348 of them underground, 215 horizontally emplaced and 133
vertically emplaced. At the Russian Novaya Zemlya test site there
have been 132 tests: 87 in the atmosphere, three underwater, and
42 underground. The total yield of tests is about 291 megatons
with some 257 megatons detonated in the atmosphere between 1949

---

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

[186] V.V. Gorin, et al., ``Semipalatinsk Test Site: Chronology of Underground Nuclear Explosions and Their Primary Radiation Effects (1961-1989),'' *The Bulletin of the Center of Public Information on Atomic Energy (Biulleten tsentra obshchestvennoi informatsii po atomnoi energi)*, No. 9, 1993, pp. 21-32; Y.V. Dubasov, et al., `` The Chronology of Nuclear Tests Carried Out in Atmosphere, Space and Underwater (1949-1962),'' *The Bulletin of the Center of Public Information on Atomic Energy (Biulleten tsentra obshchestvennoi informatsii po atomnoi energi)*, No. 2, 1994, pp. 36-43; ``Lists of Tests at Semipalatinsk,'' Original article by Toqtasyn Saybekov in *Ata Meken* in Kazakh, 14 August 1993, p. 4 (translated in JPRS-TAC-93-019, 29 September 1993, pp. 33-34). ``Soviet Nuclear Weapons Tests Through 1958,'' *Office of Naval Intelligence (ONI) Review*, March 1959, pp. 104-106; ``Soviet Thermonuclear Weapon Development,'' *ONI Review*, October 1961, pp. 418-419; ``Recent Soviet Nuclear Testing,'' *ONI Review*, January 1962, p. 10; Correspondence with Paul G. Richards of Lamont-Doherty Earth Observatory. A four part series on Soviet nuclear testing is being prepared, which should establish an authoritative list of Soviet tests and explosions. Viktor N. Mikhailov is the executive editor. Parts 1 and 2 concern the Northern test Site, Part 3 is about Semipalatinsk, and Part 4 covers Peaceful Nuclear Explosions.

and 1962.[187]

    The Soviet Union had an extensive Peaceful Nuclear Explosion (PNE) program comprising 116 events that began in January 1965 and continued to September 1988. By comparison the U.S. conducted 27 PNEs between 1961 and 1973. The primary purpose of the Soviet PNEs were to support the oil, gas, and mineral industries. Thirty-nine explosions were used in the deep seismic sounding program. Seismic waves, generated by one or more nuclear detonations, are recorded by stations and analyzed to understand geological features at great depths. Thirty-six PNEs were to create underground storage cavities, mainly for gas condensate, mostly in the area north of the Caspian Sea. Another 21 assisted in the extraction of gas and oil, and five were exploded to extinguish burning gas or oil wells. One was conducted for a canal-building project that was to link the northern Kara Sea to the Caspian Sea via the Pechora and Kama Rivers. Other excavation projects created reservoirs. Eighty one of the PNEs were conducted in Russia, 30 in Kazakhstan, two each in Ukraine and Uzbekistan, and one in Turkmenistan.

Semipalatinsk-21[188]

    As discussed in Chapter One, establishment of the test site near Semipalatinsk in Kazakhstan was the result of a special resolution of 21 August 1947. Originally called ``N 2,'' the more recent name was Semipalatinsk-21, or the ``Polygon.'' The secret city is called Kurchatov.[189]

    With a few exceptions, most of the tests were exploded within a rectangle of about 2000 square miles (49.700 to 50.125 North by 77.700 to 79.100 East). Tests occurred in three distinct areas-- Shagan River, Degelen Mountain, and Konyastan. Most of the tests at Semipalatinsk-21 in the 1960s occurred at Degelen Mountain and were confined to yields less than a few tens of kilotons. After 1968 most of the larger tests (50 kilotons or larger) were detonated at Shagan River. The last test at Semipalatinsk-21 was conducted on 19 October 1989. On 29 August 1991, in the aftermath of the failed coup attempt against President Gorbachev, the president of the newly independent Kazakhstan, Nursultan A. Nazarbayev, formally closed the test site. At that time the head

---

[187] As we have seen in the U.S. case the definition of a test, and the distinction between a test and an explosion may produce a different total than 715, a number first used by V. Mikhailov, in ``Why the Country's Nuclear Tests are Silent,'' *Krasnaya Zvezda*, 13 September 1990, p. 3 (translated in FBIS-SOV-90-180, 17 September 1990, p. 1).

[188] Reiner Luyken, ``Seeing Red: Inside a Soviet Top-Secret Nuclear Base,'' *London Sunday Times*, 13 September 1992, p. 18.

[189] Interview with the Mayor of Kurchatov, Evgeni Chaykovsky, *Izvestiia*, in Russian 13 April 1991, p. 3 (translated in JPRS-UMA-91-017, 1 July 1991, pp. 58-60). See also Giles Whittell, ``Blasts From the Past in Old Kazakhstan,'' *Financial Times*, 5/6 June 1993, p. 12.

of the test site was A.D. Ilyenko, and the deputy head was Major
General Fedor Safonov.[190]

Novaya Zemlya[191]

While the first nuclear weapons were tested in Kazakhstan,
the development of thermonuclear weapons led the Soviets to
conclude that a new test site would be needed for those weapons
with larger yields. In the early 1950s, and in part as a result
of U.S. testing at Bikini Atoll, a special commission of military
and technical specialists was established under the chairmanship
of Rear Admiral N. Sergeyev to identify a suitable second test
site. The commission proposed the use of the islands of the Novaya
Zemlya archipelago, and upon government approval construction
started. Until the 1963 Limited Test Ban Treaty, Novaya Zemlya was
the most important Soviet test site, accounting for at least 87 of
the 184 known tests through 1962.[192]

Novaya Zemlya is an archipelago in the Arctic Ocean between
the Barents and Kara Seas. It includes two large islands--
Northern (Severnyj) and Southern (Yuzhnyj)--divided by the
Matochkin Shar Strait, as well as numerous small islands. The
area of Severnyj is 48,904 km^2, the area of Yuzhnyj, 33,275 km^2,
and the smaller islands some 1000 km^2 in total.

The southern tip of Novaya Zemlya is at about the same
latitude as the northernmost point of Alaska. It is a raw
environment with a great deal of snow and arctic winds up to 100
mph, while the islands themselves are rugged and mountainous.
Novaya Zemlya is an extension of the Ural Mountains, with maximum
height of 1547 meters above sea level. About half of the surface
of Severnyj is taken up by glaciers, the depth of many of which
exceed 300 meters. The climate is severe. The coldest month is
March, when the average monthly temperature is around -20 degrees
Celsius. In August the average temperature is +4.5 degrees
Celsius. The average yearly precipitation on the Northern island
residents began to settle there. By 1954, when the test site was
established, there were some 300 inhabitants (104 families),
mostly Nenets, on the islands. They were given the choice of

---

[190] Moscow Russian Television Network, Documentary broadcast, 1400 GMT, 8 June 1991 (FBIS-SOV-91-111, 10 June 1991, pp. 58-60).

[191] Much of this section is drawn from ``Yadernyy poligon na Novoy Zemle,'' *Morskoy sbornik*, No. 9 (September, 1991), pp. 6-11; an Interview with Vice Admiral Gennadi Y. Zolotukhin, *Izvestiia*, 3 May 1990, p. 4 (translated in FBIS-SOV-90-092, 11 May 1990, pp. 58-60); Anatoli Pavlov, *Chas Pik*, No. 20 (20 May 1991), p. 4 (translated in JPRS-UMA-91-021, 7 August 1991, pp. 65-67); V.N. Mikhailov and A. Chernyshev, ``Novaya Zemlya,'' Report presented at the International Symposium on Underground Nuclear Tests, Ottawa, 21-26 April 1991.

[192] Vitali Adushkin and Gennadi Krasilov, ``Novaya Zemlya Test Site and the Problem of the Radioactive Pollution of the Polar Ocean'' (unpublished).

staying or relocating to the mainland (the Archangel oblast). They ``chose'' to resettle.

The Novaya Zemlya test site was officially established by a decree on 31 July 1954, and its first director was Captain (1st Rank) V. Starikov. His responsibilities apparently also included underwater nuclear tests in the Barents Sea, for he oversaw the first such Soviet test on 21 September 1955. This test was prepared by Evgeni A Negin, one of the senior weapons specialists from Arzamas-16, and Georgi P. Lominsky, who would become Director of Chelyabinsk-70 from 1963 to 1986. In its first year, Novaya Zemlya would also be the site of air-bursts, two surface tests, and the test of a nuclear torpedo.

In the second half of the 1950s, Starikov was replaced by Rear Admiral I. Pakhomov. In 1958, at least 26 tests took place, a dozen of which were in October. The test site then fell silent due to the moratorium on testing announced by Khrushchev. In April 1959, six months after the moratorium started, Pakhamov was replaced. His successor, General Lieutenant G. Kudryavtsev, had previously been involved in testing missiles with the Black Sea Fleet. Because of the moratorium, Kudryavtsev was told to use the time to improve the conditions at the test site.

The moratorium lasted until late 1961. In early July, Kudryavtsev received a telegram directing him to prepare for new nuclear tests after 1 September. After that date, four tests took place at Semipalatinsk and Sary Shagan, and on 5 September the State Commission responsible for testing nuclear weapons began its work at Novaya Zemlya. The Minister of Medium Machine Building (Slavsky), the Commander-in-Chief of the Strategic Rocket Forces (Kirill S. Moskalenko), and a Deputy Minister of Health (A.I. Burnazian) arrived four days later to observe the first post-moratorium test on Novaya Zemlya. This test took place on 10 September and had a yield of about two megatons; eight more tests took place before 22 September 1961. Immediately following these tests, Kudryavtsev was told to prepare to test a ``superbomb'' and a number of smaller weapons for army missiles, torpedoes, and cruise missiles. The first rocket was tested 20 October and the first torpedo three days later. The ``superbomb,'' with a yield of approximately 50 megatons, was successfully tested (at one-third its full yield) on 30 October 1961.[193]

The years 1961 and 1962 were the period of the most intense testing at the Novaya Zemlya test site. In a sixteen month period

---

[193] The bomb was exploded at an altitude of four kilometers over Novaya Zemlya using a Tu-95 Bear bomber piloted by A.E. Durnovtsev. Khariton and Smirnov, ``Khariton Version,'' *BAS*, p. 30.

from September 1961 to Christmas day 1962, 56 atmospheric tests were conducted, some of them very, very large. The total number of tests conducted at Novaya Zemlya is 132, with 87 in the atmosphere, 42 underground and three underwater.[194]

Overseeing the annual handful of tests as chief of the test site has been a succession of naval officers: Vice Admiral Ye. Zbritsky, Rear Admiral V. Steshenko, Rear Admiral N. Minenko, Vice Admiral S. Kostritsky, Vice Admiral V. Chirov, Rear Admiral Ye. Gorozhin, and Rear Admiral V. Gorev, current chief of the site. In October 1992 the deputy commander was Captain Valeri Lepsky.[195] According to Gorev, the length of service at the site is five years.

The main settlement is called Belyushy Guba (Whale Bay). In October 1992 about 10,000 people lived on Novaya Zemlya, half military, half civilian.[196] The site has been under the authority of the Navy's Sixth Main Directorate, headed by P.F. Fomin, N. Voshchinin, Ye. Shitikov, and, currently (early 1990s), G. Zolotukhin. Nuclear weapons design specialists who have worked at the site include Ye. Negin, A.D. Zakharenkov, M. Sadovsky, Ye. Fedorov, G. Tsyrkov (currently responsible for nuclear weapons research and development), Yu. Izrael, N. Semenov, S. Kristiano-vich, and V. Chuganov.[197] Admiral V. Vyskrebentsev was identified as head of the testing commission in 1990.[198]

While there has been a moratorium on nuclear testing at Novaya Zemlya since October 1990, there has been pressure on President Yeltsin to reopen the test site. While opposed by the local population and leadership, Russian nuclear weapons designers have argued that testing is necessary to maintain quality control of new and existing warheads. As a result, on 27 February 1992, Yeltsin signed a presidential decree, Number 194, renaming the polygon the ``Central Test Site,'' and directing the Ministry of Atomic Energy and the CIS High Command to prepare to resume testing on Novaya Zemlya in the event the moratorium is not extended beyond 26 October 1992.[199]  The ``Hatfield-Exon-Mitchell'' amendment, signed into law by President Bush as part of the Fiscal Year 1993 Energy and Water Appropriation Bill, called for, *inter alia*, a moratorium on U.S. testing for a minimum of nine months

---

[194] I. Bentsa, ``Novaya Zemlya: A Hush Over the Contaminated Territory,'' *Izvestiia*, 30 October 1991, Union Edition, p. 7 (translated in FBIS-USR-91-48, 11 November 1991, pp. 86-87); Vladimir Gondusov, ``Ministry Invites Newsmen to Nuclear Range,'' ITAR-TASS in English 1440 GMT, 14 October 1992 (FBIS-SOV-92-200, 15 October 1992, p. 18).

[195] Fred Hiatt, ``Russian Test Site Displays Pride, Perils of a Superpower,'' *Washington Post*, 18 October 1992, p. A1.

[196] Ibid.

[197] See Kudryavtsev and *Rabochaya tribuna*, 3 October 1990, p. 3 (translated in FBIS-SOV-90-197, 12 October 1990, pp. 94-96).

[198] Ibid.; *Trud*, 7 November 1990, p. 3.

[199] *Nezavisimaya gazeta*, 24 March 1992, p. 6 (translated in FBIS-SOV-92-060, 27 March 1992, p. 1); ``Pokazelenyye ishchut lysogo olenya,'' *Komsomolskaya pravda*, 27 May  1992, p. 1; Viktor Makarov, ``Komi Region Views Draft Law on Nuclear Testing,'' *Moscow ITAR-Tass*, in English, 29 July 1992, 0853 GMT.

until 1 July 1993. On 3 July 1993 President Clinton extended the moratorium through September 1994, and on 15 March 1994 he extended it through September 1995. As a consequence no nuclear testing by Russia or the United States is anticipated.

Nuclear Weapon Production Facilities

The first Soviet atomic bomb was designed and assembled at Arzamas-16, with a plutonium core manufactured at Chelyabinsk-65, and the device was tested on 29 August 1949 at the Semipalatinsk test site. In the early years, Chelyabinsk-65 continued to manufacture the plutonium and HEU components, and Arzamas-16 was the final warhead assembly site.

As the stockpile grew, new facilities were built for specialized components and for large scale final assembly. Production of pits--either plutonium, HEU, or composites--takes place at the Plant 20 complex at Chelyabinsk-40 (now-65) and at a similar complex at Tomsk-7. Uranium components are also manufactured at Sverdlovsk-44. Tritium components are manufactured and filled at Chelyabinsk-65.

Penza-19, with its closed city of Zarechnyy (population 61,400), is at Kuznetsk, 115 km east of Penza and 300 km southeast of Sarova, where Arzamas-16 is located.[200] The site is characterized by the Defense Intelligence Agency as, ``a small component fabrication and assembly plant.''[201] It is said to manufacture electronic warhead components perhaps like those manufactured at the Kansas City Plant for U.S. nuclear warheads. At Penza-19 there a branch of a Moscow Institute, probably the Institute of Automation, which is thought to be the lead institute for the development and production of electronic components (e.g. neutron generators and PALs).

Final warhead assembly takes place at three locations: Sverdlovsk-45, Arzamas-16, and Zlatoust-36. The final assembly of ``physics packages'' takes place at Sverdlovsk-45 and Arzamas-16. These two complexes also are responsible for stockpile maintenance, including replacement of tritium and warhead modification.

Sverdlovsk-45 (with its closed city of Lesnoy, population 54,700) is a ``very large plant,''[202] at Nizhnyaya Tura,[203] on the

---

[200] The city of Kuznetsk is located at 53° 08'N/46° 35'E.

[201] Clapper, DIA, SASC, pp. 55-56. Gershwin, CIA, said the Russians have two disassembly facilities, at Nizhnyaya Tura and Yuryuzan; HAC DOD FY 1993, Part 5, p. 498. Presumably Arzamas-16 was not counted because assembly and disassembly are not its primary mission and because of its small assembly/disassembly capacity. Penza-19 was probably excluded because it is a component fabrication, rather than final assembly, plant.

[202] Lt. Gen. James R. Clapper, Jr., USAF, Director of the U.S. Defense Intelligence Agency (DIA), Hearings Before the Senate Com-

eastern edge of the Urals, 200 km north of Yekaterinburg. It serves as one of the larger weapon storage sites in the former Soviet Union. The complex includes several separate plants, the Electrokhimpribor Plant, the Ural Electromechanical Plant, and Nizhneturinsky Machine-Building Plant, all subordinate to the Sixth Main Directorate. The Electrokhimpribor Plant is reportedly where final assembly takes place.[204]

Co-located within the Arzamas-16 site is a final assembly plant called the Electromechanical Plant ``Avangard.'' Dismantlement of tactical nuclear warheads removed from Ukraine has already started at Arzamas-16, according to the Russian press.[205]

Zlatoust-36, with its closed city of Trekhgorny (population 29,800), is at Yuryuzan, 85 km southeast of Zlatoust, which is in the Urals in Chelyabinsk Oblast, 110 km west of Chelyabinsk.[206] Zlatoust-36 is characterized by DIA as ``a much smaller facility'' than Sverdlovsk-45.[207] Assembly of ballistic missile reentry vehicles takes place at Zlatoust-36.

Minatom Minister Mikhailov in 1992 said that the total capacity (for assembly and disassembly) of the four warhead assembly plants--Sverdlovsk-45, Zlatoust-36, Penza-19, and Arzamas-16--was about 7000 warheads per year. The total dismantlement capacity was given as 5500 to 6000 warheads per year.[208] It was explained that the process of dismantling warheads takes more time than the assembly process.[209] Previously Russian officials have said that some 3000 to 4000 units of capacity per year would be available for disassembly of the warheads to be retired under the Gorbachev and Yeltsin arms control initiatives of 1991 and 1992. According to CIA testimony:

mittee on Armed Services, S. Hrg. 102-755, 22 January 1992, pp. 55-56.

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

[204] Sverdlovsk-45 has been referred to as the ``Elektrochimpribor'' Combine, which translates Electrochemical Instrument Combine. ``CPSU Central Control Commission Meets,'' *Moscow Tass International Service*, 10 October 1990, 1837 GMT.

[205] ``Unichtozhayetsya ukrainskoye yadernoye oruzhiye,'' *Izvestiia*, 23 August 1992, p. 1.

[206] Ibid.; Furumoto, *Tokyo Yomiuri Shimbun*, p. 1 (in FBIS-SOV-91-225-A, 21 November 1991, p. 3). Yuryuzan is located at 54° 42'N/58° 25'E.

[207] Clapper, DIA, SASC, pp. 55-56. Though Larry Gershwin, National Intelligence Officer for Strategic Programs, Central Intelligence Agency, says that the two facilities ``are several times larger than the U.S. Pantex facility.'' HAC, DOD FY 1993, Part 5, p. 498. U.S. satellite imagery evidence indicates that Zlatoust-36 has done most of the work on dismantlement of warheads so far. Ibid.

[208] Earlier in 1992 Boris Nikepelov, at the time First Deputy Minister and acting Minister of MAPI, said the complex was capable of dismantling up to 8000 warheads per year in the absence of any requirement for warhead production. ``Report of the Fourth International Workshop on Nuclear Warhead Elimination and Nonproliferation,'' held in Washington,D.C., 26-27 February 1992, Federation of American Scientists and the Natural Resources Defense Council, pp. ii, 7.

[209] 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 Pantex plant 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 handle close to 4500 warheads per year.

Recent claims by different Russian officials of
dismantlement capacity range from 4000 to 8000 warheads
per year. We judge that they can dismantle more than
1500 per year and their claim of 4000 annually is
credible, but there is a question whether they will get
up that high because of the disposal of materials from
the dismantlement and their view that they don't think
that it can be done safely. They also have facilities
at Tomsk [Tomsk-7] and Kyshtym [Chelyabinsk-65] for
converting nuclear pits into non-weapon shapes.
However, Russia apparently plans to store their weapon
components intact, rather than to distort them, until
the final disposition can be determined.[210]

There are other industrial plants and institutes under the
authority of Minatom 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 Automation Research Institute (with a
branch at Penza-19) is a Minatom institute that develops and
manufactures electronic components for warheads. It also
manufactures commercial pulsed neutron generators and portable X-
ray devices. The A.A. Bochvar All-Russian Scientific Research
Institute of Non-organic Materials (VNIINM), founded in 1945 in
Moscow, is the principal research center in the area of fuel cycle
technologies and fissile material processing. Numerous other
Minatom 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
2.1).

Fissile Material Production and Disposition

Russian data suggests that the Soviets had about 140 metric
tons (t) of weapon-grade plutonium in weapons when the stockpile
peaked in 1986 at about 45,000 warheads.[211] We estimate that
through 1994, the 13 graphite production reactors produced some
170 t of plutonium-equivalent (see Appendix 3). A Soviet tritium
inventory growing to about 90 kilograms (kg) by 1986, when the

---

[210] HAC, DOD FY 1993, Part 5, p. 498.

[211] According to Academician Yuri Trutnev, discussing an Arzamas-16 proposal to destroy plutonium pits with underground nuclear
explosives, there are about 62 t of plutonium in 20,000 pits. this implies 3.1 kg per warhead, or about 140 t of plutonium in the
45,000 warheads stockpile. ``Report of the Third International Workshop on Verified Storage and Destruction of Nuclear Warheads,''
held in Moscow and Kiev, 16-20 December 1991, Natural Resources Defense Council, p. 22. According to another Russian estimate,
Russia has produced 130 ± 15 t of weapon-grade plutonium.

warhead stockpile peaked, could have been produced in the available heavy water and light water production reactor capacity, leaving the graphite reactor production devoted essentially entirely to plutonium. With allowances for losses at the chemical separation facility, nuclear testing, and use of military plutonium for breeder reactor research and development, we estimate that up to 165 t of plutonium is in, or available for, weapons.[212] Allowing approximately 25 t for what is in the production pipeline, in scrap, and any reserve--this represents about 15 percent of the total inventory--the remaining 140 t would appear to be a good estimate of what was in weapons when the stockpile peaked in 1986. The uncertainty in these estimates is on the order of 10 percent.

It is not possible to accurately estimate the quantity of highly-enriched uranium (HEU) in weapons and available for weapons, because Russian enrichment plant production data are classified. The United States has produced almost 1000 t of HEU (>20 percent U-235). Of that amount more than 500 t of weapon-grade equivalent HEU (93 percent U-235) were produced for a weapons stockpile that peaked at about 32,000 warheads in 1967. There is also a substantial quantity of HEU of lower enrichment, i.e., between 20 percent and 93 percent U-235, in U.S. weapons. If the Soviet HEU requirement was comparable on a per warhead basis, their stockpile of up to 45,000 warheads would have entailed on the order of 700 t of HEU enriched to about 93 percent U-235 and a substantial quantity of lower enriched HEU, in and available for warheads. Russia has agreed to sell at least 500 t of weapon-grade equivalent HEU from weapons to the United States. Minatom Minister Mikhailov indicated that the 500 t figure represented about 40 percent of Russia's total HEU reserves-- implying that the total Russian stockpile is close to 1250 t.[213] This figure may include a substantial quantity of HEU with enrichment levels between 20 percent and 93 percent U-235. In Chapter Five we estimate that the HEU inventory is approximately 1100-1300 t, which is consistent with Minister Mikhailov's statements

The Soviet Union followed a pattern of nuclear weapons materials production similar to that of the United States. Each began with construction of natural-uranium-fueled, graphite-moderated thermal reactors for plutonium production and devel-opment of gaseous diffusion technology for the enrichment of uranium. More recently, Russia relied on graphite reactors for

---

[212] We assume one percent losses (1.7 t) at the chemical separation plants, 2.2 t used in 715 nuclear tests, and about 1.5 t used for making breeder reactor fuel.

[213] Elizabeth Martin, ``A View From the Top: Russia's Minister N. Mikhailov,'' NUKEM, Inc., Vol. 3, 1993.

plutonium production: heavy water and (since the 1980s) light water reactors for tritium production; and primarily on gas centrifuge technology for uranium enrichment. Since 1986 the stockpile of weapons has declined by about 20 percent, and there are now large surpluses of each of these materials.

The Soviet government announced in October 1989 that ``this year it is ceasing the production of highly enriched uranium,'' and that it had adopted a program to close down all plutonium-producing reactors by the year 2000, three by 1996 and the last three by 2000.[214] This policy was affirmed by President Boris N. Yeltsin, who said in his 29 January 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.'' On 27 May 1994 the governments of the United States and the Russian Federation initialed an agreement concerning the shutdown of plutonium production reactors and the cessation of the use of plutonium for weapons in the United States and Russia.[215] The Goodby-Yegorov agreement was revised slightly and the new agreement was signed by Vice President Albert Gore and Prime Minister Viktor S. Chernomyrdin in Washington, D.C. on 23 June 1994.[216] Under the Gore-Chernomyrdin text, Russia has agreed to permanently cease operation by no later than the year 2000 of all 13 of its graphite-moderated plutonium production reactors. The two isotope production reactors at Chelyabinsk-65 were not covered by this agreement. The two parties agreed that any plutonium produced by the two countries after the agreement entered into force would not be used in any nuclear weapon, and they agreed to develop procedures necessary to assure compliance of this. Under the Goodby-Yegorov agreement Russia reserved the right to use plutonium for nonweapon nuclear explosive use.

---

[214] 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,''' 25 October 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 was blended with freshly produced plutonium to meet impurity specifications. In order to maintain stockpile in the future, without the need for additional fresh plutonium Russia has recently acquired the capability to remove americium from plutonium. 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. This and other operations associated with plutonium pit manufacture at the Rocky Flats plant have now ceased.

[215] Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Shutdown of Plutonium Production Reactors and the Cessation of the Use of Plutonium for Nuclear Weapons, 27 May 1994 [Agreement initialed in Moscow by Ambassador James Goodby and Minatom Deputy Minister Nikolai Yegorov].

[216] Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Shutdown of Plutonium Production Reactors and the Cessation of Use of Newly Plutonium for Nuclear Weapons, 23 June 1994.

As of late-1994, three of 13 graphite-moderated plutonium production reactors remained operational. These last three are dual-purpose reactors--two at Tomsk-7 and one at Krasnoyarsk-26-- producing heat and electricity. The year 2000 production cut-off was chosen as a date by which new power plants could be brought on line to replace these last three plutonium production reactors. A variety of alternative power sources are under consideration. Minatom would like to replace them with light water-cooled or gas-cooled thermal reactors and to use these to burn plutonium from weapons. The United States would prefer to see Russia choose non-nuclear alternatives which can be brought on line more quickly and cheaply. A natural gas-fired turbine system has been proposed for Tomsk and a coal-fired plant for Krasnoyarsk.

Two light water reactors at Chelyabinsk-65 are used for special isotope production, including tritium (if it is still being produced). A MAPI official stated in 1989 that the Soviets would have a continuing requirement for ``two to three tritium production reactors.''[217] Since the rate of warhead retirements-- the fraction of those remaining each year--is projected to exceed the rate of tritium decay (5.5 percent per year) through the remainder of the decade, requirements for new tritium production can be postponed for at least a decade, and at most only one of the reactors will be needed thereafter.

Several tens of tonnes of weapon-grade plutonium (perhaps as much as 120 t) and several hundreds of tonnes of HEU (at least 500 t and perhaps as much as 800 t) will be removed from warheads committed to be eliminated by Presidents Gorbachev and Yeltsin. Current government policy is to store all the plutonium from dismantled warheads for at least a decade. Construction of a new fissile material storage facility is slated to begin in 1995 at Chelyabinsk-65. A second facility may be constructed at Tomsk-7 in later years.

How Russia will ultimately dispose of the plutonium may not be decided for several years. Senior Minatom officials want to complete the construction of mixed-oxide (MOX)[218] fuel plant at Chelyabinsk-65 and use the plutonium as MOX fuel in civil reactors. Senior Minatom officials have also indicated a strong preference for burning the plutonium in Russian liquid metal fast breeder reactors and have used this as an argument for completing the three BN-800 reactors at Chelyabinsk-65 and constructing a

---

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

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

fourth at Beloyarsky. Some Western experts have advocated burning the plutonium in Russia's seven VVER-1000 [voda-vodyanoi energetichesky reaktor-1000] light water reactors.[219] (For a more detailed discussion of these options, see Chapter 5.) Another option--one favored by Minatom Minister Mikhailov in 1994--is to replace the three remaining dual-purpose production reactors at Tomsk-7 and Krasnoyarsk-26 with light water or gas cooled reactors and use these to burn MOX produced with plutonium from weapons. Whatever the choice, it will take decades to convert the weapon plutonium into spent fuel by fueling Russian reactors. Experts from Arzamas-16 propose that the plutonium pits be destroyed by underground PNEs.[220] 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. As noted above, Russia has agreed in principle to sell 500 t of HEU from weapons to the United States for this purpose.

Waste Management Activities

The Russians classify liquid radioactive wastes as:
low-level - $<10^{-5}$ curies/liter (Ci/l);
intermediate-level (or medium-level) - $>10^{-5}$ Ci/l and <1 Ci/l; high-level - >1 Ci/l.

---

[219] As of 1994 there was an additional VVER-1000 reactor in Russia in an advanced stage of construction; and there are 15 VVER-1000s operating and in advanced stages of construction in Ukraine and Bulgaria, but the chances of loading them with Russian plutonium is remote.

[220] According to Arzamas-16 experts, as a rule of thumb, each kiloton of nuclear explosive yield could produce about 1000 t of ``melted substance.'' Thus, a 100 kiloton explosion would melt 100,000 t of plutonium and rock. If 62 t 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 6×10^{-4} grams of plutonium in each gram of vitrified rock.

Solid wastes are classified as:
    low-level - <0.3 millirem/hour (mrem/h);
    intermediate-level (or medium-level) - 0.3 to 10 mrem/h; and
    high level - >10 mrem/h,
with the measurements in each case taken 10 cm from the surface.
Because radioactive waste is typically a mixture of radioisotopes
with very different half-lives, there are several conventions that
are often used for reporting the amount of activity in the waste--
for example, reporting (a) the sum of Sr-90 and Cs-137 activity,
both isotopes having radioactive half-lives of 30 years; (b) Sr-
90 and Cs-137 plus their respective daughter products Y-90 and Ba-
137m; (c) only the beta emitters among these four, that is, Sr-90
+ Y-90 + Cs-137, but not including Ba-137m; or (d) the total
activity, including all fission products and actinides. There is
no accurate accounting of how much activity is in some storage
locations even where figures are reported, because reports often
fail to clarify what constituents are included in the totals.

The total quantity of radioactive waste formed during
production and separation of nuclear materials is said by
Gosatomnadzor to total about 2.8 billion Ci, with a volume of
approximately 610 million m^3; this radioactive waste is
concentrated primarily at Chelyabinsk-65, Tomsk-7, and
Krasnoyarsk-26.[221] While it is not clear which constituents are
included, the reported activity is presumed to be measured in
terms of Sr-90 and Cs-137, plus their respective daughter products
Y-90 and Ba-137m. Using this convention we estimate that 3.4
billion Ci were produced through 1994, and 2.4 billion Ci remain.

At the first plutonium production site, Chelyabinsk-65,
beginning in late-1948 the high-level liquid radioactive wastes
were discharged directly into the Techa River. After the
discovery of extensive radioactive contamination and severe
radiation sickness among inhabitants downstream, the liquid wastes
were diverted to nearby Lake Karachay. Precipitation of the solid
radioactive pulp from the liquid slurry and tank storage of these
wastes began at Chelyabinsk-65 in 1953. This same practice--tank
storage of the pulp fraction and discharging the liquid fraction
into open reservoirs--was used initially at Tomsk-7, where
chemical separation of plutonium began in 1956. One of the waste
storage tanks at Chelyabinsk-65 exploded in 1957, resulting in
severe land contamination.

As a consequence of the 1957 accident and the contamination
resulting from storing liquid wastes in open ponds and natural

---

[221] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' 13 May 1994,
Part I, Chapter 2.

reservoirs at Chelyabinsk and Tomsk, a decision was made to investigate the possibility of injection of the liquid wastes into the ground.[222] Deep-well injection began at Tomsk-7 in 1963, and at Krasnoyarsk-26 in 1967, some three years after its chemical separation plant was put into operation. Geologic conditions did not permit deep-well injection of liquid wastes at the Chelyabinsk-65 site. Initially, deep-well injection of liquid wastes was considered a temporary measure while the technology for the salification of radioactive wastes was developed. However, because of significant technological difficulties in solidifying wastes and the allegedly positive results in the disposal of liquid waste, deep-well injection continues today at Tomsk-7, Krasnoyarsk-65, and at the All Russian Institute of Atomic Reactors (NIIAR) at Dimitrovgrad.[223] As a consequence, in Russia about one-half of all radioactive wastes chemically separated from spent fuel have been disposed via deep-well injection.

At least two of the sites, Chelyabinsk-65 and Tomsk-7, have been badly contaminated with radioactivity as a consequence of operating the installations for years without even a rudimentary appreciation of good health physics practices. None of the production reactors meet western safety standards. As recently as 1993, as a result of independent investigations of accidents at radiochemical plants at these two sites, Gosatomnadzor discovered gross violations of regulations, insufficient professional education and discipline of certain specialists and operators, design and construction errors, lack of design documentation, unilateral alteration of equipment, absence of systematic safety analyses, and other safety problems.

At Chelyabinsk-65 and Tomsk-7 highly radioactive effluent continue to be discharged into open reservoirs. These may result in radioactive contamination of large territories in the event of an earthquake, tornado, flood, or similar event. Substantiation of the nuclear safety of these sites does not exist according to Gosatomnadzor.[224]

In open storage reservoirs at Chelyabinsk-65 and Tomsk-7, the bottom sediments contain more than ten kilograms of plutonium; and tens of kilograms of plutonium have been pumped underground into

[222] A.I. Rybalchenko, M.K. Pimenov, and E.N. Munaev, ``Application of Accumulated Experience of Deep-Well Injection in Hazardous and Industrial Waste Management,'' DRAFT, 1994.
[223] A.I. Rybalchenko, V.M. Kurochkin, P.P. Kostin, and P.N. Pavlov, ``Basic Principles of the Safety Assessment and System Control During a Deep-Well Injection of Radioactive Wastes,'' DRAFT, 1994. There is a pilot reprocessing plant for civil reactor R&D at the Institute of Atomic Reactors (NIIAR) at Dimitrovgrad. Approximately 100 million Ci of liquid wastes have been injected at a depth of 1000-1500 m at this site.
[224] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' 13 May 1994, Part I, Chapter 2.

the injection wells at Tomsk-7 and Krasnoyarsk-26.[225]

[225] Ibid.

CHAPTER THREE
CHELYABINSK-65/MAYAK CHEMICAL COMBINE

Introduction

Mayak was initially called the Plutonium Integrated Works, much later the Mayak Integrated Works, and now the Mayak Chemical Combine, or simply Mayak (translated ``Lighthouse'' or ``Beacon'').[226] Following the Soviet practice of identifying secret installations by a code name--the name of a nearby city followed by a post office box number--Mayak was also called Chelyabinsk-40. About 1990 this code name was changed to Chelyabinsk-65. In 1994 the Russian government indicated its preference for referring to the once code-numbered secret nuclear installations by the names of the still closed cities that house the work force, which for Chelyabinsk-65 is Ozersk.

Mayak (Chelyabinsk-65) is about 15 km east of the city of Kyshtym on the east side of the southern Urals in Chelyabinsk Oblast.[227] It occupies an area on the order of 200 square kilometers (km^2) in the area around Lake Kyzyltash, in the upper Techa River drainage basin among numerous other lakes with interconnecting watercourses.[228] The industrial area bordering the southeast shore of Lake Kyzyltash, where the reactors and chemical separation plant are located, is about 90 km^2.[229] Located on the southeastern shore of Lake Irtyash (between Lakes Irtyash and Kyzyltash), about 10 km northwest of the industrial area, is Ozersk, the military-industrial city built to house the Chelyabinsk-65 work force (see Figure 3.1). Ozersk was sited adjacent to Staraya Techa, a village that was absorbed into the complex. Ozersk once bore the name of Beria. Today, some local inhabitants still refer to it as Sorokovka (``Forties Town'').[230]

The Chelyabinsk-65 complex is run by the Production Association Mayak (PO Mayak),[231] and as noted above, the defense enterprise is referred to as the Mayak Chemical Combine.[232] In

---

[226] A.K. Kruglov, ``On the History of Atomic Science and Industry,'' *The Bulletin of the Center of Public Information*, No. 10, 1993, p. 46.

[227] The plutonium production area of Chelyabinsk-65 is located at 55° 43'N/060° 43'E, near the cities of Kyshtym (population about 40,000) and Kasli (population about 20,000), and about 70 km north of Chelyabinsk (population 1.2 million), the capital of Chelyabinsk Oblast which covers 88,500 km^2, an area about the size of Indiana, and had a population of 3.6 million ca. 1990. 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. Diane M. Soran and Danny B. Stillman, ``An Analysis of the Alleged Kyshtym Disaster,'' Los Alamos National Laboratory (LANL), LA-9217-MS, January 1982.

[228] 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, 11-14 April 1991. According to an undated (ca. 1960s) ``Plant Summary'' by the CIA [enclosure 14 attached to 11 November 1977 reply by G.F. Wilson, CIA, to a 2 September 1977 FOIA request by Richard B. Pollock], the restricted area of Kyshtym, which includes Chelyabinsk-65 and Chelyabinsk-70, covered approximately 60 km north-south and 45 km east-west (2700 km^2).

[229] 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).

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

[231] Or Industrial Association Mayak (IA Mayak).

[232] In a 1957 CPSU Central Committee document it was referred to as Combine No. 817; Ye. Slavsky, ``Whose Sins Are We Paying for Today?,'' *Moscow Rossiyskiye Vesti*, 27 January 1993, p. 1 (translated in the Joint Publications Research Service series, JPRS-

1989, an American delegation--the first foreigners to visit the site-- was told that there were some 10,000 employees and 40,000 dependents at Chelyabinsk-40. In 1991 Ozersk's population was reported to be 83,500.[233]

Chelyabinsk-40 was the Soviet Union's first plutonium production complex. It was at this site that Kurchatov, working under Beria, built the Soviet Union's first plutonium production reactors, chemical separation plant and plutonium and HEU metallurgy plant. Chelyabinsk-40 is the Soviet equivalent of the U.S. Hanford Engineering Works (subsequently the Hanford Reservation), and was fashioned after Hanford.[234] The site had been chosen by A.P. Zaveniagin, then Deputy People's Commissar of Internal Affairs (NKVD) under Beria and a member of both the Special Committee and the First Main Directorate (PGU).[235] It was an area that Zaveniagin knew well because he had been selected in December 1937 to represent the Kyshtym district in the Supreme Soviet.[236] Chelyabinsk-40 was built on land that before the October Revolution had been part of the Kyshtym Estates, which were the property of Baron Zakomelsky, a distant scion of the Romanov family.[237] Zaveniagin put Iakov Rappoport, a major-general in the NKVD, in charge of construction.[238] Rappoport had been one of the men responsible for building the White Sea Canal in the early 1930s, a notorious project in which hundreds of thousands of camp laborers had died.[239] Construction was started on the first buildings of the new city in November 1945. To construct the complex reportedly some 70,000 inmates of 12 labor camps were used.[240] General M.M. Tsarevski, whose previous experience included construction of the Gorki Motor Vehicle Plant, Nizhni Tagil Steel Plant and other major construction projects, was places in charge of construction of the first reactor building and other facilities at the Combine, as well as the town. Tsarevski's appointment was made by Beria when he visited the site on 8 July 1947.[241] The first plutonium production reactor (A-Reactor) was brought on line in June 1948.[242]

Construction of Chelyabinsk-40 was under the direct supervision of the Special Committee

---

TEN-93-004, 8 March 1993, pp. 51-52); Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, pp. 56-57.

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

[234] In March 1946 Henry DeWolf Smyth's official report on the development of the U.S. atomic bomb, *Atomic Energy for Military Purposes*, appeared in Russian translation. It became a basic textbook during development of the Soviet bomb.

[235] David Holloway, *Stalin and the Bomb: The Soviet Union and Atomic Energy, 1939-1956* (New Haven: Yale University Press, 1994), p. 184.

[236] Ibid., p. 184.

[237] Ibid., p. 185. For some years before World War I the estates had been managed by an American firm, of which Herbert Hoover, the future U.S. President, was a director.

[238] Ibid, p. 185.

[239] Ibid.

[240] Undated (ca. 1960s) ``Plant Summary'' by the CIA, enclosure 14 attached to 11 November 1977 reply by G.F. Wilson, CIA, to a 2 September 1977 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 1957.

[241] Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, p. 60.

[242] Colonel L. Nechayuk, ``In the City Without a Name,''*Krasnaya Zvezda*, 19 October, 1990, First Edition, p. 2 (translated in FBIS-SOV-90-208, 26 October 1990, p. 56); Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, p. 62.

(L.P. Beria), the overall scientific director (I.V. Kurchatov), the leadership of the PGU (P.L. Vannikov, A.P. Zaveniagin, and A.N. Komarovsky), and the board of the Plutonium Integrated Works (P.T. Bystrov, B.G. Muzrukov, and Ye.P. Slavsky).[243] Fursov, who with Kurchatov had designed the F-1 pile at Laboratory No. 2, oversaw Chelyabinsk-65 as Kurchatov's main representative.[244] Academician Khlopin was the first scientific director of Chelyabinsk-40. Nikolai A. Dollezhal, Director of the Scientific Research Institute of Chemical Machine-Building (NIIKhimmash) in Moscow, was responsible for the design of the first production reactor at Chelyabinsk-40 and was appointed Chief Engineer of the project. Khlopin and workers from the Radium Institute completed B Plant, 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.[245] A. Bochvar was responsible for processing the plutonium and fabricating the two sub-critical fissile masses for the bomb.[246]

From 1948 until 1 November 1990, the Combine produced plutonium for nuclear weapons. Chelyabinsk-65 now produces special isotopes and reprocesses naval and civil power reactor fuel and HEU fuel from the plutonium and tritium production reactors. Uranium, recovered from irradiated HEU fuel is used for fabrication of naval reactor fuel. The Combine also produces instruments for nuclear material production and processing.[247] No longer producing weapon-grade plutonium, the complex in recent years has begun to produce a variety of equipment for civilian use.[248]

The first plutonium production facilities placed into operation (during the period 1948-1949) were the A-Reactor, the chemical separation plant (B Plant), and the Chemical Metallurgical Plant (C Plant; in Russian, V Plant, since V is the third letter of the alphabet) for purifying plutonium and converting it to metal. Additional supplementary facilities, placed in operation by mid-1948, included a thermal electric power plant, water supply plants, the central plant laboratory, and a mechanical repair shop. The known facilities today (some shut down) at Chelyabinsk-65 are listed in Table 3.1. There are seven production reactors--five graphite-moderated water-cooled reactors and two water-moderated and cooled reactors, one of which was a heavy-water reactor which may have been converted into a light-water reactor in the late-1980s. The graphite reactors, which had a combined capacity of 6565 megawatts thermal (MW_t),[249] were used for plutonium production before being shut down between 1987 and 1992. The two water-moderated reactors, each with a capacity of about 1000 MW_t, are used for the production of tritium and other isotopes.[250]

---

[243] Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, p. 46.

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

[245] Ibid.

[246] Ibid.

[247] Nechayuk, ``In the City Without a Name.''

[248] ``Conversion at Chelyabinsk Plant Viewed,'' *Vremya* newscast, 27 January 1991, 1530 GMT, in Russian (translated in FBIS-SOV-91-029, 12 February 1991, p. 58.)

[249] *Nucleonics Week,* 26 July 1990, p. 12, reported a total capacity of 6000 MW_t.

[250] The Soviet nuclear weapons stockpile peaked in 1986, and has since declined by more than 20 percent. Consequently, tritium production may have cease.

Within what is now called Site 235 are two chemical separation areas--Sites 25 and Site 35. Site 25 is the site of the original B Plant, the first chemical separation plant used to recover plutonium for weapons. The B Plant was shut down in the mid-1970s and replaced by RT-1, a 400 metric ton of heavy metal per year (tHM/y) chemical separation plant but is now used to reprocess civil power reactor (VVER), naval reactor, and research reactor fuel. RT-1 is also used to reprocess the spent enriched-uranium fuel elements from the two water-moderated production reactors at Chelyabinsk-65 and from the spiked rings of the plutonium production reactors. A separate chemical separation area, Site 35, began as the BB Plant, the second plant for the recovery of plutonium for weapons. It now houses the Radioisotope Plant that is used to recover tritium and other special isotopes which are produced in targets elements irradiated in the light water production reactors. Mayak also has several small MOX fuel fabrication facilities and a larger MOX fuel fabrication plant whose construction was suspended after being 50-70 percent completed.[251] There are also some 48 or more tanks of radioactive high-level wastes (HLW), a pilot vitrification plant and various other production related facilities. The history and status of these facilities is discussed separately below.

At a separate industrial area, but now part of Chelyabinsk-65, plutonium is processed and plutonium, HEU, tritium, and probably beryllium weapon components are manufactured. This, and a similar complex at Tomsk-7, are comparable to the U.S. Rocky Flats plant, one of the sites where the United States manufactured weapon pits.

The South Urals (Yuzhno-Uralsk) 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 is questionable.

The first Director of the Combine was P.T. Bystrov. The precise beginning date is not known but he served until 10 July 1947 when he was replaced by Ye.P. Slavsky. Slavsky's tenure as Director was short, only serving until 29 November 1947 when B.G. Muzrukov replaced him and served until 16 November 1953.[252] 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 7-8 July 1989.[253] At least since 1990, Viktor Ilich Fetisov has been identified as the director of the Mayak Production Association. In 1994, A.P. Suslov was identified as Mayak's chief engineer. Alexander I. Pishchepov was identified as the deputy director for procedures in 1990.[254]

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

---

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

[252] Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, p.60. Slavsky was transferred to Chief Engineer and on 3 December 1949 G.V. Mishenkov was named Chief Engineer.

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

[254] Nechayuk, ``In the City Without a Name;'' and S. Sergeyev, ``Novosti'' newscast, *Moscow Teleradiokompaniya Ostankino Television First Program Network*, in Russian, 31 July 1992, 1700 GMT (translated in JPRS-TND-92-027, 5 August 1992, p. 26).

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.

All of the production reactors are located about 1 km southeast of Lake Kyzyltash, and all relied on open cycle cooling with water from the lake pumped directly through the core.[255] The average temperature of the discharged water from A-Reactor was 70° C; and a high of 80-85° C.

A-Reactor

The first reactor, ``A'' reactor, was originally designed to operate at 100 megawatts thermal (MW$_t$), but was later upgraded to 500 MW$_t$.[256] Called ``Annushka'' or ``Anotchka'' (``Little Anna'') A-Reactor was designed by Dollezhal, and constructed in 21 months.[257] It is located in Building 1 in the Plant 156 area. A-Reactor was loaded with all the uranium then available in the country, ~150 tonnes (t), achieved criticality on 7 June 1948, and began operation at full power on 22 June 1948.[258] 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 29 August 1949.[259]

It used aluminum-clad natural uranium fuel in vertical fuel tubes (channels) and gravity fuel discharge. The core contains 1168 fuel and control rod channels in 1353 t of graphite blocks (20 cm x 20 cm x 60 cm). 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.

---

[255] Upon the recommendation of specialists from the All-Union Heat Engineering Institute (VTI) at a 12 January 1946 meeting of Section No. 1 of the Engineering-Technical Council, chaired by M.G. Pervukhin, who was then working as People's Commissar of the Chemical Industry; Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, p. 56.

[256] ``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 7-8 July 1989].

[257] In his memoirs, Chief Engineer Dollezhal remarks that he was enlisted into carrying out the nuclear program in January 1946 by M.G. Pervukhin, who was then working as People's Commissar of the Chemical Industry; Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, pp. 56-57. According to Holloway, *Stalin and the Bomb*, p. 183, Dollezhal was enlisted by Kurchatov. Pervukhin was Kurchatov's superior. Dollezhal was asked to participate as chief designer of the first ``industrial'' reactor (as it is known in Soviet literature) for the production of plutonium. Kurchatov was in charge of continuous scientific direction and supervision of the design development. Dollezhal's design was approved by the Scientific-Technical Council in July 1946. Holloway, *Stalin and the Bomb*, p. 183. 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. In the autumn of 1946 the foundation for the reactor building was laid. Holloway, *Stalin and the Bomb*, p. 185. The reactor building was completed by the end of 1947: assembly of the reactor began in March 1948 and was completed by the end of May. According to posters on the wall in the A-Reactor building, the development stages before start-up 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'' 4 August 1946 and the first 40 specialists arrived on 9 October 1946.

[258] On the night of 7 June 1948, with Kurchatov assuming the functions of chief operator, the reactor was started without the flow of cooling water. At 00:30 on 8 July 1948 the reactor reached a power of 10 kW, at which point Kurchatov shut it down. At 20:00 on 10 June the reactor was restarted with cooling water, brought up to 1 MW, and operated at this power level for 24 hours. The first start-up to full power began at 12:45 on 19 June 1948, and full power of 100 MW was achieved on 22 June; Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, p. 62; and V.I. Merkin, ``Reshaiushchii eksperiment Kurchatova,'' in A.P. Aleksandrov, ed., *Vospominaniia ob Igore Vasileviche Kurchatove* (Moscow: Nauka, 1988), p. 281.

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

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

A-Reactor experienced serious unforeseen operating difficulties during its first year of operation. Corrosion of the aluminum channels and fuel cladding and overheating, due to blockage of water brought on by swelling of failed uranium fuel slugs, led to structural failure of channels and leakage of coolant into the graphite. By late 1948 there was massive leakage of tubes and soaking of the graphite structure. Unloading the uranium fuel--much of it stuck in damaged tubes--downward into the underwater buckets below the reactor (the normal discharge procedure) would have precluded reloading them in the reactor. At the time there was no spare uranium. A decision was made to extract the fuel up through the top of the reactor into the central reactor room. This resulted in very high radiation doses to the male personnel assigned to this task (see below Radiation Exposure to Workers). A total of 39,000 uranium slugs were extracted, and the reactor returned to full power operation on 26 March 1949.[260]

There were numerous departures from normal operation of the reactor and other accidents resulting in overexposure of personnel. Jamming of uranium slugs in buckets being pulled out of the unloading shaft was especially hazardous. Sometimes the consequences were tragic. As discussed below, more than 30 percent of the workers at A-Reactor received an annual dose of 100-400 rem in 1949, and some got even more. Among workers on the reactor, the frequency of cases of chronic radiation sickness was 5.8 percent.[261]

The A-Reactor is now 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 and isotope production. The IR-Reactor was the third production reactor (the second graphite-moderated reactor) constructed at Chelyabinsk-65. Construction began on 18 August 1950, and the plant was brought on line 16 months later, on 22 December 1951. After 35 years of operation it was shut down on 24 May 1987, in the same year as the A-Reactor.

---

[260] Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, p. 64.

[261] Ibid.

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 began operating on 15 July 1950 and was decommissioned on 12 August 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 on 6 April 1951, Shut down [14] July 1990.''[262] 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 B- and C-Reactors at the Hanford Reservation in the United States. The B-Reactor, the first U.S. industrial size production reactor, had 2004 channels; an original design power level of 250 MW_t; and was eventually upgraded to 2090 MW_t. The C-Reactor, similar to the B-Reactor but with its channels bored out to permit greater coolant flow, had an initial power level of 650 MW_t and was upgraded to 2310 MW_t.

The AV-2 reactor 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 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.''[263] 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.[264]

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-65. Construction of the AV-3 took place between January 1951 and September 1952. It was brought on line on 15 September 1952, and was decommissioned 1 November 1990, the last of the five to be decommissioned.[265]

Light and Heavy Water Reactors

The second reactor at Chelyabinsk-65 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. Ye.P. Slavsky, then complex chief

---

[262] Nechayuk, ``In the City Without a Name.''

[263] Ibid.

[264] Ibid.

[265] Evgeni Tkachenko, ``Southern Urals Plutonium Plant Decommissioned,'' *Moscow Tass*, in English 1710 GMT, 1 November 1990 (translated in FBIS-SOV-90-213, 2 November 1990, p. 70).

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.[266]

Lyudmila (LF-2)

There is conflicting data as to whether ``Lyudmila''[267] has always been a heavy water reactor, presumably the one just described, or whether it was rebuilt in the late-1980s as a light water-moderated and cooled production reactor.[268] We have assumed the latter. Still operational with a capacity of about 1000 MW$_t$, it is used for the production of tritium and special isotopes, e.g. Pu-238. Several serious safety deficiencies of the LF-2 and Ruslan reactors, included lack of dependable backup electric power, were identified in 1993 by Gosatomnadzor.[269]

Ruslan

A second light water-moderated production reactor, called ``Ruslan,''[270] also nominally powered at 1000 MW$_t$, is also currently being used for the same purpose.[271]

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. During the 45 year period of radiochemical plant operations at Chelyabinsk-65 the chemical separation and waste management technologies have changed substantially several times.[272] There have been several chemical separation plants at Chelyabinsk-65 at two separate chemical separation areas within Site 235. The first was B Plant, which began operating in late-1948. It was followed by BB Plant which came on line in 1959. When BB Plant came on line, processing at the B Plant began to wind down. In the mid-1970 the B Plant was modified by adding a new head-end so that it could process civil and naval reactor fuel, and the chemical separation technology was converted to a variant of PUREX. In effect B Plant was converted into a new plant called RT-1 which was commissioned in 1977. A second processing line at BB Plant was terminated in the early 1960s, and beginning in 1962 the building was used to house processing

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

[267] Lyudmila and Ruslan are names from a poem by Pushkin.

[268] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' 13 May 1994, Part I, Chapter 2, refers to two operating reactors at Mayak, LF-2 and Ruslan. We infer from this that LF-2 and Lyudmila are the same reactor.

[269] Ibid.

[270] Ibid.

[271] These two light water reactors, Lyudmila and Ruslan, are currently operational as evidenced from LANDSAT images of continued thermal discharges into Lake Kyzyltash.

[272] 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).

facilities for recovering tritium and other special isotopes. These were produced in target elements irradiated in the two light water isotope production reactors.

In 1987, when the first two plutonium production reactors were shut down, Mayak also stopped processing spent fuel from its plutonium production reactors. Presumably the BB Plant was shut down at that time. The irradiated fuel elements from the remaining production reactors at Chelyabinsk-65 were shipped by rail to Tomsk-7 for processing (see Chapter Four). Currently there are two operating processing facilities, the RT-1 at the old B Plant site, and the Radioisotope Plant at the old BB Plant site.

B Plant (Plant 25)

Construction of the first chemical separation plant, called B Plant (Building 101), also subsequently called Plant 25, was initiated in December 1946.[273] The first slugs were loaded into dissolution unit A-201 on 22 December 1948, six months after the start-up of the A-Reactor.[274] However, it was not until February 1949 that the first finished product was released by the plant's final processing stage.[275] Plutonium isolated at the B Plant was moved to the Chemical-Metallurgical Plant (Plant C), where purified metallic plutonium for weapons was obtained from it and fabricated into plutonium weapon cores.[276]

A special installation was created in parallel in Building 102 to check out a more advanced extraction process. The working conditions at B Plant were deplorable (see below Radiation Exposure to Workers). One of the chief engineers of the plant referred to the ``heightened radiation hazard which was being rectified after the catastrophe at B Plant followed by the explosion of the complex S tank.''[277] The catastrophe may be a reference to the 13 October 1954 event that destroyed part of a building at the B Plant (see below Accidents). Efforts to reduce worker exposure began to pay off in 1952. The second chemical separation plant (BB Plant) was started in 1954 and appears to have gone into full operation in the late-1950s. There were no modifications or upgrades to B Plant after 1957. The production volume remained steady until 1959, then declined to one-third, and after 1960 the entire production almost came to a halt. This continued until 1977 when the RT-1 reprocessing plant was commissioned at the site.[278] This is reflected in the much reduced occupational radiation exposures at B Plant from 1960 through 1974 (see Table 3.2).

---

[273] Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, pp. 39-74, provides a detailed history of the chemical separation activities at Chelyabinsk-65.

[274] Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, p. 48; Boris V. Nikipelov, Andrei F. Lizlov; Nina A. Koshurnikova, ``Experience with the First Soviet Nuclear Installation,'' *Priroda,* February 1990 (English translation by Alexander Shlyakhter), p. 1; Mikhail Vasilyevich Gladyshev, *Plutonium for Nuclear Bomb*, unknown publication date, p. 24. Aleksandra Ivanovna Neretina was the duty engineer at Plant B in charge of dissolving the first batch of slugs.

[275] Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, p. 48.

[276] Ibid.

[277] Gladyshev, *Plutonium for Nuclear Bomb*, p. 47.

[278] Ibid., p. 45. ``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,'' 16-27 October 1991, Trip Report For: Don J. Bradley, 11 November 1991, p. 10, claims the B Plant was not used after 1961, and it was decommissioned and dismantled at a later date.

According to the Smyth Report, the United States examined four methods for chemically separating plutonium from the spent reactor fuel on an industrial scale. The U.S. initially selected a bismuth phosphate precipitation process that had been successfully used to separated the first microgram quantities of plutonium by Seaborg and his collaborators. This process was developed on an engineering scale at the Oak Ridge X-10 plant in 1944, and then put into full operation at the Hanford's B Plant in late 1944.

The initial chemical separation technology used at the Chelyabinsk-65 B Plant was based on a different precipitation processes developed at the Radium Institute in St. Petersburg (then Leningrad) under the guidance of Academician V.G. Khlopin. The results were reported in the top secret ``Blue Book.'' The technology was demonstrated at the Installation No. 5 (U-5) pilot plant built at Scientific Research Institute No. 9 (NII-9) (subsequently the All-Russian Scientific Research Institute of Inorganic Materials imeni Bochvar (VNIINM)) in Moscow. 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 hexavalent state in the form of sodium plutonyl acetate, co-precipitates isomorphically with $NaUO_2(CH_3COO)_3$, or it remains in the solution when it is reduced to plutonium (IV) or plutonium (III). 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.[279] The resulting HLW had a sodium nitrate concentration exceeding 100 grams per liter (g/l) and sodium acetate concentration of 60-80 g/l.[280] To overcome the problem of corrosion during the final decontamination stage, which was based on fluoride technology, much of the equipment was coated with silver or gold.[281]

In order to concentrate the HLW 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.[282] This waste processing technology was put into operation in Buildings 170 and 171 in 1952. Building

---

[279] Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, p. 48, provides the following description of the initial process:

> The isolated plutonium has to be cleansed of fission products to the point where their content would be reduced by millions of times. For this, the uranium solution was subjected to repeated acetate precipitation, and the plutonium was separated from uranium and fragments. The resulting plutonium concentrate was subjected to additional purification to remove the same impurities, this time by precipitation out of fluoride solutions. The different capacities of plutonium and uranium for reduction were utilized in this case. First uranium and plutonium were oxidized with potassium bichromate in a nitric acid medium to a hexavalent state and then precipitated in the form of salts; macro-impurities and fission products remained in the solution in this case. The solution was dumped, while the precipitate was dissolved, reduced with bisulfite and once again precipitated with acetate. In this case the uranium maintained its hexavalent form, while plutonium went over to a tetravalent state, and thus remained in solution. After filtration, the uranium salts remained on the filter, while plutonium remained in solution. This procedure was embodied in the very first variant of industrial radiochemistry. This same principle of separating uranium from plutonium was used in repurification--that is, in refining, except that precipitation was carried out not in acetate but in nitric acid medium in the presence of fluorine. Then the solution was oxidized with bichromate, and hydrofluoric acid was added. A precipitate formed consisting of fluorides of rare metals together with lanthanum, which was added to the solution prior to precipitation. In the oxidized medium, plutonium remained in solution, while the fission products and lanthanum were removed with the precipitate. Then solution was reduced with bisulfate, and following addition of lanthanum, the plutonium was precipitated.

[280] E.G. Drozhko, et al., ``Experience in Radioactive Waste Management at the Soviet Radiochemical Plant.''

[281] Gladyshev, *Plutonium for Nuclear Bomb*, p. 13; Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, p. 48.

[282] E.G. Drozhko, et al., ``Experience in Radioactive Waste Management at the Soviet Radiochemical Plant.''

170 housed the alkaline concentration of solutions containing most of the fission products.[283] Considerable difficulties were encountered in mastering these new technologies since the feed materials were saturated with radioactivity, creating high beta and gamma fields. attempts to improve the equipment and pipe layout over that of Building 101 produced little effect, and the working conditions in these buildings was just as severe as in Building 101.[284]

Prior to commissioning of Buildings 170 and 171, i.e., before 1952, the decanted solutions from acetate participation at the B Plant (Building 101) were transferred to complex ``S'' tanks at B Plant (Plant 25) for ``eternal'' storage. These tanks were placed in canyons with concrete walls covered with tar. One of the ``S'' waste tanks exploded on 29 September 1957. Some of the solutions from manganese precipitation and other waste were dumped into Lake Karachay.[285]

The precipitation process was changed as a consequence of the waste tank explosion in 1957. 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 co-precipitation 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.[286]

In the early years Petr Ivanovich Tochenyy was director of B Plant. Mikhail V. Gladyshev, started work at the B-Plant in mid-October 1948 and became Chief Engineer of the plant in 1950.[287]

BB Plant, or ``Double B'' Plant

Construction of BB Plant, also subsequently called Plant 35, was started in 1954 and planned to be completed by 1957. This BB Plant construction schedule was interrupted by the September 1957 waste explosion at the ``S'' complex of B Plant. Some of the BB Plant buildings, e.g., 812, and 814-817, were finished by the time of explosion, but the first process production line, the north branch in Building 802, did not come on line until September 1959.[288] The purpose of BB Plant was to develop a more stable and safer production process. Its name derived from the fact that the acetate precipitation processed of B Plant was repeated twice in BB Plant. The final product was plutonium oxide. The original plan envisioned building two production lines; however, the rate of production at the first line (at the north branch, Building 802) exceeded the projected rate by a

---

[283] Gladyshev, *Plutonium for Nuclear Bomb*, p. 41.

[284] Ibid.

[285] Ibid.

[286] E.G. Drozhko, et al., ``Experience in Radioactive Waste Management at the Soviet Radiochemical Plant.''

[287] Gladyshev, *Plutonium for Nuclear Bomb*, pp. 13, 16, 35.

[288] Ibid., p. 47.

factor of 1.5 to 1.7, and the construction of the second line (Building 801 and 807) was frozen.[289] These building were subsequently used for recovery of special isotopes produced in targets irradiated in the Lyudmila and Ruslan reactors.

V.P. Balanovsky was Chief Engineer during construction of BB Plant; Gladyshev assumed responsibility for BB Plant in 1957; and then Evgeni I. Mikerin, who had previously worked at B Plant, became head of the process engineers and then Chief Engineer.[290]

RT-1 Radiochemical Plant

One of Mayak's currently operating chemical separation plant is designated RT-1. It is located at the site of the original B Plant (Plant 25), within Area 235, a subsequent designation for the combined sites of Plant 25 (B Plant) and Plant 35 (BB Plant). Unlike B Plant or BB Plant, the head-end of RT-1 is equipped to handle stainless steel and zircalloy clad spent fuel. In 1977 the facility shifted from processing military plutonium production reactor fuel, to processing spent fuel from naval (both submarine and civil icebreaker) reactors (which apparently occurred first), test reactors, two demonstration LMFBRs (the BN-350 on the east coast of the Caspian Sea in Kazakhstan and BN-600 at Beloyarsky in the Urals), and the light-water reactors--the 440 MW$_e$ light-water moderated and cooled power reactors (VVER-440s).[291] It is the only facility for power and naval reactor fuel reprocessing. The plant in 1992 employed about 2500 people.[292] RT-1 also processes HEU driver fuel from the water-moderated reactors used for tritium and other isotope production, spiked HEU fueled from plutonium production reactors, and HEU from research reactors.

The RT-1 reprocessing plant capacity is 400 tHM/y VVER-440 fuel, comparable to the UP2-400 (oxide) plant that was operated by Cogema at La Hague in France.[293] In 1989 it was reported that over the plants 10-year ``civilian'' lifetime, throughput has averaged 200 tHM/y.[294] In December 1993 it was reported that for the whole of its operating period 2,380 tHM of spent fuel had been received from domestic and foreign power plants.[295] In 1991 it processed 160 tHM of spent fuel; about 120 tHM in 1992, and in 1993 it was not expected to exceed the 1992 throughput.[296] The recent decline in the rate of spent fuel processing is a consequence of

---

[289] Ibid., p. 48.

[290] Ibid., pp. 46-48. Mikerin is currently Head of the Fourth Directorate within Minatom.

[291] Production reactor fuel is uranium metal. Because VVER fuel, and presumably some of 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.

[292] Frank von Hippel, Thomas B. Cochran, and Christopher E. Paine, ``Report on an International Workshop on the Future of Reprocessing, and Arrangements for the Storage and Disposition of Already-Separated Plutonium (Moscow, 14-16 December 1992), and an International Workshop on Nuclear Security Problems (Kiev, 17 December 1992),'' 10 January 1993.

[293] Oleg Bukharin, notes taken at meeting with Evgeni Mikerin, Frank von Hippel, and others, Moscow, 28 May 1992; and ``Soviet Union Postpones Completion of Siberian Reprocessing Plant,'' *Nuclear Fuel*, 16 October 1989, pp. 1-2. VVER-440 reactor cores are loaded with 42 tHM in 349 fuel elements. Therefore, RT-1 capacity is on the order of 3300 assembles/y.

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

[295] *Association Production Mayak: 45*, Mayak Production Association, 6 December 1993.

[296] In its 1993 Annual Report, Gosatomnadzor reported that ``In the course of one year approximately 200 t of spent fuel is reprocessed. It is not know whether this represents the 1993 figure of the historical average.

transportation problems and the recent Russian nuclear waste law that prohibits importing of nuclear waste into Russia. There has been a holdup in the shipment of spent fuel from Ukraine, Czechoslovakia (now Czech and Slovakia), Germany and Hungary awaiting legal clarification whether spent fuel should be regarded as a nuclear waste.

The RT-1 plant consists of a spent fuel storage pool, three chopping-dissolution process lines, and a modified Plutonium-URanium-EXtraction (PUREX)[297] process with separate plutonium, neptunium, and technetium output streams. After a planned three-year hold-up in the reactor spent fuel pools, the spent fuel arrives at RT-1 in transport casks, and is transferred to a water pool storage basin at the plant's receiving area for temporary storage. At the end of 1992 there was no backlog of spent fuel awaiting reprocessing. An interim wet storage facility for 2000 t of spent VVER-440 fuel is about 70 percent complete.[298] According to Evgeni Dzekun, chief engineer of the RT-1 reprocessing plant, ``as long as we keep reprocessing, we won't need it."[299]

One of the three chopping-dissolution lines handles the VVER-440 spent fuel; the second handles the spent HEU driver fuel from the two isotope production reactors at Chelyabinsk-65 and the spent HEU fuel from the spiked rings in the plutonium production reactors; and the third accepts naval fuel. The second and third lines are interconnected after the first extraction cycle.

In the PUREX process the uranium and plutonium extraction, purification from the major fission products, and separation are based on a two-stage extraction process using an organic mixture of 30 percent solution of tributilphosphate (TBP) in n-paraffine diluter (C_{11}-C_{14}).[300] The fuel elements are first dissolved in hot nitric acid. Next the uranium and plutonium are separated from the fission products through liquid-liquid interactions in which the plutonium and uranium are transferred between aqueous solutions (nitric acid) and organic solutions (typically comprised of tributylphosphate in a kerosene carrier). Successive separation stages provide a stream of uranium and plutonium, which is subsequently partitioned into separate plutonium and uranium streams for further purification and concentration, leading to final solution products, typically plutonium and uranyl nitrates. These are then converted into oxide powders for storage or subsequent processing into reactor fuels, or into metal shapes for processing into weapon parts.

From pool-storage the spent fuel is transferred to the preparation and chopping area at the head end. There the stainless steel or zircalloy clad fuel is cut into pieces 7-15 mm in length. These are transferred to the circular dissolver containing a nitric acid which operates in a batch mode. The loading of material into the dissolver is limited by the apparatus geometry and the nuclear safety requirements. The insoluble residual fuel and cladding materials are rinsed and pneumatically removed from the dissolver, and then directed to burial through pneumatic transport device. Uranium and plutonium losses in the insoluble residue are 0.01 percent and 0.06 percent of their content in spent fuel, respectively.[301]

---

[297] PUREX was first used in the United States in 1954.

[298] *Nuclear Fuel*, 4 January 1993, p. 4.

[299] Ibid.

[300] Ibid.

[301] Eugene G. Dzekun, ``Experience with Management of Fissile Materials at `Mayak,'" paper presented at the Workshop on the Future of the Chemical Separation of Plutonium (Reprocessing) and Arrangements for the Storage & Disposition of Already

The produced nitrate solutions are the suspension of highly dispersed particles of 0.5 to 5 micron size on the base of graphite, silicon acid and other elements with total content up to 1 g/l. The solution is clarified primarily by a filter, made of inert material hydraulically deposited in cermet cartridges, that operates periodically.[302]

After the second extraction cycle the factors of purification of uranium and plutonium from fission products are $(1-1.5) \times 10^7$ and 3×10^6, respectively. After adding additional uranium enriched in the isotope U-235, the purified and regenerated uranium, in the form of uranyl-nitrate hexahydrate (UNH), is transferred to the other plants for fresh fuel rods manufacture.[303]

The re-extract containing plutonium and neptunium (Pu 6-8 g/l, Np 0.2 g/l) is directed to the refining area. The separation of these two elements, and their final purification from uranium, macro-impurities and fission products are performed by the extraction method during stabilization of Np(IV)-Pu(III) couple at step of Pu and Np separation, followed by the Pu oxidation to valence (IV) (at step of Pu purification and concentration).[304] The purified Pu and Np re-extracts of concentration 20-30 g/l and 4-10 g/l, respectively, are brought to a dioxide form through the oxalic precipitations.

Separated Plutonium, Moscow, 15 December 1992.

[302] Ibid.

[303] Ibid.

[304] Ibid.

The output from RT-1 include: low-enriched uranium which was subsequently used to make RBMK fuel; plutonium which is stored as plutonium dioxide (PuO_2), or used to manufacture experimental MOX fuel for BN type reactors; neptunium which is stored as NpO_2, or used in the reactor production of Pu-238; technetium which is produced sporadically for research purposes; Sr-90 and Cs-137 which are periodically produced for isotope sources; and nuclear waste. The RT-1 reprocessing technology, currently provides recovery of 99 percent of the uranium and plutonium, and 85 percent of the neptunium.[305] Americium and curium are not extracted at present and remain with the fission products. From one tonne of VVER spent fuel with a burnup of 30,000 MWd/t (corresponding to a reduction in the uranium enrichment from 3.6 to 1.25 percent) one extracts:[306]

	Spent Fuel Cooling Period	
	150 days	3 years
uranium (99% recovery)	950 kg[*]	950 kg[*]
plutonium (99% recovery as PuO_2)	8.79 kg[+]	8.67 kg[#]
neptunium (85% recovery as concentrated acid	0.293 kg	0.293 kg

_____

[*] 89.27% U-238; 1.254% U-235; 0.450% U-236: 0.04% U-234
[+] 63.32% Pu-239; 19.81% Pu-240; 12.57% Pu-241; 2.91% Pu-242; 1.38% Pu-238.
[#] 64.23% Pu-239; 20.10% Pu-240; 11.30% Pu-241; 2.95% Pu-242; 1.41% Pu-238.

At the current rate of reprocessing, 120 tHM/y, RT-1 is recovering 114 t low-enriched uranium (LEU) (1.25% U-235) and one tonne of reactor-grade plutonium per year.

The original plan was to recycle the recovered LEU into fuel for the RBMK reactors without enrichment. With higher burnup achieved in the VVERs and a requirement for higher RBMK fuel enrichment, this is no longer desirable. Recovered LEU (0.8-1.25 percent U-235) is now blended with higher enriched uranium to produced the desired RBMK fuel enrichment (2.4 percent U-235).[307]

The recovered plutonium was originally destined for the cores of the Minatom's ambitious breeder reactor program. Due to delays in the breeder program and with the Complex 300 MOX fuel fabrication plant still unfinished, the PuO_2 is being placed into temporary storage at Chelyabinsk-65. Most of the NpO_2 is also sent to storage. Part of it has been used for Pu-238 production and research purposes.[308]

At RT-1 the PuO_2 is loaded into the transport canisters, each with a capacity of 1930 cm^3

[305] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' (Ordered by President M. Gorbachev, Presidential Decree # RP-1283, 3 January 1991), ca. April, 1992 [translated into English], Vol. II, p. 25 (the page numbers cited here and subsequently are for the English translation).

[306] Currently VVER-440s are being shifted from a three to four year fuel life with increase in burnup to 40,000 MWd/t; Oleg Bukharin, ``The Structure and the Production Capabilities of the Nuclear Fuel Cycle in Countries of the Former Soviet Union,'' The Center for Energy and Environmental Studies, Princeton University, Report PU/CEES 274, January 1993, p. 6.

[307] This saves about 780 kg SWU and 2.06 tU feed per t LEU (1.25 % U-255) recovered (assuming 0.2 % tail assay), or 90,000 kg SWU and 230 t feed annually, assuming the 1992 throughput of 120 tHM.

[308] Ibid.

(not greater than 3 kg PuO_2). The canister contents are weighed to an accuracy of 0.5 grams. (The uncertainties in the quantities of plutonium being extracted from the fuel are dominated by a 0.5 percent uncertainty in the volume of the reprocessing plants's fuel dissolver tank.) Each transport canister is placed into a sealed container, both made of stainless steel. This package is intended for transport to and store at the finished products storehouse, which comprises one or more shallow vaults.

The 1990 inventory of surplus plutonium in storage at Chelyabinsk-65 was 23.0 t.[309] By the end of 1992 the inventory would have grown to an estimated 25.4 t; and as noted previously, it is expected to continue to grow at a rate of about 1 t/y as long as the RT-1 throughput remains at the 1992 rate of 120 tHM/y. Through the beginning of 1992 approximately 4 t of plutonium had been recovered from processing BN-350 and BN-600 spent fuel, but some of this plutonium has been used to produce new MOX fuel.[310]

We do not know what fractions of the spent fuel processed and the separated plutonium are from naval fuel, and what fractions are from VVER and BN fuel. Nevertheless, we can approximate the annual fission product and actinide output of RT-1 by assuming all the plutonium is from VVER spent fuel. This is done in Table 3.3 for the year 1992, when 120 tHM were processed. As seen from the table, some 800,000 curies of krypton-85 (Kr-85) are being released to the atmosphere annually. There are also large quantities of liquid HLW being produced: some 35 million curies annually of long-lived Sr-90 + Y-90 and Cs-137 + Ba-137m, combined. In addition, there are the usual streams of intermediate-level and low-level liquid wastes effluent, radioactive solid wastes, an occupational radiation exposures associated with chemical separation plants.

We have not made similar estimates of the radioactive effluents from the chemical separation facilities associated with two operating water-moderated production reactors at Chelyabinsk-65. Since the capacity of these reactors is an estimated 2000 MW_t, the chemical separation effluents should be comparable to those estimated for Krasnoyarsk-26 in the right-hand column of Table 3.3.

The radioactive pollutants are virtually always mixed with a large amount of non-radioactive chemical wastes. Unfortunately, little information is available on these non-radioactive wastes from Russian chemical separations facilities. Because RT-1, and apparently the other chemical separation plants in Russia, involve the same basic PUREX process used in the U.S., information on U.S. chemical separations facilities' wastes can be used to identify types of wastes produced by Russian facilities (see Table 3.4). These wastes can pose substantial health and environmental risks by themselves. However, mixed with radioactive wastes in typical chemical separations effluents, these wastes increase the risks from the radioactive materials through chemical and biological interactions.

There are three general categories of non-radioactive wastes generated by chemical separations processes. First, acid wastes are generated during the process of dissolving the spent

---

[309] Eugene G. Dzekun, ``Experience with Management of Fissile Materials at `Mayak,''' paper presented at the Workshop on the Future of the Chemical Separation of Plutonium (Reprocessing) and Arrangements for the Storage & Disposition of Already Separated Plutonium, Moscow, 15 December 1992.

[310] V.N. Solonin, ``Utilization of Nuclear Materials Released as the Result of Nuclear Disarmament,'' paper presented at the International Symposium on Conversion of Nuclear Warheads for Peaceful Purposes, Rome, Italy, 15-17 June 1992.

fuel.[311] Nitric acid (HNO_3) is used most commonly, but other types of acid are also used (see Carboxylic Acids in Table 3.4).[312] The corrosiveness of these acids (pH usually less than 1.0) creates serious waste management problems, and often causes leaks in underground transfer pipes, which results in groundwater contamination. These acids may also hasten the reaction rates of other chemicals in the waste resulting in the generation of explosive gases, such as hydrogen. Moreover, high acidity (low pH) in the discharged waste greatly increases the mobility, especially in colloidal forms, of radioactive materials such as plutonium.[313]

A second class of non-radioactive chemicals in the waste includes a wide variety of chelating and complexing agents, which are added to the waste to reduce its reactivity or cause physical separation into supernatant and sludge (see Table 3.4). One of these agents--cyanide (CN)--may form toxic gases in an acidic environment, creating severe risks to workers. These problems of worker exposures and the threat of explosion has been identified by the DOE at the Hanford Reservation. Other chelating agents are extremely persistent or may form hazardous breakdown products.

A third class of non-radioactive wastes includes a wide variety of organic solvents such as kerosene, trichloroethylene (TCE), and tributylphosphate (see Table 3.4). These contaminants are derived from the second and third extraction cycle in the chemical separations process. Many of these solvents, such as carbon tetrachloride, are known to present substantial carcinogenic risks.[314] In addition, dense non-aqueous phase solvents (e.g., TCE) create intractable cleanup problems because they can contaminate large areas of ground water while eluding detection or extraction in aquiclude pockets.

Radioisotope Plant

Since the early 1950 the Soviets have had an extensive program of special isotope production and separation centered at Chelyabinsk-65, including recovery of tritium for weapons and a variety of special isotopes, including Sr-90 and Pu-238 for radioisotope thermo-electric generators (RTG), and C-14, Cs-137, Sr-90, Ir-192, Pm-147, Np-237, Pu-238 and Am-241 for medical, agricultural, and industrial uses.[315] The Radioisotope Plant dates back to 1962.[316] At least some of the processing lines currently in use are in Buildings 801 and 807 that were originally constructed to house a second plutonium recovery line at BB Plant. This site is also called Plant 45.

---

[311] Acids are generated primarily from the first cycle rafinnate wastes.

[312] For example, sulfuric acid H_2SO_4 is usually cheaper, but requires greater quantities, and the sulfur may threaten the integrity of the resulting glassified waste from vitrification.

[313] Mahara, Y. and H. Matsuzuru, ``Mobile and Immobile Plutonium in a Groundwater Environment,'' *Water Resources*, 23 (1): 43-50, 1989. Also see, generally, J. F. McCarthy and J.M. Zachara, ``Subsurface Transport of Contaminants,'' *Environmental Science and Technology*, 23 (5): 496-502, May 1989.

[314] WHO/IARC, ``IARC Monographs on the Evaluation of Carcinogenic Risks to Humans,'' Supplement No. 7, 1987.

[315] The operation of an RTG is based on the thermocouple principle, i.e., if two dissimilar metals are joined at their extremities and heat is applied to one metal while keeping the other metal cool, an electric current flow. The heat is supplied by the radioactive decay of selected isotopes.

[316] *Association Production Mayak: 45*, Mayak Production Association, 6 December 1993.

Alpha-sources are used in smoke detectors, static eliminators, gas chromatography and gas analyzers. Beta-sources are used in aircraft anti-icing systems, and thickness and density meters. Gamma and x-ray sources are used in industry to detect flaws in metals and in a variety of analytical and measuring devices. Fast neutron sources are used in oil well logging devices and moisture meters. Beta and gamma-sources are used in medicine in a wide variety of diagnostic, therapy and surgical instrument sterilization applications. In 1992 Mayak and Amersham International of England announced the formation of joint venture--Reviss Services. Mayak produces radioisotopes and Amersham fabricates them into finished products and provides marketing services worldwide.

The RTGs typically use energetic beta emitters, e.g., Sr-90 or Ce-144, or alpha emitters, e.g., Pu-238 or Pm-147.[317] On 8 December 1992 the U.S. DOE and Mayak Production Association signed a contract for the purchase of 5 kg of Pu-238 for $6 million. The contract allows the United States to purchase at least 5 kg of Pu-238 for $6 million, and as much as 40 kg for $57.3 million over the next 5 years. Reportedly a contract for the second 5 kg was signed in the fall 1994.[318] An agreement between the U.S. DOE and Minatom specifies that the Pu-238 will be use by the U.S. National Aeronautics and Space Administration (NASA) to power unmanned space missions and the hard currency received from the sale will be used for environmental remediation and social rehabilitation of the Chelyabinsk region.[319]

Plutonium Processing, Finishing and Component Manufacture

After chemically separating the plutonium from spent fuel it must be further purified, converted into metal and fabricated into weapon components. At Chelyabinsk-65 these functions are performed at a separate industrial area, called Plant 20, located on the northwest side of Lake Tatysh (see Figure 3.1).[320] The very first plutonium finishing plant at the site was called C Plant--described as being located in warehouse buildings of the Naval Artillery Directorate of the Ministry of Defense not far from the city of Kyshtym, near the railroad station of Tatysh.[321] The first plutonium solutions were delivered from B Plant to C Plant on 26 February 1949. The plutonium hemispheres for the first atomic bomb were not completed until August 1949. These were shipped to Arzamas-16, and from there to the Semipalatinsk test site prior to the 29 August test of the first bomb.

The second phase of C Plant was designed to produce HEU components using technology developed at the Electrostal Machine-Building Plant and NII-9 and transferred to C Plant.[322] Plant 20, however, continued to manufacture plutonium components--probably complete weapon pits. As of late-1994, plutonium pit production was still ongoing at Chelyabinsk-65 and Tomsk-7. As noted

---

[317] Some of the fission product isotopes are recovered at RT-1.

[318] *Nuclear News*, February 1993, p. 73.

[319] U.S. Department of Energy, ``U.S. - Former Soviet union Environmental Restoration and Waste Management Activities, March 1994, DOE/EM-0153P, p. 34.

[320] The map coordinates of the site are 55° 40'N/060° 40E.

[321] Kruglov, ``On the History," *Bulletin*, No. 10, 1993, p. 66. The plants experimental industrial complex was organized out of single-story barrack buildings (Shop No. 4, 8, and 9).

[322] Ibid.

earlier, plutonium for weapons is no longer produced and chemically separated at Chelyabinsk-65, and the bulk of the plutonium recovered at the RT-1 plant is reactor-grade plutonium and is stored at Chelyabinsk-65 as an oxide powder.

MOX Fuel Fabrication Facilities

At Chelyabinsk-65 there were two small MOX [(U,Pu)O$_2$] fuel fabrication facilities that are now shut down; two additional facilities are currently operating, and construction on another larger plant has been suspended.

Pilot Bay

In the 1960s and 1970s a pilot bay was used for the manufacture of pellets and pilot fuel elements for fast research reactors. A total of about one tonne of weapon-grade plutonium was used. The fuel composition was plutonium alloys and PuO$_2$ fuel.[323]

Zhemchug

In 1986-1987 a small facility called Zhemchug was used for the manufacture of MOX fuel assemblies for fast reactors. The facility had a capacity of 35 kg Pu/y (for five fuel assembles/y) and used weapon-grade plutonium from BN type reactors (fast reactors).[324]

Granat

Since 1988 this facility has been used to produce MOX fuel for testing in fast reactors. The facility has a capacity of 70-80 kg Pu/y (for ten fuel assemblies/y) and has been using weapon-grade plutonium.[325]

Paket

Using the output of Granat, this facility since 1988 has been manufacturing MOX pellets, and fabricating finished fuel elements for testing in fast reactors. The facility has a capacity of 70-80 kg Pu/y (for ten fuel assemblies/y) and has been using weapon-grade plutonium.[326]

Complex 300 MOX Fuel Fabrication Plant

This MOX fuel fabrication plant was designed to manufacture the fast breeder reactor fuel assemblies for BN-800, handling 5-6 t of plutonium annually.[327] Construction of the MOX plant

---

[323] V.N. Solonin, ``Utilization of Nuclear Materials Released as a Result of Nuclear Disarmament.''

[324] Ibid.

[325] Ibid.

[326] Ibid.

[327] Ibid. Another source claims the plant was sized to produce enough plutonium fuel assemblies for three BN-800 reactor cores annually. Since one BN-800 core contains 2.3 t, this would amount to about 7 t annually.

(and the South Urals Project) was started in 1984,[328] and then suspended after expending 71.3 million rubles through 1989.[329] The MOX plant has been variously reported as being 50 to 70 percent complete.[330] There is a research and development program in Russia on use of MOX fuel in VVERs. There were development plans for a second production line at this same plant, capable of handling 5-15 t Pu/y, for the production of MOX fuel for VVERs,[331] but more recently Krasnoyarsk-26 has been named as the site for a new VVER MOX fuel plant.

Central Research Laboratory

A Central Plant Laboratory (CPL) was set up as early as 1947 to work on a variety of technological problems associated with the reactors, the chemical separation plant, and other facilities at the Combine. Kurchatov's office was located in the CPL. The first directors of the laboratory were P.A. Meshcheryakov (from 1947 through January 1951), V.P. Shvedov (through 14 February 1952) and V.I. Shirokov (through 16 June 1955).[332] A 1993 Mayak brochure refers to the Central Research Laboratory (presumably the same laboratory as, or a follow-on to, the CPL) where specialists deal with problems arising in radiochemical processing, safety and environmental monitoring.[333]

Instrument Engineering Plant

The Instrument Engineering Plant originated from the Specialized Design Group for Measurement and Control, organized during the first years of Mayak. In 1981 the plant was redesigned to meet expanded production requirements. The plant develops and produces a wide variety of measurement and control equipment for physical and chemical monitoring, radiation monitoring, reactor core monitoring, environmental monitoring, etc. The plant had about 1,200 employees in 1993, including 200 designers.[334]

Repair and Machine Shop

The Repair and Machine Shop was founded at the same time as the commissioning of the first reactor. It produces chemical vessels, nonstandard general engineering equipment, spare parts for reactors, components for the Radiochemical Plant. It has bays for welding, machining, a foundry, and metal cutting.[335]

---

[328] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 10.

[329] Ibid., Vol. II, p. 22.

[330] V.N. Solonin, ``Utilization of Nuclear Materials Released as a Result of Nuclear Disarmament,'' claims the plant is 50 percent completed.

[331] Ibid.

[332] Kruglov, ``On the History,'' *Bulletin*, No. 8, 1993, p. 61.

[333] *Association Production Mayak: 45*, Mayak Production Association, 6 December 1993. this Mayak brochure says the laboratory dates back to 1949.

[334] Ibid.

[335] Ibid.

Experimental Scientific Research Center

In response to the 1957 waste tank explosion, the Experimental Scientific Research Center was founded in 1958 to study large-scale radioactive contamination, including the movement of radionuclides in soil, plants, animals and people. Today the Center continues to focus on radioecology and investigates advanced methods for measuring and analyzing practically all radionuclides in a variety of media.[336]

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,[337] was begun in 1984.[338] Only the concrete footings for the first two reactors were put in place before construction was suspended in 1987.[339] The third reactor did not advance beyond the planning stage.

The reactor complex is located on the northwestern edge of Reservoir No. 10 (see Figure 3.1). At the construction site the soil contamination ranges from 1.0-1.5 Ci/km^2 for Sr-90 and 4.0-4.5 Ci/km^2 for Cs-137.[340]

Construction of the South Urals project was halted after the Chernobyl accident and 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.[341]

Contrary to the returns of a 1991 regional referendum, Minatom would like to complete construction of the three reactors and has invited international institutions to participate in the project.[342] Following a review by a commission of experts from the Economics Ministry, expenditure of 1.5 billion rubles in 1993 has been allocated by the Russian government to resume work.[343] A fourth BN-800 is planned to be constructed at the Beloyarsky site. Whether construction of any of the BN-800 units is completed will depend not only on the availability of financing, but also on the outcome of the political struggle between Minatom which supports the

---

[336] Ibid.

[337] The BN-800s may actually be rated at 750 MW$_e$ each.

[338] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 10. See also, *Nucleonics Week,* 26 July 1990, p. 11.

[339] Ibid.

[340] ``Resonance,'' Chelyabinsk, 1991. The site, in the words of *Selskaya Zhizin,* is ``in a bright birch grove, which guards the secret of the Ural (radioactive) trace;'' ``The Ural Trace,'' *Selskaya Zhizin,* 1 November 1989.

[341] Ibid. and ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 22.

[342] ``Russia Plans Nuclear Plant in Yuzhno-Uralsk,'' *Moscow POSTFACTUM*, in English (reproduced in JPRS-TND-92-025, 22 July 1992, p. 24). The Japanese have expressed an interest in funding the project.

[343] ``South Urals construction to resume in 1993,'' *Nuclear News*, December 1992, p. 44.

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 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 expensive'' than power from conventional power plants.[344] Scientists at the Research and Design Institute for Power Technologies (NIKIET) in Moscow, the Physics and Power Institute (FEI) at Obninsk, and 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.

Long-Term Storage Facility for Fissile Material from Weapons

Following the unilateral commitments by Presidents Gorbachev and Bush in September 1991 to eliminate thousands of tactical nuclear weapons, Minatom was faced with a need to build additional fissile material storage capacity and sought U.S. financial assistance in that regard. The U.S. Congress responded by passage of the Soviet Threat Reduction Act of 1991 (the ``Nunn-Lugar'' Act) and additional Nunn-Lugar funds were provided in subsequent years. The United States agreed to allocate $16 million of the Nunn-Lugar funds to assist Russia in the design of the facility and $75 million for equipment. An additional $75 million is expected to be provided to assist in the construction of the storage facility. Minatom's preliminary plan was to locate a single facility for long-term storage of fissile materials from weapons at Tomsk-7. Public opposition to siting the storage facility at Tomsk-7, heightened by the 6 April 1993 accident at the Tomsk-7 chemical separation plant, forced Minatom to plan to construct two smaller facilities with the location of the first facility at Chelyabinsk-65 and the second at Tomsk-7.

As of the fall 1994, the plan was to construct the facilities in two phases, each phase would provide storage space for 25,000 containers for a total of 100,000 containers for the two sites. (Typically, three to four containers are required to store the fissile components of a single warhead.) Site preparation at Mayak started in July 1994. The tentative schedule is to complete the first phase in 1997 and the second in 1999. At Tomsk-7 site preparations is planned for the summer of 1995.

The site for the Chelyabinsk storage facility is between Lake Kyzyltash and Reservoir 10 on the south side of the Techa River. It lies within the radioactive trace from the 1957 waste tank

---

[344] ``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 7-8 July 1989].

explosion.[345]

The design of the facility has been developed by the Institute of Industrial and Energy Technologies (VNIPIET, St.Petersburg) with the U.S. technical and financial assistance.[346] The facility is designed to provide storage of 50,000 fissile-material containers over the period of 80-100 years.[347] The materials will be stored in the form of weapons components in criticality-safe, airtight, shock- and fire-proof containers.

The storage facility will be located within a high-security area. The underground bunker will accommodate hermetically isolated storage compartments and areas for vital support equipment including a diesel-generator, air-conditioning, cooling-, and accumulator stations. The design does not foresee operations involving opening the containers inside the facility. A railway terminal, administrative building, electricity generator, compressor, heater, fire-and security force stations will be built on the surface.

The United States will furnish some of the equipment that will be used to construct the facility, as well as storage containers and other furnishings. These items will be purchased from U.S. contractors with Nunn-Lugar funds. The United States and Russia have agreed on ``General Safety Criteria for the Russian Fissile Material Storage Facility.'' According to these criteria, the facility is designed to withstand the following events: a tornado, earthquake, fire, flood, increase in temperature due to plutonium phase transformations, container leak, mistake by the personnel, electricity black-out, airplane crash, bombing, and terrorist attack. The safety criteria will be met by the robust design of containers, careful geological siting of the facility, and by special engineering and institutional measures. According to designers, integrity of the storage may be violated only in the event of an attack with nuclear or conventional high-power concrete-penetrating weapons.

The design specifications require the occupational radiation exposure to be five times less than that currently used across the nuclear industry in Russia. Special efforts to localize and contain any accident within the facility are undertaken to reduce radiation exposure due to an accident. Even for worst basic design accidents, the additional cancer risk would not exceed 0.1 of that associated with the occupational radiation exposure. The population doze would not exceed occupational exposure limit under any circumstances.[348]

Radiation Exposure to Workers

Nikipelov, et al., first published in 1990 an analysis of the radiation doses to workers at the A-Reactor (the first reactor) and at the B Plant, the first chemical separation plant, at Chelyabinsk-

---

[345] At about 55° 43'N/060° 51'E.

[346] Russia and the United States have signed the agreement providing for U.S. assistance in designing a storage facility. Some $15 million of the Nunn-Lugar funds was allocated for this purpose.

[347] V. Golozubov, ``Basic Principles of the Design of the Storage for Fissile Materials in Russia,'' presented at the International Workshop ``Reprocessing of Nuclear Fuel, Storage and Disposition of Civilian and Weapons Plutonium,'' 14-16 December 1992, Moscow. The facility is being designed to permit the construction, if needed, of a ``second stage'' with the additional storage capacity of up to 60,000 containers.

[348] S.Petrin ``Safety of the Fissile Materials Storage,'' presented at the International Workshop ``Reprocessing of Nuclear Fuel, Storage and Disposition of Civilian and Weapons Plutonium,'' 14-16 December 1992, Moscow.

40.[349] The distributions of worker external exposures at these two facilities are reproduced in Table 3.2.

Between 1948 and 1958 workers at the production reactors, the radiochemical plant (B Plant) and the plutonium metallurgy plant (C Plant), worked under exceedingly bad radiation exposure conditions. Punishment was meted out in the early days for failure to fill the plutonium quota at Reactor A, for failure of the plan for isolating plutonium at the B Plant, and for untimely delivery of plutonium to the C Plant.[350] There were criticality accidents at B Plant, and such accidents occurred frequently at C Plant.[351] During the initial production period job-related radiation sickness was diagnosed in 2,089 workers, while 6,000 persons received a cumulative external dose greater than 100 rems; among them were persons who received 25 rems or more in the course of one year.[352] According to published data 17,245 persons exceeded the permissible annual exposure level (established in 1952) of 25 rems.[353] The period 1948-1952 is characterized by exceedingly high external exposures. At A-Reactor the *average* annual worker external dose peaked at 93.6 rem in 1949, the first full year of operation; and at the chemical separation B 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. At A-Reactor, for the period 1948-1955, the cumulative external gamma dose to workers in machine and power services and the central reactor room averaged just over 200 rem   , while those performing radiation monitoring and instrumentation servicing averaged 108 and 129 rem respectively.[354]

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:

---

[349] Boris V. Nikipelov, Andrei F. Ligalov, and Nina A. Koshurnikova, ``Experience with the First Soviet Nuclear Installation,'' *Priroda,* February 1990 (English translation by Alexander Shlyakhter). See also, Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, pp. 47-53 for additional data.

[350] Kruglov, ``On the History,'' *Bulletin*, No. 10, 1993, p. 51.

[351] Ibid.

[352] Ibid.

[353] Ibid.

[354] Kruglov, `` On the History,'' *Bulletin*, No. 8, 1993, p. 67.

1948:	0.1 rem for 6 hours (about 30 rem/y).
1952:	0.05 rem for 6 hours (about 15 rem/y); 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/y for workers under the age of 30 years and 12 rem/y for workers 30 years and older.
1970:	5 rem/y.

We estimate that the sum of the average annual external gamma 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,[355] the average excess 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.

During the first 20 years of plant operations, 40 persons were reported to have suffered from ``acute radiation disease, eight of whom died. Another 1500 overexposed staff developed ``chronic radiation disease.'' Of these, 22.5 percent of the cases were workers at the radiochemical plant who received an average radiation dose of 340 rem, and 5.8 percent of the cases were reactor workers that received an average dose of 264 rem.[356]

Accidents

The following are identified as the most important accidents at the radiochemical plants [and at Plant 20] at Chelyabinsk-65:[357]

15 March 1953	Criticality event. Two technicians irradiated.
13 October 1954	Technological equipment fractured and parts of a building were destroyed.
21 April 1957	Criticality event. Six hurt; one fatality.
29 September 1957	Explosion in radioactive waste storage facility (Complex ``S'' tank at the B Plant). A number of production buildings were damaged; 20 MCi of radioactive fission products were released; 18 MCi fell in the immediate vicinity and the remaining 2 MCi were dispersed in a radioactive plume, 89 km wide and 105 km long (see Waste Explosion in 1957).
2 October 1958	Criticality event. Three fatalities; one man affected by radiation sickness and lost his sight.

[355] 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.

[356] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 27.

[357] *Moscow Komsomolskaya Pravda*, 11-14 November 1994.

28 July 1959	Technological equipment fractured.
5 December 1960	Criticality event. No irradiation.
26 February 1962	Explosion in a sorption column destroyed pipelines.
7 September 1962	Self-sustaining chain reaction. Three outbreaks. No personnel irradiated.
16 December 1965	Self-sustaining chain reaction lasting 14 hours.
10 December 1968	Criticality event at Plant 20 when an organic plutonium solution was pumped into a cylindrical container whose geometry was unsafe. One person was killed; another man received a high radiation dose causing severe radiation sickness and requiring amputation of his legs.
2 October 1984	Explosion in reactors' vacuum service lines.
16 November 1990	Explosive reaction in reagent equipment. Two men received chemical burns, one died.
17 July 1993	Thermochemical reaction and explosion at the Radioisotope Plant (Plant 45) in system containing plutonium-238 (see discussion below).
27 December 1993	A small quantity of radioactivity was released as an aerosol at the Radioisotope Plant during filter change (see discussion below).

Additional information is available with regard to the two accidents that occurred at the Radioisotope plant in 1993 and an accident at a reprocessing plant in 1994. At 1645 hours on 17 July 1993, there was an accidental release of a small amount of radioactivity to the atmosphere. According to preliminary data, the accident was due to a seal failure in sorption column SN-04, a 25 liter tank, 1.5 m high and 16 cm in diameter, located in a cell covered by a layer of concrete and steel. The accident resulted from the build up of gas pressure caused by exothermic auto-decay of the sorbant (anonite VP-1AP) as a result of interaction with nitrates as the temperature increased to 130 $^{\circ}$C. The gas emission was very intense--close to explosive. Resin heating to such a high temperature occurred due to drying of a layer of sorbant, and subsequent sorption on it of a significant amount of plutonium-238. (approximately 400 g).[358] About 20 liters of plutonium solution leaked into the cell. The ventilation system of the building successfully retained most of the material. An estimated 0.192 millicuries of plutonium and other alpha emitters were released to the environment through the 120-meter high ventilation stack.[359]

On 27 December 1993 a second accident at the radioisotope plant released radioactive aerosols to the atmosphere during the changing of filter FPP at installation 3. The release contained 33 mCi of alpha activity and 0.36 mCi of beta activity. No surface contamination of the installation or buildings resulted.[360]

On August 31, 1994 a fire, described as ``minor,'' occurred at a reprocessing plant--

---

[358] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' 13 May 1994, Part I, Chapter 2.

[359] Andrei Illesh and Valeri Yakov, ``Discharge of Radioactive Substances at Chelyabinsk-65 Not as Harmless as the Ministry of Atomic Energy States,'' *Moscow Izvestiia*, in Russian, 21 July 1993, First Edition, p. 2 (translated in FBIS-SOV-93-138, 21 July 1993, p. 35); Evgeni Tkachenko, *Moscow ITAR-TASS*, in English, 0852 GMT 22 July 1993, (reproduced in FBIS-SOV-93-139, 22 July 1993, p. 45); and *Nuclear News*, August 1993, p. 88.

[360] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' 13 May 1994, Part I, Chapter 2.

presumably at RT-1. Cladding of a fuel rod caught fire while an assembly was being dismantled. Less than one curie of Cs-137 was released into the ventilation system. The stack discharge was estimated to be 4.35 percent of the authorized limit.[361]

Waste Management Activities

At Chelyabinsk-65 an estimated 930 million curies (MCi) of the Sr-90 and Cs-137, were produced through 1994, of which, following radioactive decay, some 665 MCi remained as of end-1994.[362] When the activity of the daughter products, Y-90 and Ba-137m, are included, these figures are doubled, i.e, some 1850 MCi produced and some 1330 MCi remained as of end-1992. It was reported in 1991 that throughout the Chelyabinsk-65 site one billion Ci of all types of waste has accumulated.[363]

In the first three years of operations, radioactive waste management at Chelyabinsk-65 was practically nonexistent. Beginning late-1948, HLW from the chemical separation facility was diluted and discharged directly into the Techa River as medium-level waste. By the fall of 1951, after it was apparent that this was causing massive environmental contamination, the HLW (again diluted to medium-level) was diverted into Lake Karachay. By 1953, a program was implemented whereby the insoluble 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 HLW tanks exploded in 1957, causing extensive off-site contamination. 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 HLW. These highlights are discussed in more detail below.

Discharge of Waste into the Techa River

From the start-up of the chemical separation plant in December 1948 through 1956, 78 million m^3 of intermediate-level liquid 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.[364] About 95 percent of the radioactivity (averaging 4300 curies/day (Ci/d)) was discharged from March 1950 to November 1951, after which it was sharply reduced to 26 Ci/d in 1952, and a somewhat lower rate during 1953-1956.[365] The composition of the beta-emitting radioactivity discharged into the

---

[361] *Nuclear News*, October 1994, p. 63.

[362] 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 assumed 3.3 Ci Sr-90, and 3.6 Ci of Cs-137, per gram of Pu produced in production reactors (for an assumed burnup = 500 MWd/t); and 7.3 Ci Sr-90, and 9.9 Ci of Cs-137, per gram of Pu produced in VVERs (and naval reactors) (for an assumed VVER burnup = 30,000 MWd/t). We estimate that 418 MCi of Sr-90 were produced through 1994, and 300 MCi remained after radioactive decay; and 510 MCi of Cs-137 were produced, decaying to 370 MCi. It is estimated that 9.3 MCi of Sr-90 and 12.1 MCi of Cs-137 were separated from spent fuel at Chelyabinsk-65 in 1992.

[363] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 13.

[364] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 11 and Vol. II, p. 50; and ``Supreme Soviet Committees, Commissions Meet 5 October; Committee Views on Nuclear Pollution,'' Moscow Domestic Service, in Russian, at 1130 GMT, 5 October 1990 (translated in FBIS-SOV-90-195, 9 October 1990, pp. 35-36).

[365] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 53 and Vol. II p. 50. See also, Mira M. Kossenko, Marina O. Degteva, and Nelly A. Petrushova, ``Estimate of the Risk of Leukemia to Residents Exposed to Radiation as a Result of a Nuclear Accident in the Southern Urals,'' *The PSR Quarterly*, Vol. 2, Number 4, December 1992, p. 189.

Techa--655,000 Ci (23.8 percent) is due to Sr-90 and Cs-137.[366] As best we can estimate the 630 MCi of Sr-90 and Cs-137 (95 percent of the 655 MCi) represents essentially the total inventory of these isotopes separated during this initial period, i.e., prior to November 1951--implying that all of the fission products were diluted and discharged into the Techa. The Techa River which originates at Lake Kyzyltash, 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.[367] The Tobol flows into the Irtysh which flows into the Arctic Ocean.

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 of the region. The greatest exposure was to the 1200 inhabitants of the village of Metlino, seven km downstream from the release point. There, the gamma dose on the river bank was 5 Roentgen/hour (R/h) in spots, 3.5 R/h at household patches near the river in the village, and 10-15 micro-Roentgen/hour (R/h) on roads and streets [368] (Many cities in the world have natural background levels on the order of 10-20 R/h.) 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 between 1951 and 1964 a series of artificial reservoirs was created along the Techa to retain most of the activity already discharged.

Some 124,000 people along the Techa-Iset-Tobol River system were exposed to radioactivity, none having been warned about the danger.[369] Ninety-nine percent of the radioactivity that was dumped into the Techa was deposited within the first 35 km--downstream. In 1949 there were 38 villages with 28,100 people identified along the Techa riverside 237 km downstream from the plant in Chelyabinsk and Kurgan oblasts.[370] For many of the 28,100, the river was the main source of drinking water.[371] From 1953 to 1960, 7500 people from 22 population centers in the upper reaches of the Techa were evacuated and relocated[372] (Table 3.5 identifies 21

The total release estimated is 3.0 MCi; approximately 98.9 percent released in the period 1949-1951, and 1.1 percent of the discharge (34 thousand Ci) occurred during the period 1952-1956.

[366] Strontium-90 (Sr-90) and cesium-137 (Cs-137) are produced in roughly equal amounts, 3.3 Ci of Sr-90 and 3.6 Ci of Cs-137 per gram of plutonium-239 (Pu-239) produced. Had there been any effort to concentrate the insoluble 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 300,000 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 Appendix 3).

[367] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 53.

[368] Ibid., Vol. I, p. 54.

[369] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 11.

[370] Mira M. Kossenko, Marina O. Degteva, and Nelly A. Petrushova, ``Estimate of the Risk of Leukemia to Residents Exposed to Radiation as a Result of a Nuclear Accident in the Southern Urals," *The PSR Quarterly*, Vol. 2, Number 4, December 1992, p. 188.  See also, ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 11.

[371] ``The situation on the river Techa banks was also complicated because for the local population the river had been a major and even the only source of drinking and washing water. The wells were few, they were used by part of the population, not for all purposes since the well water here was by far of a more inferior quality in taste than the river water. Moreover, the river had been used for drinking by cattle, growing fowl, and watering vegetable gardens, fishing, bathing, washing, etc.;" ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 54.

[372] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 11 and Vol. II, p. 55 says the evacuations were prior to 1960. Mira M. Kossenko, Marina O. Degteva, and Nelly A. Petrushova, ``Estimate of the Risk of

population centers). See also Table 3.6. The water supply of other residents remaining along the Techa in 1956, including 4950 residents who would be resettled by 1961, was shifted to underground sources, and the radioactive floodplain was fenced off.[373] The Techa River and 8000 hectares (ha)[374] of its floodlands were excluded from use for economic and drinking purposes, although this ban has not been strictly observed over the years.

The inhabitants of the Techa riverside villages received substantial external and internal radiation exposures. The mean effective doses estimated for the 22 population centers that were evacuated (7500 people in all) ranged from 3.6 to 140 rem, with the 1200 inhabitants of Metlino receiving the highest average effective dose, 140 rem (see Table 3.5).[375] Individual doses were estimated to range from several times lower to several times higher than the mean values estimated for the population centers.

An epidemiological study of the 28,100 exposed individuals found a statistically significant increase in leukemia morbidity and mortality that arose between five and 20 years after the initial exposure.[376] A search was made for other cancers, but the small increase is barely significant and unconvincing.[377]

As noted above, between 1951 and 1964, a cascade of four artificial reservoirs (Numbers 3, 4, 10, and 11, shown in Figure 3.3) were created along the Techa, just below Lake Kyzyltash (reservoir Numbers 2 in the same figure), to isolate water from the most contaminated areas.[378] As

Leukemia to Residents Exposed to Radiation as a Result of a Nuclear Accident in the Southern Urals," *The PSR Quarterly*, Vol. 2, Number 4, December 1992, p. 188 says the evacuations occurred from 1953 to 1961.

[373] Mira M. Kossenko, Marina O. Degteva, and Nelly A. Petrushova, ``Estimate of the Risk of Leukemia to Residents Exposed to Radiation as a Result of a Nuclear Accident in the Southern Urals,'' *The PSR Quarterly*, Vol. 2, Number 4, December 1992, p. 188.

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

[375] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 11; Mira M. Kossenko, Marina O. Degteva, and Nelly A. Petrushova, ``Estimate of the Risk of Leukemia to Residents Exposed to Radiation as a Result of a Nuclear Accident in the Southern Urals,'' *The PSR Quarterly*, Vol. 2, Number 4, December 1992, pp. 187-197; G.I. Romanov, ``Radioecological Conditions Accounted for the 1957 and 1967 Accidents and Production Activities of the Industrial Complex ``Mayak,'' paper presented at the International Radiological Conference, Chelyabinsk, Russia, 20-25 May 1992; 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, 12-20 March 1991, Moscow.

[376] Mira M. Kossenko, Marina O. Degteva, and Nelly A. Petrushova, ``Estimate of the Risk of Leukemia to Residents Exposed to Radiation as a Result of a Nuclear Accident in the Southern Urals,'' *The PSR Quarterly*, Vol. 2, Number 4, December 1992, pp. 187-197. Thirty-seven leukemias (morbidity) were found versus 14-23 expected. For commentaries on the paper by Kossenko, et al., see Scott Davis, ``Understanding the Health Impacts of Nuclear Weapons Production in the Southern Urals: An Important Beginning,'' *The PSR Quarterly*, Vol. 2, Number 4, December 1992, pp. 216-220 and David Rush, `Response to the Paper of Kossenko, et al., *The PSR Quarterly*, Vol. 2, Number 4, December 1992, pp. 221-222. ``Medical examinations of the population were initiated only two years after the start of nuclide dumping into the river system and were performed on the residents of the village Metlino--a single population center in the upper reaches of the river. In other villages medical examination started only 3-6 years after the initial dumping of radionuclides into the Techa, so the early aftermath of radiation could not have been registered.'' ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 45.

[377] Mira M. Kossenko, ``Medical Effects of Population Irradiation on the River Techa,'' paper presented at the Harvard School of Public Health, 4 May 1992.

[378] The first dam, creating reservoir 3, was built in 1951. Dam 4, which existed before 1917, was expanded in 1956. Dam 10 was built in 1957 at a cost of 2.7 million rubles; and dam 11 was built in 1964 at a cost of 7 million rubles. The left bank channel was built in 1963 at a cost of 7.5 million rubles; and the right bank channel was built in 1972 at a cost of 900 thousand rubles.

of about 1990 the reservoirs (including Kyzyltash), with a combined area of 84 km^2 and volume of 380 million m^3, contained about 193,000 Ci of Sr-90 and Cs-137 activity (see Table 3.7). They are said to have ``isolated about 98 percent of the radionuclides deposited in the flood-lands from the open hydrographic network,''[379] but judging by the amount of Sr-90 and Cs-137 remaining, 80 percent would appear to be a more reasonable estimate. The decline in the concentration of radioactivity in the Techa slowed after 1952. It was hypothesized that ``about 70 percent of the activity dumped in 1950-1951 had migrated into the bottom deposits of the Kohsharov and Metlinsk ponds in the upper reaches of the Techa and about 10 percent--into bottom deposits of the lower section of the river down to 78 km from the discharge spot. In subsequent years the radioactively contaminated bottom deposits have become a powerful source of secondary contamination of the river water.''[380]

The measured concentration of alpha activity (10-50 percent Pu-239) in bottom deposits (0-5 cm depth) of the Techa was 15 nano-curies/kg (nCi/kg) at Asanovo; 8 nCi/kg at Nadirovo; and 1.9 nCi/kg at Muslyumovo.[381]

The Asanovski marshes (or swamps), an area of 30 km^2 accessible to the public through which the Techa flows just below the last reservoir (No. 11), contains some 6000 Ci of Sr-90 and Cs-137.[382] These marshes are said to be a major constant open source of radioactivity, flowing into the Techa[383] (see Table 3.8), although there seems to be no data quantifying how much radioactivity is transported from the marshes into the Techa. Estimated deposits of Sr-90 and Cs-137 in the vicinity of Muslyumovo are at least 400 Ci. Cs-137 in river slime at Muslyumovo reach 300-500 nCi/kg.[384] Contamination levels of the river bed sandy-slimy and sandy sediments in the floodplain within the village of Muslumovo, reported in 1993, were: Cs-137 - 43-1370 kBq/kg; Sr-90 - 25-800 kbq/kg; Pu-239 - 20-910 Bq/kg (1 kBq = 27 nCi).[385] The Cs-137 in forage grass within the floodplain of the Techa at Muslumovo was found to be as great as 6.55 kBq/kg.[386] The external gamma dose rate of various objects in the area ranged from a 2-560 mrem/h; and the beta dose from 0-830 particles/cm^2-s.[387]

Measurement of the dose rate along the Techa made in July 1990 are given in Table 3.9.[388]

---

[379] B.V. Nikipelov, et al., ``Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes.''

[380] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, pp. 50-51.

[381] Ibid., Vol. II, p. 51.

[382] Ibid. See also, V.N. Chykanov, et al., ``Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym.''

[383] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 52. See also, ``Resonance,'' Chelyabinsk, 1991.

[384] Ibid., Vol. II, p. 51.

[385] I.G. Berzina, V.A. Chechetkin, M.V. Hotuleva, N.A. Melnichenko, V.I. Bolkhin, V.P. Yemelyanov, and I.G. Sheinker, ``Radioactive Contamination of Biological Objects and Environment in the Muslumovo Village District (Chelyabinsk Region),'' *Radiat. Biol. Ecol.*, 1993, 33, 111-117.

[386] Ibid.

[387] Ibid.

[388] A.V. Trapeznikov, N.V. Pozolotina, M.Ya. Chebotina, V.N. Chukanov, V.N. Trapeznikova, N.V. Kulikov, S.P. Nielsen, and

Lake Karachay (Reservoir 9)

Prior to 1951 Lake Karachay was a natural lake with no surface outlet. There were fish in the lake during high-water years. In dry years the lake became a bog with a small to nonexistent layer of water. When the water surface level was at 249.32 m, the lake's surface area was 0.265 km^2 (26.5 ha, or 65.5 acres; length - 750 m, width - 450 m, and depth - 1.3 m) and the banks swampy.

In 1949 a chromate slurry line was laid from B Plant toward Lake Karachay and a huge stainless steel reservoir was erected along the line and the entire construction was covered with earth.[389] As noted above, in November 1951, the practice of diluting and discharging the HLW directly into the Techa was curtailed, and instead the diluted HLW were diverted into Lake Karachay.[390] The complex ``S'' tanks at B Plant (Plant 25) for intermediate waste storage (discussed below) was not put into operation until 1953. Consequently, this practice must have continued for more than a year.

As a consequence of continued dumping over the years the water volume, level and surface area were significantly increased. By 1958 the surface level had increased 0.67 m and the water volume increased to about 200 thousand m^3. In May 1962 the water level and surface area peaked at 251.07 m and 0.51 km^2 (126 acres), respectively.

Comparing the concentrations of cesium and strontium in the lake and the intermediate waste storage tanks, it appears that with the advent of HLW storage tanks ca. 1953, the precipitated 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 into the lake. In order to have accumulated the reported Cs-137 inventory, 98 MCi in 1990, it appears that for several years after 1953 the Soviets must have been discharging most of the Cs-137 directly into Lake Karachay.

During 1962 measures were taken to limit the reservoir drainage by the addition of embankments around the edge of the lake; and during the next few years the water level fluctuated between 250.43 m and 250.53 m.

The water level in March 1967 had fallen to 250.07 m. Sometime in the spring or summer of 1967--probably just prior to May when 160 thousand m^3 of water was added to the reservoir (one report says in the spring and another says ``following a dry winter and a hot summer''), radioactive silt from the then dry rim of the lake, containing some 600 Ci of Cs-137 and Sr-90, was blown over a tract 75 km long and 1800-2700 km^2 in area (contaminated in excess of 0.1 Ci/km^2 of Sr-90 and 0.3 Ci of Cs-137).[391] The reactor site was contaminated with Cs-137 and Sr-90 in the ratio of 3:1

Aarkrog, ``Radioactive Contamination in the Techa River, the Urals,'' *Health Physics*, 65, No. 5, November 1993, 481-488.

[389] Gladyshev, *Plutonium for Nuclear Bomb*, p. 41.

[390] The lake originally was roughly 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, 15-28 June 1990,'' Office of Technology Development, DOE.

[391] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 12, and Vol. II, p. 32; B.V. Nikipelov, et al., ``Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes,'' report an area of 1800 km^2 contaminated in excess of 0.1 Ci/km^2 in Sr-90 and 0.3 Ci/km^2 Cs-137.

with Sr-90 contamination up to 10 Ci/km^2.[392] The contaminated area, which overlapped the trace from the 1957 accident (discussed below), contained 41,500 people in 63 towns and villages.[393] The external radiation dose to 4800 nearby residents was 1.3 rem, while for residents in remote regions it was 0.7 rem.[394]

In October 1967 another 46.7 m^3 of water was added to the lake and in the following year work was carried out to reduce the reservoir surface and watershed area by filling 0.019 km^2 with earth. After 1969 the reservoir surface area was maintained at 0.32 km^2 (79 acres).

In 1990 it was reported that recently annual additions to the lake have exceeded 1 MCi.[395] This represents an estimated 6 percent of the Cs-137 from chemical separation activities for that year.

As noted above the first efforts to reduce the surface area of 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.[396] From 1984 through December 1991 the lake has been filled with 8088 blocks and 736,600 m^3 of rock.[397] The plan as of 1990 was to completely fill the reservoir by 1995. In June 1990, it was reported that the size of the lake had shrunk to 25 ha (62 acres) and its volume to 400,000 m^3.[398] 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.[399] But in 1994 it was reported that only one-third of the work had been completed.[400] A 1993 LANSAT photograph reveals that the lake's surface area was still about two-thirds its

---

[392] B.V. Nikipelov, et al., ``Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes.''

``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 45; and ``Resonance,'' Chelyabinsk, 1991, report an area of 2700 km^2 contaminated in excess of 0.1 Ci/km^2 Sr-90. See also, ``Supreme Soviet Committees, Commissions Meet 5 October; Committee Views on Nuclear Pollution,'' Moscow Domestic Service in Russian at 1130 GMT, 5 October 1990 (translated in FBIS-SOV-90-195, 9 October 1990, pp. 35-36).

[392] B.V. Nikipelov, et al., ``Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes.''

[393] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 12 and Vol. II, p. 32.

[394] Ibid., Vol. I, p. 45.

[395] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 31; the accompanying table gives 1.15 MCi/y as the amount of incoming medium-level radioactive waste.

[396] Falci, ``Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, 15-28 June 1990.''

[397] Data from a photograph of a chart on the wall at Mayak (ca. 1992). The fill material by year was:
1984: 93 blocks; 18,400 m^3 rock; 1985: 559 blocks; 15,700 m^3 rock; 1986: 774 blocks; 22,000 m^3 rock; 1987: 1476+32 blocks; 33,500 m^3 rock; 1988: 977+12 blocks; 36,000 m^3 rock; 1989: 2188 blocks; 165,000 m^3 rock; 1990: 614 blocks; 193,000 m^3 rock; 1991: 1363 blocks; 253,000 m^3 rock.

[398] 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.

[399] ``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,'' 16-27 October 1991, Trip Report For: Don J. Bradley, 11 November 1991.

[400] Anna Bakina, ``Reservoirs Around Chelyabinsk-65 Highly Radioactive,'' *Moscow ITAR-TASS* in English, 25 July 1994, 1640 GMT (reprinted in FBIS-SOV-94-143, 26 July 1994, p. 26).

original size. Minatom lacks the funds to complete the work.[401]

By 1990 the lake had accumulated 120 MCi of the long-lived radionuclides Cs-137 (98 MCi) and Sr-90 (20 MCi).[402] This compares with 2.4 MCi of Cs-137 and 0.22 MCi of Sr-90 released from Chernobyl.[403] As shown in Table 3.7 under the entry Reservoir No. 9, 110 MCi (93 percent) of the accumulated activity is in ground deposits (41 percent absorbed on the clay bed and 52 percent in mobile deposits), with the remaining 8.4 MCi (7 percent) in the water.[404] The volume of sediments is over 160,000 m^3.[405] The lake currently has a surface radiation exposure level of 3-4 rad/h.[406] When a visiting delegation approached within a few hundred feet of the water, the radiation reading in the bus reached 80 mrem/h.[407] A second delegation received 300-600 mrem/h at a point about 10-12 m from the edge of the lake.[408] On the lake shore in winter the radiation dose is about 20 rem/h, and summer about 18 rem/h.[409] In the region near where the waste is discharge into the lake, where the specific activity of the ground deposits is up to 20 Ci/kg (dry weight; 2-3 Ci/l wet),[410] the radiation exposure rate is about 600 R/h, sufficient to provide a lethal dose within an hour.[411]

---

[401] Ibid.

[402] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' (Ordered by President M. Gorbachev, Presidential Decree # RP-1283, 3 January 1991), ca. April, 1992, [translated into English], Vol. I, p. 37 (of the English translation); B.V. Nikipelov, et al., ``Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes;'' Tables given to Thomas B. Cochran by Victor N. Chukanov, USSR Academy of Sciences, Ural Department, Ecological Security Center, Sverdlovsk, private communication, 13 April 1991.

[403] ``Health and Environmental Consequences of the Chernobyl Nuclear Power Plant accident,''U.S. Department of Energy, DOE/ER-0332, June 1987, pp. ix, 3.4, 3.18-19. The Soviet's estimated 1 MCi of Cs-137 released; 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, 25-29 August 1986, Vienna, (translated by the U.S. Department of Energy, NE-40, 17 August 1986), Appendix 4, p. 21.

[404] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 31. B.V. Nikipelov, et al., ``Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes,'' report about 35 percent of the ground deposits are in the loam screen of the reservoir bed (up to 4 m) and 60 percent in mobile deposits.

[405] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 30.

[406] Falci, ``Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, 15-28 June 1990.''

[407] Ibid.

[408] ``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,'' 16-27 October 1991, Trip Report For: Don J. Bradley, 11 November 1991.

[409] Gerard Sevestre, ``USSR Nuke Testing Site Legacy,'' 27 September 1990, *The Greenbase,* 20:51:50 GMT.

[410] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 31.

[411] B.V. Nikipelov, et al., ``Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes.'' 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.

In the 1960s it was discovered that radioactivity from the lake was entering the ground water. Systematic observation of the ground water contamination was initiated in 1970. 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. The groundwater flows primarily toward reservoirs 2 and 3 (the Techa) in the north and northeast direction, and to the south it drains toward the Mishelyak River, a tributary of the Techa.[412] Radioactive groundwater has reached the Mishelyak, flowing under the river bed at a depth of 15 m.[413] Table 3.10 compares the concentration of radioactivity in Karachay with that in a 45 m deep sampling well located 130 m to the south of the lake. The total volume of contaminated groundwater is estimated to be over 4 million m^3, with a halo area of 10 km^2 and a depth to 100 m, containing in excess of 5000 Ci of long-lived fission products.[414] The discharge of contaminated groundwater is 65 m^3/d, and the flow speed is 0.84 m/d.[415] The speed at which the contaminants move is:[416]

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)

Built in 1949 by erecting an earthen dam this 17 ha (42 acre) drainless lake located 5 km northeast of Lake Karachay, has a volume of 35,000 m^3 and has been used a storage reservoir for medium-level liquid waste, including tritium condensate since 1971.[417] By 1990 it had accumulated about 2 MCi of radioactivity, mainly in bottom sediments (see Table 3.7).[418] Medium-level waste continues to be added to Staroe Boloto today.[419] The bottom of Lake Staroe Boloto absorbs radionuclides more readily than that than the bottom of Karachay. Consequently, the contaminated halo is considerably smaller.[420]

Waste explosion in 1957

---

[412] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 34.

[413] Ibid., Vol. I, p. 14. The Mishelyak river begins at lake Ulagach and flows 16 km into the Techa river. It use to enter the Techa near what is now Reservoir 10. With the construction of the reservoirs it was diverted to discharge into the Techa below Reservoir 11 via the concrete channel along the southern shores of Reservoirs 10 and 11. An old ash dump of the Argayash heat and electric power plant is situated along the lower stretch of the Mishelyak. Beside the old dump is a new dump which receives 6000 tons of ash/day. Filtered water from the Novogorny settlement is discharged into the Mishelyak at the rate of 3500 m^3/day.

[414] Ibid., Vol. II, p. 34.

[415] Ibid.

[416] 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.

[417] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 30; V.N. Chykanov, ``Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym.''

[418] Ibid.

[419] Ibid., Vol. I, p. 13.

[420] 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, 8 April 1992.

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.[421] As noted above, during the initial period of operation of the chemical separation plant, the irradiated fuel elements were treated by an ``all-acetate precipitation scheme,''[422] resulting in HLW solutions containing as much as 100 grams per liter (g/l) of sodium nitrate and 80 g/l of sodium acetate.[423] The solution was stored for a year in tanks (presumably the complex ``S'' tanks at B Plant (Plant 25), 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.[424] 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).[425]

The intermediate storage facility was put into operation in 1953.[426] 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.[427] Called ``permanent storage containers,''each tank was 300 cubic meters (m^3) (80,000 gal. (U.S.)) in volume.[428] 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.[429] Some of the instruments for monitoring the tanks failed and could not be repaired due to the high radiation field in the canyon.[430] 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.''[431] The cooling system in one of the unmonitored tanks failed, however, and the waste began to dry out. Nitrates and acetates in the waste precipitated, heated up to 350°C (660 ^{o}F), and on 29 September 1957 at 4:20 PM local time, exploded[432] with a force equivalent to 70 to 100 tons of TNT.[433] The meter-thick concrete lid was blown off and hurled 25 meters away, and 70-80 t of waste containing some 20 MCi of radioactivity were ejected.[434] By comparison, an estimated 50 to 150 MCi of fission products (excluding noble gases), was released into the environment from the Chernobyl accident.[435]

[421] 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); *Nuclear Disaster in the Urals* (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. Averbach, ``Analysis of the 1957-58 Soviet Nuclear Accident,'' Oak Ridge National Laboratory, ORNL-5613, December 1979 (subsequently published in condensed form in *Science,* 18 July 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,* 26 October 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.

[422] 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.

[423] Ibid., p. 48.

[424] Ibid.

[425] Ibid.

[426] Ibid.

[427] Ibid. In a 1957 CPSU Central Committee document the tank that exploded was identified as ``storage tank No. 14 in a complex consisting of 20 such tanks;'' Slavsky, ``Whose Sins Are We Paying for Today?,'' p. 1. *Nuclear News,* January 1990, p. 74 says ``one

The composition of the ejected waste is given in Table 3.11.[436] About 18 MCi (90 percent of the activity) fell out in the immediate vicinity of the vessel. The initial contamination density was in excess of 70,000 Ci/km^2, of which about 4000 Ci/km^2 was due to Sr-90. The remaining, approximately 2.1 mCi formed a kilometer-high radioactive cloud that was carried through Chelyabinsk, Sverdlovsk, and Tyumensk Oblasts reaching the neighborhood of Kamensk-Uralsky after 4 hours, and Tyumen after 11 hours.[437] 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 tract 300 km in length and 30-50 km wide, were contaminated at a level greater than 0.1 Ci/km^2 (Sr-90); 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); 117 km^2 contaminated at a level greater than 100 Ci/km^2 (Sr-90); and 17 km^2 contaminated to 1000-4000 Ci/km^2 (Sr-90) (see Table 3.12).[438] (The Sr-90 integrated deposition density from all atmospheric nuclear weapons testing is 0.08 Ci/km^2 at this latitude.[439]) Sr-90 (beta activity) comprised only 2.7 percent of the total beta activity initially. The total activity

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, 31 October 1990.

[428] ``Hearing in Committee on Preparation of Law on Nuclear Safety: 1957 Accident,'' *Moscow Home Service,* (SU/0519i), 1200 GMT, 25 July 1989. In a 1957 CPSU Central Committee document the volume of the tank was given as 250 m$^3$. Slavsky, ``Whose Sins Are We Paying for Today?,'' p. 1.

[429] Ibid., pp. 48-49.

[430] Ibid.

[431] Ibid.

[432] 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, 28 May 1989, [revised and published as ``Radiation Accident in the Southern Urals in 1957,'' *Atomnaya Energiya,* 1989, Vol. 67, No. 2, pp. 74-80]; Nikipelov and Drozhko, ``An Explosion in the Southern Urals,'' p. 48.

[433] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 29.

[434] Nikipelov and Drozhko, ``An Explosion in the Southern Urals,'' p. 48. Two adjacent tanks were also damaged; *Nuclear News,* January 1990, pp. 74-75.

[435] ``Health and Environmental Consequences of the Chernobyl Nuclear Power Plant accident,''U.S. Department of Energy, DOE/ER-0332, June 1987, p. ix, estimated 51.4 MCi. A more recent estimate by Alexander R. Sich places the total in the range 120-150 MCi. *Science,* 9 December 1994, pp. 1627-1628.

[436] 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.

[437] G.N. Romanov and A.S. Vorovov, ``The Radiation Situation After the Explosion,'' *Priroda,* May 1990, p. 50; Nikipelov and Drozhko, ``An Explosion in the Southern Urals,'' p. 48; B.V. Nikipelov, et al., ``Accident in the Southern Urals on 29 September 1957;'' ``Hearing in Committee on Preparation of Law on Nuclear Safety: 1957 Accident,'' *Moscow Home Service,* (SU/0519i), 1200 GMT, 25 July 1989; ``A Nuclear Deadlock: Can a Nuclear Power Plant Save Us from Radioactive Contamination,'' *Sovietskaya Rossiya,* 21 November 1989, 2nd Edition.

[438] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 41 and Vol. II, p. 58; Romanov and Vorovov, ``The Radiation Situation After the Explosion,'' p. 50.

[439] 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.

level dropped 10-fold in the first three years, and by a factor of 44 after 36 years (in 1993). The highest contamination level, 4000 Ci/km (Sr-90) at the head of the trace immediately after the accident, corresponds to 150,000 Ci/km^2 (total beta activity). The initial dose rate near the epicenter was 1200 R/h.[440] 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.[441] Guards received the largest reported dose, about 100 R. During the initial period the external gamma dose rate was about 150 R/h (equivalent to 1.3 R/y) in open areas where the Sr-90 contamination was 1 Ci/km^2.[442] 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.[443] After about 3 years of radioactive decay, Sr-90 was the dominant isotope with respect to contamination and exposure. At the end of 1992, Sr-90 comprised 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 of 1959.[444] 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 contaminated to greater than 100 Ci/km^2 (Sr-90).[445] Water supplies along the East Ural Trace 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.[446] These three villages, in which at least 1054 and perhaps as many as 1908 people lived, were evacuated, but not until 7-10 days after the accident.[447] The average dose received before evacua-

[440] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 29.

[441] B.V. Nikipelov, et al., ``Practical Rehabilitation of Territories Contaminated as a Result of Implementation of Nuclear Material Production Defence Programmes.''

[442] Romanov and Vorovov, ``The Radiation Situation After the Explosion,'' p. 50; Nikipelov and Drozhko, ``An Explosion in the Southern Urals,'' p. 48; B.V. Nikipelov, et al., ``Accident in the Southern Urals on 29 September 1957.''

[443] Romanov and Vorovov, ``The Radiation Situation After the Explosion,'' p. 50.

[444] D.A. Spirin, E.G. Smirnov, L.I. Suvornova, and F.A. Tikhomirov, ``Radioactive Impact on Living Nature,'' *Priroda*, May 1990, p. 59. ``Contamination of pine forests above 300 Ci/km^2 in Sr-90 (13,200 Ci/km^2 in total beta activity) resulted in complete elimination of all trees,'' ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 44 and Vol. II, p. 64.

[445] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 41 and Vol. II, p. 58; Romanov and Vorovov, ``The Radiation Situation After the Explosion,'' p. 50; B.V. Nikipelov, et al., ``Accident in the Southern Urals on 29 September 1957;'' A.I. Burnazyan, 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 [translated into English by Frank C. Farnham Company, Philadelphia for Lawrence Livermore National Laboratory (LLNL), and reproduced as: A.I. Burnazyan, ed., ``A Case of Accidental Regional Contamination by Uranium Fission Products: Study Results and Cleanup Experience,'' LLNL, UCRL-TT-106911, July 1991].

[446] Burnazyan, ed., ``Results of Study and Experience in the Elimination of the Consequences of Accidental Contamination by Fission Products,'' p.14. A 1957 CPSU Central Committee document identified the village of Satlykovo (46 homes, 300 people) as the most seriously contaminated area and said a decision had been made to resettle this village by 5 October 1957; and Berdyanish (85 homes, 580 people) and Golikayevo (97 homes, 1028 people) were to be resettled prior to 1 March 1958. Slavsky, ``Whose Sins Are We Paying for Today?,'' p. 1.

[447] M.M. Kossenko, V.A. Kostyuchenko, V.L. Shvedov, and L.A. Buldakov, ``Consequences of Irradiating the Population in the Main Part of the Eastern Urals Radioactive Footprint,'' *Atomnaya Energiya*, November 1991, Vol. 71, No. 5, pp. 444-448 [translated into English by Plenum Publishing Corporation], reports that a later register of persons confirmed that 1059 persons lived in these

tion reached 17 rem from external radiation and 52 rem of equivalent effective dose (150 rem to the gastrointestinal tract).[448] Accounting for nonuniformity individual doses could be two times higher and lower.[449] Despite the high radiation doses received, no excess late effects (e.g., cancers) were detected in a follow up study of the residents of these three villages due to the small size of the population (1059 persons), limited period of observation, and lack of a good control population.[450]

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.[451] 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 rem from external radiation and 44 rem of equivalent effective dose; 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.[452] Finally, 3100 people where the contamination density was 2-4 Ci/km^2 (Sr-90) and averaged 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.[453] In all, inhabitants of 23 villages, about 10,700 people, were evacuated from areas having contamination levels greater than 2 Ci/km^2

three villages. A 1957 CPSU Central Committee document identified 1908 people in the three village: Satlykovo (300 people), Berdyanish (580 people), and Golikayevo (1028 people). Slavsky, ``Whose Sins Are We Paying for Today?,'' p. 1. ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 41, and N. Chykanov, et al., ``Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym,'' reported 1054 persons. 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, et al., ``Accident in the Southern Urals on 29 September 1957,'' 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; Burnazyan, ``Results of Study and Experience in the Elimination of the Consequences of Accidental Contamination by Fission Products,'' p. 52, reports 1500 inhabitants in the area, and in February 1990 (p. 14), reports 1100 inhabitants evacuated in 7-10 days.

[448] 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, et al., ``Accident in the Southern Urals on 29 September 1957,'' Table 4. See also, M.M. Kossenko, V.A. Kostyuchenko, V.L. Shvedov, and L.A. Buldakov, ``Consequences of Irradiating the Population in the Main Part of the Eastern Urals Radioactive Footprint,'' *Atomnaya Energiya*, November 1991, Vol. 71, No. 5, pp. 444-448 [translated into English by Plenum Publishing Corporation].

[449] B.V. Nikipelov, G.N. Romanov, L.A. Buldakov, et al., ``Radiation Accident in the Southern Urals in 1957,'' *Atomnaya Energiya*, 1989, Vol. 67, No. 2, pp. 74-80.

[450] M.M. Kossenko, V.A. Kostyuchenko, V.L. Shvedov, and L.A. Buldakov, ``Consequences of Irradiating the Population in the Main Part of the Eastern Urals Radioactive Footprint,'' *Atomnaya Energiya*, November 1991, Vol. 71, No. 5, pp. 444-448 [translated into English by Plenum Publishing Corporation].

[451] 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.

[452] Ibid. ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 75, claims, ``There was a massive relocation which was implemented in two stages. The population centers located on areas having a contamination density 80 Ci/km^2 [sic, probably 8.9 Ci/km^2] in Sr-90 were relocated 330 days following the accident (3860 persons). A subsequent relocation was implemented 700 days following the accident, 3030 residents of population centers averaging contamination density of 6 Ci/km^2 in Sr-90.''

[453] Ibid.

(Sr-90).[454]

The 1957 harvest, contaminated with radionuclides, was eaten by the population.[455] By 1959 all areas contaminated in excess of 4 Ci/km^2 (ca. 700 km^2 = 270 mi^2) were subject to special sanitary protection regulations.[456] In 1962, this ``Sanitary Protection Zone" was reduced in size to 220 km^2.[457] In 1958-1959, about 20,000 ha (80 mi^2) of agricultural land at the head of the cloud track were plowed under, and in 1960-1961 an additional 6200 ha (25 mi^2).[458] In 1958, 106,000 ha (410 mi^2) of land were removed from agricultural use in Chelyabinsk and Sverdlovsk Oblasts.[459] 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.[460]

In experimental study areas where the ground was not plowed 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-90 exponentially with a half-life of 4-5 years.[461]

As of 1990 no registry had been initiated to follow the medical histories of the exposed population in all 217 towns and villages within the trace,.[462] and therefore no careful epidemiological study has been performed on the exposed population. In 2-5 years after the accident 2767 people were examined in outpatient clinics and compared against a control group of 964 people.[463] None of the patients showed the clinical pattern of radiation sickness.[464] One-fifth of 5000 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.[465] No deviations

---

[454] ``Hearing in Committee on Preparation of Law on Nuclear Safety: 1957 Accident," *Moscow Home Service,* (SU/0519i), 1200 GMT, 25 July 1989; and ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 75.

[455] 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, 12-20 March 1991, Moscow.

[456] 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; ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, pp. 75-76. B.V. Nikipelov, et al., ``Accident in the Southern Urals on 29 September 1957," suggest that the Sanitary Protection Zone was defined by the 2 Ci/km^2 isoline, but this is the area from which people were evacuated.

[457] Ibid.

[458] Ibid.

[459] Ibid.

[460] Ibid.

[461] 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, 21 October 1991.

[462] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 27.

[463] Burnazyan, ed., ``Results of Study and Experience in the Elimination of the Consequences of Accidental Contamination by Fission Products," p. 51.

[464] Ibid.

[465] B.V. Nikipelov, et al., ``Accident in the Southern Urals on 29 September 1957."

in the incidence of diseases of the blood and in the incidence of malignant tumors have been registered,[466] but this is attributable to the lack of a careful epidemiological study. 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.[467] Over their lifetimes the collective radiation exposure from this accidental release could result in as many as 1000 additional cancers in the population.[468]

High-Level Waste Tanks

In the early years the practice of managing HLW 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 HLW involves first evaporation and then fixation in sparingly soluble compounds, i.e. hydroxide and ferrocyanide compounds. Since 1968 radioactive HLW at Mayak have been stored in five categories:[469]

Product 1	suspension of $Al(OH)_2$ after acid digestion of $NaAlO_2$;
Product 2	suspensions after hydroxide-sulfate-ferrocyanide treatment of supernates from the standard fuel element dissolution process as well as supernates from alkaline digestion;
Product 3	suspensions after ferrocyanide decontamination of the PUREX raffinate obtained from reprocessing HEU spent fuel elements;
Product 4	suspensions of Al, Fe, and Ni-K ferrocyanides obtained after decomposition of $NaASlO_2$ and ferrocyanide decontamination; and
Product 5	alkaline supernate from the Radioisotope Plant.

---

[466] Ibid.

[467] V.N. Chykanov, et al., ``Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym.''

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

[469] ``Foreign Travel Report,'' to the Fourth Meeting of the U.S. DOE-Minatom Joint Coordinating Committee on Environmental Restoration and Waste Management (JCCEM), September 9-17, 1994, report prepared by D.J. Bradley, 26 October 1994, p. 24.

The concentrated waste are stored in instrumented single shell stainless steel storage tanks housed in metal-lined reinforced concrete canyons. A recent report indicates that there are a total of 48 high-level waste tanks at Mayak,[470] but earlier reports cite ``more than 60 specialized tanks,''[471] and 99 tanks.[472] A 1990 inventory indicated that there were 546 MCi of radioactive solutions and sediments at Mayak, including (note sum is 528 MCi):[473]

374 MCi	sodium nitrate solution
149 MCi	hydroxide and ferrocynide pulps
4.9 MCi	sediments (purlite pulp).

At the time of this survey a small portion of the wastes (4 MCi) has been vitrified. These data are consistent with other sources that indicate that there are some 150 MCi (a volume of 20,000 m^3) of HLW sediments stored in 48, or more, tanks.[474]

At one tank ``farm'' there are two buildings containing 20 tanks used for long-term storage of HLW sediments, one with 14 tanks and the other with six tanks. Placed into operation in April 1968, these concrete tanks are lined by stainless steel 3 mm thick and are 19.5 m x 9.5 m x 7 m (capacity = 1300 m^3 each; working volume = 1170 m^3).[475] The 14 stainless steel tanks at this facility have not developed any leakage problems, but have problems with heat removal. Eight of the tanks do not have any heat removal system, while the remaining six tanks are internally cooled by cooling coils situated along the longest side of the tanks at 40 cm intervals.[476] The coils have a 186 m^2 radiator surface.[477]. The tanks are monitored for temperature and leaks. They attempt to keep the waste at or below 90 $^\circ$C. Seven of the tanks have boiling at the bottom and three others are very close to boiling. Tank number 14 contains 14 million Ci, and four others contain over nine

---

[470] Ibid., p. 25, reviews a presentation by Dr. Revenko during which he describes 14 tanks and notes that there are 34 additional HLW tanks at Mayak.

[471] V.N. Chykanov, et al., ``Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym.''

[472] Alexander Penyagin is reported to have said there are a total of 99 waste tanks at Mayak.

[473] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, pp. 28-29; also cited in 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, 8 April 1992.

[474] ``Foreign Travel Report,'' to the Fourth Meeting of the U.S. DOE-Minatom Joint Coordinating Committee on Environmental Restoration and Waste Management (JCCEM), September 9-17, 1994, report prepared by D.J. Bradley, 26 October 1994, p. 25 reviews a presentation by Dr. Revenko during which he describes 14 tanks and notes that there are 34 additional HLW tanks at Mayak. V.N. Chykanov, et al., ``Ecological Conditions for the Creation of Atomic Weapons at the Atomic Industrial Complex Near the City of Kyshtym,'' referred to over 60 specialized tanks. For additional characteristics see Falci, ``Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, 15-28 June 1990.''

[475] ``Foreign Travel Report,'' to the Fourth Meeting of the U.S. DOE-Minatom Joint Coordinating Committee on Environmental Restoration and Waste Management (JCCEM), September 9-17, 1994, report prepared by D.J. Bradley, 26 October 1994, p. 25; and a paper provided by Russian representatives at Chelyabinsk-65 to U.S. Department of Energy representatives, 22 October 1992 (translated by Lydia Papova).

[476] Ibid.

[477] Paper provided by Russian representatives at Chelyabinsk-65 to U.S. Department of Energy representatives, 22 October 1992 (translated by Lydia Papova).

million Ci each. Sixty-five percent of the radiation level in the tanks is caused by ruthenium.[478]

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 matrices 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 HLWs 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.[479]

The Soviets developed a process for extracting Sr-90 from acidic HLW using a crown-ether based extractant, and 1.5 million curies had been extracted by the mid-1990s.[480]

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 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).[481] 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 t of phosphate glass (998 m^3) containing 3.97 million Ci was poured into 366 canisters.[482] The aluminum-carrying waste were

---

[478] ``Foreign Travel Report,'' to the Fourth Meeting of the U.S. DOE-Minatom Joint Coordinating Committee on Environmental Restoration and Waste Management (JCCEM), September 9-17, 1994, report prepared by D.J. Bradley, 26 October 1994, p. 25.

[479] E.G. Drozhko, et al., ``Experience in Radioactive Waste Management at the Soviet Radiochemical Plant and the Main Approaches to Waste Reliable Confinement Development.''

[480] Falci, ``Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, 15-28 June 1990.''

[481] E.G. Drozhko, et al., ``Experience in Radioactive Waste Management at the Soviet Radiochemical Plant and the Main Approaches to Waste Reliable Confinement Development.''

[482] Falci, ``Final Trip Report, Travel to USSR for Fact Finding Discussions on Environmental Restoration and Waste Management, 15-28 June 1990.''  According to E.G. Drozhko, et al., ``Experience in Radioactive Waste Management at the Soviet Radiochemical Plant and the Main Approaches to Waste Reliable Confinement Development,'' ``About 1000 m^3 high active solutions, containing 3.9×10^6 Ci of total activity, was vitrified during 1987-1988. The total weight of the obtained glass blocks has constituted 160 metric tons.''

from reprocessing highly enriched fuel elements,[483] presumably naval reactor fuel and HEU cermet fuel from plutonium and tritium production reactors. 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 25 June 1991. As of 1 October 1991, 440 m^3 of HLW solution had been processed, producing 88 t 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 t/d. Originally, the concentration of radioactivity was 100 Ci/l (50 Ci/kg); currently 400 Ci/l is achieved.[484] Evgeni Dzekun, chief engineer of the RT-1 reprocessing plant in late-1992 said the current backlog of liquid HLW would amount to about 10 years work for the vitrification plant.[485] In 1993 Gosatomnadzor reported that the EP-500 oven had vitrified more than 600 m^3 of waste containing 150 MCi.[486]

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, 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 is experiencing public opposition.

Solid Waste Burial[487]

There are 227 solid waste burial sites (about 10 percent of which were still receiving waste in 1990) comprising total area of about 30 ha, with the burials themselves occupying 21.3 ha (see Table 3.13).[488] The site contained in 1990 some 525,000 t of solid radioactive wastes containing 12 MCi of activity: 150,000 t of low-level waste (LLW); 350 t of intermediate-level waste; and 25 t of HLW.[489] The burial sites for low-level and medium-level solid radioactive waste are trenches dug in the ground. After being filled the trenches are covered with clay to reduce the intrusion of water. Burials sites usually are located where the water table is greater than four meters below the bottom

[483] ``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,'' 16-27 October 1991, Trip Report For: Don J. Bradley, 11 November 1991.

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

[485] Frank von Hippel, Thomas B. Cochran, and Christopher E. Paine, ``Report on an International Workshop on the Future of Reprocessing, and Arrangements for the Storage and Disposition of Already-Separated Plutonium (Moscow, 14-16 December 1992), and an International Workshop on Nuclear Security Problems (Kiev, 17 December 1992),'' 10 January 1993.

[486] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' 13 May 1994, Part I, Chapter 2.

[487] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, pp. 26-28. See also, 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, 8 April 1992.

[488] Ibid. See also, ``Resonance,' Chelyabinsk, 1991.

[489] Ibid., Vol II, p. 26.

of the burial. The bottom and the walls are lined with a layer of clay for further hydraulic isolation. 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 by diffusion in moist soil.

Solid radioactive HLW 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 HLW 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 123 MCi of long-lived radionuclides (Sr-90 and Cs-137) into the environment, about 15 percent of that produced over its 45 year history, 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--certainly in terms of radioactivity. The industrial site grounds have been contaminated by 24,000 Ci of Cs-137 (maximum density 1000 Ci/km^2) and 50,000 Ci of Sr-90 (maximum density 1000 Ci/km^2).[490] Parts of the Chelyabinsk-65 site have a dose rate of up to 15 milli-Roentgen/hour (mR/h). The average value for the remainder of the site is in the range of 10 to 30   R/h. (As noted previously, many cities in the world have natural background levels on the order of 10-20   R/h.) There are 340 million m^3 of radioactive water in open reservoirs on site. In 1991 it was reported that 90 million Ci of high-level, 1 million Ci of medium-level, and 6000 Ci of liquid LLW were being produced annually from continued chemical separation activities.[491] The medium- and low-level wastes continue to be dumped into Lake Karachay, Staroe Boloto, and the Techa reservoirs (Numbers 2, 3 and 4).[492] In 1991 it was reported that Lake Kyzyltash was receiving 4000 Ci/y of long-lived radionuclides, and Reservoir 3 more than 2000 Ci/y[493]. Fish in Reservoir No. 10 are reported to be ``100 times more radioactive than normal."[494] 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, but there are many stories of farmers cutting fences so that their animals can reach the river. The children of Muslyumovo, a village 78 km down stream that was not evacuated, were reported in 1991 to be

---

[490] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 13.

[491] Ibid.

[492] Ibid.

[493] Ibid., Vol. II, p. 36.

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

receiving an effective dose equivalent of 0.5-1.0 rem/y.[495]

The production complex, by consuming contaminated water for its needs, regulated the water level in the lakes. With five of seven production reactors shut down, 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.[496] The South Urals nuclear power station is now being proposed, in part, to avert this sort of catastrophe by using radioactive water to cool turbine condensers, thus increasing evaporation.[497] But, as noted above, the South Urals project may never be completed.

[495] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. I, p. 11.

[496] Ibid., Vol. I, p. 39.

[497] Ibid.,; and ``Chain Reaction of Wastefulness - Do We Need the South Urals AES?,'' *Sovietskaya Rossiya,* 24 December 1989.

CHAPTER FOUR
TOMSK-7 AND KRASNOYARSK-26

Tomsk-7 (The Siberian Chemical Combine, Seversk)

In 1949 *The Voice of America* revealed ``in the environs of Tomsk near the village of Belaya Boroda [Beloborodovo on some U.S. maps] an atomic factory is being built."[498] The Siberian Chemical Combine (Sibkhimkombinat), known also by its code name Tomsk-7, was thus founded on the Tom River in Tomsk Oblast, about 15 km northwest of the city of Tomsk. At Belaya Boroda (or Beloborodovo on some U.S. maps) the closed city of Seversk was built to house the Tomsk-7 work force, and is now a satellite town of Tomsk.[499] Seversk has a population of 107,700, with about 20,000 employed at the production facility. Tomsk, itself has about 500,000 inhabitants. In 1994 the Russian government indicated its preference for referring to the once code-numbered secret nuclear installations by the names of the still closed cities that house the work force, which for Tomsk-7 is Seversk.

Tomsk-7 is said to occupy an area greater than 20,000 ha (200 km^2).[500] This undoubtedly refers to the sanitary protection zone, established in 1970, which elsewhere is reported to cover 192 km^2.[501] Tomsk-7 is the site of the Siberian Atomic Power Station, a chemical separation plant, facilities for plutonium processing and blending and pit fabrication, plutonium storage, an enrichment plant, and nuclear waste management facilities.[502] The Siberian Atomic Power Station houses five graphite-moderated reactors, four of which are dual-purpose. Three of the reactors have been shut down, two in 1990 and the third in 1992. The remaining two dual-purpose reactors are to be shut down by 2000. Additional power is also provided by a fossil fueled plant.[503]

As noted in Chapter Three (see Long-Term Storage Facility for Fissile Material from Weapons), for a couple of years Tomsk-7 was the proposed site of the first of possibly two new facilities for the storage of fissile material recovered from retired weapons. The first fissile material storage facility, to be constructed with some assistance from he United States, is now under

---

[498] Tomsk Ecological Initiative, ``Information about the Siberian Chemical Facility (Tomsk-7)."

[499] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, 17 November 1991, Morning Edition, p. 1 (translated in the Foreign Broadcast Information Service series, FBIS-SOV-91-225-A, 21 November 1991, p.3.); *Izvestiia*, 4 May 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, 2 January 1991 (translated in FBIS, London UK, Serial: LD0201170891); and ``Open Deal in a Closed City,"*Izvestiia,* 25 January 1991, Union Edition, p. 2 (translated in FBIS, London UK, R 251109Z Jan 1991).

[500] Viktor Kostyukovsky, et al., ``Secrets of a Closed City," *Moscow Izvestiia*, Union Edition, 2 August 1991 (translated in JPRS-TEN-91-018, 11 October 1991, pp. 71-72).

[501] Aleksandr 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, 8 April 1992. Bolsunovsky claims, ``it is not a rare occasion that within this area [the sanitary protection zone] vegetables are planted, berries and mushrooms are collected, [and] fish caught." According to Tomsk Ecological Initiative, ``Information about the Siberian Chemical Facility (Tomsk-7)," ``The borders of the sanitary protection zone (SPZ), which was established only in 1970, run from the point of sewage release along the right flood plain and the left bank of the Chernilshchikov canal to Vetpyanii Lake (6-7 km). The village of Chernilshchikov, which is located 4 km downstream from the sewage release point, is not included in the SPZ. The border of the SPZ runs along the right bank of the canel and is marked with special signs."

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

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

construction at Chelyabinsk-65. If a second storage facility is built it may be built at Tomsk-7.

Gennadiy Khandorin has been identified as the director of the Siberian Chemical Combine, at least since 1991.[504] Leonid Khasanov is (in 1993) chief of ``Sibkhim'' Production and Technology Association.[505]

Siberian Atomic Power Station

The five graphite-moderated plutonium production reactors are identified as Ivan-1, Ivan-2, ADE-3, ADE-4, and ADE-5. These reactors are fueled with natural uranium (about 98.5 percent of the fuel elements) and a ``spiked'' ring of HEU-Aluminum cermet elements (about 1.5 percent of the total) to increase the reactivity and levelize the flux (and therefore the power density).

Ivan-1. The first reactor, Ivan-1, is a large graphite-moderated plutonium-production reactor which was directly cooled with Tom River water. It began operating on 20 November 1955, and operated until 21 August 1990.[506] The reactor has 2001 channels (process tubes) and operated solely to produce plutonium.

Ivan-2. The second reactor, Ivan-2, was the first of four graphite-moderated dual-purpose reactors. It began operating in September 1958 and operated until 28 December 1990.[507] This reactor was described at the Second International Conference on Peaceful Uses of Atomic Energy in 1958 at Geneva. It produced plutonium, electricity and steam for process heat. With 2001 channels it is identical in size to Ivan-1.

ADE-3. The third reactor, ADE-3, was a larger graphite-moderated dual-purpose reactor with about 2828 channels (process tubes). It began operating on 14 July 1961 and was shut down on 14 August 1992.[508] It provided approximately 150 MWe of electricity and 300 giga-calories/hour (GCal/h) (300 GCal/h = 350 MW_t) steam for heating. Other characteristics of ADE-3, and the other four ADE-type dual-purpose reactors are given in Table 4.1).

ADE-4. The fourth reactor, ADE-4, has 2832 channels and is said to be identical to ADE-3 and ADE-4. It began operating in 1965 and is still operating. Under a U.S. Russian bilateral

---

[504] Viktor Kostyukovsky, ``Tomsk-7: Nuclear Ordinariness after the Explosion,'' *Moscow Izvestiia*, in Russian, 12 May 1993, p. 7. The head of the station in 1990 was named Meshceryakov.

[505] Moscow Ostankino Television First Channel Network, in Russian, 27 February 1993, 0955 GMT.

[506] Ibid.; ``Siberian Atomic Reactor Closes,'' *Moscow Tass,* International Service in Russian, 21 August 1990, 1449 GMT. *Nuclear News* has been reporting semi-annually for many years that the first reactor began operating September 1958; the second December 1959; and the remaining reactors spaced a year apart (see *Nuclear News*, September 1994, p. 75); and all are located at Troisk. These reports are wrong with respect to the both the startup dates and location of the reactors.

[507] 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.

[508] *Moscow Komsomolskaya*, in Russian 6 August 1992, morning edition, p. 2 (translated JPRS-TND-92-029, 20 August 1992, p. 20). The Collegium of Gosatomnadzor (GAN), Russia's atomic energy inspectorate, earlier in the year had directed that a third reactor at Tomsk-7 be shut down in 1992; Yuri Khots, ``Plutonium Producing Reactors in Krasnoyarsk to be Shut Down,'' *Moscow ITAR-Tass World Service*, in Russian, 19 May 1992, 1352 GMT.

agreement it is scheduled to be shut down by the end of the year 2000. The reactor produces between 150-200 MWe of electricity and 300 GCal/h (= 350 MW_t) of steam for residential and process heat.

ADE-5. The fifth reactor, ADE-5, is also said to be identical to ADE-3 and ADE-4. It began operating in 1968 and is still operating. Under the same U.S. Russian bilateral agreement it is also scheduled to be shut down by the end of the year 2000. The reactor produces between 150-200 MWe of electricity and 300 GCal/h (= 350 MW_t) of steam for residential and process heat.

In 1958, 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.[509] In 1981, A.M. Petrosyants, then Chairman of the State Committee for Utilization of Atomic Energy, admitted that the reactors served a dual-purpose plutonium production for warheads and power generation.[510] Not until 4 May 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.[511]

The first reactor--not dual-purpose and now shut down--utilized once through cooling. In announcing its shut down, *Tass* reported ``soon another reactor [the second] will be shut down. As a result it is said that the amount of harmful effluent going into the Tom River will be halved.''[512]

The four dual-purpose reactors at Tomsk-7 (two still operating) have closed cycle cooling systems, with heat transferred from the closed primary loop to the secondary loop via an intermediate heat exchanger. The last three reactors, ADE-3, -4, and -5, are the same as the ADE-1 and ADE-2 at Krasnoyarsk-26. ADE-4 and ADE-5 (still operating) share a single steam collector, 12 electric generators and four emergency diesel generators. The 12 electric generators have a nameplate rating of 424 MW_e combined, when cooled with hydrogen. Typically, they are not cooled with hydrogen and produce 360 MW_e. The emergency generators are tested about every six weeks. There have been times when they did not start when tested, but never all failing. Two are needed for emergency cooling. All diesel generators can be used with either reactor.

The thermal power output of all units were probably increased significantly over time.[513] For purposes of estimating plutonium production, we assume their thermal power levels were increased to about 2000 MW_t each. The four dual-purpose reactors at Tomsk-7--two still operating--produce about 180 MW_e and 300 GCal/h (= 350 MW_t) each.[514]

---

[509] 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.

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

[511] *Izvestiia,* 4 May 1990, morning edition, p. 6 (translated in FBIS, London UK, Serial: PM0405112290).

[512] ``Siberian Atomic Reactor Closes,'' *Moscow Tass,* International Service in Russian, 21 August 1990, 1449 GMT.

[513] 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.

[514] In 1964, it was reported that the Siberian [Tomsk-7] station had exceeded its design capacity of 600 megawatts-electric (MW_e),

With a combined reactor output of 4000 MW$_t$, the two remaining operating reactors typically provide off-site winter peak outputs of 360 MW$_e$ to the Siberian Integrated Power System grid--supply 40 percent of the Tomsk region's electricity requirement--and 660-700 MW$_t$ (570-600 GCal/h) delivered to the district heating grid and to meet process steam needs of a nearby petrochemical plant. It is assumed that the power station operators have the ability to vary the proportion of steam used for electricity generation versus district heat generation. The Tomsk city heat requirement is 2500 GCal/h, while the current capacity is about 2125 GCal/h--a 15 percent deficit. Thus, shutting down the last two reactors, which together supply 570-300 GCal/h, without providing replacement power would increase the district heating deficit by an additional 25 percent. The district heating pipelines between Tomsk-7 and Tomsk are controlled by Minatom; much of the pipelines are said to be uninsulated.

As noted previously the remaining two dual-purpose reactors are to be shut down by the end of 2000. In 1992 Minatom was proposing to construct two 500 MW$_t$ AST reactors at Tomsk, bring them on line between 2001-2005."[515] In 1994 Minatom was favoring replacing the two remaining dual-purpose reactors with Russian VVERs, or U.S. designed high temperature gas-cooled reactors. Since these reactors cannot be brought on line until after 2000, Minatom is examining the option of extending the burnup of the fuel of the existing reactors, so that the separated plutonium would be fuel-grade instead of weapon-grade. At Tomsk-7 the U.S. would prefer to see the Russians complete a nearby partially completed coal-fired plant, or some other fossil-fueled plant alternative.

Chemical Separation Plant

The chemical separation and fuel storage facilities probably date from 1956 shortly after the first reactor went on line. The original plant used the acetate process but was converted to a pulse-column based solvent extraction process in 1983. As noted in Chapter Three under the discussion of chemical separation at Chelyabinsk-65, Mayak stopped chemical separation of the Chelyabinsk-65 plutonium production reactor fuel in 1987. As a result, the Tomsk began receiving by rail the plutonium production reactor fuel from Chelyabinsk-65 for processing.[516] These shipments probably ceased shortly after the last of the plutonium production reactors at Chelyabinsk-65 was shut down at the end of 1990.[517] Spent natural uranium fuel is cooled for 180 days before processing. The HEU-Al cermet ``spiked'' ring spent fuel elements are sent to Chelyabinsk-65 where they are processed after being cooled for two years.

---

and in 1979 it was reported that ``the capacity of this nuclear power station considerably exceeds 600,000 kw [kilowatts];'' A.M. Petrosyants, *Problems of Nuclear Science and Technology,* 4th ed., translated from the Russian by W. E. Jones (Oxford: Pergamon Press, 1981), p. 103. Western sources always describe the Siberian station as now consisting of six 100 MW$_e$ units, and this appears to have been the original intention; *Nuclear News*, August 1993, p. 73. However, there are only four dual-purpose units. Aleksandrov mentions five units--presumably counting the first unit that did not produce electricity--with the second unit producing 200 MW$_e$; *Kommunist,* No. 1, 1976, p. 65. In 1993, *Moscow Rossiyskiye Vesti* reported that each of the three remaining dual-purpose reactors (the two at Tomsk-2 and one at Krasnoyarsk-26) produces up to 200 MW$_e$; Sergei Ovsiyenko, ``Weapons-Grade Plutonium Stocks Dwindling,'' *Moscow Rossiyskiye Vesti*, in Russian, 19 May 1993, p. 7.

[515] The Concept of Development of Nuclear Power in Russian Federation. 14 July 1992, The Council (Kollegia) of the Minatom RF.

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

[517] We assume the fuel elements from the light water production reactors at Chelyabinsk-65 are processed at RT-1. If not, they may have been, and perhaps continue to be, shipped to Tomsk-7.

The spent fuel from the two remaining operating production reactors at Tomsk-7 was being processed at the only operating chemical separating plant (Building 15) when an accident (described below) crippled the plant on 6 April 1993. The plant was brought back on line after being shut down for several months.

The director of the chemical separation plant at the time of the accident was V. Korotkevich.[518]

Plutonium Processing, Pit Manufacture, and Fissile Material Storage

Tomsk-7 has the capability to produce plutonium metal components for nuclear weapons, and as late as October 1994 Tomsk-7 was still manufacturing plutonium pits for weapons.

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.[519] A former employee of Plant 25 has alleged that in 1967, management officials at Plant 25 falsified plutonium blending ratios, apparently creating a ``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.''[520]

Plutonium and HEU recovered from retired nuclear weapons are stored at Tomsk-7 as metal. As of the fall 1994, approximately 23,000 containers with fissile materials from weapons were stored at Tomsk-7. Minatom is constructing a new fissile material storage facility at Chelyabinsk-65 and plans to construct a second storage facility (50,000 containers) at Tomsk-7. Site preparation for the first phase (25,000 containers) is planned for the summer of 1995. The first phase is expected to become operational in 1999.

Accidents

The following are identified as the most important accidents at the radiochemical plant at Tomsk-7:[521]

18 March 1961	Explosion in condenser, two fatalities.
30 January 1963	Self-sustaining chain reaction lasting 10 hours. Four men received large doses of radiation.
13 December 1963	Self-sustaining chain reaction lasting 18 hours. No personnel irradiated.
18 November 1967	Explosion in sorption column.

---

[518] Kostyukovsky, ``Tomsk-7: Nuclear Ordinariness after the Explosion,'' p. 7.

[519] L.V. Stryapshin, ``We Need Independent Assessments,'' Tomsk-37, 8 July 1991.

[520] Ibid.

[521] *Moscow Komsomolskaya Pravda*, 11-14 November 1994.

24 March 197?	Equipment in the reagent manufacturing reactor destroyed.
1991	Aerosol contamination of finished output store.
6 April 1993	Technological equipment destroyed, accompanied by explosion in the gas phase, the destruction of some production buildings, and the discharge of radioactive aerosols inside and outside plant territory.

There is additional information concerning the most recent accident. On 6 April 1993, at 2:00 pm (0600 GMT) a tank (technical apparatus 6102/2) used in the PUREX process exploded causing extensive damage to the plant and extensive off-site contamination. To understand where in the process the explosion occurred, it is useful to review some of the basic elements of the PUREX process. In the first extraction stage, irradiated uranium fuel is dissolved in nitric acid forming an aqueous solution of uranium nitrate, tetravalent plutonium nitrate, and fission product nitrates. The aqueous solution is then fed to the center of a counter current solvent extraction contractor. The contractor is fed from the bottom with organic solvent tributyl-phosphate (TBP) in solution with a carrier such as kerosene. It is fed from the top with a dilute nitric acid. The uranyl and plutonium nitrates concentrate in the organic solvents along with some fission products. The nitric acid scrub cleans the solvent of fission products, which leave the bottom in an aqueous stream while the plutonium and uranium leave the top in an organic stream. The uranium and plutonium are separated from each other in further extraction steps involving valence changes of plutonium. The organic stream containing tetravalent plutonium nitrate and uranyl nitrate is fed to a second contractor. This second contractor is also fed from the bottom by TPB, and from the top with a dilute nitric acid solution of ferrous sulfumate that reduces the plutonium to the trivalent state, leaving the uranium in its hexavalent state. As a result the plutonium is transferred to the aqueous phase and leaves the bottom of the contractor. The uranium and neptunium and some plutonium and fission product impurities remain in the organic stream, which is fed to a third contractor for further purification of the uranium.

The 35 m^3 tank that exploded appears to be a holding tank between the second and third contractor. It contained 25 m^3 of a uranium-plutonium solution (8.7 t of uranium and approximately 500 g of plutonium) with some residual fission products.[522] Nitric acid was being added to the tank to increase the acidity of the solution.[523] To avoid the formation of a thin layer of ``red oil''--the name given to a nitrite produced in mixtures of TBP and HNO_3 that can explode when heated above 130 ^{o}C--compressed air is used to mix the solution and stop the layer from forming. In violation of operating procedures this was not done. Exactly what happened next is uncertain. Russian experts believe gases from the reaction increased the pressure in the tank until it ruptured. The gases mixed with air outside the tank; and a short circuit ignited the gases causing a violent explosion. An alternative hypothesis is that failing to monitoring the temperature in the tank, the thin layer of ``red oil'' that formed on the surface overheated and exploded violently.[524] Three explosions involving ``red oil'' have occurred at U.S. chemical separation plants: in 1975 in the A-line at the Savannah River Site's H-Canyon, at Savannah River in 1953, and at Hanford in 1953.[525] In any case the

[522] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' Part I, Chapter 2.

[523] ``Tomsk-7 Caused Minimal Radiation Hazards, IAEA Team Reports,'' *Nuclear Waste News*, Vol. 13, No. 16, 22 April 1993, p. 157.

[524] Ibid.

explosion is attributed to human error.

The violent explosion blew a hole in the roof; and blew out the upper wall of the galley for a distance of 100 m, or so. The pressure wave passed down the galley of about 100 m in length, bursting the lateral brick wall and causing extensive damage to other areas of the plant.[526] A fire broke out on the roof, but was put out within five minutes.[527] The building in which the blast occurred is said to have been destroyed over several hundred square meters.[528]

At the actual site of the explosion, the dose rate was 10-15 R/h, ``after 20 days of washing.''[529] The highest recorded external dose received by a worker was 0.7 rem, while a fireman received about 0.2 rem.[530] No internal dose estimated have been reported. Within one hour of the explosion, the dose rate was several mrem/h within the plant site and 0.4 to 0.5 mrem/h at the perimeter fence. At the same time, fission product contamination was reported as 20 Ci/km^2, and plutonium 20 mCi/km^2.[531] Light winds limited the spread of the contamination. A sketch of the radioactive plume was published in the Russian press. The principal radioactive contaminants were ruthenium-105, ruthenium-106, zirconium-95, and niobium-95.[532] Radioactive material spread 20 km beyond the perimeter fence in the northeast direction; and the total area of the trace was about 250 km, defined by the 20   rem/h external dose rate isoline [2][533]; 50 km^2 outside the plant boundary above 30   em/h;[534] and 30-35 km^2 above 60   rem/h.[535] Outside the contaminated area the background dose rate ranges from 5 to 17   rem/h.[536] The accident contaminated mostly forest, 100 ha of stock producing fields, and two villages, Georgievka and Chyornaya Rechka.[537] Sixteen km from the accident center, Georgievka, with a population of 200, was exposed to an initial external dose rate of 18-45   rem/h from external beta/gamma contamination reported at 150 Ci/km^2, and plutonium at 0.4-0.5 mCi/km^2.[538] The radiation levels in Chyornaya Rechka ranged from 12-15

---

[525] George Lobsenz, ``DOE Studies Tomsk-7 for U.S. Ramifications,'' *The Energy Daily*, 7 June 1993, p. 1.

[526] Kostyukovsky, ``Tomsk-7: Nuclear Ordinariness after the Explosion,'' p. 7.

[527] AFP Wire Service, Moscow, 7 April 1993, 05:40.

[528] AFP Wire Service, Vienna, 7 April 1993, 06:21.

[529] Kostyukovsky, ``Tomsk-7: Nuclear Ordinariness after the Explosion,'' p. 7.

[530] Ibid. UPI Wire Service, Moscow, April 7, 01:16, reported that fire fighters who fought the flames received 0.6 R of exposure.

[531] Kostyukovsky, ``Tomsk-7: Nuclear Ordinariness after the Explosion,'' p. 7.

[532] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' Part I, Chapter 2.

[533] Veronika Romanenkova, ``Independent Experts on Tomsk-7 Accident Aftermath,'' *Moscow ITAR-TASS*, in English, 20 April 1993, 1321 GMT.

[534] *Moscow Izvestiia*, in Russian, 17 April 1993, First Edition, p. 2.

[535] Tomsk Ecological Initiative, ``Information about the Siberian Chemical Facility (Tomsk-7);'' this source claims the extent of the fallout above 15 μrem/h was 28 km with a maximum width of 6 km and an area of 123 km^2.

[536] *Moscow INTERFAX*, in English, 9 April 1993, 1655 GMT (reproduced in FBIS-SOV-93-068, 12 April 1993, p. 39).

[537] Ibid and *Moscow Izvestiia*, in Russian, 17 April 1993, First Edition, p. 2.

[538] ``Tomsk-7 Caused Minimal Radiation Hazards, IAEA Team Reports,'' *Nuclear Waste News*, Vol. 13, No. 16, 22 April 1993, p. 157.

rem/h,[539] essentially background levels. The width of the radioactive trace where it crossed the northern road of the Tomsk region was 3 km (28 to 31 km from Tomsk.[540] There was no timely notification of the population about the accident, and they were not provided with regular official bulletins.

The chemical separation plant was put back into operation sometime prior to 18 August 1993.[541]

Geography and Hydrology

Both Tomsk and Krasnoyarsk are on the southeastern border of the Western Siberian artesian groundwater basin. Both sites are located within a few kilometers of the edge of the basin; waste disposal practices have the potential of contaminating the basin by surface water drainage or through groundwater flow in rocks underlying the basin.[542]

Drainage from the Tomsk facility is complicated by the potential areas of stagnation about 70 km to the north; a confined recharge flow from the Kuznetsky Altai and Salair mountains to the south from basin and rocks has also been inferred. General flows are into the adjacent Tom River, which is feeds the Ob 45 km downstream, with ultimate discharge to the Kara Sea through the Obsakaya Guba (the Ob is also fed by the Irtysh, which is fed by the Chelyabinsk contaminated Techa River.[543]

Waste Management Activities

We estimate that some 500 million Ci of Sr-90 and Cs-137 have been produced at Tomsk-7; twice that amount if the daughter products, Y-90 and Ba-137m are included in the total. Thus, over one billion curies of radioactive waste have been dumped onto the environment at Tomsk-7--most of it has been injected into the ground, but large quantities of medium- and low-level radioactive wastes have been dumped directly into open reservoirs on site.[544] During the 39 years of plant operations, about 127,000 tons of solid and about 33 million m^3 of liquid radioactive wastes have accumulated.[545] According to Ecological Initiative, a grass roots environmental movement in the Tomsk area, ``Until 1963 wastes [presumably the HLW, perhaps after dilution to medium-level] were simply poured into an open lake, which is still found on the site of the SCC [Siberian Chemical Combine]."[546] The Combine is apparently in the process of filling in this reservoir,

---

[539] Tomsk Ecological Initiative, ``Information about the Siberian Chemical Facility (Tomsk-7)."

[540] Ibid.

[541] Interview with Viktor Mikhailov by Andrei Vaganov, *Moscow Nezavisimaya Gazeta*, in Russian, 18 August 1993, pp. 1,3 (translated in FBIS-SOV-93-159, 19 August 1993, pp. 34-37).

[542] R.A. Brown and G.J. McManus, ``Tomsk-Krasnoyarsk Background Information," Idaho National Engineering Laboratory, ca. 1994 (undated).

[543] Ibid.

[544] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993," Part I, Chapter 2.

[545] Kostyukovsky, et al., ``Secrets of a Closed City."

[546] Tomsk Ecological Initiative, ``Information about the Siberian Chemical Facility (Tomsk-7)." There is reason to question the

similar to what is taking place at Lake Karachay. As described in a Russian television report, ``As soon as the snow melts, these lead-plated machines and mechanisms will again be moving earth to the radioactive reservoir. Several years will be needed to fill in the reservoir and thus prevent lethal evaporation. The question is, however, what will happen to the water. . . . We were allowed to run to the edge of the reservoir, on condition that we would shoot for no more than a minute and then run back again. . . . This is no place for gawkers.''[547] *Izvestiia* 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.[548]

Since 1963 there has been some treatment of high-level radioactive wastes with some of the higher activity waste stored in containers and the larger volume of lower activity waste injected into the ground.[549] About 30 million m^3 of liquid radioactive wastes have been injected at the Combine's burial sites located 10-20 km from the river Tom (Figure 4.1). At these sites radioactive wastes of unknown quantity and concentration have been pumped into sandy beds at a depth of 250-460 m. 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.''[550]

Another source describes the wastes as, ``buried underground, in sand strata of chalk deposits at a depth of 320-460 m and 12-15 km from the water supply. The quantity of buried RAW is around 36 million cubic meters containing 1.06 billion curies of radioactivity.''[551] According to this source,

> ``Beginning in 1989-1990, there was a threat of contamination to the underground
> water supply by the radioactive material due to the fact that wells in the northern part
> of the aquifer hit water that was in contact with the buried liquid RAW. The results
> of the investigations carried out by the PGO `Birch Geology' clearly show major
> tectonic faults in the earth's crust in the Tomsk region: these faults create the
> conditions for the mixing of subterranean waters from different strata. It is
> specifically in the region between two deep breaks that the operational wells of the 3
> lines of the water supply are found. This break follows the right bank of the Tom
> and encloses the zone where the liquid RAW is buried. This creates a corridor

---

accuracy of this reference. The report goes on to say, ``The radioactivity on the shore is 600 megacuries. A person standing on the lake shore receives in 10 seconds his annual norm of radiation (5 rem) [i.e., 1800 rem/h].'' But by our calculations only about 356 MCi of Sr-90 + Cs-137 would have accumulated from all production reactor operations at Tomsk-7 through 1992; and only about 20 MCi would have accumulated prior to 1963, half of which would have decayed by 1993.

[547] Moscow Ostankino Television First Channel Network, in Russian, 27 February 1993, 0955 GMT.

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

[549] See Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' Part I, Chapter 2.

[550] Kostyukovsky, et al., ``Secrets of a Closed City,'' 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.

[551] Tomsk Ecological Initiative, ``Information about the Siberian Chemical Facility (Tomsk-7).''

within which there exists the possibility of the mixing of underground waters of the strata with another. This intensive pumping out of water from the wells of the 3 lines of the water supply (the Ob-Tomsk water shed is the only source of drinking water for 2/3 of the oblast population, which is concentrated in this region) forms favorable conditions for the contamination of underground water in a strata due to the unloading of the lower water carrying strata of chalk deposits. The active movement of underground waters in the chalk deposits causes the pulling up of a front of underground water which is in contact with the buried RAW. This can lead to a speeding up of the contamination of operational water in the northern part of the water supply. In this case, the population would lose 50-60% of the volume of water now used in Tomsk."[552]

Sometime during the 1970s, a senior engineer responsible for ``monitoring stocktaking and storage of special output'' discovered a ``vast quantity of radioactive output'' at the plant. *Izvestiia* claims that his letter to the Central Committee and L.I. Brezhnev only resulted in his reprimand and threatened expulsion from the party.[553] Not until 18 April 1990, when Tomsk-7 radio warned that people had been contaminated, did the public learn of this problem.[554]

At one solid waste burial site surrounded by several fences, ``Containers of toxic waste are deposited in special burial vaults and underground bunkers. There is also a surface bunker. What protection the walls of the containers offer can be judged from this radiation reading on opening the bunker, which has not yet been bricked up. . . . Fifty-six millisieverts/hour [5.6 rem/h]"[555]

A series of dams along Romashka Creek, a tributary of the Tom River, form temporary holding ponds for reactor coolant water, prior to discharge into the Tom. The hold up affords some cooling of the discharged water and partial decay of radionuclides. With only two reactors still operating and the only reactor that utilized once-through cooling now shut down, cooling the discharged water is less of a problem. However, other sources of radioactivity also may be discharged into the Romashka, and the holding ponds may still serve to retain radioactivity. In July 1990, French scientists took radiation measurements just outside the Tomsk-7 site.[556] 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/hour (rad/h) in air and 400   rad/h in the water in the canal.[557] On the bank of the Tom, 2 km downstream from the creek or canal, the gamma radiation level was 150   rad/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.[558] The

---

[552] Ibid.

[553] ``Urgent Warning: Radioactive Waste Available to All,'' *Izvestiia,* 4 May 1990, morning edition, p. 6 (translated in FBIS, London UK, Serial: PM0405112290).

[554] Ibid.

[555] Ibid.

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

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

[558] Lariviere and Denis-Lampereur, *Science & Vie*, 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.

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

Tomsk-7 produces uranium hexafluoride and is the site of one of the four Russian uranium enrichment plants (see the discussion under Uranium Enrichment in Chapter Five). On 25 January 1991, *Izvestiia* reported a commercial deal whereby the Siberian Chemical Combine would enrich up to four percent uranium recovered from reprocessed French power reactor fuel.[559] A contract (No. 54-02/60006) was signed in March 1991 by Techsnabexport and Cogema providing for shipment to Tomsk-7 ``in 1992-93 of recovered uranium in the form of mixed uranium oxides (U_3O_8) in quantities up to 150 tonnes annually, and in 1994 and subsequent years in the form of uranium hexafluoride (UF_6) in quantities up to 500 tonnes annually. This contract shall remain in effect until the year 2000.''[560] The Russians would be paid around $50 million a year under the cooperative arrangement.[561] Later that year it was reported that these were precontract negotiations.[562] 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.

The solid waste burial site at the uranium hexafluoride plant contains more than 70 kg of plutonium in the waste.[563]

Military Conversion Activities

The Siberian Chemical Combine has created the Siberian Group of Chemical Enterprises (SGCE) to develop and market the following civilian products:[564]

*   enriched uranium and its chemical compositions;
*   high energy permanent magnets based on rare earth elements;
*   ultra-dispersed powders of metals and their oxides, e.g., Al_2O_3, Fe_2O_3, MgO, Cu;
*   high purity inorganic fluorides and fluorinating agents, e.g., FeF_3, NdF_3, UF_6;
*   stable isotopes, e.g., Se-74, Cr-50;
*   special optics and television equipment for visual surveillance of industrial activities; and
*   household ``mixers,''i.e., faucets, for bathrooms and washstands.

---

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

[560] Kirill Belyaniov, ``Version: French Nuclear Wastes Exploded at Tomsk-7,'' *Moscow Novaya Yezhednevnaya Gazeta*, in Russian, 21-27, 1993 [signed to press 20 May 1993], pp. 1,5 (translated in FBIS-USR-93-071, 9 June 1993, p. 39).

[561] Ibid.

[562] Kostyukovsky, et al., ``Secrets of a Closed City.''

[563] Gosatomnadzor, ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993,'' p. 44.

[564] ``Siberian Group of Chemical Enterprises,'' marketing brochure, ca. 1994.

Krasnoyarsk-26 (Mining and Chemical Combine, Zheleznogorsk)

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 Stolby National Preserve,[565] 50 km (64 km by road) northeast of Krasnoyarsk.[566] Thus, in the same year was born, ``Sibkhimstroy'' (Siberian Chemical Complex), now known as the Mining and Chemical Combine [Gorno-Khimichesky Kombinat (GKhK)].[567] Some local inhabitants still call it Devyatka [translated ``Number 9,'' since it was originally identified as Chemical Combine No.9], but it is usually called by its code name, Krasnoyarsk-26.

The Combine, which is fenced off, covers more than 17 km^2.[568] A larger sanitary protection zone covering 13,100 ha (131 km^2) was established in 1971.[569] About 10 km to the south of the Combine is the closed city Zheleznogorsk (population 90,000 living on 35 km^2)[570], often called ``Atomgrad.'' by *Gorod i Gorozhanye*, the local newspaper. There use to be a small village called Dodonovo at or near the closed city. The Combine's 11,000 employees produced plutonium for warheads.

The Combine comprises five ``plants''--the ``reactor plant,'' with three plutonium production reactors, of which only one is still operating; a radiochemical plant used to recover the plutonium from the reactor spent fuel; the reactor coolant water preparation plant; the partially completed RT-2 radiochemical plant; and the engineering and repairs plant--and 22 individual workshops and sections.[571]

Unlike Chelyabinsk-65 and Tomsk-7, the plutonium production and separation at Krasnoyarsk-26 takes place primarily underground. The three plutonium production reactors, the reactor coolant water preparation plant, the chemical separation plant, which has operated since 1964, the waste treatment and storage facilities, and ``innumerable laboratories,'' are all located within a huge multilevel cavern some 200-250 m underground (120-150 m below the level of the river). There are three tunnels into the underground complex, one for transportation, one for

---

[565] The Mining and Chemical Combine was built by the USSR Council of Ministers Order No. 13523 RS/OP, dated 26 August 1950; V.I. Korogodin, V.F. Idimechev, S.V. Lopatko, A.I. Maslyuk, G.P. Matrosov, A.G. Pakulo, A.A. Samarkin, V.G. Khizhnyak, and O.I. Shamov, ``Report of the Interdepartmental Commission for Assessment of the Radiation Situation in the Vicinity of the City of Krasnoyarsk,'' *Krasnoyarsk DOKLAD*, in Russian, 1990, pp. 1-12, appendices. See also, ``The Nuclear City: A Trip to a Populated Area Which is Not on the Map,'' *Pravda,* 26 June 1989; Alexei Tarasov and Dmitri Khrupov, ``Spy Satellites are Made Here: Report from a Closed Military City,'' *Moscow Izvestiia*, in Russian, 11 January 1992, Union Edition, pp. 1, 8; Steven Erlanger, ``A Siberian Town: Not a Secret and Ready to Deal,''*New York Times*, 29 March 1992, pp. 1,6.

[566] Krasnoyarsk-26 is located at 56° 20'N/93° 36'E.

[567] Postal address: 660033, Krasnoyarsk-33, ul. Lenia 53.

[568] T.N. Zhabina, From the ``This is How We Live'' Series, subtitled ``Closed City,'' Moscow Russian Television Network, in Russian, 15 October 1992, 1500 GMT.

[569] It was established by resolution 886, dated 15 January 1971, of the executive committee of the closed city, Krasnoyarsk-26; V.I. Korogodin, et al., ``Report of the Interdepartmental Commission for Assessment of the Radiation Situation in the Vicinity of the City of Krasnoyarsk,'' *Krasnoyarsk DOKLAD*, in Russian, 1990, pp. 1-12, appendices.

[570] Furumoto, *Tokyo Yomiuri Shimbun* (translated in FBIS-SOV-91-225-A, 21 November 1991, p. 3). ``Sibkhimstroy'' (Siberian Chemical Complex) should not be confused with ``Sibkhimkombinat'' (Siberian Chemical Combine), which is Tomsk-7 at Tomsk.

[571] Ibid.

ventilation, and a third for supply lines.[572] ``A concrete road that stretches along the shore of the Yenisey leads to a tunnel situated at the base of an enormous mountain.''[573] The 11,000 employees[574] of the combine go to work by train along the five km long tunnel.

Digging the multilevel system of underground tunnels and 3,500 rooms took three years and more than 65,000 prisoners. Some 100,000 military construction workers replaced the prison labor in 1953, after the death of Beria. The first reactor began operating five years later in 1958. In 1992, it was reported that some 7 million m^3 had been excavated, more than three times the 2 million m^3 volume of the Pyramid of Cheops.[575] In the 1970s, the volume of excavation was compared to that of the Moscow metro.[576] Its dimensions may be judged by the fact that every hour 5.5 million m^3 of air are pumped underground into the combines shops and living premises.[577] The underground ventilation system reportedly changes the air volume every ten hours. 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.[578]

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 in 1985 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. Some 500-600 wells were drilled for this purpose.

The director of the Mining and Chemical Combine (in 1994) is Valeri Lebedev. The Chief Engineer (in 1994) is Yuri S. Volozhanin.

Also located at Krasnoyarsk-26 is the Scientific Production Association of Applied Mechanics, a leading enterprise for space missile complexes for communications and television broadcasting. Headed by Academician Mikhail F. Reshetnev, the production association produces the Molniya, Raduga, Gorizont, Ekran, and Luch communication satellites, including the Tsikada and Glonass satellites); and geodesy satellites (Geoik and Etalon).[579] Satellites under recent development include Gals, Ekspress, Arkas, Genets, Soveanstar, and Mayak telecommunications satellites. Established in 1959 as a subsidiary of the experimental design bureau headed by Sergei Korolev,[580] the production association employs 11,000 workers.

---

[572] Moscow Ostankino Television First Channel Network, in Russian, 27 February 1993, 0955 GMT.

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

[574] *Izvestiia*, 1 July 1992.

[575] *Pravda*, 30 June 1992, p. 1, translated in FBIS-SOV-92-130, 17 July 1992, p. 47.

[576] Tarasov and Khrupov, ``Spy Satellites are Made Here.''

[577] V. Nelyubin, ``Mountains Cause Excess Misfortune from Excess Cleverness,'' *Moscow Komsomolskaya Pravda*, in Russian, 20 October 1992, p. 2 (translated in FBIS-USR-92-137, 24 October 1992, p. 25).

[578] Tarasov and Khrupov,``Spy Satellites are Made Here.''

[579] Ibid.

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

Adjacent to Krasnoyarsk-26, and sometimes linked in discussions of defense conversion, is the Krasnoyarsk Machine Building Plant (Krasmash). This plant, also called Krasnoyarsk-35, is part of a larger defense industry enterprise with facilities in and around Krasnoyarsk. The START Treaty data exchange identifies Krasmash as a production facility for liquid-fuelled Submarine-Launched Ballistic Missiles (SLBMs).[581] Krasmash also designs, manufactures, and tests spy satellites, space vehicles, special communications, and satellites for the Academy of Sciences.[582] More than one-third of the Cosmos space vehicles were worked on here.[583] The firm was originally intended to produce cannons and missiles underground, but this goal was changed by Khrushchev in 1961.

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 Zelenogorsk (population 63,300) (see Chapter Five).[584]

Graphite Reactors

The three graphite-moderated production reactors at Krasnoyarsk-26, hidden 200-250 m underground,[585] are identified as AD, ADE-1, and ADE-2. Like the Tomsk reactors they are fueled with natural uranium (about 98.5 percent of the fuel elements) and a ``spiked'' ring of HEU elements (about 1.5 percent of the total) to increase the reactivity and levelize the flux (and therefore the power density).

AD. The first reactor, AD, was a large graphite-moderated reactor with 2832 channels (process tubes) that were directly cooled by Yenisey River water (once through cooling). It began operating on 25 August 1958[586] and was shut down on 30 June 1992,[587] because its operation contravened Russian law on protection of the environment.

ADE-1. The second reactor, ADE-1, is identical in size to the AD reactor--2832 channels. It began operating on 20 July 1961, and was shut down on 29 September 1992, because it also contravened Russian law on protection of the environment.

ADE-2. The third reactor, ADE-2, with 2832 channels is the same size as AD and AD-1, and is identical to the ADE-3, -4, and -5 reactors at Tomsk. It began operating in 1964, began

---

[581] 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.

[582] Tarasov and Khrupov, ``Spy Satellites are Made Here.''

[583] Ibid.

[584] Furumoto, *Tokyo Yomiuri Shimbun* (translated in FBIS-SOV-91-225-A, 21 November 1991, p. 3).

[585] ``Out from Under the Earth,'' *Pravda*, 21 December 1991.

[586] The start-up dates for all three reactors is given by V.I. Korogodin, et al., ``Report of the Interdepartmental Commission for Assessment of the Radiation Situation in the Vicinity of the City of Krasnoyarsk,'' *Krasnoyarsk DOKLAD*, in Russian, 1990, pp. 1-12, appendices.

[587] Alexei Tarasov, ``In Secret Caverns of Krasnoyarsk-26 Reactor Which Produced Weapons-Grade Plutonium Has Been Shut Down,'' *Moscow Izvestiia*, in Russian, 1 July 1992, Morning Edition, p. 2 (translated in JPRS-TEN-92-015, 30 July 1992, p. 67).

supplying the underground facility and closed city with electricity and steam heat in 1965, and is still operating as a dual-purpose reactor--producing weapon-grade plutonium, 150-200 MWe of electricity, and 350 GCal/h of process steam[588] for district heating.[589] In 1993, *Moscow Rossiyskiye Vesti* reported that each of the three remaining dual-purpose reactors (the two at Tomsk-7 and one at Krasnoyarsk-26) produces 200 MW$_e$.[590]

For estimating plutonium production it is assumed that prior to 1990 all three reactors operated at about 2000 MW$_t$. In March 1990 the thermal capacity of AD and ADE-1, the two once-through cooling reactors, was reduced by 20 percent.[591]

The third reactor is scheduled to be shut down by 2000,[592] but must await the availability of replacement power (electricity and steam). The Sosnovoborsk power and heating plant, under construction near Krasnoyarsk, has been cited as the source of replacement power.[593] But this plant is too far removed to supply steam to the closed city at Krasnoyarsk-26, and in any case, there is public opposition to completing the plant.

As noted above, the first two reactors utilized once-through cooling.[594] Since water from the Yenisey was pumped through these reactors and returned directly to the river, the river is contaminated with fission product leakage and neutron induced radioactivity. In 1991 it was reported that radioactive contamination of the discharged cooling water ``results in an increase in the radioactivity level of the dumped water to 3000 micro-roentgen per hour."[595] These two reactors were ordered closed in 1992 due to their pollution of the Yenisey River. The dual-purpose reactor (the third reactor) has a closed cooling cycle and is therefore less polluting. Two streams of thermal effluents into the Yenisey River are visible in a composite of LANDSAT images, a day image from 17 December 1989 combined with a night image from 5 September 1989. The southern most, or upstream, discharge is the combined flow of water from the two reactors with open cycle cooling, which were still operating at the time. The northern most, or downstream, discharge is from the secondary loop of the dual-purpose reactor.

---

[588] *Moscow Reuters*, 30 June 1992; Khots, ``Plutonium Producing Reactors in Krasnoyarsk to be Shut Down:" Yuri Khots, ``Plutonium Producing Krasnoyarsk Reactor Shut Down," *Moscow ITAR-Tass World Service*, in Russian, 29 September 1992, 0518 GMT (translated in FBIS-SOV-92-194, 6 October 1992, pp. 38-39); Khots, ``Underground AES [Nuclear Power Station] Will No Longer Produce Plutonium;" V. Yaroslavtsev, ``The Yenisey's X-Rays" from ``What Troubles our Conscience: A Polar Chernobyl Syndrome," *Vozdushnyy Transport*, 4 October 1990, p. 3; and *The Washington Post*, 21 April 1992, P. A15.

[589] The heat and electricity serve the underground facility and the closed city.

[590] Sergei Ovsiyenko, ``Weapons-Grade Plutonium Stocks Dwindling," *Moscow Rossiyskiye Vesti*, in Russian, 19 May 1993, p. 7.

[591] V.I. Korogodin, et al., ``Report of the Interdepartmental Commission for Assessment of the Radiation Situation in the Vicinity of the City of Krasnoyarsk." *Krasnoyarsk DOKLAD*, in Russian, 1990, pp. 1-12, appendices. See also, V. Yaroslavtsev, ``The Yenisey's X-Rays" from ``What Troubles our Conscience: A Polar Chernobyl Syndrome," *Vozdushnyy Transport*, 4 October 1990, p. 3.

[592] Ibid.

[593] Aleksandr 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, 8 April 1992.

[594] Called single-flow [pryamotochnyy] reactors.

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

Tritium has not been produced at Krasnoyarsk-26. The three reactors have produced only plutonium.[596] Assuming the one remaining reactor is operating at 2000 MW$_t$, with a capacity factor of 0.8, and a fuel burnup of 500 MWd/t, it is producing about 0.5 t of weapon-grade plutonium annually.

Chemical Separation Plant

In 1964 a radiochemical plant, housed in the underground facility, was put into operation to process irradiated fuel from the three production reactors.[597] Presumably the plant is still in operation to process fuel from the one remaining production reactor. From 1958 to 1965, spent fuel from the production reactors presumably was shipped to Tomsk-7 or Chelyabinsk-65 for processing.

Accidents

One serious accident is identified as having occurred on 21 September 1987 at the Radiochemical Plant. It resulted in radioactive contamination of drainage passages in the production building.[598]

RT-2

Design of the RT-2 complex for storage and reprocessing (i.e., chemical separation) of irradiated fuel from 1000 MW$_e$ pressurized water reactor (VVER-1000 power reactor) began in 1972. Construction of the first phase of the facilities was begun in 1976 at a 140 ha hill-top site overlooking the Yenisey River about 4-5 km distant, and about the same distance north of the underground reactors.

Spent Fuel Storage. The spent fuel storage facility (Building 1) and auxiliary and service buildings were put into service in December 1985. The storage pool has a design capacity of 12,000 fuel assemblies, or 6000 tHM. A VVER-1000 fuel assembly is a hexagonal fuel bundle containing 317 fuel elements or rods, 12 guide channels for control rods, one channel for a power density sensor, and a hollow central tube. Inside the 9.1 mm diameter zirconium cladding of each fuel rod are fuel pellets of uranium dioxide--1565 g per fuel rod--which were initially enriched to 4.4 percent U-235.[599] Thus, each fuel assembly initially contained about 0.5 tHM. The height of a fuel assembly with control rod bundle is 4.7 m. Each assembly is stored some eight meters below ground under three meters of water.[600] The storage building is divided into 15 sections, one of which must remain empty. The fuel assemblies are stored in containers of 12 assemblies each.

---

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

[597] V.I. Korogodin, et al., ``Report of the Interdepartmental Commission for Assessment of the Radiation Situation in the Vicinity of the City of Krasnoyarsk.'' *Krasnoyarsk DOKLAD*, in Russian, 1990, pp. 1-12, appendices.

[598] *Moscow Komsomolskaya Pravda*, 11-14 November 1994.

[599] U.S. Department of Energy, ``Overall Plant Design Descriptions VVER Water-Cooled, Water-Moderated Energy Reactor,'' DOE/NE-0084, Rev. 1., October 1987, p. 5-9.

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

In February 1993 the spent fuel pool held 800 tHM of spent fuel from VVER-1000 power reactors;[601] at the end of 1993 it held 1900 fuel assemblies (16 percent of the design capacity); in September 1994 it was reported to contain 1000 tHM; and in September 1994, of 15 sections in the storage pool, two were completely full and a third almost full, which indicated that the pool then contained close to 1200 tHM. The seven Russian VVER-1000s discharge about 130 tHM/y, and the ten Ukrainian VVER-1000s discharge about 185 tHM/y, giving a total of about 315 tHM/y (41 percent from Russia), exclusive of five or more new reactors that could come on line. In 1992 the Russian parliament passed an environmental law that prohibited the import of radioactive waste into Russia. No spent fuel was returned to Russia during the following year pending resolution of whether spent fuel constituted radioactive waste. A total of 150 tHM was delivered in 1992, all from Russia.[602] The law was overridden by Yeltsin's Presidential Decree of 21 April 1993, which provided for the return of spent fuel from abroad for reprocessing.[603] If shipments are resumed from Ukraine and five new VVER-1000 reactors are brought on line by 1995, RT-2 has sufficient storage capacity until about 2005. If only Russian fuel is shipped the capacity is adequate until well into the next century.

Building 1 has a water purification system to remove salts (demineralization) from the water to prevent corrosion. Also, a purification system (ion exchange and filtration) removes radionuclides, the most common of which is Cs-137. Noble gases are not trapped.

Reprocessing Plant. The second section of RT-2, the 1500 tHM/y fuel reprocessing plant,[604] which is adjacent to and surrounds the spent fuel facility, was begun in 1984 and scheduled to be completed by 1997-98. It was to employ 5000 people. There was a sharp reduction in funding for the project in 1985.[605] It was only about 30 percent complete when construction was interrupted and then halted in 1989, as a result of public controversy.[606] 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 actually produced nine years after construction started.[607] In 1990, by order of the Ministry of Atomic Power and Industry, the construction of RT-2 stopped for a five year period due to lack of funding.[608] Two hundred million rubles were spent on the project. Just preserving the construction

---

[601] In early 1992, it was reported to contain some 750 tHM of spent fuel from VVER-1000s, including spent fuel shipped from Ukraine prior to 1991.

[602] *Nuclear Fuel*, 4 January 1993, p. 6.

[603] Boris Yeltsin, ``Decree of the President of the Russian Federation on the fulfillment of the Russian Federation of intergovernmental agreements on cooperation in the construction of nuclear power stations abroad,'' Decree No. 472, 21 April 1993.

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

[605] Tarasov and Khrupov, ``Spy Satellites are Made Here.''

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

[607] ``Regular Daily Spot: Commission is Here for 1 Hour But We...,'' *Komsomolskaya Pravda,* 15 June 1989.

[608] V.I. Korogodin, et al., ``Report of the Interdepartmental Commission for Assessment of the Radiation Situation in the Vicinity of the City of Krasnoyarsk.'' *Krasnoyarsk DOKLAD*, in Russian, 1990, pp. 1-12, appendices reports construction was halted in 1989 by order of the ministry. Valeri Lebedev, director of Krasnoyarsk-26 is reported to have said that the Minister of Atomic Power and Industry in 1990 ordered the construction of RT-2 stopped for a five year period due to lack of funding; ``Nuclear Storage and

would require 30 million rubles, but in 1991 only 1.5 million rubles was allocated.[609] On 21 April 1993, President Yeltsin signed Decree No. 472, which approved completion of RT-2, and Minatom is seeking financial assistance from abroad to complete the construction.[610] After objecting to the completion of the plant for 30 months on environmental grounds, in October 1994 the local authorities of the Krasnoyarsk territory consented to the construction of the plant. The project is now estimated to cost 3.5 trillion rubles (early 1994 rubles) and take 10 years to complete. Ukraine, Slovenia, Switzerland, Taiwan, and Japan have expresses various degrees of interest on the plant.[611]

As currently designed, the spent fuel is to be transferred from Building 1 via water filled channels to Building 2 where it is to be chopped and dissolved. The undissolved zirconium cladding hulls are to be stored in Building 2C. The first and second extraction cycles would occur in Building 3, which is a canyon design. In Building 3A, plutonium nitrate would be converted to an oxide for the production of MOX fuel. Thus, technical plans for the RT-2 plant include:

> * storage of spent fuel rods, dissolution of chopped fuel and clarification of solutions received;
> * separation and purification of uranium and plutonium in the first extraction cycle with parallel extraction of neptunium, technetium and zirconium from the starting solution;
> * extraction of plutonium and production of oxides of plutonium and uranium for preparation of MOX fuel;
> * preparation of MOX fuel rods for VVER-1000 reactors;
> * separation of long-lived fission products and trans-plutonium elements and subsequent solidification for long-term geologic storage.
> * recovery of uranyl-nitrate for subsequent U-235 enrichment for reactor fuel;

In discussing the proposed RT-2 reprocessing plant, L.N. Lazarev of the St. Petersburg Radium Institute promised 99.98 percent recovery of plutonium; 95 percent capture of the volatile fission products Kr-85 band I-129; partitioning (99 percent) for separate treatment of the long-lived radionuclides, neptunium-237 and technicium-99; zero discharge of contaminated water into the surface environment and deep injection of tritium contaminated water into an aquifer where water has an ``age'' (before contact with surface water) of 40,000 years.[612]

Site 27. A key feature of the RT-2 reprocessing plant was the method of handling radio-active waste. According to Lazarev, the final extraction of actinides, neptunium, and transuranic isotopes from the high-level waste of RT-2 would be carried out in the underground chemical

Weapon Plutonium Facilities at Krasnoyarsk,'' *1991 The British Broadcasting Corporation; Summary of World Broadcasts*, 20 December 1991, Postfactum in English 2147 GMT 9 December 1991.

[609] Tarasov and Khrupov, ``Spy Satellites are Made Here.''

[610] Vladimir Gubarev, ``Opposition Stalls Krasnoyarsk Nuclear Reprocessing Plant,'' *Moscow Rossiyskaya Gazeta*, in Russian, 2 July 1994, p. 2 (translated in FBIS-USR-94-085, 8 August 1994, p. 60).

[611] *Moscow INTERFAX* in English, 1624 GMT 31 October 1994 (Reproduced in FIBS-SOV-94-211, pp. 28-29).

[612] L.N. Lazarev, ``Reprocessing and the Environment in Russia,''paper presented at the International Workshop on the Future of Reprocessing, and Arrangements for the Storage and Disposition of Already-Separated Plutonium,'' Moscow, 14-16 December 1992. See also, Frank von Hippel, Thomas B. Cochran, and Christopher E. Paine, ``Report on an International Workshop on the Future of Reprocessing, and Arrangements for the Storage and Disposition of Already-Separated Plutonium (Moscow, 14-16 December 1992), and an International Workshop on Nuclear Security Problems (Kiev, 17 December 1992),'' 10 January 1993.

separation facility used for weapons plutonium production. Here also, the high-level waste was to be partitioned into its liquid and solid components. The solid waste precipitate would be stored in tanks at the underground facility. According to *Moscow Trud,* the liquid waste was to be injected between layers of clay at a depth of 700 meters.[613] The waste was to be piped to Site 27, the injection location comprising 100 or so injection wells located some 16 km from the site of the reprocessing plant on the opposite side of the Yenisey River.[614] Before construction of Site 27 was halted completely in 1989 or 1990, at a cost of more than 30 million rubles (1991 prices) a 2150 m long tunnel had been dug some 50 meters under the river. Shaped like the mathematical sign for an integral, it was conceived as a two-story tunnel. The lower part was to house a pipeline, and the upper part was to be a corridor for the transportation of service personnel. The tunnel and the decision to inject liquid waste into the ground generated substantial controversy and undoubtedly was partially responsible for the controversy leading to cancellation of construction. Work on the tunnel was also halted. No piping and no pumping stations were built.[615] The tunnel has been damaged, and water is spraying into it from the concrete arch.[616] The tunnel is now serving as an ordinary transport route linking the two sides of the river.[617]

Geography and Hydrology

As noted previously both Krasnoyarsk and Tomsk are located within a few kilometers of the southeastern border of the Western Siberian artesian groundwater basin. Drainage from Krasnoyarsk is to the Yenisey River, which feeds the Kara Sea through the Yeniseysky Zaliv, about 300 km east of Obskaya Guba. Local geological features suggest that fractures and folds affecting ground-water flows are generally oriented in a north-south direction. The flow path of the Yenisey through the deepest part of the basin could facilitate contaminant infiltration from surface waters.[618]

Waste Management Activities

Beginning in 1964, when the chemical separation plant began operating, high-level and other liquid radioactive wastes were stored in large steel tanks. Three years later the Combine began injecting the bulk of the liquid wastes into the ground.

Waste Tanks.[619] High-level radioactive waste tank facilities at Krasnoyarsk-26 commenced

---

[613] ``Secret Site,'' *Moscow Trud,* 11 July 1989. During a trip to Krasnoyarsk-26 in June 1992, Greenpeace representatives were told that the shafts were 975 m deep and about 15 m in diameter.

[614] ``Checking for Stability,'' *Sotsialisticheskaya Industriya,* 23 July 1989; and T.N. Zhabina, From the ``This is How We Live'' Series, subtitled ``Closed City,'' Moscow Russian Television Network, in Russian, 15 October 1992, 1500 GMT. The distance to the injection location has been variously reported as 10, 16 and 20 km.

[615] T.N. Zhabina, From the ``This is How We Live'' Series, subtitled ``Closed City,'' Moscow Russian Television Network, in Russian, 15 October 1992, 1500 GMT.

[616] Tarasov and Khrupov, ``Spy Satellites are Made Here.''

[617] Zhabina, ``This is How We Live.''

[618] R.A. Brown and G.J. McManus, ``Tomsk-Krasnoyarsk Background Information,'' Idaho National Engineering Laboratory, ca. 1994 (undated).

[619] ``Foreign Travel Report,'' to the Fourth Meeting of the U.S. DOE-Minatom Joint Coordinating Committee on Environmental Restoration and Waste Management (JCCEM), September 9-17, 1994, report prepared by D.J. Bradley, 26 October 1994, p. 24.

operations in 1964 and now consist of 26 large steel tanks. Eighteen of the tanks are constructed of stainless steel, each with a volume of 3000 m^3. Seven of these tanks are used for current operations. Two have been pumped clean after leaks were discovered in 1964, and have not been used since. The eight additional tanks have a volume of 8500 m^3. Four of these are carbon steel tanks that have been decommissioned, and four are stainless steel tanks that are still in use.

There are six categories of stored tank wastes:

Product 1   suspension from decontamination of chemical separation operations by inorganic sorbants, namely, Fe, Cr hydroxides, Ni-K ferrocyanides;

Product 2   suspensions from alkaline precipitation of decontamination solutions;

Product 3   suspensions from decomposition of aluminate solutions arising in the standard fuel element dissolution process;

Product 4   suspensions from clarification of evaporated intermediate-level waste residues;

Product 5   waste from manganese dioxide-niobium hydroxide decontamination of solutions after the uranium extraction cycle (Mn-Nb sludge); and

Product 6   spent ionates, basically strong alkaline and polyvinylpyridine anionites as well as phosphorus acidic cationites (styrene-divinylbenzene matrices).

Another type of waste present at Krasnoyarsk-26 consists of precipitates of CaF_2, and silica gel.

Krasnoyarsk-26 has developed a 40 t/d processing capability for purification of sodium nitrate wastes to 10^{-7} Ci/kg and for plutonium to 10^{-10} Ci/kg. They have also developed a waste retrieval and purification technology for their 3000 m^3 tanks, and are now developing the technology for their 8000 m^3 tanks. The process is designed to pump the sludge from these tanks, and then dissolve the sludge. The process could by placed into operation on an industrial scale in 1995 were it not for economic difficulties.

Deep-Well Injection. Beginning in 1967 liquid radioactive waste were injected into the ground at the ``Severny Polygon'' (Northern test area) and this practice continues today. The site is about 16 km north of the underground facility, some 4-6 km from the Yenisey River. The subsurface environment consists of about 440-500 m of sediments deposited upon crystalline basement rock. Three separate aquifers, identified as Horizons I, II, and III, are spaced within the sedimentary layers. The uppermost aquifer, Horizon III, is reserved as a ``protective buffer.'' Low-level radioactive wastes are injected into the middle aquifer at a depth of about 150 m to 260 m below the surface. This storage aquifer is protected by 50 m to 70 m of clay overhead. Alkaline and acidic medium-level radioactive wastes (which appear to be simply diluted high-level wastes) are injected into Horizon I at a depth 370-500 m below the surface. Horizon I is covered by about 170 m of clay.[620] Waste injections are to cease sometime around 2000-2001, when the remaining production reactor is scheduled to halt operations.

A 6-inch diameter stainless steel pipeline, about 16 km long, is used to transport the liquid

---

[620] N.N. Yegorov, A.V. Nosukhin, Y.A. Revenko, and A.I. Rybalchenko, ``Deep Disposal od Liquid Radioactive Wastes at the Krasnoyarsk-26 Site in Russia,'' DRAFT, 1994.

medium-level waste from the chemical separation plant to underground reinforced concrete holding tanks for interim storage at the ``underground storage facility.'' The pipeline is laid in a reinforced concrete containment culvert buried to a depth of 5 m. Two intermediate pumping stations are located along the pipeline. Seven injection, eight recovery, and 54 observation wells grouped in three principal areas form part of the alkaline medium-level waste injection system. Special pumps at the pumping station, operating at a pressure of 0.6 to 1.2 megapascal (MPa) inject the liquid wastes into Horizon I. Waste injection and clean water discharge from the injection zone are performed simultaneously. Between 1967 and 1992, 2 million m^3 of alkaline medium-level waste were injected through eight injection wells. The resulting plume covers an area of nearly 120 ha, and extends a distance of 500 m south and 300 m east of the injection wells. The volume disposed annually is between 50 and 60 thousand m^3 (40-350 m^3 per well per day).[621]

Between 1972 and 1993, several thousand m^3 of acidic medium-level waste were injected into Horizon I through two wells. During injection of acidic waste into the wells, the formation heating reached the designated 180°C; and within the aquifer, the maximum specified design temperature after 20-25 years of operation is between 230-240°C, close to the boiling point of water of 262°C at the formation pressure of 4-6 MPa. These wastes have migrated no more than 200 m from the injection wells.[622]

The low-level waste pipe was laid in a trench excavated in soil without a concrete culvert. For low-level waste injection into Horizon II, there are 4 injection, 4 withdrawal, and 37 observation wells. Pumping at a pressure of 1.0 and 1.6 MPa takes place in summer months from surface storage at a rate of between 200 and 250 m^3 per day (60 to 120 thousand m^3 per year). A total volume of 2.5 million m^3 of low-level waste has been injected into the lower part of Horizon II. The plume now covers 170 ha, and extends 600 m north, 560 m south, and 250 m east. There appears to be no penetration of the upper and lower confining beds. About 30 thousand Ci of radioactivity are present in Horizon II, which is estimated to be no more than 44 percent of the initial activity.[623]

The 4-5 million m^3 of radioactive waste injected underground at Krasnoyarsk-26 has a reported combined activity of 700 mCi, most of it in the 2 million m^3 of alkaline waste pumped into Horizon III.[624] We estimate that 145 million Ci of Sr-90 and 160 million Ci of Cs-137 were produced at Krasnoyarsk-26; or double these figures if the two respective daughter products are included. Were the shorter-lived radioisotopes included in the total, the total activity in curies would be substantially higher. Most of the Cs-137 activity has probably been deep-well injected into the ground, while most of the Sr-90 is probably retained in the waste tanks.

Reservoirs. There are two above ground open radioactive waste reservoirs about 2-3 km north of the RT-2 site. The larger of the two is about 8-9 ha in area, and the smaller about 2 ha. As described in a Russian television report, ``This white field is a snow-under reservoir, a radioactive

---

[621] Ibid.

[622] Ibid.

[623] Ibid.

[624] *Moscow INTERFAX* in English 1901 GMT 29 September 1994 (Reproduced in FBIS-SOV-94-190, p. 39.

waste sedimentation tank. Behind it, [about 2 km distance] the Yenisey is winding its way. In order to minimize the risk of the reservoir overflowing, a drain has been installed. Via the pipe water is siphoned off into the Yenisey. However, during major floods, the drain is not sufficient."[625] This same television report showed a closeup picture of a leaking injection well pump.

Atmospheric Releases. With respect to atmospheric releases of radioactivity, Combine officials claim that the gas purification efficiency is 99.9 percent, but this must apply to iodine and other particulates, and not to noble gases. The average accumulation of Cs-137 in the top 5 cm of soil over a distance of 12 km from the plant chimney-stack is reported to be 38 mCi/km^2, of which 40 percent (15 mCi/km^2) represents discharges from the plant and the remaining 60 percent from nuclear weapons fallout.[626]

Reactor Coolant Discharges. Due to the discharge of coolant water from the production reactors (and presumably from laboratory operations and the chemical separation plant within the same underground tunnel complex), radioactivity is discharged into the Yenisey River. In July-August 1990 (and again the following year), prior to the shutdown of the two reactors using once-through cooling, an investigation of the radioactive contamination in the Yenisey showed that:[627]

1. The discharge from the Mining and Chemical Combine occurs in the sanitary protection zone 50 to 100 m from the right shore of the Yenisey River, one meter below the surface. The gamma dose in the water along the axis of a radioactive jet at the discharge site was 600 to 3000 R/h. In some places on shore at a distance of 5-7 m from the water line the radiation dose exceeds 60 R/h (0.5 R/y). By 20 km downstream the dose rate has dropped by a factor of 150 due primarily to dilution.

2. The contamination of the river could be traced for a distance of more than 800 km (due primarily to the presence of 27.7 d half-life chromium-51), and the contamination of the floodland for a distance of 1500 km, down the river from the discharge site.

3. The trail of contaminated water to the Kan River valley (25 km below the discharge)

---

[625] Moscow Ostankino Television First Channel Network, in Russian, 27 February 1993, 0955 GMT.

[626] Lazarev, ``Reprocessing and the Environment in Russia."

[627] In August-September, 1990 specialists of the Applied Geophysics Institute of the State Committee for Hydrometeorology and Environmental Monitoring (Roskomgidromet), together with scientists of the Krasnoyarsk Research Centre of the Siberian Branch of the Russia Academy of Sciences, investigated into the current state of the radiation situation of the Yenisey River from Krasnoyarsk to Igarka. Some chapters of the report made by the expedition were published in *Ekologichesky Vestnik*, a newspaper of Krasnoyarsk ecologists, No 3, 1991, pp.2-4, and detailed in a 4 April 1992 letter from Yu.F. Zubov, chairman of Roskomgidromet, to A.V. Yablokov, Russian Federation advisor on Environmental and Health Protection Policy. A summary of these results were reported by Aleksandr 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, 8 April 1992. Bolsunovsky also reported that the results of the investigation carried out by the scientists of the Institute of Applied Geophysics, as well as by the North Yenisey geophysical expedition, and by the Krasnoyarsk complex geophysical expedition in 1991, confirmed the fact the Yenisey has been contaminated by the chemical combine. The results of the Roskomgidromet survey are summarizes in a letter from Yu.F. Zubov, Chairman of Roskomgidromet, to Alexei V. Yablokov, Russian Federation Advisor on Policies of Ecology and health Protection, 4 April 1992; reproduced in ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," (Ordered by President M. Gorbachev, Presidential Decree # RP-1283, 3 January 1991), ca. April, 1992 [translated into English], Vol. I, pp. 29-34 (the page numbers cited here and subsequently are for the English translation).

passes against the right bank, while the left channel remains relatively clean. The higher rate of contamination along the right side of the river persists for a distance of 250 km (virtually to the settlement of Strelko), and along the right bank for a distance of 50 km from the discharge site. Sodium-24 (half-life = 15 h) is the main contributor to the exposure dose of the river water used for drinking in the segment of the river to Strelko. In the discharge zone concentrations of sodium-24 and manganese-56 (half-life = 2.6 h) exceeded the permissible standard by factors of 10 and 2. The river also contained the following medium- and long-lived radionuclides below permissible limits: phosphorus-32, chromium-51, zinc-65, manganese-54, cobalt-60, europium-152 and -154, and cesium-137.

4. The village of Atamanovo (2,200 inhabitants),[628] the first population center below the point of discharge, is 5 to 6 km downstream on the left bank. It gets its water from artesian wells, rather than the river. The density of bottom deposits contamination along the right bank at Atamanovo was: 35 Ci/km^2 of chromium-51, 3.3 Ci/km^2 of cobalt-60, 2.5 Ci/km^2 of zinc-65, 2.2 Ci/km^2 of cesium-136. An uniform distribution of cobalt-60 and cesium-137 was observed to the depth of 15 cm.

5. Contaminated algae can be a secondary source of radioactive contamination of bottom deposits in the Yenisey River and the river-side. The coefficient of accumulation of long-lived nuclides by the algae was (1-6) 10^3. The body of the fish caught at 700 km from the discharge site downstream contained (3-9) 10^{-10} Ci/kg of cesium-137 and (5-6) 10^{-9} Ci/kg of zinc-65. Migrating fish can carry radioactivity for long distances, both downstream and upstream as far as the city of Krasnoyarsk, from the source of contamination.

6. Radioactive contamination of the floodland of the Yenisey River is extremely uneven. The maximum soil contamination found was 41 Ci/km^2 (dose rate = 136 R/h) at Atamanovo island 6 km below the discharge. Measured contamination concentrations ranged from 0.03 to 41 Ci/km^2 at Atamanovo; from 0.74 to 17 Ci/km^2 at Bolshoy Balchug (300 inhabitants) 16 km downstream, and from 0.07 to 11 Ci/km^2 at Kononovo 25 km downstream. After that, for a distance of 500 km the contamination density does not depend on the distance from the source, but fluctuates within the range of 3-10 Ci/km^2, due to hydrological peculiarities of the river. For a distance from 500 to 1500 km from the source the contamination density of the floodland is up to 0.1 Ci/km^2 of cesium-137 and cobalt-60. The zone of radioactive contamination of the floodland of the Yenisey River is a narrow, 5-50 m wide, strip of land along the river.

7. Of the nuclides contained in the soil the most important in terms of potential health effects are: plutonium-238, -239, -240; cobalt-60; cesium-137, -134; manganese-54; zinc-65; europium-152, -154, -155; cerium-144; and strontium-90.

8. At Atamanovo island the soil contamination density reached 47 Ci/km^2 (0.23 Ci/kg) of plutonium-239/240 and 23 Ci/km^2 (0.11 Ci/kg) of plutonium-238.

Others report that the level of gamma activity in the river exceeds background by a factor of

---

[628] The Norilsk Mining and Metallurgy Combine, a 5,000-bed prisoner camp which was built before 1940, is located below Atamanovo.

five or six.[629] More than 400 km down the Yenisey, radiation levels up to 100 R/h have been observed (the natural background level is 10 to 15 R/h).[630] In the region of Lesosibirsk and Yeniseisk, the radiation level exceeds background by a factor of 10 to 14. In these same regions, and lower down the river, crumbly silty radioactive deposits are being discovered in many locations.[631]

Military Conversion Activities

With the shutdown of the two production reactors in 1992, the combine joined a Russian program for the development and production of super-pure materials and components for the micro-electronics industry. The goal was to produce products such as polycrystaline silicon, gallium arsenide, germanium and tellurium.[632]. The plan included building a plant for the production of polycrystaline silicon for semiconductor technology, producing 200 tons within two or three years.[633] ``We have set up the production of printed circuit boards, transformer units, and scans [razvertki] for the `Rassvet' monochrome television sets produced in Krasnoyarsk. We have concluded a contract with the Samsung firm."[634]

Desiring to complete the RT-2 reprocessing plant, officials have discussed accepting spent fuel for storage and reprocessing from a number of Asian, East and West European countries, and former Soviet republics.

---

[629] V. Yaroslavtsev, ``The Yenisey's X-Rays" from ``What Troubles our Conscience: A Polar Chernobyl Syndrome," *Vozdushnyy Transport*, 4 October 1990, p. 3. The article stated that the activity levels were established by two research expeditions by specialists from the Krasnoyarsk Scientific Center and the State Committee for the Protection of Nature.

[630] Ibid.

[631] Ibid.

[632] Khots, ``Plutonium Producing Reactors in Krasnoyarsk to be Shut Down."

[633] ``Russian Plutonium Reactors Closed for Conversion," *Moscow Rissiyskaya Gazeta*, in Russian, (translated in JPRS-TND-92-026, 31 July 1992, p. 25).

[634] V. Nelyubin, ``Mountains Cause Excess Misfortune from Excess Cleverness," *Moscow Komsomolskaya Pravda*, in Russian, 20 October 1992, p. 2 (translated in FBIS-USR-92-137, 24 October 1992, p. 25).

CHAPTER FIVE
NUCLEAR FUEL CYCLE ACTIVITIES

The fuel cycle of a nuclear reactor can be divided into three main stages. The first stage, the so-called front-end, involves mining and milling of uranium ore, conversion of uranium into U_3O_8 (called yellow cake), conversion of U_3O_8 into a chemical and physical form suitable as a reactor fuel (e.g., uranium metal or uranium oxide (UO_2), fabrication of the reactor fuel, and its delivery to the reactor. If the reactor operates with uranium enriched in the isotope U-235, U_3O_8 is first converted into UF_6 and enriched at an enrichment plant, before the enriched product is converted into appropriate chemical and physical form for the reactor fuel. The second stage of the fuel cycle is the use of the fuel--its irradiation--in the reactor. And the third stage, the so-called back-end of the fuel cycle, involves management and disposition of irradiated reactor fuel. In Russia, the fuel cycles of the production reactors are thoroughly integrated with the fuel cycles of the research, naval, and civil power reactors. Moreover, the front-end fuel cycle activities were integrated with the production of enriched uranium for weapons. This section addresses various aspects of the fuel cycle infrastructure--developed over the period of more than 40 years--focusing on production capabilities and potential developments of the facilities associated with the front-end, research, naval, and civil power reactors, and civil use and disposition of plutonium at the back-end of the fuel cycle.

Front-End of the Fuel Cycle

Uranium Flows in the 1980s

Figure 5.1 shows the flows of natural, low-enriched, and highly enriched uranium in the Soviet nuclear complex of the 1980s, the time when the complex was in its prime. A large fraction of uranium produced in the USSR and Eastern Europe was shipped to the metallurgical plant in Glazov for purification and conversion to metal. (Some uranium was used for enrichment or placed in the national reserve, and, starting in the late 1980s, uranium was exported to the West.) Metal ingots were fabricated into aluminum-clad natural uranium fuel for plutonium production reactors at the fuel plant at Novosibirsk. After irradiation in the production reactors at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26, fuel was reprocessed at the reprocessing plants at Tomsk-7 and Krasnoyarsk-26.[635] Plutonium that was extracted from irradiated fuel, was transferred to other facilities for fabrication into nuclear weapons components. Recovered uranium was converted to uranium hexafluoride at the conversion facilities at Angarsk and Tomsk-7, and then enriched from 0.66 percent U-235 to various levels of enrichment at the centrifuge plants at Sverdlovsk-44, Tomsk-7, Krasnoyarsk-45, and Angarsk.

Hexafluoride of low enriched uranium was converted to uranium oxide powder and pellets for civil VVER and RBMK reactors at the fuel fabrication plant at Ust-Kamenogorsk (Kazakhstan). The pellets were subsequently fabricated into fuel rods and assemblies at the fuel fabrication facilities at Electrostal (VVER-440 and RBMK) and Novosibirsk (VVER-1000). Irradiated fuel from VVER-1000 and RBMK reactors was placed in storage;[636] and fuel from VVER-440 reactors was reprocessed at Mayak together with BN-, naval-, and research-reactor fuel. Extracted reactor-grade plutonium was stored at Mayak, and reprocessed uranium was sent to Ust-Kamenogorsk for fabrication into RBMK fuel.

The flow of natural and low-enriched uranium was closely integrated with that of highly enriched uranium. Most HEU was produced from uranium recovered from irradiated natural uranium fuel of plutonium production reactors. Some HEU was used in nuclear weapons as well as fabricated in fuel of HEU-fueled naval and research reactors.[637] The rest was sent to the Novosibirsk plant for fabrication of HEU spike rods for the plutonium production reactors and HEU cores for two of Mayak's tritium production reactors. HEU fuel, irradiated to burnups

---

[635] Between 1987 and 1990 fuel from the plutonium-production reactors at Mayak was reprocessed at Tomsk-7.

[636] RBMK fuel has been stored on-site; VVER-1000 fuel has been transported (after a period of on-site storage) to a central storage facility at Krasnoyarsk-26.

[637] Some 1.5 t HEU is used for naval and research reactors each year. The material is drawn from the HEU stockpile. (E. Mikerin, Workshop in Rome and interview in Moscow in May 1992.)

of up to 75 percent, was reprocessed at Mayak; and the recovered uranium (about 50 percent enriched) was fabricated into naval reactor fuel at the Electrostal fuel fabrication plant.[638] Irradiated fuel of naval reactors was sent back to Mayak where it was reprocessed together with irradiated fuel of VVER-440 and other reactors.

Uranium Flows in the Early 1990s

To a certain extent, the above description of the uranium flows holds today. There are, however, major differences (see Figure 5.2). Because of cancellation of uranium mining operations in East European countries, or their re-direction to meet domestic requirements, and because of decentralization of the former Soviet uranium-production complex, the flow of natural uranium to the Russian nuclear complex has been significantly reduced. Minatom is responding to these changes by increased reliance on new sources of uranium, including the enormous stocks of natural and recycled uranium, and uranium recovered by ``mining'' the tails of past enrichment operations.

The uranium flows have also been changed because of dramatic reductions in defense requirements that have occurred since the late 1980s. The number of plutonium production reactors has been reduced from 13 in 1987 to three at present. Assuming that a 2000 MWt plutonium production reactor consumes approximately 1200 t uranium per year,[639] the shut down slashed the natural uranium requirements for plutonium production reactors from 15,000 t to 3600 t per year. The natural uranium requirements for the Soviet-built power reactors amount to approximately 7000 tU/y. Thus, a significant fraction of uranium bypasses the production reactors. Minatom plans to close the uranium fuel cycle of the plutonium production reactors by recycling recovered uranium into fresh fuel for these same reactors.

The shut down of 10 plutonium production reactors has reduced the demand in HEU fuel for material production reactors from about 1500 kg to 900 kg 90 percent enriched uranium per year.[640] The demand for HEU output from the production reactors has also dropped following the reductions in maritime activities by the Russian Navy and associated reductions in the demand for naval reactor fuel (fabricated from uranium recovered at Mayak). As a result, Mayak reportedly has been refusing to reprocess HEU fuel from the plutonium production reactors since the early 1990s.

The break up of the Soviet Union has lead to significant changes in the fuel fabrication complex. Mayak has already stopped sending reprocessed uranium to Ust-Kamenogorsk for fabrication into RBMK fuel, mothballing the recycle of uranium recovered from spent fuel of civil reactors. The break up also has stimulated Minatom to start consolidating fuel fabrication capabilities in Russia by rebuilding production lines to produce uranium oxide powder and fuel pellets at Electrostal for VVER-440 and RBMK reactors and at Novosibirsk for VVER-1000 reactors.

Uranium Resources

In the Soviet Union exploration of deposits of radioactive materials started in the 1920s and at that time was primarily related to the production of radium.[641] The first significant deposit of uranium was discovered in 1926 at

---

[638] A burnup of 75 percent means that 75 percent of the fissile content (atoms U-235) have been fissioned. Remaining uranium, 42.3 percent of the original amount of 90-percent enriched uranium, is about 53 percent enriched in U-235 and contains about 23 percent U-236 (ignoring formation of plutonium in U-238 and assuming capture-to-fission ratio of 0.169).

[639] Report at Working Group on Nuclear Reactors, Joint Study on Plutonium Production Reactor Replacement, USDOE, 14-16 March 1994.

[640] At a load factor of 0.7, HEU burnup of 75 percent, and HEU energy value of 1.05 grams per MWt-day, production of one MWt-year requires 0.36 t 90-percent enriched uranium. Thus, a 1000 MWt HEU reactor consumes 362.5 kg HEU per year. According to US sources, three plutonium-production reactors consume about 200 kg HEU per year (or 33 kg HEU per MWt-year). Thus with the combined capacity of about 22,600 MW, 13 plutonium-production reactors would have consumed about 750 kg HEU per year.

[641] Radium was considered to be precious metal and was produced for the national treasury.

Taboshar in Tajikistan.[642] In 1940 the Uranium Commission was set up. Its primary mission was to map out uranium reserves. However, industrial-scale exploration of uranium was not started until in 1945, when it became a part of the nuclear weapons program. Geologorazvedka (Geologic Exploration), a special unit of the Ministry of Geology was assigned responsibility for the geological survey.[643] The first effort led to discoveries of the Krivorozh, Stavropol, and Karamazar uranium districts.[644] In the 1950s, application of new geological survey methods, including airborne radiometry, resulted in discovery of major uranium ore districts in Kazakhstan and Uzbekistan, which became the basis for the uranium-production industry in the USSR. In the 1960s, systematic theoretical research in the area of geology of uranium deposits and ore formation models permitted discovery of deposits which are inaccessible for study by airborne radiometry. In particular, the Strelitsa district and new deposits in the Krivorozh and Kyzylkum districts were found. The Strelitsa and Kyzylkum district became the most important uranium mining areas in Russia and the Soviet Union respectively. Discoveries of sandstone type deposits in the Zauralsk and Vitimsk districts and black-shale deposits in the Kyzylkum and Onezhsk districts in the 1970s and 1980s completed the Soviet period of exploration of uranium resources.

The break up of the USSR has drastically reduced the domestic uranium base available to the Russian nuclear complex. To compensate the loss of resources, Russian geologists are exploring the Vitimsk and Zauralsk uranium bearing areas. No uranium exploration at new deposits is taking place in non-Russian republics.[645]

Known uranium resources are located in twelve districts with developed uranium deposits called ``uranium ore areas,'' and five undeveloped districts called ``uranium bearing areas'' (see Table 5.1). Most resources are located in Russia, Kazakhstan, and Uzbekistan. As of 1993, the known uranium resources in the categories Reasonably Assured Resources (RAR) and Estimated Assured Resources, Category I (EAR-1) in these republics amounted to 299,700 tU in Russia, 576,700 tU in Kazakhstan, and 230,000 tU in Uzbekistan.[646] (The figures likely provide for in-situ resources and do not account for mining and milling losses as well as for already mined uranium. As much as 340,000 tU might have been mined prior to 1991.[647])

Uranium Production

History and Technology. In 1942 the State Committee for Defense resolved to start uranium mining at the Taboshar deposit in Tajikistan.[648] In 1945 this first Soviet uranium production center was code named Combine

---

[642] A.K. Kruglov, ``On the History of Atomic Science and Industry,'' *Bulletin of the Center of Public Information*, No. 12, 1993, p. 32.

[643] The comprehensive geological survey was initiated by the governmental Decree of 13 September 1945.

[644] ``Uranium Raw Material Base,'' Science and Technology/Central Eurasia Engineering and Equipment, JPRS-UEQ-93-002, 5 February 1993.

[645] For example, ``Volkovgeologia,'' the geological exploration unit in Kazakhstan, is now working to identify the richest areas of the already known uranium deposits.  In addition, the unit conducts geological surveys of deposits of coal, gold, and polymetallic ores. Interview with S. Sushko, Deputy Director of ``Volkovgeologia,'' 2 August 1994 (translated in FBIS-USR-94-086, 9 August 1994, pp. 106-108).

[646] Uranium resources estimates are from the following: ``Uranium In The New World Market: Supply And Demand 1993,'' Uranium Institute, 1993, A. Mazurkevich, ``Uranium Mining in Uzbekistan,'' Nukem Market Report, and Yazikov, ``Kazakhstan's Uranium Resources,'' Uranium Institute Symposium, 8-10 September 1993, London. In addition, Russia and Kazakhstan respectively have 145,000 tU and 380,000 tU of the categories EAR-II and SR (speculative resources). Reasonably assured resources (RAR) are defined as resources that occur in known deposits and recoverable within the given production cost range (up to $130/kgU). Estimated assured resources, category 1 (EAR-I) correspond to resources that are expected to occur, the expectations are based on direct geological evidence or geological continuity; the data, however, are not sufficient to classify the resources as RAR. EAR-II corresponds to resources that are less certain than EAR-I; speculative resources (SR) are thought to exist on the basis of geological exploration or indirect evidences. ``Uranium: Resources, Production and Demand,'' OECD, 1986.

[647] ``Report on the OECD NEA Uranium Group Mission to the USSR,'' OECD, 1991, p. 20. In the report, OECD experts point out that 304,000 tU might be an over-estimate of the total production.

[648] Extraction of radium at the Taboshar mine started in 1930-1931. In 1941 the plant was expanded to produce strontium and bismuth. Kruglov, ``On the History,'' *Bulletin*, No. 12, 1993, p. 32.

No. 6 and resubordinated to the First Main Directorate. At that time, production of natural uranium was a bottleneck of the Soviet nuclear program. By the end of 1945, Combine No. 6 had produced seven t uranium. This covered only about one-half of the requirements of the experimental reactor F-1. The balance was drawn from the 100 t uranium stock which had been seized in Germany. However, the German uranium was not enough to meet uranium requirements of the uranium enrichment plant and plutonium production reactors under construction in the Urals.[649]

    In the late 1940s and in the 1950s, the increase of uranium production was based mainly on the expansion of Combine No. 6 in Tajikistan. Relatively small deposits were also developed in Central Asia, Russia, Kyrgyzstan, Kazakhstan, and Estonia. Additional amounts of uranium came from Czechoslovakia and East Germany with whom the Soviet Union signed uranium agreements in 1945 and 1946 respectively. Uranium shortages were not eliminated until in the 1960s, when large uranium production centers were put into operation in Ukraine, Uzbekistan, Kazakhstan, Kyrgizia, and Russia. The new facilities included the Eastern Combine (Kirovograd, Ukraine), Lermontov Mining Directorate (Piatigorsk, Russia), Prikaspyisky Combine (Mangyshlak, Kazakhstan), Navoi Combine (Kyzylkum, Uzbekistan), Tselynny Combine (Northern Kazakhstan), Malyshev Mining Directorate (the Urals, Russia), and Priargunsky Combine (Streltsovsky, Russia).[650]

    Exploration of uranium resources and construction of new production capacities were paralleled by advances in the technologies of uranium mining and extraction. Many advanced technologies were developed in the Institute of Chemical Technologies (formerly NII-10).[651] These for example, included the ``sorption non-filter continuous process,'' in which ion-exchange resins are put in contact with uranium ore at the step of ore leaching, and use of autoclaves for acid leaching.[652] The institute also developed processes involving co-recovery of phosphates, molybdenum, rare-earths and other minerals. Because of relatively low grades of uranium ores in former Soviet republics--0.01-0.3 percent--most uranium production was by- or co-production. By the early 1960s, the industry had also gained substantial practical experience in application of in-situ leaching mining techniques (ISL) allowing more effective and economic development of sand-stone and fish-bone deposits.[653]

    In the 1970s and 1980s, uranium demand was met by extensive and well coordinated mining and milling operations in the Soviet republics and by imports of uranium from Hungary, Czechoslovakia, East Germany, Bulgaria, and Mongolia with production amounting to approximately 16,000-17,000 tU/y. The break up of the Soviet Union has resulted in major restructuring of the tightly integrated Soviet uranium production industry. Uranium production centers were converted into independent commercial operations (see Table 5.2).[654] The uranium output has declined, reflecting the economic crisis in the former Soviet republics, reduction in or termination of defense requirements, depression of the international uranium market, and restrictive trade policies of the Western countries. Significant mining and production of uranium continue in four republics: Kazakhstan, Uzbekistan, Ukraine, and Russia.

---

[649] During 1946-1947, 200 t uranium metal were required to load the F-1 experimental and first industrial plutonium-production reactors. Kruglov, ``On the History,'' *Bulletin*, No. 12, 1993, p. 49.

[650] Kruglov, ``On the History,'' *Bulletin*, No. 12, 1993, p. 39.

[651] Initially, R&D on uranium hydrometallurgy was carried out in the Institute of Rare Metals and NII-9 (currently VNIINM).

[652] Conventional treatment of uranium ore starts with radiometric separation, classification and grinding. From the ground ore, uranium is recovered by leaching with sulfuric acid or alkali carbonate solution, subsequent concentration by ion exchange or selective precipitation, and purification in the process of solvent extraction.

[653] Typically, in-situ leaching techniques involve injection of sulfuric acid and oxidizer underground through a system of wells and subsequent pumping out of uranium-bearing solutions.

[654] Some of uranium producers have formed a voluntary association Redmetzoloto. The association provides its members with scientific support and assets in the procurement of equipment and raw materials.

Kazakhstan. In Kazakhstan, mining takes place in the Kokchetavsk, Pricaspiysk, Chu-Saryisk and Syrdarya uranium ore areas. In the past, uranium ore was processed at the milling facilities at Kokchetavsk and Actau, and in-situ leaching slurries from the mines of the Syrdarya and Chu-Saryisk areas were shipped for processing to Tajikistan and Kyrgyzstan respectively. The republic is in the process of reassessing the economics and organization of the uranium industry. There is an intention to phase out more expensive underground and open-pit mining at the Kokchetavsk and Pricaspiysk areas and to concentrate on in-situ leaching operations in the southern part of the country (the Chu-Saryisk and Syrdarya areas). The republic has already announced the suspension of uranium production at Aktau. Beginning in 1993, Kazakhstan terminated shipments to Tajikistan and scaled down the uranium supply to Kyrgyzstan. Uranium deliveries to Kyrgyzstan are planned to cease by 1996-1997. Kyrgyzstan plans to downsize its milling operation, to convert a part of it to the production of precious metals, and to explore local deposits of uranium. Tajikistan has already stopped uranium production. Instead, uranium slurries are shipped for processing to the Tselynny complex at Kokchetavsk. All produced uranium is for export to the international market.[655]

Uzbekistan. The Navoi Mining and Metallurgical Combine is also planning to phase out the open-pit operations at the Uchkuduk deposit and underground mining at Zarafshan (Vostok mine). During the period 1993-2000, the Combine plans to produce approximately 3000 t uranium annually, most of it by in-situ leaching techniques. This output can be increased to 3500-4000 tU/y depending on market conditions.[656] All Navoi uranium is marketed internationally.[657]

Ukraine. In order to cover its high domestic requirements, Ukraine continues underground mining in the Zheltye Vody uranium ore area. The ore is milled at the Eastern Combine at Zheltye Vody. Produced uranium is sent to Russia for enrichment and fabrication of reactor fuel. In 1993, Ukraine sent to Russia 1000 tU. The deficit of uranium (about 700 tU) was covered by Russia. Nuclear arms reductions provide another source of reactor fuel. According to the trilateral statement, signed by the presidents of the US, Russia, and Ukraine on 14 January 1994, Ukraine will be compensated for 50 t HEU from tactical and strategic nuclear warheads that have been returned for dismantlement to Russia. In 1994, Ukraine will receive 100 t of reactor fuel (apparently for VVER-1000 reactors). The total amount of fuel to be supplied to Ukraine corresponds to the equivalent of three to three and one-half years of its fuel requirements.[658]

Russia. The domestic Russian uranium requirements can be estimated at 6800 tU/y (see Table 5.3 and Table 5.4). In addition, Russia uses its uranium to fabricate fuel for Lithuania, and Kazakhstan, and, in part, covers uranium requirements of Ukraine and Eastern Europe. Russia provides 300 tU/y in addition to 1300 tU/y coming from Eastern Europe. Significant amounts of natural uranium are exported abroad. Annual exports involve 2200 t of natural uranium, 1000 tU recovered from uranium enrichment tails, and additional amounts of enriched uranium product exported through spot-market operations.[659] The current natural uranium production capacity is capable of

---

[655] Katep, the governmental nuclear corporation of Kazakhstan, supplies approximately 1,400 tU/y to Nukem Inc. according to the March 1993 agreement between the two companies. Kazakhstan also has supply agreements with Energy Resources of Australia and with a joint venture of Cameco/Uranerz. *Nuclear Fuel*, 14 March 1994.

[656] *Nukem Market Report*, No. 7, 1993.

[657] During the period of February 1 through August 31 1993, uranium exports from Uzbekistan amounted to 3,325 tU. Approximately 3,135 t U_3O_8 was sold to European buyers (reportedly Nukem GmbH); 190 t was imported to the U.S. by Nukem Inc. under grandfather contracts. The accuracy of export data is 10 percent. *Nuclear Fuel*, 6 December 1993.

[658] Interview with Mr. Grischenko of the Ukrainian Foreign Ministry, Kiev, June 1994. At present, the nuclear power program of Ukraine requires 25.4 t of 3.6-percent enriched fuel for VVER-400 reactors, 185 t of 4.4-percent enriched fuel for VVER-1000 reactors and 75.6 t of 2.4-percent enriched fuel for the Chernobyl reactors (2 units).

[659] The Program of Development of Nuclear Power in the Russian Federation.

supporting uranium exports at the level of 3500 tU/yr. According to Russian officials, it can be easily expanded to support export potential of 5000 tU/y.[660] Reportedly, the Russian government has made available for exports 60,000 t uranium from the national reserve.[661]

The domestic and export uranium requirements are met in Russia by procuring uranium from several sources. In 1993, approximately 2300 tU was produced by the Priargunsky uranium production complex. In the past, most of uranium ore processed at the complex was mined from underground and open-pit mines located in the Strelitsa district and Mongolia. As of 1991, only nine percent of the complex's output were from in-situ leaching operations. Recently, the underground mining was phased out. There is speculation that the high production costs may cause the complex to shut down. The Vitimsk and Zauralsk areas have been suggested for the development of new uranium operations.[662] Most of future uranium production is expected to rely on in-situ leaching mining techniques.

In addition to the mining of natural uranium, Russia produces uranium by reprocessing fuel from power reactors and by enriching tails of enrichment plants. Uranium is recovered from irradiated fuel of VVER-440, BN-350/600, and naval propulsion reactors at the Mayak reprocessing plant. Between 1981 and 1992, recovered uranium was fabricated into fuel pellets for RBMK reactors at the fuel fabrication plant in Ust-Kamenogorsk.[663] The break up of the Soviet Union and economic difficulties resulted in termination of recycle of uranium in Ust-Kamenogorsk. The uranium recycle was carried out on a pilot scale and has never reached the status of industrial application.[664]

Minatom plans to restart large-scale recycle of reprocessed uranium. The plan calls to cover fuel requirements of RBMK with reprocessed uranium after 1996; it is also planned to close the nuclear fuel cycle of the plutonium-production reactors starting in 1994.[665] Presently, the reactors are fueled with natural uranium. Some 1000 t/y of the equivalent of natural uranium is produced by enriching tails of enrichment plants. In the process of enrichment, the U-235 content in the tails is increased to the level of natural uranium. The rest of the uranium requirements-- an equivalent of about 1000 tU/y--is covered from the national stocks, estimated to be approximately 150 tU.[666]

Uranium Conversion

Except for the graphite moderated plutonium production reactors, essentially all reactors in Russia use enriched uranium fuel. Before uranium is enriched it is converted into UF_6, a uniquely suitable feed for gaseous diffusion and gas centrifuge uranium enrichment facilities. At atmospheric pressure UF_6 sublimates from solid into

---

[660] E. Mikerin, ``The Uranium Supply Picture through 2010. Russia,'' International Uranium Seminar 92, USCEA, 20-23 September 1992.

[661] Communication with Western experts, October 1994, Moscow.

[662] *Post-Soviet Nuclear Complex Monitor*, June 8 1994.

[663] The final uranium product of the RT-1 plant is uranium ``plav,'' $UO_2(NO_3)_26H_2O$ with the enrichment of 2.0-2.5 percent U-235.  To achieve the required level of enrichment the plav was mixed with HEU solution.  The level of enrichment could also be adjusted at the fuel fabrication plant at Ust-Kamenogorsk. Yu. Babilashvilli, F. Reshetnikov, ``Nuclear Fuel Cycle with Reactors VVER, RBMK, BN in Russia,'' *Izvestia Vuzov* (in Russian), No. 2-3, 1994, pp. 55-65.

[664] The principal problem relates to the presence of the uranium isotope U-232, which is an occupational safety problem. U-232 decays to Bi-212 and Tl-208, both high-energy gamma emitters.

[665] The Program of Development of Nuclear Power in the Russian Federation.

[666] See discussion of the HEU and natural uranium inventories. Some estimates suggest that the uranium stockpile is 227,000 tU. D. Bradley and K. Schneider, ``Radioactive Waste Management in the USSR: A Review of Unclassified Sources, 1963-1990,'' PNL, March 1990, pp. A.23-A.24.

gas at 57^oC; at elevated pressures (1.5 atmospheres) the substance can be liquefied at temperatures higher than 65^oC. Of special importance for isotopic separation is that UF_6 is a stoichiometric compound (unlike uranium oxides) and that fluorine does not have isotopes others than F-19. UF_6 is a conventional form of uranium in which it is traded on the world nuclear fuel market and fed into facilities fabricating fuel for power reactors.

In the Soviet Union, research on uranium fluorination was begun by the People's Committee of Chemical Industries early in the 1940s. The first 10 grams of UF_6 were produced in 1943.[667] Industrial deployment of fluorination technologies began in 1947 at the Rulon plant in Dneprodzerzhinsk. From Dneprodzerzhinsk, uranium hexafluoride was sent to the uranium metallurgy plant at Electrostal for reduction to uranium metal and fabrication into fuel for the experimental reactor F-1. At first, UF_6 was produced in a relatively ineffective process of direct fluorination of uranium oxide. In the 1950s it was replaced by the process of fluorination of uranium tetrafluoride (UF_4). The technology was based on dissolution of U_3O_8 in sulfuric acid, electrolytic regeneration of uranyl sulfate, and, in the final step, hydrofluorination. The principal conversion facility was built at Kirovo-Chepetsk in Russia. The plant had the capabilities to produce elemental fluorine, UF_4, and UF_6. At some point, the UF_4 and UF_6 conversion capability was transferred from Kirovo-Chepetsk to Tomsk-7, and the Kirovo-Chepetsk plant was essentially shut down.[668] Another large conversion facility was built at Angarsk. At each of these sites, the conversion plants are co-located with the uranium enrichment facilities. At present, the plants produce UF_6 in the process of fluorination in a single-stage flame reactor (fluorination in dust infusions). The technology was introduced in the mid-1960s and made possible fluorination of both uranium oxides and tetrafluoride.[669]

Both natural and reprocessed uranium are processed at the Tomsk-7 and Angarsk conversion plants. But the Tomsk-7 plant is likely to work primarily with reprocessed uranium feed. The plant in Angarsk is believed to be a principal conversion facility to support the nuclear power requirements. Its name-plate capacity is estimated at 22,000 t/y, the effective capacity at 18,700 t/y, and the 1993 production at 10,800 t.[670]

Uranium Enrichment

History and Technology. A coordinated effort on uranium enrichment was initiated in the fall of 1945.[671] It included research on gaseous diffusion (under I. Kikoin), electromagnetic (under L. Artsimovich), and counter-current thermo-diffusion methods (under A. Aleksandrov and I. Kikoin) of isotope separation. These activities started at Laboratory 2 of the Academy of Science and were coordinated by the Section 2 (uranium separation, molecular methods) of the First Main Directorate's Scientific-Coordination Council (Section 2 of the NTS PGU, under V.A. Malyshev). The section was assigned responsibility for technical decisions and recommendations on uranium enrichment. Early in 1946, after publication of the ``Smyth Report'' the NTS PGU decided to concentrate research on the gaseous diffusion technology.[672]

To intensify R&D work and to accelerate industrial deployment of designed equipment, the government

---

[667] Kruglov, ``On the History,'' *Bulletin*, No. 12, 1993, p. 55.

[668] The Kirovo-Chepetsk plant may have retained capability to process hexafluoride of depleted uranium and produce uranium tetrafluoride.

[669] Uranium conversion occurs in a continuous process and involves the following steps: a) production of elemental fluorine gas (F_2), b) fluorination of powdered uranium compounds in a fluorine flame, c) filtration of ashes and other solid impurities, d) sublimation of UF_6 in cold traps, and e) recycle of un-reacted fluorine and intermediate uranium-bearing compounds. See *Nuexco Monthly Report*, No. 272, 1991.

[670] The numbers are from, C. Grey ``Up Front in the CIS,'' *Nuclear Engineering International*, May 1994, pp. 16-20.

[671] The discussion on the development of enrichment technologies in 1945-52 is based on N. Sinev, ``Enriched Uranium for Nuclear Weapons and Power,'' *CNIIAtominform*, 1991.

[672] The Smyth Report, published 12 August 1945, confirmed that gaseous diffusion was the preferred technology used by the United States.

created Special Design Bureaus at the Leningrad Kirov Metallurgical and Machine-Building Plant and Gorki Machine-Building Plant.[673] The Design Bureaus and the plants were intended to compete in designing and manufacturing of gas-diffusion machines and other equipment. The research was also supported by the group of German scientists and technicians working out of the Sukhumi Physical-Technical Institute as well as by research institutes of the Academy of Sciences and various industries.

In late 1945 it was decided to begin construction of the first gaseous diffusion enrichment plant, designated D-1. An unfinished aircraft production facility at Verkh-Neyvinsk, 50 km northwest of Yekaterinburg (formerly Sverdlovsk) in the Urals, was chosen as the construction site. The plant, code-named Sverdlovsk-44, was brought on-line in the early 1949. However, technical problems, preventing it from production weapons-grade material, continued during most of the year. The principal problems were related to poor design, unreliability of equipment, and ``corrosion'' of $UF_6$. The latter, which referred to decomposition of $UF_6$ into uranium tetrafluoride ($UF_4$, called ``green powder''),[674] led to unacceptable losses of UF_6. As a result, the plant was capable of producing uranium enriched to only 75 percent U-235, when using an ineffective double-cycle arrangement (double use of the end enrichment stages). The 75-percent enriched product was subsequently enriched by the electromagnetic method to weapon-grade level at Sverdlovsk-45.

The problems were overcome in 1950 and the D-1 plant started production of tens of kilograms of 90-percent enriched uranium per year on its 7,040 machines organized in 56 cascades. The plant's enrichment capacity was 7,500 kilograms separative work units per year (kg SWU/y, more often shortened to SWU/y). In 1951 the plant was augmented by the D-3 plant with a six-fold increase in production of 90-percent enriched uranium production. The D-4 plant and the first stage of the D-5 plant were brought into operation in 1953. By that time, weapons-grade uranium was produced by about 15,000 machines of the Ural diffusion plant of Sverdlovsk-44 working around the clock.

``Diffusion machines were actively developed during the first decade [from 1949]. During that period, production techniques were mastered and 16 different models were manufactured. The separation capacity of the last model was 6500 times bigger than the separation capacity of the first model. The electricity consumption rate was reduced from 35,000 to 3500 kWh per SWU. The specific metal requirement decreased to two percent of the first model's. The newer diffusion machine models were much larger than the former ones. The flow rate of uranium hexafluoride through the diffusion barriers increased considerably. The production costs of compressors and refrigerators improved, and diffusion characteristics of porous filters improved. However, all gaseous diffusion plants in Russia were phased out due to their high electricity consumption. Gaseous diffusion technology used to produce enriched UF_6 has been completely replaced with gas centrifuge technology.''[675]

The technology of electromagnetic isotope separation also achieved the status of industrial application. The electromagnetic enrichment facility SU-20, a calutron, was brought into operation in Sverdlovsk-45, simultaneously with commissioning of the D-1 gaseous diffusion plant at Verkh-Neyvinsk (Sverdlovsk-44). The calutron was used to raise the level of enrichment of 75-percent enriched uranium, the product of the D-1 plant. After the gaseous diffusion technology has been mastered, the SU-20 calutron was used for the separation of stable isotopes. Finally, the facility was shut down and replaced by a weapons assembly complex. Another calutron, called S-2, was built at Arzamas-16 in 1969. The facility was used exclusively for production of high purity

---

[673] The present names are the Central Design Bureau of Machine-Building (TsKBM, St. Petersburg) and Pilot Design Bureau of Machine-Building (OKBM, Nizhni Novgorod).

[674] Decomposition of uranium hexafluoride was caused by the presence of moisture in the air, insufficient effectiveness of isolation filters designed to maintain high vacuum, corrosiveness of equipment, and increased temperatures.

[675] E. Mikerin, V. Bazhenov, and G. Solovjov, ``Directions in the Development of Uranium Enrichment Technology,'' 1993. According to *Nuexco Monthly Report*, No. 272, 1991, ``enrichment provided by gaseous diffusion accounts for less than five percent of their total output.''

isotopes of transuranic elements including plutonium, americium, and curium. Small quantities of these elements were used for establishing their physical properties, such as fission cross sections.[676]

In the 1940s, laboratory research on gas centrifuge separation was conducted by the German group leaded by Dr. Max Steenbeck, a former Siemens Company official in Germany. The group, based at the Sukhumi Physical-Technical Institute at Sinop (a suburb of Sukhumi on the Black Sea coast), was working on both subcritical- and ultracentrifuge designs. This research effort was shifted from Sinop to the Kirov plant in Leningrad by the fall of 1951. By the governmental decree of 1952, the R&D responsibilities for development of industrial application of gas centrifuge technology were assigned to the Leningrad Design Bureau leaded by N. Sinev. The Bureau was reinforced by the German group transferred to Leningrad in December 1952. Originally, the research was centered around the design offered by Max Steenbeck's group. However, in 1953 the work on Steenbeck's design was canceled and the Bureau started to work on indigenous centrifuge designs.[677] Other research institutes and design bureaus that participated in the development of the centrifuge technology include:
   * Molecular Physics Department of the Russian Research Center Kurchatov Institute (Moscow);[678]
   * Institute of Aviation Motors (VIAM, Moscow);
   * Pilot Design Bureau of Machine-Building (OKBM, Nizhny Novgorod);
   * Ural Electrochemistry Plant (Sverdlovsk-44).

Industrial deployment of the centrifuge technology started at a pilot-scale facility commissioned at Sverdlovsk-44 on 4 October 1957, some 4-5 years after the first pilot-production centrifuges were built in 1952. The pilot-scale facility contained 2500 centrifuges and was used to validate designs of centrifuges and support equipment.[679] The first industrial plant equipped with subcritical gas centrifuges was built and placed into operation in three phases extending from 1962 to 1964 in Sverdlovsk-44.[680] The centrifuge technology became the backbone of the Soviet enrichment program in the 1970s.[681]

Over the course of 35 years the industry has designed, built and operated five generations (eight models) of centrifuges; and as of 1993, centrifuges of the sixth generation were being built and installed.[682] All Russian centrifuges are based on subcritical designs.[683] Centrifuge rotors are made of aluminum reinforced with rings of composite materials. There are also reports that rotors are made of maragine steel and that carbon-fiber centrifuges have been developed and deployed on a limited scale. Typically, centrifuges operate at 15,000 rpm. The fifth-generation machine has a throughput about 40 percent higher than the fourth generation machines.[684] The

---

[676] *Nuclear Fuel*, August 15, 1994.

[677] Russian designs retained some of ideas developed by the German group. Specifically, N. Sinev, Chief Designer of the Leningrad Design Bureau, mentions the centrifuge's needle bearing and an oil dampener. N. Sinev, *Enriched Uranium for Nuclear Weapons and Power*. By the end of 1953, the Germans were transferred to the research institute of the Ukrainian Academy of Sciences in Kiev to work on unclassified projects. They were repatriated back to Germany in 1956.

[678] Research in the Kurchatov Institute of Atomic Energy in Moscow was started in 1954.

[679] Nuexco, ``Conversion and Enrichment in the Soviet Union,'' *Nuexco Monthly Report*, No. 272, 1991.

[680] Mikerin, Bazhenov, and Solovjov, ``Directions in the Development of Uranium Enrichment Technology,'' 1993.

[681] See, *Nuexco Monthly Report*, No. 272, 1991.

[682] Mikerin, Bazhenov, and Solovjov, ``Directions in the Development of Uranium Enrichment Technology,'' 1993.

[683] Ibid. Starting in 1957, development of every generation of subcritical centrifuges was accompanied by development of their supercritical analog. However, because of increased failure rate, the work on supercritical models were limited to the production of several hundred experimental machines, which were never used in industrial application.

[684] Ibid.

separation capacity of the latest centrifuge model is about ten times higher than the first model.[685]

The centrifuges currently in operation in Russia use three to five percent of the electricity required by gaseous diffusion.[686] Specific energy consumption has dropped more than three-fold from 180 to 50 kWh per SWU; with fourth generation machines operating at about 120 kWh per SWU, and fifth generation machines at 80 kWh per SWU.[687] The latest centrifuge model, currently being installed in some plants, requires about 50 kWh per SWU.[688] The Russian gas centrifuge machines are designed to be in continuous operation for 15 years with a failure rate of tenths of percent per year.[689] Compact unit designs allow easy replacement of failed machines. Production flexibility of the Russian enrichment facilities is achieved by low working inventories of UF_6 in the centrifuges, allowing easy reconfiguration of the cascade for a different product or tails assay.

Several alternatives to the gaseous diffusion and centrifuge methods of uranium enrichment have received attention in Russia, including experimentation with photochemical technology using lasers;[690] but these have not advanced beyond paper studies. According to the Russian enrichers, accumulated experience in R&D and commercial application of the gas centrifuge technologies in Russia, as well as its potential advances during the next 20-30 years make the technology to remain competitive well into the future.

Enrichment Plant Sites. There are four Russian uranium enrichment plant sites: the Ural Electrochemistry Combine, also called Sverdlovsk-44, near Verkh-Neyvinsk, which in turn is 50 km northwest of Yekaterinburg; the Siberian Chemical Combine at Tomsk-7; the Electrochemistry Combine, also called Krasnoyarsk-45, on the Kan River, 90 km east of Krasnoyarsk and 75 km west of Kansk in Siberia; and the Electrolyzing Chemical Combine at Angarsk, 30 km northwest of Irkutsk, near Lake Baikal.[691] Each of these sites is near large sources of electricity, which were needed to operate the gaseous diffusion plants that were previously used at these sites.[692] There are said to be 10 separate gas centrifuge plants (processing lines or cascades), replacing five gaseous diffusion plants, at these four sites.[693] Tomsk-7 and Angarsk are the only sites capable of producing UF_6, the enrichment plant feed material. Krasnoyarsk-45 began operations in 1964. Angarsk was the last of the enrichment sites to be built. In addition to these four principal facilities, enrichment cascades are installed at a number of R&D centers. For example, a 1000-centrifuge enrichment cascade is used for separation of non-uranium isotopes at Kurchatov Institute in Moscow.

Enrichment Production. As noted above, the Soviets relied on gaseous diffusion technology from 1949 to 1959, shifting to the more efficient gas centrifuge technology during the period 1959 to 1992.[694] Gaseous diffusion

---

[685] Ibid.

[686] Ibid.

[687] Ibid.

[688] Ibid.

[689] Ibid. In earlier designs, centrifuge's thrust bearings was expected to operate without replacement for three years; in modern designs bearings last for 20 years with the failure rate below 0.2 percent.

[690] Central Intelligence Agency, *USSR Energy Atlas*, January 1985, p. 43.

[691] The sites and locations are identified in Table 2.2.

[692] CIA, *USSR Energy Atlas*, January 1985, pp. 56-57.

[693] Christopher Paine, ``Military Reactors Go on Show to American Visitors,'' *New Scientist*, 22 July 1989, p. 22 (condensed from ``Soviets Reveal Nuclear Production Complex to visiting Americans,'' unpublished).

[694] The last gaseous diffusion cascades were shut down at Tomsk-7 in 1991-1992.

machines are still used for filtering out chemical impurities and for other support functions. The transition increased the combined enrichment capacity by a factor of 2.4 and reduced the electricity consumption by a factor of 8.2.[695] Currently the total enrichment capacity of Russia is estimated to be 14-20 million SWU/y (likely in the upper end of this range)--now composed entirely of gas centrifuge technology--at the four plant sites.[696] In part, this capacity is used to support fuel requirements for Soviet-built power reactors in Russia and other countries (see Table 5.3 and Table 5.4). A fraction of this capacity is used to enrich tailings from 0.18, 0.24, 0.32, 0.36, and 0.40 percent to 0.7 percent U-235, the level of natural uranium. In 1992, approximately 40 percent of the enrichment capacity was dedicated to tails enrichment.[697] An additional 1.3-2 million SWU per year, which corresponds to about six percent of the world SWU market, are exported as a part of long-term contracts and spot-market operations.[698] According to the estimate of the level of SWU consumption, the plants are operating at about one-half of their capacity. Evgeni Mikerin, the head of the Russian fuel cycle complex, has stated that Russia can increase its exports capabilities to up to 10 million SWU/y.[699]

In the past, all enrichment facilities except that at Angarsk produced HEU for weapons. Today, the facilities at Tomsk-7, Krasnoyarsk-45, and Angarsk are licensed to enrich uranium to the level of up to five percent U-235; the Sverdlovsk-44 facility is licensed to produce 30-percent enriched uranium.

The Ural Electrochemical Combine at Sverdlovsk-44 has exported enriched uranium product to the West since 1973. The complex is operating several enrichment cascades composed of centrifuge machines of the fourth and fifth generations. The cascades are housed in five buildings. The capacity of the plant accounts for 49 percent of the combined Russia's capacity and is reported to be approximately 10 million SWU/y.[700] Two enrichment cascades (with the combined capacity of 2-3 million SWU/y) are dedicated to enrichment of natural (unreprocessed) uranium. These are the only cascades that are capable of producing uranium for exports. The rest of the enrichment capacity in Russia has been used for enrichment of uranium recovered from irradiated fuel of plutonium-production reactors and is contaminated with U-232. Sverdlovsk-44 will be a principal facility involved in converting 500 t HEU to LEU according to the US-Russian agreement. The plant will probably be producing 1.5-percent enriched LEU from enrichment tails. Subsequently, the material will be blended with HEU from weapons to produce 4.4-percent enriched LEU. Blending and purging of impurities will be carried out in centrifuges. The facility will be capable of converting up to 10 t HEU a year.

The Tomsk-7 plant accounts for 14 percent of Russia's enrichment capacity. This corresponds to 2.8

---

[695] Kruglov, ``On the History,'' *Bulletin*, No. 11, 1993, p. 84.

[696] The combined capacity of the Russian enrichment plants remains a highly controversial figure. Most Western sources estimate it at 10-14 million SWU/y. Victor Mikhailov, in remarks at a meeting in Washington, DC hosted by the Committee on International Security and Arms Control of the National Academy of Sciences, 17 February 1993, gave a figure of 20 million SWU/y. This figure is consistent with several considerations. First, it has been stated that the domestic nuclear power requirements account for approximately 50 percent of the available capacity--we estimate the requirements to be approximately 9 million SWU/y and--second, there are reports that the capacity of the Ural Electrochemistry Plant, which accounts for 49 percent of the Russian enrichment capacity, is 10 million SWU/y.

[697] See Yu. Babilashvilli and F. Reshetnikov, ``Nuclear Fuel Cycle with Reactors VVER, RBMK, BN in Russia,'' *Izvestia Vuzov* (in Russian), No. 2-3, 1994, pp. 55-65. The Program of Nuclear Power provides a much lower projection, about 1.29 million SWU/y, for the use of enrichment plants for tails enrichment. According to Russian sources, if the centrifuge cascades are forced to shut down, there are excessive centrifuge breakdowns when the cascade is placed back into operation. By using enrichment tails, rather than using natural uranium, as the cascade feed material, more separative work is required to achieve the same amount of product. By mining the tails which are free, the enrichment enterprise is able to operate at a higher capacity, preserving equipment and jobs in periods of reduced product demand.

[698] The Program of Development of Nuclear Power in the RF. The projected worldwide enrichment demand for 1995 is 30.398 million SWU. M. Humphries, ``Uranium Enrichment Issues,'' Congressional Research Service Issue Brief, 5 November 1992.

[699] E. Mikerin, ``The Uranium Supply Picture through 2010. Russia,'' International Uranium Seminar 92, USCEA, 20-23 September 1992.

[700] Interview with nuclear fuel cycle experts.

million SWU/y (assuming the combined capacity of 20 million SWU/y). The plant consists of separation cascades, a condensation-evaporation facility, a facility for UF_6 homogenization, loading and sampling, and a quality control laboratory. A part of the enrichment capacity of the Tomsk-7 plant is dedicated to re-enrichment of reprocessed uranium under a long-term contract with the French firm Cogema.[701] Enriched uranium product is also produced by mixing reprocessed uranium from Cogema, uranium recovered from irradiated fuel of the Tomsk-7 plutonium production reactors, and HEU.[702] Uranium is enriched to some four percent U-235 at a rate of up to 500 t of reprocessed uranium per year. The contract will be in effect until the year 2000.

The Krasnoyarsk-45 and Angarsk enrichment plants account for 29 and 8 percent of Russia's enrichment capacity, respectively. Similar to the plants at Sverdlovsk-44 and Tomsk-7, they produce LEU and enrich uranium tailings. Some of the separation capacity is also used to separate non-uranium isotopes. According to Russian officials ``Centrifuge technology is . . . successfully used in Russia for isotopic separation of other chemical elements. Industrial gas centrifuge units satisfy the demands for stable isotopes of iron, tungsten, xenon, sulfur, molybdenum and a number of other elements. Centrifuge units have also been built for production of some high purity radioactive isotopes, such as Kr-85 and Fe-55.''[703]

HEU and Natural Uranium Inventories. The production of HEU for weapons in the Soviet Union continued from 1950 to 1988.[704] For a rough estimate of the inventory of weapons-grade uranium we assume the following:

a) A linear increase in gaseous diffusion enrichment capacity from zero in 1950 to 8.3 million SWU/y in 1962 (beginning of deployment of the centrifuge technology), and subsequently to 18.8 million SWU/y in 1988 (this corresponds to linear growth to 20 million SWU/y in 1991, when gaseous diffusion was phased out; 20 million SWU/y is a factor of 2.4 larger than 8.3 million SWU/y.)

b) A linear growth in enrichment capacity dedicated to the nuclear power program from zero in 1970 to 9 million SWU/y in 1988.

c) The assay of uranium feed is 0.66 U-235 for 120,000 t uranium recovered from irradiated fuel of plutonium production reactors;[705] and 0.71 percent U-235 for the rest of the uranium feed requirements. The HEU product is 90 percent enriched; the enriched uranium product produced for exports and the domestic nuclear power program is 3.6 percent enriched. The tails assay is 0.36 percent between 1950 and 1962 and 0.3 percent (case A) and 0.2 percent (case B) thereafter.[706] (In reality, the U-235 content in tails has decreased from 0.4 to 0.11 percent; the intermediate steps are 0.36, 0.32, 0.24, and 0.18 percent U-235.)

d) The Soviet Union and Russia have fabricated 500 HEU cores (200 kg HEU each) for its naval propulsion

---

[701] Assuming feed and tails assays of 0.9 and 0.3 percent U-235, the plant uses approximately 0.4 million SWU to produce 120 t enriched uranium product annually.

[702] Communication with Russian nuclear industry experts, October 1994, Moscow.

[703] Mikerin, Bazhenov, and Solovjov, ``Directions in the Development of Uranium Enrichment Technology,'' 1993.

[704] ``Since 1988 no highly enriched uranium has been produced for defense purposes;'' Mikerin, Bazhenov, and Solovjov, ``Directions in the Development of Uranium Enrichment Technology,'' 1993. Here, ``defense purposes'' probably implies ``for weapons.''

[705] Assuming annual consumption of 1200 to 1400 t natural uranium for one 2000 MW reactor, the cumulative uranium requirements through 1988 amount to approximately 110,000 to 130,000 t uranium.

[706] Production of 1 kg 90-percent HEU from 0.66-percent enriched uranium requires 185.87, 201.15, and 237.62 SWU at a tails assay of 0.36, 0.3, and 0.2 percent U-235 respectively. With natural uranium feed, production of one kilogram 90 percent HEU requires 193.09 SWU and 227.53 SW at a tails assay of 0.3 and 0.2 percent U-235.

program and for other HEU fueled reactors.[707]

e) Other uses and losses are adopted, as in Albright et al.,[708] and include nuclear weapons tests (10 t HEU), losses (3 percent of production), SWU exports to the West (40 million SWU starting 1973), and tritium production (7 million SWU).

Under these assumptions, the cumulative enrichment work to produce HEU was 49.8 million SWU before 1962 and 224.3 million SWU thereafter. In addition, 81 million SWU has been used to produce fuel for the Soviet Built power reactors. The HEU inventory can be estimated to be 1,270 t (case A) and 1,097 t (case B) 90-percent enriched uranium. The corresponding cumulative uranium feed requirements for the defense and nuclear power programs would be approximately 489,000 t uranium (for tails assay 0.3 percent) and 396,000 t uranium (for tails assay 0.2 percent).[709] In addition, approximately 71,000 t would be required for the production of LEU for exports.[710] The total uranium production in the former Soviet Union and Eastern Europe is estimated to be approximately 740,000 tU.[711] Thus, the estimated natural uranium inventory is 180,000 t (for tails assay 0.3 percent) and 309,000 t (for tails assay 0.2 percent) uranium. This does not account for exports of natural uranium which began in 1988-1989.

Fabrication of Uranium Fuel

Soviet-designed reactors are fueled with a variety of fuels. The plutonium production reactors are fueled with aluminum-clad metallic uranium. The cores of the plutonium production reactors are spiked with HEU cermet fuel made of uranium oxide particles in an aluminum matrix.[712] HEU cermet fuel is used in some other reactors as well (e.g., tritium production reactors and some research reactors). Some naval and research reactors are fueled with uranium alloys of different levels of enrichment. Virtually all commercial reactors are fueled with uranium dioxide ceramics.[713]

At present, fuel fabrication activities take place at three principal facilities (see Table 5.5): the Ulbinsky Metallurgical Plant in Ust-Kamenogorsk (in northeast Kazakhstan), Machine-Building Plant in Electrostal (50 km east of Moscow) and Chimconcentrate Plant in Novosibirsk. All three complexes became involved in the Soviet nuclear-weapons program at an early stage of its development.

The Electrostal Machine-Building Plant. The Electrostal plant (codenamed Plant No. 12) was transferred to the First Main Directorate in 1946.[714] During the first decades of its operation the plant had the following

---

[707] Soviet/Russian naval reactors are fueled with uranium of various levels of enrichment.

[708] David Albright, Frans Berkhout and William Walker, *World Inventory of Plutonium and Highly Enriched Uranium*, SIPRI (New York, Oxford University Press, 1993), p. 60.

[709] The HEU and tritium production would require 345,400 t before and 263,920 (case A) and 184,285 t (case B) uranium after 1962. The use of 81 million SWU to produce 3.6 percent LEU for the nuclear power program would require 143,350 t (case A) and 95,670 t (case B) uranium.

[710] Assuming that 40 million SWU have been used to produce 3.6-percent LEU from natural uranium and with the tails assay of 0.3 percent U-235.

[711] J. Stein, ``World Uranium Stockpiles: Potential Impact,'' paper presented at the International Uranium Fuel Seminar, Beaver Creek, Colorado, September 25-28, 1994, p. 2.

[712] Plutonium-production reactors use a ring of HEU rods to levelize the power output throughout the core. The tritium-production reactors use the driver-target core configuration.

[713] The first Soviet power reactor in Obninsk is fueled with vibropack-made dispersed uranium fuel (UO_2 particles in non-fissile matrix).

[714] Kruglov, ``On the History,'' *Bulletin*, No. 12, 1993, p. 49.

responsibilities:[715]

a) Starting 1946, the plant's main task was the production of uranium metal and its fabrication into fuel for the experimental reactor F-1 and plutonium-production reactors.[716] The process of production of uranium metal included processing of uranium ore, production of U_3O_8, conversion of U_3O_8 to uranium dioxide, and its subsequent reduction to metal in a reaction with metallic calcium. At first, the project was based on German technologies, experts and materials.[717] However, already in 1946 the Soviet scientists developed a more advanced technology based on reduction to metal of UF_4 and UF_6. Production of uranium-metal reactor fuels continued at Electrostal until 1968.

b) Development of technologies for processing and machining of metallic HEU and natural uranium into semi-spheres (pit- and reflector bomb components). This work was closely coordinated with NII-9 (currently VNIINM) which was responsible for the research of properties of uranium and plutonium and development of technologies to process these materials. The technologies were transferred to the Plant V at Chelyabinsk-65 which was producing fissile material components for nuclear weapons.

c) Production of magnets (1960-1967) and diffusion barriers for gaseous diffusion enrichment machines (1948-1960).

d) Production on neutron- and gamma-sources (1956-1967).

e) Development of technologies of separation of light elements and production of Li-6 and Li hydrides (1956-1962).[718] Li-6 was shipped to Chelyabinsk-40 for irradiation in a tritium production reactor (the first reactor AI was put into operation in Chelyabinsk-40 in 1951-1952); lithium hydrides were used for fabrication of thermonuclear weapons.

In the mid- to late 1960s, the focus of activities at the Electrostal plant shifted to the development of technologies and production of fuels for naval, research and power reactors. At present, the plant produces the following types of reactor fuel:

a) UO_2 powder, pellets, fuel rods and assemblies for VVER-440 reactors.[719]

b) Fuel rods and assemblies for RBMK reactors. Fuel pellets are supplied by the Ulbinsky plant in Kazakhstan.[720] The Electrostal plant is developing the capability to produce UO_2 powder and pellets for RBMK reactors: as of June 1994, the capacity of the RBMK UO_2 powder production line was 10 t/y.[721]

---

[715] Ibid., p. 59.

[716] The R&D support was carried out by the Institute of Rare Metals (the first batch of metallic uranium was produced here in 1944) and by NII-9 (VNIINM). Ibid., p. 50.

[717] In addition to uranium, the Soviets evacuated the German stocks of metallic calcium. The Electrostal facility was dependant on German calcium until 1948. Ibid., p. 55.

[718] Subsequently, the production of lithium was moved to Kirovo-Chepetsk, and, from there, to Novosibirsk.

[719] The technology of re-conversion of UF_6 to UO_2 is based on the ``dry'' gas-plasma technology. $UO_2$ powder is produced in two steps in the reaction $UF_6 + 3H_2 + O_2 \rightarrow UO_2 + 6HF$. The product is further processed to convert it into free-flowing ``press-powder,'' feed for the pellet production line. Yu. Babilashvilli, F. Reshetnikov ``Nuclear Fuel Cycle with Reactors VVER, RBMK, BN in Russia,'' *Izvestia Vuzov* (in Russian), No. 2-3, 1994, pp. 55-65.

[720] Before the Soviet break up, the Ulbinsky plant covered virtually all Soviet requirements in UO_2 powder and pellets.

[721] Correspondence with C. Grey, June 1994.

c) Fuel for naval reactors.

d) Fuel for the reactors BN-350/600, EGPs (Bilibino NPP), and AM (AM is the first Soviet power reactor in Obninsk).

e) Experimental fuels. Starting 1974, experimental fuels were produced at the Scientific and Production Enterprise ``Politekh,'' also located in Electrostal. As of 1994, the production was transferred to the Electrostal Machine-Building Plant.

The Plant of Chemical Concentrates (the Chimconcentrate plant, Novosibirsk). Production of fuel for plutonium production reactors began in Novosibirsk in the late 1950s or early 1960s. Currently the plant produces the following fuels:

a) Natural uranium metal aluminum-clad fuel for plutonium production reactors. The uranium metal ingots are supplied by the metallurgical plant at Glazov.[722]

b) HEU fuel for the material production reactors. This includes spike rods for the plutonium production reactors and reactor cores for the tritium production reactors.

c) HEU fuel for research and other types of reactors.

d) Fuel rods and assemblies for VVER-1000 reactors. Fuel pellets for VVER-1000 are provided by the Ulbinsky plant.[723] The plant's capacity is 1000 t VVER-1000 reactor fuel per year.

In addition to reactor fuel, the plant is a major producer of lithium and lithium products.

The Ulbinsky Metallurgical Plant (Ust-Kamenogorsk).[724] The plant was built in 1949. At first it specialized in uranium metallurgy. The plant, for example, produced beryllium-HEU alloys for naval reactor fuels. However, the plant's primary mission was to provide beryllium metal products for the Soviet nuclear and aerospace industries. Since 1976 the plant has been the principal producer of UO_2 power and fuel pellets for VVER and RBMK power reactors. At present, the complex consists of the following principal plants:

a) Beryllium plant. The plant produces beryllium metal, alloys, ceramics, and beryllium finished products. After the break up of the Soviet Union the plant has lost virtually all beryllium orders from its former clients.

b) Tantalum and super-conductor plant. The plant produces tantalum products for high-quality electronics and super-conductor devices.

c) Nuclear fuel plant. The plant operates two production lines for RBMK and VVER fuels. The VVER line operates on a batch basis: that is, after a batch of VVER-440 has been produced, the line is cleaned-out and ready to produce VVER-1000 fuel. The plant receives enriched uranium hexafluoride from Russia. The material is reduced to uranium dioxide powder, which is subsequently granulated in the presence of organic binder, compacted into

---

[722] In Novosibirsk the metal ingots are rolled into slugs and inserted into aluminum cladding. At first, the fuel fabrication technology in Novosibirsk was based on the processing of uranium ore, production of uranium metal and production of fuel.

[723] The plant is possibly producing or plans to produce UO_2 powder and pellets for VVER-1000 reactors.

[724] Discussions with plant's officials and site visit, October 1993.

pellets, and sintered.[725] The pellets are sent for fabrication into fuel rods and assemblies to the fuel fabrication plants at Electrostal (VVER-440 and RBMK) and Novosibirsk (VVER-1000). The name-plate capacity of the plant is 2,650 t/y of UO_2 fuel with enrichment levels between 1.6 and 4.4 percent U-235. Recently the plant operated well below its capacity. The situation is likely to become worse as the Electrostal plant develops the capability to produce UO_2 powder and pellets for VVER-440 and RBMK reactors.

In November 1994 600 kg of HEU were shipped from Ust-Kamenogorsk to Oak Ridge, Tennessee in the United States.[726]

The fuel fabrication complex also includes the Moscow Plant of Polymetals and the Chepetsk Mechanical plant in Glazov. The Moscow Plant of Polymetals produces control rods for nuclear reactors. The Chepetsk plant produces the following principal products:
   * natural uranium metal feed for the Novosibirsk fuel plant;
   * zirconium metal and zirconium alloys (the plant has been the principal producer of these materials since 1956);[727]
   * fuel rod tubing;
   * metallic calcium; and
   * depleted uranium products.

Future Prospects. Kazakhstan and Russia will remain principal manufactures of fuel for VVER and RBMK reactors. However, their monopoly has already eroded. Major Western fabricators of PWR fuels-- Westinghouse, Framatome, and Siemens--have developed their designs of VVER-440/1000 reactor fuels. The emerging competitiveness of the fuel market in Eastern Europe was demonstrated by Westinghouse winning the tender on supply of fuel for 2 VVER-1000 units which are under construction in Temelin, Czech Republic.[728] In order to retain traditional markets in Eastern Europe and non-Russian states of the Former Soviet Union and to become competitive on the Western fuel fabrication market, the Russian nuclear industry is pursuing an intensive R&D program of improvements in reactor fuel technologies. The program, called the Complex Program ``Fuel Rods and Assemblies of NPP Reactors,''[729] is designed to improve the economics of VVER reactors and extend their refueling campaign, as well as to develop fuels for new generation nuclear reactors. Designated areas of advances include the following:[730]
   * stability of properties and quality of uranium oxide   ceramics powder;
   * pellet fabrication technologies;
   * advanced structural materials and cladding (quality, recrystallization, Zr cladding with less than 0.01 percent Hf, bi-metal cladding, and welding technologies);

---

[725] Production of UO_2 is based on the conventional ADU process which involves hydrolysis of UF_6, production of $(NH_4)_3UO_2F_5$-type poly-uranium compounds in a reaction with ammonia, and calcining of the compounds to produce UO_2. Yu. Babilashvilli and F. Reshetnikov, ``Nuclear Fuel Cycle with Reactors VVER, RBMK, BN in Russia,'' *Izvestia Vuzov* [in Russian], No. 2-3, 1994, pp. 55-65.

[726] Michael R. Gordon, ``U.S. Negotiates Deal to Remove Bomb Fuel in Ex-Soviet Republic,'' *New York Times*, 23 November 1994, p. A1.

[727] V. Goncharov, ``First Period of Development of Nuclear Power in the USSR,'' IAE-5089/4, Moscow 1990. In the past, the Pridneprovsky Chemical Plant at Dneprodzerzhinsk was another significant producer of zirconium and hafnium.

[728] On 17 May 1993, Westinghouse and the Czech industry signed two contracts totalling $434 million. The contracts cover instrumentation and control equipment and fuel arrangements for two VVER-1000 units to be constructed at Temelin. The fuel contract involves design and fabrication of the first core and four reloads for each unit together with related services and equipment. Fuel will be fabricated at Westinghouse's fuel division in Columbia, South Carolina. *Nuclear Engineering International*, July 1993, p. 2.

[729] The Program ``TVEL and TVS for NPP reactors'' (Concern TVEL, VNIINM, Minatom, 17 April 1992). The second edition of the program is nearly complete. It will also address the problems of in-core fuel management. Konovalov, presentation at the Nuclear Society Meeting in Obninsk, June 1994.

[730] The Concept of Development of Nuclear Power in Russian Federation. 14 July 1992, The Council (Kollegia) of the Minatom RF.

* quality control of fabrication process;
* development and commercialization of the technology of gadolinium- and erbium-based in-fuel-burnable absorbers for VVER- and channel-type reactors respectively;[731]
* development of VVER fuel rods for dynamic regimes of reactor operation;
* development of plutonium fuel for fast and thermal reactors.

The work is carried out in the Bochvar Institute of Inorganic Materials (VNIINM, Moscow), Institute of Chemical Technologies (VNIIChT, Moscow), OKB Gidropress (OKB GP, Podolsk), OKB Machine Building (OKBM, Nizhny Novgorod), Research and Design Institute of Energy Technologies (NIKIET, Moscow), and Science Center ``Kurchatov Institute."

Nuclear Reactors, Other than Military Production Reactors

Civil Power Reactors

The Soviet program of nuclear power was begun in 1954 with the commissioning of the 5 MWe nuclear power plant in Obninsk. The serial deployment of civil nuclear power reactors began in the early 1970s. At present, Rosenergoatom, the state-owned nuclear utility organization, operates 29 units at nine sites in Russia.[732] As of the end of 1993, the installed capacity was 21,242 MWe (see Table 5.6). At the average load factor of about 65 percent for VVER, and 69 percent for RBMK reactors, the nuclear power generated in 1993 was 119.2 billion kilowatt hours (kwh) of electricity. The share of nuclear generated electricity in 1993 was 12.7 percent. Despite the economic crisis and chronic non-payments, the nuclear industry was developing at a steady pace. Unit No. 4 of the Balakovo nuclear power plant (NPP) near Saratov went critical in late March 1993 and was raised to the nominal power in December 1993. Unit No. 3 at the Kalinin NPP (Tver) and unit No. 5 at the Kursk NPP are about 80 and 60 percent complete and may be started in 1995.

In July 1992, Minatom put forward the conceptual program of development of nuclear power in Russia (the Concept).[733] The Concept foresees two phases. During the first phase of ``renovation" (1990-2000), the industry would modernize available generating capacities and develop a new generation of enhanced-safety reactors. The installed capacity will increase to 27,000 MWe mainly due to start-up of reactors already under construction. During the second phase (2000-2010), the capacity will increase to 39,000 MWe. The additional capacity will be provided by VVER-1000 and new-generation reactors. Simultaneously, the process of decommissioning old reactors will take place: 14 units totaling 7400 MWe will be shut down by 2010. After 2010, the Concept expects large scale development of nuclear power, including introduction of the closed nuclear fuel cycle and fast reactors. As a result, nuclear power would provide about 30 percent of electricity of Russia. The program was essentially confirmed by the Governmental Decree #1026 directing the Minatom to present its new power reactor projects to environmental and economics ministries for review and considerations. Projected reactors, Units 5 and 6 in Balakovo, a Voronezh district-heating station, and South-Ural and Beloyarsky BN-800 fast reactors, are planned to come on line by the end of the 1990s. Minatom will also start feasibility studies for the projects of three new nuclear power plants in the Far East and a 630 MWe unit at the Sosnovy Bor NPP near St. Petersburg. However, implementation of these plans is uncertain in view of the financial crisis both in the nuclear complex and in supporting industries (construction, machine-building, etc.).

Nuclear power continues to be an important source of electricity in Ukraine. In 1993, 14 nuclear power

---

[731] In-fuel-burnable-absorber allow extension of refueling campaigns. This leads to reduction in refueling outages and improves economics of a nuclear power plant.

[732] The Leningrad nuclear power plant has a considerable degree of autonomy.

[733] The Concept of Development of Nuclear Power in Russian Federation. 14 July 1992, The Council of the Minatom RF.

reactors with the combined capacity of 12,808 MWe produced 100.5 billion kwh electricity or 32.4 percent of its total production. Power shortages in the republic have forced the government to extend operation of units No. 1 and No. 3 of the Chernobyl NPP. At the G-7 summit in June 1994 Western countries launched international initiative to close the Chernobyl plant permanently in exchange for financial and technical aid to bring on line three VVER-1000 reactors: 95-percent complete Zaporozhye-6, and 80-percent complete Rovno-4 and Khmelnitsky-2.[734] New units would compensate for the closure of the units Chernobyl-1, -2, and -3. The Ukrainian government has agreed in principle to shut down the Chernobyl NPP. However, it would like to have an alternative power supply source prior to plant's shutdown. It is believed that the three new VVER-1000 reactors (see above) would cover only the already existing deficit of electricity and that completion of the units Khmelnitsky-3 and Khmelnitsky-4 or construction of two Western-designed units might be needed to meet energy requirements.[735]

The BN-350 reactor in Kazakhstan generates approximately 0.7 percent electricity and fresh water. The Kazakhstan Atomic Energy Agency has licensed the reactor to operate until 2003 when it might be replaced by a similar reactor. Reactor-designers in Russia, however, insist that the reactor must be shut down sooner on the safety grounds. The Kazakh authorities have determined that in the future, the republic will have to increase its reliance on nuclear power. As many as three light water reactors may be constructed in Kazakhstan by 2005.

In 1993, two RBMK units of the Ignalina plant in Lithuania generated 12.3 billion kwh electricity, or 87 percent of the total electricity production in the country. More than half of the plant's output was exported abroad: 33.8 percent to Belarus, 17.2 percent to Latvia, and some to the Kaliningrad area of Russia. The plant is expected to operate for another eight to ten years--time which is needed to consider alternative supply options.[736]

Plans to develop nuclear power exist in Belarus and Armenia. The Armenian government has decided to bring into operation the two VVER-440 units at Oktembryan that were shutdown in 1989 following the disastrous earthquake. Belarus, which imports electricity from Smolensk and Ignalina NPPs, has a tentative plan to construct 2000 MWe of nuclear generating capacity by 2005.

Naval Propulsion Reactors

The development of nuclear naval propulsion in the Soviet Union was initiated by Stalin's decree of 9 September 1952.[737] Two projects were started simultaneously in the Kurchatov Institute (under A. Alexandrov) and in the Physics and Power Institute in Obninsk (under A. Leipunsky). The Kurchatov Institute was mainly responsible for the development of a water-cooled water- moderated reactor (PWR); and the Obninsk Institute--for a lead-bismuth cooled reactor (liquid metal reactor, LMR). In 1953, the construction of full-scale prototypes of naval propulsion units with associated machinery installed inside submarine compartments began in Obninsk. The 27/VM and 27/VT facilities were prototypes of a light-water and liquid-metal reactors. They were started up in March 1956 and January 1959 respectively. In parallel, a naval training center was established in Obninsk and the first submarine ``Leninsky Komsomol'' (K-3) was under construction at the Severodvinsk plant. The submarine went into sea in 1958. In 1959 the first civilian nuclear-powered vessel--the icebreaker *Lenin*--was put into operation.[738]

---

[734] The Naples summit of G-7 (9 July 1994) approved a $200-million grant towards a Chernobyl closure program, in addition to $120-million in grants and $480-million in Euratom loans which were promised by European leaders earlier. *Nucleonics Week*, 21 July 1994 and 14 July 1994.

[735] *Nucleonics Week*, 10 November 1994.

[736] *Nucleonics Week*, 8 July 1993; *Nuclear Engineering International*, July 1993, p. 18.

[737] V. Stepanov, ``Numbered Building,'' *Gorod*, 3-4, 1994 Obninsk, pp. 76-79.

[738] Sea trials of ``Lenin'' began in 1957.  T. Nilsen and N. Bohmer ``Sources of Radioactive Contamination in Murmansk and Arkhangelsk Counties,'' *Bellona Report*, Volume I, 1994, p. 77.

At the peak, the Soviet Navy operated more than 400 propulsion reactors, on nuclear submarines and surface vessels. The nuclear Navy and the intensity of its operations are shrinking. As of 1992, Russia maintained only three SSNs and one SSBN on patrol at sea;[739] and 155 submarines are planned to be decommissioned from the Navy by the year 2000.

Soviet/Russian submarines were equipped with reactors of different designs. One November-class boat and six Alfa-class boats were powered with lead-bismuth cooled reactors. Because of high power density and small size of reactors, the LMR submarines were very fast. However, safety problems and high levels of noise from the propulsion units have lead to early retirement of LMR-powered submarines. Currently almost all Russian submarines are powered by one or two PWR reactors having power between 15,000 and 100,000 shp (shaft horse power).

The Russian nuclear-powered commercial fleet consists of five 54 MW-powered icebreakers of the *Arctica*-class (*Arctica, Sibir, Russia, Soyuz, Jamal*), two 32.5-MW powered *Taimyr*-class icebreakers (*Taimyr* and *Vaigach*), and one 29.42-MW powered *Sevmorput* transport ship.[740] One more *Arctica*-class icebreaker (*Ural*) is under construction in St. Petersburg.

The *Arctica*-class icebreakers are powered with dual reactor propulsion units with one reactor operating at low power. The *Taimyr*-class icebreakers are powered with one reactor. Beginning in 1970, the icebreaker program is based on a standard water-cooled water-moderated reactor KLT-40. The mission of the icebreaker fleet is to ensure 5-6 month-a-year navigation in the eastern part of the Severny Morskoy Put (Sevmorput, Northern Sea Way, the sea line connecting Murmansk with Russian Arctic ports including Petropavlovsk-Kamchatsky). The *Sevmorput* transport ship is powered by one KLT-10 reactor, fueled with 200 kg 90-percent HEU. Its primary mission is to provide shipment on the Murmansk-Dudinka (Norilsk industrial area) route.

Research Reactors

The information about research reactors, their design and applications continues to be sketchy. According to the 1993 report by Gosatomnadzor, the nuclear regulatory agency of the Russian Federation, 43 research reactors, 52 critical assemblies, and 18 subcritical assemblies are in the various stages of their life cycle in Russia.[741] (See Table 5.7). The report organizes these facilities into three classes according to their power and potential safety risks. Class 1 facilities include 12 research reactors with power levels of up to 100 MW. Their main use is for research on nuclear materials and reactor equipment. Class 2 facilities are 16 research reactors with power levels of up to 20 MW. Class 2 research reactors are used for fundamental research and production of radioisotopes. Class 3 facilities include 15 low-power (up to 1 MW) research reactors and 52 critical and 18 subcritical assemblies. They are used for neutron-activation analysis, training and R&D on reactor core systems. Out of these 113 units, 11 units are under construction (six research reactors, four critical and one subcritical assemblies), and 14 units are being decommissioned (nine research reactors and five critical assemblies). Additional number of research reactors are probably used for defense-related activities and are not reported in the Gosatomnadzor's report.

Back-End of the Fuel Cycle

---

[739] *Aviation Week and Space Technology*, 23 November 1992.

[740] The information is derived from interviews with naval propulsion reactors designers and booklets by the Murmansk Shipping Company, which operates the fleet.

[741] ``Report on Activities of Gosatomnadzor in 1993,'' RD-03-02-93, (order No. 61, 13.05.94), pp. 24-26.

Minatom policy, at least since the mid-1970s, has been to close the back end of the civil power reactor fuel cycle, that is, to reprocess the spent fuel from the VVER type power reactors, recycle the recovered plutonium and uranium, and vitrify the high level nuclear waste. The recovered plutonium was intended primarily for fast breeder reactors, although an R&D program also existed for use of MOX in VVERs. To date the overall objective has not been realized. An overview of the principal activities related to the back end of the fuel cycle is provided below. More detailed descriptions of the specific facilities at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26 are discussed in Chapters Three and Four.

Fuel Cycle of Fast and VVER Reactors

Irradiated fuel of VVER and BN-350/600 reactors is kept in water pools on-site for at least 3 years. After that, fuel of VVER-440 and BN-350/600 reactors is shipped to the RT-1 plant at Chelyabinsk-65 where it is reprocessed together with naval and research reactor fuel. The RT-1 chemical separation plant was shifted away from recovering plutonium from military plutonium production reactor fuel to processing naval and power reactor fuel in 1977.[742] Recovered plutonium is stored as plutonium dioxide powder on-site. About 27 t of separated reactor-grade plutonium has been accumulated at Chelyabinsk-65 through the end of 1997. Uranium recovered from spent fuel is 2-2.5-percent enriched in U-235. In the past it was recycled in RBMK reactors. Currently it is probably stored on-site in the form of uranyl nitrate hexahydrate. HLW, which results from reprocessing operations, are vitrified in a glass melter. Radioactive glass blocks are slated for disposal in geological formations. An international laboratory to study geological disposal has been proposed by Minatom for the Mayak site.

Spent fuel of VVER-1000 reactors is transferred to the RT-2 spent fuel storage facility at Krasnoyarsk-26. The facility with auxiliary and service buildings was brought into operation in December 1985. It was designed as a part of the 1500 tHM/y RT-2 chemical separation plant. The construction of the RT-2 plant began in the 1970s and halted in 1989 as a result of public opposition and lack of funds.

Management of spent fuel is more difficult for the Ukrainian operators of VVER-1000 reactors as no shipment of spent fuel from Ukraine to Krasnoyarsk-26 has occurred for more than two years. Some reactor units were able to re-rack their cooling pools and thus to increase storage capacity. However, the Ukrainian authorities see more durable solution in the development of on-site dry storage capacities. In December 1993 the Zaporozhye NPP, operation of which is threatened by the lack of at-reactor storage, signed an agreement with Duke Engineering and Services Inc., for concrete ventilated storage casks, similar to those which are currently used in the US.[743]

RBMK Fuel Cycle

Because of low concentrations of fissile isotopes, there are no plans to reprocess RBMK spent fuel. As of the end of 1992, there was about 7700 tHM of RBMK spent fuel in storage at the reactor sites, containing about 32 t of plutonium, distributed as follows:[744]

Country	Spent Fuel (tHM)	Plutonium (t)
Russia	5500	23
Ukraine	1500	6

[742] The plant was modified to process spent fuel from naval reactors (both submarine and icebreakers) in 1976.

[743] *Nuclear Fuel*, January 17, 1993.

[744] E.G. Kudriavtsev, ``Russian Prospects for Plutonium Accumulation and Utilization,'' Minatom, 1992. and V.N. Sololin, ``Utilization of Nuclear Materials Released as a Result of Nuclear Disarmament,'' International Symposium on ``Conversion of Nuclear Warheads for Peaceful Purposes,'' Rome, Italy, 15-17 June 1992; reported about 25 t of plutonium in about 6000 tHM as of the beginning of 1992.

Lithuania   700   3

Up to 35,000 tHM of spent fuel is projected to accumulate over the lifetimes, assumed here to be 40 years, of all the RBMK reactors.[745] RBMK spent fuel is kept in the reactor building for three to five years and, afterwards, in pools of water in special on-site buildings. Each special store has the capacity to hold 17,500 spent fuel assemblies, representing about 2000 tHM. This is sufficient storage capacity for a plant with four reactor units for 10 years. As of 1993, stores were in operation at the St. Petersburg and Kursk nuclear power plants, and were under construction at the Smolensk nuclear power plant. Due to the delay in a project for a centralized store for spent fuel assemblies from RBMKs, plans to double the capacity of each plant store are under way. Also, in the summer of 1994 the Russian nuclear utility Rosenergoatom signed a contract with the French engineering group SGN/Reseau Eurisys. The contract is to build dry storage facilities at the Kursk (8000 t) and Smolensk (5000 t) nuclear power plants. It is expected that the facilities will be in service by 1997-1998. A similar but smaller facility will be built by SGN's subsidiary GNB at the Ignalina plant in Lithuania.

No final decision on how to dispose of RBMK spent fuel has been made so far. Several options under consideration include, burial of fuel in super-deep boreholes and its disposal in the permafrost. Since Novaya Zemlya has been used as a test site, Minatom considers this area more politically acceptable than other potential disposal sites in northern Siberia.[746]

Mixed-Oxide Fuel Fabrication and Use

Early research on plutonium fuel were initiated in Bochvar's Institute of Inorganic Materials (VNIINM, Moscow) in the 1950s. Since then, the industry has operated a number of research installations fabricating plutonium into fuel which was tested in critical assemblies, research and power reactors (see Tables 5.8 and 5.9). At present, the principal work on design and fabrication of plutonium fuel, and reactor core concepts is carried out in the Institute of Inorganic Materials, Physics and Power Institute (Obninsk), Institute of Atomic Reactors (NIIAR, Dimitrovgrad), Khlopin's Radium Institute (St. Petersburg), and Production Association Mayak (Chelyabinsk-65) (see Table 5.10). The R&D program has engaged in MOX fuel fabrication technologies and in use of plutonium fuel in research and BN-type power reactors.

The principal MOX fuel technology is based on the Institute of Inorganic Material's ammonia process. The technology involves granulation of co-precipitated U/Pu hydroxides using surface agents, production of oxide powder and fuel pellets, and conventional process of fabrication of fuel pins and assemblies.[747] Mechanical and reactor features of produced MOX fuel are close to those of uranium oxide fuel. Another technology was developed in the Institute of Atomic Reactors (Dimitrovgrad). Dimitrovgrad's technology is based on pyroreprocessing, electrochemical granulation and vibrocompaction of Pu and U oxides. Both technologies have been validated at laboratory and pilot-scale facilities operating at NIIAR and Mayak. About 2000 fuel pins have been fabricated and subjected to reactor tests.[748] In 1984 the industry initiated construction of the industrial MOX fabrication plant ``Complex 300''at Chelyabinsk-65. A fully automatic production line with the design throughput

[745]   B. Zakharkin (VNIINM), ``Reprocessing and the Future of Nuclear Fuel Cycle in Russia,'' paper presented at the international workshop ``Reprocessing of Nuclear Fuel, Storage and Disposition of Civilian and Weapons Plutonium,'' 14-16 December 1992, Moscow.

[746] *NUKEM Marketing Report*, February 1993, p. 39.

[747] The technology involves dissolution of plutonium and uranium in nitric acid and their oxidation to the valence 6, co-precipitation by peroxide and flocculation in the presence of high-molecular surface agents (polymers), filtering and reduction of co-precipitated uranium and plutonium to oxides at 120-150°C, and heating the product at 800°C to produce stoichiometric powder. The process is controllable and stable. It allows production of granulate with specified bulk density, particle size, and flowability. V. Soloukhin, ``Conversion of Nuclear Warheads for Peaceful Purposes,'' Rome, June 1992.

[748] The operating parameters for the fuel are as follows: the cladding temperature of 690°C, linear power density of 490 W/cm and burn-ups up to 10 percent.

of 5-6 tPu a year, would produce conventional pelletized fuel for BN-type fast reactors of the South-Ural and Beloyarsk nuclear power plants. Financial problems and uncertainty with the BN-800 reactors put the MOX plant on hold when it was about 50 percent constructed.[749]

Minatom's plans for closing the fuel cycle and developing fast breeder reactors call for completion of the ``Complex 300'' MOX plant and construction of three BN-800 reactors at the Chelyabinsk-65 and one at Beloyarskaya sites.[750] BN-type reactors are designed for both production of power and utilization of plutonium. With current designs of reactor cores, BN-600 and BN-800 reactors are capable of utilization of about 0.6-0.75 tPu/y and 1.6-1.8 tPu/y with the initial loads of 1.2 and 2.3 tPu respectively.[751] (See Table 5.11). Minatom has conducted technical and economical evaluations of several options of utilizing plutonium in BN-type reactors. They include use of MOX fuel in BN-type reactors with traditional designs of reactor cores and uranium oxide blankets, modernized cores and thorium metal blankets, and use of new ``cold''[752] cermet fuel in reactors with advanced cores and thorium blankets.[753] On the basis of this analysis, the industry has proposed a concept of utilizing plutonium from weapons which comprises the following elements: a) long-term storage of plutonium, b) fabrication of plutonium into MOX fuel for BN reactors using existing technologies, c) development of Mayak-type nuclear centers comprising power reactors, fuel fabrication, and reprocessing facilities, and d) development of a dedicated plutonium burner.

The Minatom plans for closing the fuel cycle and developing breeders have been, and are being, modified to account for the disposition of the excess plutonium from retired weapons. Some U.S. experts have advocated burning excess Russian plutonium in Russia's seven VVER-1000 [voda-vodyanoi energetichesky reaktor-1000] light water reactors at a concentration of 0.35 tPu per reactor (one-third core loading), with an annual consumption of 2.5 tPu for all seven reactors.[754] Use of plutonium in thermal reactors has always been perceived by some Minatom experts as both unsafe and ineffective. The R&D program on use of MOX fuel in VVER-1000 light water reactors was not initiated until recently, when it became apparent that the program of fast reactors may not be completed or that fast reactors may not be able to handle the accumulated stockpiles of military and civil plutonium in Russia. Currently the research program is coordinated by the Khlopin's Radium Institute. Technology to produce MOX fuel for VVER-1000 reactors would likely be based on that developed for production of fast reactor fuel. More research is needed for the development of a reactor-core concept. If the results of the research are positive, a MOX plant fabricating fuel for VVER-1000 reactors may be constructed at Krasnoyarsk near the RT-2 chemical

---

[749] Minatom's experts estimate the total cost of the project to be about $30 million. International Workshop ``Reprocessing of Nuclear Fuel, Storage and Disposition of Civilian and Weapons Plutonium,'' 14-16 December 1992, Moscow.

[750] Under the decree ``On Construction of Nuclear Power Plants on the Territory of the Russian Federation,'' adopted by the government, the first two BN-800 reactors are to be constructed by the year 2000--one at the South-Urals plant at Chelyabinsk-65 and the other at Beloyarskaya. Two additional BN-800 reactors at the South-Ural plant are to be brought on line by 2006. The BN-600 reactor is to be decommissioned around 2005. The Concept of Development of Nuclear Power in the Russian Federation. 14 July 1992, the Council of the Minatom RF.

[751] It is assumed that only one half of the BN-600 core would be MOX. With a modified 100 percent MOX core, the BN-600 reactor would consume 1 tPu/y.

[752] Because of high thermal conductivity, the temperature at the center-line of a fuel pin of cold fuel would not exceed 600-700°C (against 2,000-2,500°C in uranium oxide ceramic fuels). Use of ``cold'' fuel would allow a substantial increase in reactor safety.

[753] V. Murogov, ``Energy Conversion of Weapons Plutonium,'' paper presented at the international workshop ``Reprocessing of Nuclear Fuel, Storage and Disposition of Civilian and Weapons Plutonium,'' 14-16 December 1992, Moscow.

[754] Assuming a capacity of 3000 MW$_t$, a burnup of 40,000 MWd/t, 4.4% enriched fuel, and a capacity factor of 0.677 (the average for 1992), a one-third plutonium loading for one reactor would be $(3000*365*0.677*0.044)/(40000*3) = 0.27$ t; or 1.9 t for seven reactors. At a burnup of 36,000 MWd/t, and capacity factor of 0.8 (assumptions used in Table 20), the consumption increases to 0.35 Mt per reactor.   Some Russian experts argue that the amount of weapon-grade plutonium that can be loaded into a VVER is less than the amount of reactor-grade plutonium due to differences in the reactivity of plutonium-240. Consequently, the rate of consumption of weapon-grade plutonium consumption may be even less than 1.9 t/y for seven VVER-1000s.

separation plant after the year 2005.[755]

Another option--one favored by Minatom Minister Mikhailov in 1994--is to replace the three remaining dual-purpose production reactors at Tomsk-7 and Krasnoyarsk-26 with light water or gas cooled reactors and use these to burn MOX produced with plutonium from weapons. Whatever the choice, it will take decades to convert the weapon plutonium into spent fuel by fueling Russian reactors.

---

[755] The Concept of Development of Nuclear Power in the Russian Federation. 14 July 1992, the Council of the Minatom RF.

CHAPTER SIX
RADIOACTIVE CONTAMINATION FROM NUCLEAR-POWERED VESSELS*

Introduction

From the early 1950s, the Soviet Union had an active program for the construction of nuclear-powered submarines and surface vessels for military and civilian purposes. By the beginning of 1994, the Soviet Union (now Russia) had constructed 256 nuclear-powered vessels including: 243 submarines, three cruisers, one communications/missile-range ship, eight icebreakers, and one transport ship.[756] Some 466-481 nuclear-reactors were on board these vessels (see Appendix D). In addition, the Soviet Navy made use of several land-based training reactors including at least two at a naval training complex in Paldiski, Estonia. Historically, two-thirds of the submarines and surface ships were in the Northern Fleet and based on the Kola peninsula. The rest were in the Pacific Fleet mostly based near Vladivostok and Petropavlovsk. All of the civilian ships were based at Murmansk.

The normal operation of these submarines and ships resulted in the production of considerable amounts of low-, medium-, and high-level radioactive waste. Waste was disposed by dumping in waters near the Soviet Union in the Baltic, Arctic, and Pacific; by placement in shore-side naval storage sites on the Kola peninsula, at Severodvinsk on the White Sea, on the Shkotovo peninsula near Vladivostok, and on the Kamchatka peninsula and; by storage on naval service ships found at nuclear naval facilities in the North and Far East. Some spent naval fuel was also sent to the reprocessing facility at Mayak.

Accidents aboard these nuclear-powered vessels also lead to the creation of additional amounts of radioactive waste. Liquid waste from accidents was discharged from land-based facilities or further at sea from service ships. Solid waste was transferred to shore-side storage facilities or dumped at sea. In the most extreme cases, six nuclear reactors and one reactor screen assembly along with their nuclear fuel were dumped in the Kara Sea in the Arctic. Accidents also resulted in the permanent loss of three nuclear-powered submarines (carrying five nuclear reactors and as

*Joshua Handler contributed substantially to this chapter and to Appendices D, E, and F.

---

[756] Numbers of nuclear-powered submarines from: V. Marinin and V. Dotsenko, ``90 Years of Russian Submarine Building,'' *Military Parade*, (Moscow), July-August 1994, p. 11 and author's estimates. Numbers of nuclear-powered military surface vessels from *Jane's Fighting Ships 1994-1995*, pp. 547, 583. Numbers of nuclear-powered civilian vessels from Russian Federal Nuclear Inspectorate [Gosatomnadzor], ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993, Parts I, II,'' Approved by Order of the Gosatomnadzor, No. 61 from 13 May 1994 (Moscow), p. 48.

many as 38 nuclear warheads in total) in the Atlantic and one
additional nuclear-armed but diesel-powered submarine (carrying an estimated five nuclear warheads) in the Pacific.[757]

Waste disposal procedures and accidents have lead to contamination of naval facilities and adjacent land and water areas and naval service ships in the North and Far East. The dumping of radioactive waste at sea, particularly damaged reactors with their spent nuclear, also has created the possibility of serious contamination of the marine environment in the Arctic and northern Pacific.

In addition to these past issues, the Russian Navy currently faces an ongoing problem in dealing with the waste being generated by operational submarines and the decommissioning of large numbers of nuclear-powered submarines. Shipyards and naval facilities in the North and Far East are crowded with decommissioned nuclear submarines and storage for radioactive waste are at capacity and in poor shape. This chapter will examine the problems of dealing with the radioactive waste resulting from the operation of nuclear-powered vessels by the Soviet Union and now Russia.

Background

In 1989-1990, reports of large-scale dumping of nuclear waste at sea by the Soviet Union began to circulate in the Murmansk and Vladivostok areas. Only in September 1991, however, did authoritative information about the former Soviet Union's practice of dumping RW in the Northern seas become available.

Andrei A. Zolotkov, a nuclear engineer from the Radiation Safety Service of the state owned Murmansk Shipping Company (MSC), and a Union People's Deputy for the Murmansk region, revealed how the MSC had dumped liquid and solid radioactive waste in the Barents and Kara Seas from 1963 to 1986, including the damaged reactor screen containing spent nuclear fuel from the icebreaker *Lenin*.[758] Much of this dumping seemed in contradiction to the Soviet Union's obligations under the London Convention--the international forum which regulates the disposal of radioactive and other hazardous wastes into the oceans. His disclosure drew international attention, and his information was provided to the annual meeting of the London Convention in November 1991.

Due to concerns about the reactions of the authorities, Zolotkov's presentation was careful to focus on the activities of the civilian MSC and to skirt the issue of the Navy's dumping. But in February 1992, Aleksandr F. Yemelanenkov, a Union People's Deputy from the Arkhangelsk region and a critic of the Navy's safety record, provided information about extensive dumping of radioactive waste by the Navy. In an article in *Sobesednik*, he wrote that the Navy had dumped 12 damaged submarine reactors, five containing their fuel in the Kara Sea in bays and areas near Novaya Zemlya. Also, three damaged reactors from the icebreaker *Lenin* and some 17,000 containers of radioactive waste had been dumped in the Barents and Kara Seas. The radioactive inventory of the dumped materials was incomplete, but at least 22,250 Ci had been dumped.[759]

Throughout the summer and fall of 1992, there was increasing pressure on Russia to provide further

---

[757] William Arkin and Joshua Handler, *Neptune Paper No. 3, Naval Accidents 1945-1988* (Washington, DC: Greenpeace, June 1989); Joshua Handler, Amy Wickenheiser and, William M. Arkin, *Neptune Paper No. 4, Naval Safety 1989: The Year of the Accident*, (Washington, DC: Greenpeace, April 1990).

[758] Andrei A. Zolotkov, ``On the Dumping of Radioactive Waste at Sea Near Novaya Zemlya,'' paper presented at Greenpeace Nuclear Free Seas Campaign/Russian Information Agency Seminar, ``Violent Peace--Deadly Legacy,'' Moscow, 23-24 September 1991. The MSC--part of the Russian Ministry of Transportation--operates the fleet of nuclear-powered icebreakers and the transport ship out of the port of Murmansk (at the Atomflot facility). Zolotkov worked aboard the *Imandra*, a nuclear service ship.

[759] Alexander F. Yemelanenkov, ``The Secret Logbook or the Second Discovery of the Novaya Zemlya Archipelago,'' *Sobesednik* (Moscow), 4 February 1992.

information about the past radioactive waste dumping at sea.[760] As a result of mounting concerns and questions, on 24 October 1992, Russian President Boris Yeltsin ordered the formation of a government Commission--chaired by Professor Alexei V. Yablokov, the adviser to the President on ecology--to investigate the dumping of radioactive waste (RW) at sea. The Commission examined Russia's observance of international commitments and her future ecological safety. The Commission submitted its report (the so-called Russian White Book or Yablokov Report) to the President in February 1993, and to the Administration (on behalf of the President) on 18 March 1993.[761]

The Commission focussed on providing information about deliberate dumping and burial of liquid and solid RW in the seas surrounding the Russian Federation. Some information was also provided about several Soviet nuclear submarine accidents which have lead to the contamination of the marine environment.

Origins and Overview of Total Amounts of RW Dumped at Sea

According to the White Book, the Soviet Union failed to develop or invest in the technology necessary to reprocess, store, and dispose of naval RW, including tens of thousands of spent nuclear fuel elements generated by naval nuclear reactors. Initial efforts were made in the 1960s to design and build liquid RW treatment plants and solid RW compacting complexes, but they were halted in 1972, in part because the former Soviet Union had approved plans for the sea burial of low- and medium-level RW (the cheapest option), and in part because of the perceived absence of immediate hazards from such dumping. In addition, the Soviet Government never implemented its resolution, passed in 1985, to construct special land-based storage facilities in the Northern and Pacific fleets for the burial of submarine reactor compartments.[762]

The first ocean dumping of RW by the Soviet Union was connected with performance tests of nuclear-powered submarines and icebreakers. The earliest recorded dumping occurred in October 1959 in the White Sea as a result of the first voyages of the first Soviet nuclear-powered submarine--around 600 m^3 of low-level liquid waste (0.02 Ci) was dumped.[763] Then in 1960, 100 m^3 of liquid RW (total activity of 0.2 Ci) from the *Lenin* nuclear-powered icebreaker--the world's first nuclear-propelled surface ship--was dumped near Gogland Island in the Gulf of Finland.[764]

The USSR began dumping liquid[765] and solid RW[766] on a regular basis in the seas surrounding the Russian

---

[760] A joint Russian-Norwegian scientific expedition to the Kara Sea took place in August-September 1992 and a Greenpeace expedition attempted to document the condition of a damaged submarine dumped in Novaya Zemlya's Stepovov Gulf in mid-October 1992.

[761] Unless otherwise noted, all data on ocean-dumping of radioactive waste is taken from this comprehensive report: Alexei V. Yablokov, et al., *Facts and Problems Connected with the Disposal of Radioactive Waste in the Seas Adjacent to Our Territory* (Moscow: Administration of the President of the Russian Federation, February 1993), translated and reproduced by the Joint Publications Research Service, Environmental Issues, ``Russian Federation State Report on Sea Burial of Radioactive Wastes,'' JPRS-TEN-93-005-L, 17 June 1993, 46 pages. Hereafter the report is referred to as the White Book. Page numbers referenced refer to the JPRS translation.
   The Commission was comprised of representatives of the Russian Ministry of the Environment and Natural Resources, the Ministry of Defense, the Ministry of Foreign Affairs, the Ministry of Public Health, the Ministry of Atomic Energy, the Committee for the Supervision of Nuclear and Radiation Safety, the Committee for the Supervision of Sanitary Engineering and Epidemiological Monitoring, and other ministries and departments, as well as representatives of the administrations of Russia's Northern and Far Eastern regions. White Book, p. 1.

[762] White Book, p. 33.

[763] The first Soviet nuclear-powered submarine was constructed at Severodvinsk on the White Sea in the late 1950s. Its first sea trials occurred in 1958 and it was taken into service in March 1959. Lev Giltsov, Nikolai Mormoul, Leonid Ossipenko, *La Dramatique Histoire des Sous-Marins Nucleaires Sovietiques* (Robert Laffont: Paris, 1992), p. 127; Rear Admiral S. Yefremov (Ret.), ``Engineer Officer Boris Akulov: The First Engineer Officer Aboard the First Nuclear-Powered Submarine,'' *Krasnaya Zvezda*, 30 August 1991, (translated in JPRS-UMA-91-025, 16 October 1991, p. 36). It was a November-class SSN, the known as the K-3 and later named the *Leninskii Komsomolets* in recognition of its exploits.

[764] White Book, p. 11.

[765] The majority of the liquid waste (up to 70 percent by volume) consists of low-salt circuit effluent and circuit flushing fluid with an activity of around 1 μCi/liter. The second category of liquid waste (15 percent of total volume)--consisting of higher level waste from the deactivation of circuits and the

Federation (Arctic and Pacific) in 1960 and 1964, respectively.[767] Through 1992, a total of almost 317,000 m³ of liquid RW was discharged. Large amounts of solid waste were dumped at sea, using various methods, including placing the waste inside some 13,500 containers (a further 256 items were not contained) and in the holds of 55 scuttled vessels.[768] Also dumped at sea were 18 propulsion reactors (15 submarine, three *Lenin* icebreaker), six with their nuclear fuel still in place, and two reactor ``screen assemblies,'' one with partial load of fuel from the *Lenin*, and the other defuelled. All seven objects containing nuclear fuel were dumped in the Kara Sea following accidents.

The White Book estimated that the radioactive inventory of the sources of radioactive pollution of the seas from all Soviet/Russian sources except nuclear testing during 1961-1991 to be some 10,000 kCi at the time of disposal.[769] This inventory included the radioactive waste deliberately dumped in the Atlantic and Pacific Oceans, lost nuclear munitions, satellites, radio-isotopic thermal generators, and run-off from the Yenisey and Ob rivers.

As for the radioactive inventory of the RW resulting from naval nuclear operations and deliberately dumped at sea during 1961-1991, the White Book estimated this to be between 325 kCi (12 PBq) and 2,500 kCi (92 PBq) at the time of disposal.[770] The larger number is almost twice the combined inventory total of the radioactive waste disposed of at sea by the 12 other nations who dumped during this period.[771]

The actual mix of the original isotopes is uncertain and this has complicated efforts to estimate the current levels of radioactivity. If the number 2,500 kCi refers to relatively cool wastes that had lost much of their short-lived isotopes (such as iodine-131, with a half-life of 8.6 days) by the time of dumping, then the current radioactivity of the dumped wastes is estimated to lie between 300 kCi[772] and ``a little less than a million curies

_____

water cooling ponds of spent fuel assemblies--has a high salt content and accounts for most of the total activity. The third category (the remaining 15 percent) includes the waste water of the special on-shore decontamination centers, laundries, deactivation booths, and radiation safety laboratories. The activity of this group is low (up to 10 nCi/l), with a similar salt content to the second category, but containing surfactants. White Book, p. 30.

[766] The highest levels of solid waste contamination are found in equipment used in reactor compartments and in operations with spent nuclear fuel. High levels of activity are also accumulated during the filter-decontamination of liquid RW. A large portion (by volume) consists of contaminated film coatings, protective clothing, and other objects.
    In the White Book, the information about the activity of the solid RW (excluding reactors elements and reactor cores with spent nuclear fuel) was presented in units of ``activity (strontium-90 equivalent), Ci.'' This artificial measurement was intended as a general description of solid RW at the time of dumping, and was derived from readings of the dose rate near the waste, including some prior knowledge about its radionuclide composition.

[767] White Book, p. 11.

[768] None of the scuttled vessels--which included barges, lighters, tankers, fishing vessels, refrigerator ships, seiners, and repair ships--were designed for this purpose. Rather than dismantle or scrap these vessels at the end of their operational service, they were taken over by the government, filled up with solid RW, taken out to sea (either under their own power or under tow), and deliberately scuttled.
    Among the scuttled vessels are at least four special-purpose tankers with the ``TNT'' designation which were laden with solid RW. Two TNTs were dumped in site No. 9 of the Sea of Japan (the *TNT-14* and *TNT-11* in 1988 and 1992) and two were dumped in site No. 1 of the Kara Sea (the *TNT-15* and *TNT Goryn* in 1973 and 1974). White Book, Table A.4, p. 39 and Table A.7, p. 45.
    TNTs are specially modified tankers for the transport and dumping of liquid and solid radioactive waste. Two types of tanker are known to fit in this TNT category: some seven Vala-class tankers, and the *Ural* radioactive waste tanker. *Jane's Fighting Ships 1994-1995*, p. 595; Norman Polmar, *Guide to the Soviet Navy, 5th edition*, (U.S. Naval Institute Press: Annapolis, MD 1991), p. 257. These tankers are divided up between the Northern and Pacific Fleets.

[769] White Book, Table 8, p. 22.

[770] Comprising of some 25 kCi of LRW dumped by the Navy and MSC in the North Atlantic and over 12 kCi in the Northwest Pacific, and some 300 - 2,500 kCi of SRW including dumped reactors. White Book, p. 21, Table 8, p. 22, and p. 33.

[771] Twelve countries--Belgium, France, West Germany, Italy, Japan, South Korea, the Netherlands, New Zealand, Sweden, Switzerland, the United Kingdom, and the United States--dumped an estimated 1.24 MCi (46 PBq) of radioactive waste in dump sites in the Atlantic and Pacific from 1946 to 1982. International Atomic Energy Agency, ``Inventory of Radioactive Material Entering the Marine Environment: Sea Disposal of Radioactive Waste,'' IAEA-TECDOC-588, March 1991, p. 7.

[772] According to Dr. Vitali N. Lystsov, deputy director of the Russian Ministry of the Environment and Natural Resources, who helped prepare the White

[1000 kCi]."[773] In regards to the dumped reactors, based on new, post-White Book information provided by Russian authorities on the condition of the reactors, the International Atomic Energy Agency estimates the total activity of the dumped reactors (with and without nuclear fuel) is now 970 kCi [36 PBq]. This compares to an estimate of 2,400 kCi [89 PBq] provided in May 1993 by the Russian authorities.[774]

As for the current situation, the White Book estimated Russian nuclear-powered vessels generated up to 20,000 m^3 of liquid RW and up to 6,000 tonnes (t) of solid RW annually.[775] Most of this waste results from Russian Navy activities. The last disposal at sea occurred in the Northern Fleet in 1992,[776] and in the Pacific Fleet in October 1993, when 900 t of liquid RW was discharged from the TNT-27 tanker in the Sea of Japan. Although the possibility exists, as of late 1994, the Navy does not plan to resume its dumping operations.

The Murmansk Shipping Company continues to generate liquid and solid waste, but stopped dumping it at sea in 1984 and 1986, respectively.[777] Liquid radioactive waste is now processed at a land-based facility at the Atomflot base.

RW Dumped in the Arctic

The RW dumped in the Arctic originates from 14 major facilities, 12 on the Kola peninsula and two shipyards at Severodvinsk on the White Sea. As illustrated in Figure 6.1, these facilities which produce RW include the Northern Fleet bases where nuclear-powered submarines and warships are homeported; the icebreaker homeport at Murmansk; the land-based nuclear waste storage sites, including those for spent nuclear fuel; nuclear service ships; and shipyards and submarine repair facilities.[778]

The Soviet Navy and the Murmansk Shipping Company began the regular dumping RW in the Barents and Kara seas in 1960.[779] The MSC stopped dumping all waste by 1986 and the Northern Fleet last dumped in 1992.[780] The nuclear dumping was carried out using both Northern Fleet and MSC ships. About half of the MSC's dumping operations were conducted on behalf of the Northern Fleet.[781]

Book. William J. Broad, ``A-Waste Dangers Described as Low,'' *New York Times*, 13 June 1993, p. 9.

[773] According to Mark Mount, a nuclear engineer at the Lawrence Livermore National Laboratory, California. William J. Broad, ``Russians Describe Extensive Dumping of Nuclear Waste,'' *New York Times*, 27 April 1993.

[774] International Atomic Energy Agency (IAEA), ``International Arctic Seas Assessment Project (IASAP)--Progress Report No. 2,'' August 1994.

[775] White Book, p. 30.

[776] In 1993, the Northern Fleet did not dispose of any radioactive waste at sea. Captain 1st Rank Vladimir Pyzh, Press Center of the Red Banner Northern Fleet, ``Answers to the Questions Addressed by Greenpeace to the Command of the Northern Fleet,'' letter, No. 37, 23 August 1993. During 1992, the Russian Navy dumped 55.2 Ci/2050 GBq of waste at sea, comprised of 6,652 m^3 of liquid RW, with an activity of 28.2 Ci/1,050 GBq, and 2,741 m^3 of solid RW with an activity of 27.0 Ci/1,000 GBq. White Book, Table 9, p. 22.

[777] White Book, p. 12.

[778] White Book, Figure 4, p. 10. Joshua Handler, ``The Northern Fleet's Nuclear Submarine Bases,'' *Jane's Intelligence Review*, December 1993, pp. 551-556. Figure 6.1 does not depict all the sources of RW in the Northern seas, such radioactive runoff from the Ob' and Yenisey rivers and contamination from the Novaya Zemlya nuclear test site.

[779] White Book, p. 16.

[780] White Book, Table 9, p. 22.

[781] Frederic Hauge, Thomas Nilsen, and Knut Erik Nilsen, *Dumping of Radioactive Waste in the Barents and Kara Seas*, Working Paper No. 3:92 (Oslo, Norway: Environmental Foundation Bellona, November 1992), p. 4.

Liquid RW

Five sites were officially chosen for liquid RW dumping in the Barents Sea, including two larger areas off the west coast of Novaya Zemlya, one in the open Barents Sea, and two smaller areas off the Kola peninsula (see Figure 6.2).[782]

The amounts of liquid RW dumped at sea varied from year to year--the highest levels of dumping occurred in 1965, 1975, 1988, and 1989. The highest cumulative levels of activity were found in sites 1 and 2. The cumulative activity total for all five sites through 1992 was 12,171 Ci (450.67 TBq), with a total volume of 192,700 m^3.[783] An additional 11,600 Ci (429 TBq) of liquid RW was disposed of in six unsanctioned areas of the Northern seas, much of it by accident,[784] bringing the total activity of liquid RW for all 11 sites in the Northern seas, through 1992, to almost 24 kCi (903 TBq).[785]

The Northern Fleet was responsible for the majority of the liquid waste, with dumping operations conducted in all five areas. In the early years, radioactive water from the submarines' reactors was pumped aboard tankers, transferred to special containers at the naval bases, diluted, and then pumped back onto the same tankers where it was taken to the Barents Sea and discharged.[786] From 1987 to 1989, the Northern Fleet also operated a single Amur-class radioactive waste tanker, the *Amur*, to collect, process, and discharge liquid radioactive waste, particularly the cooling waters from submarines.[787]

The MSC dumped liquid RW in the Barents Sea from the early 1960s until 1984.[788] The MSC used several of its service ships for this purpose including most recently the service ship *Serebryanka*. This ship would take on reactor cooling water directly from the icebreakers or via the service ship *Imandra* for dumping at sea. Since 1984, the liquid RW has been transferred to land-based storage tanks or to a liquid radioactive waste treatment plant at the

---

[782] These five areas were chosen by the staff of the Northern Fleet, and approved by the General Staff of the Navy between 1960 and 1966. White Book, p. 12.

[783] The totals for 1960 through 1991 were 12,153 Ci (450 TBq) and 189,634 m^3, and for 1992 -- 18 Ci (.666 TBq) and 3066 m^3, in site no. 5 (see Figure 6.2). White Book, p. 12, Table 9, p. 22, and Table A.2, pp. 37-38.

[784] The liquid RW dumped in the six unsanctioned areas was as follows:
    * White Sea--low-level waste dumped in 1959 (0.02 Ci); explosion at the Severodvinsk plant in 1965 (100 Ci/3.7 TBq);
    * Baltic Sea--waste from the *Lenin* icebreaker dumped off Gogland Island (Gulf of Finland) in 1960 (0.2 Ci/0.007   TBq);
    * Kara Sea--waste from the *Lenin* dumped in 1976 (8,500 Ci/315 TBq);
    * Barents Sea--leakage from on-shore storage facility at Andreyev Guba [Bay] in 1982 (1,000 Ci); accident on nuclear-powered submarine in Ara Guba in 1989 (2,000 Ci). White Book, pp. 11-12 and Table A.2, p. 38.

[785] The exact figures are 23,771 Ci (879.67 TBq), with a total volume of at least 193,500 m^3.

[786] Oleg Volkov, ``To Catch a Reactor, Big and Small: Confessions of an Eyewitness,'' *Komsomolskaya Pravda*, 6 July 1991.

[787] The Amur-class tankers--Amur and Pinega--were built at Vyborg. The Amur was completed in 1986 and is in the Northern Fleet. The Pinega was completed in 1987 and transferred to the Pacific in 1989. Their displacement is 10,500 tons full load; *Jane's Fighting Ships 1993-1994*, p. 566. The ships were meant to process higher-level liquid RW--around 10^{-3} to 10^{-5} curies/liter such as that typically found in the primary loop--down to 10^{-6} curies/liter. Yet the best they may achieved when they were operational was to 10^{-5} curies/liter; Russian Ministry of Ecology's Press Report, ``By 1995 Russia May Halt Dumping Liquid Radioactive Waste at Sea,'' and accompanying report, ``Problems of Handling Liquid Radioactive Waste Generated by Transport Nuclear Power Plants In Russia, and the Possible Options,'' 16 December 1993. Neither ship is currently used for this purpose. According to the Northern Fleet press spokesman, the Amur was last at sea in November 1991. It went from Severodvinsk to the Andreyev Guba to transfer solid radioactive waste to the storage site; Press Center of the Red Banner Northern Fleet, Captain 1st rank Vladimir Pyzh, Chief, ``Answers to the Questions Addressed by Greenpeace to the Command of the Northern Fleet,'' letter, dated 23 August 1993. Other Russian Navy sources report it was unable to engage in any processing of LRW after helping to deal with the consequences of an accident on a Northern Fleet nuclear-powered submarine in 1989. The Pinega also has not functioned as planned, reportedly due to poor equipment, poor maintenance, and lack of qualified personnel to run the equipment. As of 1994, the Russian Navy plans to rehabilitate both vessels.

[788] White Book, pp. 11-12.

Atomflot facility. At the plant the liquid RW is processed, further diluted, and then discharged into the Kola fjord.[789]

Solid RW

Solid RW was dumped in eight areas of the Kara Sea--one site in the open Kara Sea and seven sites in the shallow bays on the east coast of Novaya Zemlya, as illustrated in Figure 6.3--and one minor site in the Barents Sea (the barge *Nikel*, see below). None of these sites corresponds to the international requirements for solid RW dumping, neither in terms of depth (>4000 m), nor in distance from shore (>200 miles), nor for location on the globe (between 50 degrees north and 50 degrees south).[790]

Three categories of solid waste were dumped in the Arctic: low- and medium-level waste; six reactors and one reactor screen assembly with spent nuclear fuel; and ten reactors without spent nuclear fuel. The collective activity of this solid RW has been estimated, at the moment of dumping, at up to 2,400 kCi.[791]

By volume the majority of the solid RW buried in the Northern seas consists of low- and medium-level waste resulting from the operation of nuclear-powered ships and submarines of the Navy, and of the nuclear-powered icebreaker fleet, along with their respective refit and construction wharfs.

The Northern Fleet was responsible for the greatest amount of dumped material, although as mentioned earlier, the MSC dumped some of their waste for them. The MSC dumped low- and medium-level solid RW in the Kara Sea from the early 1960s through 1986.[792] During this period, the MSC used two methods of dumping--first via the scuttling of Atomflot barges that were full of solid waste (these barges included the *N. Bauman*,[793] *Nikel*,[794] and *SB-5*[795]), and through the repeated use of certain icebreaker service ships, the *Volodarsky* and *Lepse*, to dump multiple containers of solid RW. When this dumping came to a halt in 1986, the *Volodarsky* and *Lepse* were instead used for the long-term storage of this radioactive waste.[796]

As a rule, low- and medium-level solid RW was sealed in metallic containers (6,508 in total) before they were dumped in the Northern seas. Other large items of RW[797] were dumped separately (a total of 154 uncontained items) or inside specially designated vessels--barges, lighters, and tankers--17 in total. The combined activity of the low- and medium-level solid RW dumped in the Kara Sea was about 15.5 kCi (574 TBq), with an additional 40 Ci (1.5 TBq) dumped in the Barents Sea. The greatest volume of solid RW is buried in area No. 1 (a 380 m-deep trench in the Kara Sea known as the Novaya Zemlya depression or deep), and for total activity--in area No. 2 (Sedov Guba [Bay]). By years, the largest number of disposal operations of low- and medium-level solid

---

[789] Thomas Nilsen and Nils Bohmer, ``Sources to Radioactive Contamination in Murmansk and Arkhangelsk Counties,'' Bellona Report, Vol. 1, (Oslo, Norway: Environmental Foundation Bellona, 1994), pp. 81-89.

[790] White Book, pp. 3-4, Figure 1, p. 4, Table 2, pp. 12-13.

[791] White Book, Table 2, pp. 12-13, Table 3, p. 13, Table 4, p. 16.

[792] White Book, pp. 11-12.

[793] This barge was scuttled in 50 meters of water in the Tsivolka Guba in 1964, with 1600 containers (total radioactivity of 977.37 Ci). White Book, p. 40.

[794] This barge was scuttled 20 nm NW of Kolguyev Island in the Barents Sea in 1978, with 1100 m^3 of low-level waste (40 Ci total). White Book, p. 40.

[795] This barge was scuttled in Og Guba in 1968, with 400 m^3 of RW (4 Ci). White Book, p. 39.

[796] Nilsen and Bohmer, ``Sources to Radioactive Contamination,'' Bellona Report, pp. 85-88.

[797] Including contaminated pipes, filter cases, pumps, steam generators, film coatings, instruments, protective gear and clothing. White Book, p. 12.

RW were conducted in 1967 and 1982, and for activity--in 1983 and 1988.[798]

Reactors with Spent Nuclear Fuel. According to the White Book, the greatest environmental danger in the Northern seas arises from the deliberate dumping of nuclear submarine reactors with their fuel rods still in place.[799] Six reactors with spent nuclear fuel and one reactor ``screen assembly'' with a partial load of fuel were dumped[800] in the shallow bays along the east coast of Novaya Zemlya and in the Novaya Zemlya depression, as illustrated in Figure 6.3 and detailed below:[801]

* submarine compartment no. 285 with two reactors (only one with spent nuclear fuel), dumped in Abrosimov Guba (at a depth of 20 m) in 1965, combined activity not more than 800 kCi;

* submarine compartment no. 901 with two reactors, dumped in Abrosimov Guba (depth of 20 m) in 1965, combined activity not more than 400 kCi;

* 125 irradiated fuel assemblies (60 percent of the original uranium dioxide fuel) lodged in the recessed shield (also known as the ``screen assembly'') of the OK-150 reactor unit of the *Lenin* icebreaker, and dumped in Tsivolka Guba (depth of 49 m) in 1967, activity of about 100 kCi;[802]

* submarine plant no. 421, one reactor, dumped in the Novaya Zemlya depression (depth of 300 m) in 1972, activity not more than 800 kCi; and

* an entire damaged submarine with two liquid metal-cooled reactors from submarine plant no. 601 (with an activity not more than 200 kCi) was scuttled in Stepovoy Guba (depth of about 20 m) on 1 September 1981.[803]

Before dumping, all the above submarine reactor compartments were filled with a furfural-based solidifying

---

[798] White Book, p. 12.

[799] White Book, p. 13.

[800] Due to the ``critical state of the cores''--apparently a reference to the partial melting of the fuel rods during on-board accidents--it was not possible and too dangerous to unload the fuel from these six submarine reactors, nor to remove the remaining 125 irradiated fuel assemblies from the recessed shield (screen) of the OK-150 reactor unit of the *Lenin* icebreaker. White Book, p. 13.

[801] The White Book authors could not accurately assess the radionuclide composition or total activity of the submarine reactor cores buried near Novaya Zemlya. Such an analysis would have required data on the reactor cores and the operating conditions of each of the nuclear reactors and this information was not available or not provided by the Navy (such an analysis, however, was done for the *Lenin*--and the activity of its spent nuclear fuel, at the time of dumping, was estimated at 100 kCi).
    Estimates provided by the Russian Navy for the White Book suggested the total activity (at time of dumping) of the submerged submarine reactors was 120 kCi. The White Book's authors thought this estimate was ``low'' and ``not adequately substantiated.'' According to one of the experts on the Commission, their maximum combined activity--assuming the reactors generated 12.5 GW/day, and with due consideration for the reactor ``cooling'' time prior to disposal (1 to 15 years)--could be as high as 2,300 kCi. White Book, pp. 14-15.
    As noted above, new information provided to the IAEA by the Russian authorities in 1994, suggests the higher estimates were and are more appropriate. As of the 1994 time-frame, the IAEA calculates, the total activity of the dumped reactors (with and without nuclear fuel) is now 970 kCi [36 x 10^{15} Bq]. This compares to an estimate of 2,400 kCi [89 x 10^{15} Bq] provided in May 1993 by the Russian authorities. International Atomic Energy Agency (IAEA), ``International Arctic Seas Assessment Project (IASAP)--Progress Report No. 2,'' August 1994.

[802] The White Book estimated the radionuclide composition of the 125 irradiated fuel assemblies as follows: cesium-137 (about 50,000 Ci); strontium-90 (about 50,000 Ci); plutonium-238; americium-241; curium-244 (about 2000 Ci). White Book, Table 3, p. 13.

[803] White Book, Table 3, p. 13 and Figure 11, p. 26. The submarine was the K-27, project 645, an experimental modified-November class submarine. It had a serious accident in its port-side reactor during its second voyage on 24 May 1968. Fleet Admiral V. Chernavin, ``Trips and Flights: Test-Commander,'' *Morskoi Sbornik*, No. 8, August 1991. Alexander F. Yemelanenkov, ``From the Sobesednik Files--Split Atom: The First 50 Years,'' *Sobesednik*, No. 12, March 1992. Vitali Novozhilov, ``The K-27: The Atomic Ship of Heros and Laureates,'' *Krasnaya Zvezda*, 3 June 1993. V. Vildin, ``Experimental Torpedo SSN Project 645,'' *Morskoi Sbornik*, No. 8, August 1993, pp. 59-62. Yemelanenkov inaccurately lists the submarine as being dumped in 1982. Vildin mistakenly says the accident occurred on 24 August 1968.

agent--with one exception, no. 421, which had a metallic container with lead jacket. According to the estimates of the nuclear propulsion unit designer, these procedures will prevent the spent nuclear fuel from coming into contact with sea water for several hundred years (up to 500).[804]

Reactors without Spent Nuclear Fuel. A total of ten reactors without spent nuclear fuel were dumped in the bays along the east coast of Novaya Zemlya and in the Kara Sea. Figure 6.3 pinpoints the location of these ten objects dumped between 1965 and 1988:[805]

* submarine reactor, no. 285, dumped in Abrosimov Guba (at a depth of 20 m) in 1965 (see also previous heading);

* submarine reactor compartment (two reactors) no. 254, dumped in Abrosimov Guba (depth of 20 m) in 1965;

* submarine reactor compartment (two reactors) no. 260, dumped in Abrosimov Guba (depth of 20 m) in 1966;

* block of nuclear unit OK-150 of the *Lenin* icebreaker (three reactors with first circuit piping and hermetically sealed equipment)--dumped in Tsivolka Guba (depth of 50 m) in 1967;[806] and

* two submarine reactors, no. 538, dumped in Techeniye Guba (depth of 35-40 m) in 1988.

The Commission did not have information on the metallurgical composition of the submarine reactors or their operational history. Such information was only available for the icebreaker *Lenin*'s reactors. While noting further analysis was required, the Commission estimated the total induced activity of these ten reactors to be at least 100 kCi at the time of dumping.[807]

RW Dumped in the Far Eastern Seas

The majority of the RW that was dumped in the Pacific originated from ten major naval nuclear facilities in the Pacific region, most of which are concentrated near Vladivostok and Petropavlovsk. As illustrated in Figure 6.4, these facilities which produce or store RW include the Pacific Fleet bases where nuclear-powered submarines and warships are homeported; the land-based nuclear waste storage sites, including one for spent nuclear fuel; nuclear service ships; and shipyards and submarine repair facilities.[808] While icebreakers are stationed in the Far Eastern seas, none are nuclear-powered.

---

[804] On the *Lenin*, the remaining spent nuclear fuel was held together with the furfural-based mixture, while the ``screen assembly'' was encased in a reinforced concrete container with metallic shield. White Book, Table 3, p. 13 and p. 16.

[805] White Book, Table 4, p. 16.

[806] Cobalt was used in the structural elements of the *Lenin* reactor, which resulted in an extremely high level of induced cobalt-60 activity (approximately 50 kCi). White Book, p. 16.

[807] White Book, p. 16.

[808] For location and description of facilities see: Joshua Handler, ``Russia's Pacific Fleet--Submarine Bases and Facilities,'' *Jane's Intelligence Review*, April 1994, pp. 166-171. Joshua Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific Fleet, Nuclear Waste Disposal Problems, Submarine Decommissioning, Submarine Safety, and Security of Naval Fuel,'' (Moscow/Washington, DC: Greenpeace, 27 October 1994), pp. 6-8.
    Figure 6.4 does not depict all the sources of RW entering the Far Eastern seas, such as the accident aboard the nuclear-powered submarine in Chazhma Bay in 1985 (see Appendix F); the loss of a radioisotope thermoelectric generator (RITEG)--with an activity level of 350 kCi--during transport near Sakhalin Island; or the radioactive contamination as a result of fallout and river outflow.

The Russian Navy dumped liquid and solid RW (including two reactors without spent nuclear fuel) in ten officially sanctioned areas in the Far Eastern seas starting in 1966, including: six sites in the Sea of Japan (south of Vladivostok); one in the Sea of Okhotsk (east of Sakhalin Island); and three in the North Pacific Ocean (southeast of the Kamchatka peninsula)--see Figure 6.5. Of the ten disposal sites used, only site No. 4 satisfies the IAEA depth and location requirements for RW dumping.[809] In 1992, the Russian Navy dumped both liquid and solid RW in the Far Eastern seas.[810] In 1993, only one dumping of liquid RW was known to have occurred. As of late 1994, all dumping of RW had ceased.

The total activity of the RW discarded in Far Eastern seas, 1966 through 1992, was 18,565 Ci (685 TBq), as follows:[811]

* liquid RW--12,337 Ci (456 TBq)

* solid RW of low- and medium-level activity--6,228 Ci (229 TBq),[812] which includes 116 Ci (4.3 TBq) of irradiated material in two reactors and one ``screen assembly'' (none with spent nuclear fuel).

Liquid RW

The Pacific Fleet dumped liquid RW in nine of the ten allocated areas (all except No. 8). The largest quantity of liquid RW (by volume) was dumped in area No. 7, and for total activity--in area No. 9. The maximum quantity of liquid RW (in terms of activity) was discharged in 1986 and 1987. Altogether, the USSR/Russia dumped an estimated 123,497 m^3 of liquid RW in the Far Eastern seas from about 1966 through 1992, with a combined activity of 12,337 Ci (456 TBq).[813]

In 1993, the Pacific Fleet planned to discharge 1700 tons (equal to about 1700 m^3) of low-level liquid radioactive waste-- which had accumulated aboard two Russian Navy tankers--TNT-5 and TNT-27 specifically allocated for storage of this waste[814] --into the Sea of Japan. The first 900 t of liquid waste was dumped by the TNT-27 tanker--which had to be towed from the Pavlovsk submarine base to area No. 9--on 16/17 October 1993. After a Greenpeace ship monitored the dump, on 21 October 1993, bowing to pressure from Japan, the United States, and other countries, Russian Prime Minister Viktor S. Chernomyrdin suspended plans to dump a second load (800 t) of liquid waste into the Sea of Japan, originally scheduled for 23-24 October 1993.[815] As of late 1994, despite several suggestions it may have to do so, the Pacific Fleet has not dumped any liquid radioactive waste at sea.

---

[809] White Book, p. 17 and Figure 8, p. 19.

[810] The Russian Navy dumped in four of the ten areas during 1992:
      * site no. 5: 906 m^3 of liquid RW, activity of 1.3 Ci/48 GBq;
      * site no. 7: 906 m^3 of liquid RW, activity of 1.3 Ci/48 GBq;
      * site no. 8: 46 m^3 of solid RW in 41 containers, activity of 12 Ci/444 GBq;
      * site no. 9: 1774 m^3 of liquid RW, activity of 7.6 Ci/281 GBq; 2640 m^3 of solid RW aboard the scuttled TNT-11 tanker, activity of 14.5 Ci/534 GBq; and 55 m^3 of solid RW in 41 containers, activity of 0.5 Ci/19 GBq. White Book, Table 9, p. 22.

[811] White Book, p. 21.

[812] The White Book cites two different totals for solid radioactive waste dumping in the Pacific, 6,851 Ci on page 17 and 6,112 Ci on page 21. The lower number from page 21 is used here.

[813] White Book, p. 21 and Table A.6, p. 42.

[814] These two Vala-class tankers--the *TNT-5* and *TNT-27*--were at capacity and were in a dangerous condition.

[815] Craig R. Whitney, ``Russia Halts Nuclear Waste Dumping in Sea,'' *New York Times*, 22 October 1993.

Since 1988, the Pacific Fleet also has operated a Amur-class radioactive waste tanker--the *Pinega*--designed for gathering, storing, and purifying reactor coolant water from submarines. Most likely based out of the Zvezda shipyard at Bolshoi Kamen, it has not functioned as anticipated, and is currently used as a tanker to transport liquid radioactive waste.[816]

Solid RW

The Pacific Fleet dumped solid RW in four of the ten allocated sites--Nos. 6, 8, 9, and 10. This waste included low- and medium-level solid RW, two reactors without spent nuclear fuel, and one reactor shield. The USSR/Russia did not dump any reactors with spent nuclear fuel in the Far Eastern seas.[817]

Low- and medium-level solid RW was dumped in the four allocated sites starting in 1968. Site No. 9 received the greatest volume of this solid RW, while site No. 8 has the highest combined activity. The maximum amount of low- and medium-level solid RW (by activity) was buried in the Far Eastern seas in 1975 and 1985. The total activity of this solid RW dumped in the Far Eastern seas was, according to available data, 6,112 Ci (225 TBq). This volume of this waste is 21,876 m^3, and is enclosed in 6,953 submerged containers, 38 scuttled vessels, and more than 102 other ``large objects."[818]

Two reactors without spent nuclear fuel and one reactor ``shield" are buried in the Far Eastern seas (see Figure 6.5):

* two submarine reactors dumped in the Sea of Japan (site No. 10, depth of 3000 m) in 1978, volume of 31 m^3, activity of 46.2 Ci (1.7 TBq) at the time of dumping, in a metal container with a lead jacket; and

* submarine reactor ``screen assembly (shield)," no. 714, dumped in the North Pacific Ocean (site No. 8, depth of 2,500 m) in 1989, volume of 7 m^3, activity of 70 Ci (2.6 TBq) at the time of dumping, in a metal container with a lead jacket.[819]

The Extent of Radioactive Contamination

The Hazards of Liquid RW

Almost 317,000 m^3 of liquid waste was discharged into the seas by the Northern and Pacific Fleets and the Murmansk Shipping Company. Citing earlier Soviet studies, the White Book claimed that this liquid RW posed ``no significant radiational-hygienic hazard" to the population as a whole and to the groups most at risk (fisherman and the people living in coastal areas).[820] The Commission concluded that additional research could clarify this preliminary assessment, but was ``unlikely to change it appreciably."[821]

---

[816] Handler, ``Russia's Pacific Fleet," pp. 166, 171.

[817] White Book, pp. 19-21.

[818] White Book, pp. 17-21, and Table A.7, pp. 43-46.

[819] White Book, Table 6, p. 21.

[820] Measurements of the surface radioactivity of these bodies of water did not indicate any dangerous increase in comparison with background readings. White Book, pp. 24-25.

[821] White Book, p. 25. The Commission found it more difficult to assess the effects of liquid RW on the marine ecosystems, and conceded that knowledge of the Northern and Polar ecosystems is too fragmentary for any definitive final conclusions. They provided the example of hydrography, where the lack of knowledge was amply demonstrated by the recent discovery of powerful seabed currents which change with the seasons, and of deep-

The Hazards of Buried Solid RW

The potential harm to the environment depends not only on the type of solid radioactive material buried at sea, but also on whether the waste was enclosed in sealed containers and whether it had other protective barriers.[822]

The Commission acknowledged that the reactors with spent nuclear fuel in the Kara Sea present the most serious threat from the standpoint of radioecological contamination. Nevertheless, the Commission drew the preliminary conclusion that there was little danger of any significant seepage of radionuclides from these reactors in the near future, *provided* they were buried with water-tight protective barriers (such as case-hardening, additional pressure sealing, and the filling of cavities with furfural).[823] But since the actual rate of corrosion of the protective barriers is not known, nor is the length of the depressurization process, the Commission conceded that it could not draw any final conclusions until all of the buried high-level solid RW had been studied.

Several reactors without spent nuclear fuel, along with much of the solid RW buried in containers[824] and in the holds of scuttled vessels, were buried at sea without any additional shielding to guard against the migration of radionuclides into the marine environment. Also, starting in the 1960s many of the hermetically sealed metallic containers (holding low-level solid RW) were deliberately perforated to speed up their submersion. According to eyewitnesses, because many of the containers floated, various puncturing methods were adopted--including cutting two holes in each container,[825] and shooting at them with rifles and machine guns[826] --to ensure that they filled with water and sank to the bottom. As a consequence, the leakage of radionuclides could have started immediately following the dumping of these containers.

The last category of solid waste is the ``uncontained'' items, usually consisting of large pieces of equipment made of high-grade steels. The Commission observed that since this steel corrodes at a rate of around 1 mm every 100 years, and as the thickness of the radioactive layer on the steel items (removed from a reactor) is 0.1-0.5 mm, all of the ``activity should be transferred from this type of RW to the marine environment within 10-12 years'' after dumping. As for radionuclides in RW submerged without containers, the Commission noted a ``high percentage'' should enter the marine environment. However, since the combined activity of this waste is not high, the Commission concluded that it ``cannot have a perceptible effect on the overall radioecological situation in the seas.''[827]

Expeditions to the Solid RW Dump Sites. Prior to the publication of the White Book, very little data

---

sea storms in which the water moves at a speed of several knots.

[822] However, as the container material itself is subject to corrosion in sea water, eventual contamination of the ocean is inevitable. According to the Commission, the marine environment breaks down most metal containers within 10 years, and reinforced concrete containers within 30 years. Furthermore, the process of corrosion accelerates considerably when metal alloys are used (for example, steel mixed with copper, zinc, or titanium). When these alloys come in contact with sea water, electrolytic reactions multiply the speed of corrosion. This explains the rapid breakdown of the steel hull of the *Komsomolets* nuclear-powered submarine (see Appendix E). White Book, pp. 25-27.

[823] According to the White Book, the reactor compartment of the *Lenin* icebreaker (three reactors without nuclear fuel) could remain structurally sound (and watertight) for as many as 500 years. Comparable data on other dumped reactors were not submitted to the Commission. White Book, p. 25.

[824] According to the Commission, the walls of the containers (grade-3 steel, 3-4 mm thick) could undergo significant corrosion within 20-30 years after dumping (during this time all of the radionuclides with a half-life of less than three years will disintegrate, and the strontium-90 and cesium-137 activity will be reduced by approximately half). White Book, p. 25.

[825] Zolotkov, ``On the Dumping of Radioactive Waste at Sea Near Novaya Zemlya,'' p. 3.

[826] Volkov, ``To Catch a Reactor, Big and Small.''

[827] White Book, p. 26.

existed on the radioactivity concentrations within the solid RW dump sites in the Northern and Far Eastern seas. According to the Commission, the solid RW dump sites (including those containing reactors with spent nuclear fuel) had not been directly monitored since 1967; all studies were done at some 50-100 km from these sites. As a result, it has been impossible to determine the state of the protective barriers of the buried solid RW or the speed and extent of radionuclide migration into the sea water (and thus possibly into the food chain and marine flora and fauna). The Commission proposed that these observations be conducted without delay, including scientific studies of the radionuclide content of the submerged objects.[828]

In late July 1993, a group of Russian and Canadian scientists departed on a three-month expedition--aboard the R/V *Geolog Fersman* --to the southeast Barents Sea and to the solid waste dump sites off Novaya Zemlya. This was the first international expedition which managed to work within Russian territorial waters (12 nm from shore).[829] The expedition attempted to enter Abrosimov Guba--the location of eight reactors, three with spent nuclear fuel--but the entrance was too narrow and the weather too rough. Instead the expedition concentrated its efforts on finding three specific submerged objects in the Kara Sea. While they could not find the submarine reactor that was dumped in the Novaya Zemlya depression (it was not located at the coordinates provided by the White Book), they did locate the *MBSN-801250* barge--full of containers of radioactive waste (118.4 Ci)--that was scuttled in 1980 in site No. 1, at a depth of 350 m. According to Drs. Leonid Polyak and Gennadi Ivanov, co-Chief Scientists on the R/V *Geolog Fersman*, the preliminary examination of the sediment samples obtained 20-30 m from the barge did not reveal any significant anomalies compared with background radiation levels, possibly because of the relatively high sedimentation rates (3-4 meters/year) in the Kara Sea.[830] The biological samples were still being analyzed. No significant ocean currents were detected at the bottom of the Kara Sea trough.

In early September 1993, a joint team of Russian and Norwegian scientists departed Murmansk on a month-long expedition aboard the research ship *Viktor Buinitsky* to examine some of the nuclear reactors dumped at sea. Equipped with a remote-operated vehicle (ROV), towed high-frequency side-scanning sonar, video equipment, and sampling gear, the scientists visited two of the three bays on Novaya Zemlya's east coast where reactors were dumped: Stepovoy Guba (location of the K-27 submarine with two reactors) and Tsivolka Guba (site of the fuel assemblies and three reactors from the *Lenin* icebreaker). The expedition also visited the dumping site in the Novaya Zemlya depression in the Kara Sea (the site of one reactor with fuel).[831]

Preliminary results of the expedition to the above three sites were reassuring but not conclusive. The expedition managed to locate the K-27 submarine in Stepovoy Guba with the side-scan sonar and the ROV, and take a sediment sample next to the reactor compartment section. As for the Tsivolka Guba, the expedition located an object they thought was the *Lenin*'s screen assembly with the spent fuel with the side-scanning sonar. However, due to poor light conditions they could not find it with the ROV, but they did collect sediment samples less than a hundred meters from the object detected by the sonar. The expedition also took samples near the point where the submarine was dumped in the Novaya Zemlya depression.

---

[828] White Book, pp. 24, 29, and 33.

[829] Russian military authorities had barred previous missions from entering the restricted area. As a consequence, even though a Russian/Norwegian expedition of 14 August-10 September 1992 (aboard the *Viktor Buinitsky*) was allowed to obtain sand and water samples at 11 sites in the Kara Sea, the fact that they were prevented from approaching closer than 12 nm from Novaya Zemlya (the location of the dump sites) rendered their conclusions--that radioactivity had not migrated beyond the dumping sites--trivial.

[830] Drs. Leonid Polyak and Gennadi Ivanov (Okeangeologia, St. Petersburg), ``Russian Surveys At and Near the Radioactive Waste Dump Sites in the Kara Sea of the Arctic Ocean,'' presentation at the U.S. Naval Research Laboratory, Washington, DC, 13 January 1994.

[831] Lars Føyn and Alexander Nikitin, ``The Joint Norwegian/Russian Expedition to the Dump Sites for Radioactive Waste in the Open Kara Sea, the Tsivolki Fjord and the Stepovogo Fjord. September-October 1993.'' Report from the Expedition on board R/V *Viktor Buinitsky* with Some Preliminary Results, 3 October 1993. Julian Rose, ``Russia to Let Norwegians Visit Nuclear Graveyard,'' *Nature*, Vol. 365, 2 September 1993, p. 6.

The expedition leaders concluded that the ``very preliminary'' on-board measurements of cesium-137 in the sediment samples show the ``level of radioactive contamination in the investigated area is low.'' Samples taken near the dump site of the reactor fuel from the *Lenin*, next to the dumped K-27 submarine, and near the dumped submarine in the Novaya Zemlya depression, ``showed no signs of contamination above 'normal' values for the area.'' Only at one site for solid RW dumping in the Stepovoy Guba were elevated levels of cesium-137 (90 Bq kg^{-1} wet) and cobalt-60 found in the sediments. But the expedition leaders concluded, that although particularly the presence of cobalt-60 might point to leakage from the dumped waste, the true origins were difficult to define based on their preliminary measurements.[832]

Another joint Russian/Norwegian expedition to the dump sites in the Novaya Zemlya bays was mounted in August-September 1994. This time the expedition, again aboard the R/V *Viktor Buintsky*, visited the Abrosimov Guba, site of the largest amount of dumped reactors. The expedition also made a follow-up visit to the Stepovoy Guba.[833]

In the Abrosimov Guba, the expedition managed to locate three of the four dumped submarine reactor compartments, and also three of the four dumped barges containing solid RW. Based on external radiation measurements carried out by the ROV, two of the compartments were thought to contain spent fuel. One of the dumped barges had two large cylindrical containers on top of the cargo holds. Close to these containers, cobalt-60 gamma-radiation was measured, raising the possibility that they may contain reactors without spent fuel. Small containers containing RW were also found.

In the Stepovoy Guba, the expedition repeated some the sampling done near the site of the sunken K-27 submarine in 1993. Also, more of the solid RW dumped in the inner part of the bay was located, and samples were taken. Finally, some soil samples were collected from land to better be able to pinpoint the sources of contamination found in the sediments.

In both bays, the expedition found some spots of high radioactive contamination, mainly near the dumped solid RW containers. For example, a maximum detected cesium-137 content of up to 2,000 Bq/kg^{-1} wet weight was found in some sediments in the dumping area of the containers in Abrosimov Bay. Container walls were observed to be highly corroded and some had regular holes in them, leading the expedition leaders to conclude the radioactive contamination came from the ``wash-out'' of these containers. In Stepovoy Guba, some sediment samples were estimated to have a cesium-137 content as high as 60,000 Bq/kg^{-1} dry weight. Some contamination was found near the dumped reactors in Abrosimov Bay, but it was of a lower magnitude (400 Bq/kg^{-1} wet cesium-137 content). In general, the expedition leaders concluded that although there are spots of radioactive contamination in both bays, ``the levels of radioactive contamination in the investigated areas is low.'' What radioactive contamination exists mainly comes from the dumped solid RW and seemingly not from the dumped reactors.[834]

The On-going Waste Disposal Problems
of the Navy and the Murmansk Shipping Company

As noted, a large amount of nuclear waste continues to be generated by the daily operation of the nuclear-

[832] Føyn and Nikitin, ``The Joint Norwegian/Russian Expedition to the Dump Sites1.'' p. 11.

[833] Ibid., p. 2.

[834] Ibid., pp. 8-9, 14-15, 17.

powered submarines, surface ships, and icebreakers. In addition, the Russian Navy in particular is facing an acute crisis in dealing with the waste generated by the increasing number of decommissioned nuclear submarines.

Decommissioned Nuclear-powered Submarines

The nuclear accident aboard an Echo II SSGN in 1989, lead the Russian Navy to accelerate the retirement of its aging first generation submarines. Since then, the numbers of retirements has continued apace. Through January 1993, a total of around 80 nuclear submarines had been decommissioned.[835] By October 1994, the number of officially retired submarines had grown to 121. The actual number of out-of-operation submarines may be as high as 150. In any even, in total, some 200 nuclear submarines are now expected to be decommissioned by the end of the decade.[836] Decommissioned nuclear submarines are found at nuclear submarine bases and nuclear naval shipyards in the Northern and Pacific Fleet (see Figures 6.1 and 6.4). Approximately, two thirds are in the Northern Fleet and one-third in the Pacific.

Advanced planning on the part of the Soviet Navy to deal with the decommissioning problem was inadequate. As noted, a 1985 resolution of the USSR government on the construction of burial sites in the Northern and Pacific Fleets by 1993 for reactor compartments of nuclear submarines was never implemented.[837] Throughout the early 1990s, the Navy has continued to try to formulate a decommissioning program, and in addition get special government funding, but with no success. As a result, the Russian Navy has faces problems implementing every step of the decommissioning process.

Spent nuclear fuel. Spent nuclear fuel should be offloaded from retired submarines in a timely manner. The Soviet and now Russian Navy utilizes special ``floating workshop'' nuclear submarine service ships to offload spent fuel from submarines.[838] These service ships take on the spent fuel for transhipment to a land-based storage site, where the fuel sits for further cooling before being shipped to Mayak. However, there is a shortage of these special service ships. Of the six such ships in the Pacific Fleet, as of 1993, three were inoperable due to accidents or old age. The other three were also not in the best condition.[839] A similar situation pertains in the Northern Fleet.

Shipments of spent nuclear fuel from the land-based storage sites has been hampered by the problems of introducing new TUK-18 spent fuel shipping containers into the Fleet. These containers are considerably heavier than the older versions -- TUK-11, TUK-12s and TUK-12/3s -- they are replacing. The old infrastructure for loading the containers at railhead was not upgraded quickly enough to accommodate their introduction into the fleet and there were safety prohibitions on shipping spent fuel in the old containers. Thus in 1993-1994, there were only a minimal amount of shipments of spent fuel in the new containers.[840] The Navy also lacks funding for paying

---

[835] Roman Zadunaysky (ITAR-TASS correspondent), ``Navy Commander Admiral Gromov Comments on the Problem of the Russian Navy Shipbuilding Program,'' *Krasnaya Zvezda*, 23 January 1993 (FBIS-SOV-93-015, 26 January 1993).

[836] Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific Fleet,'' 27 October 1994, pp. 41, 51.

[837] White Book, p. 33.

[838] Two types of floating maintenance base have been identified. The older PM-124 class ships were ``converted Finnish-built cargo barges, employed in nuclear submarine maintenance.'' Arthur D. Baker III, ``Their Ship Types: Part III,'' *U.S. Naval Institute Proceedings*, October 1982, p. 172. They are some 30 years old. Some nine of these vessels may currently exist: five have been identified in the Pacific Fleet--PM-125, PM-133, PM-80, PM-124, and PM-48. Four have been identified in the Northern Fleet.
     The newer Malina class support ships entered the fleet in 1984. Three are known to be in the Navy, two in the Northern Fleet and one in the Pacific (PM-74). A fourth may be under construction. Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific Fleet,'' 27 October 1994, p. 29.  Nilsen and Bohmer, ``Sources to Radioactive Contamination,'' Bellona Report, pp. 46-47. *Jane's Fighting Ships 1994-1995*, p. 590. Joshua Handler, ``Russia's Pacific Fleet,'' *Jane's Intelligence Review*, April 1994, p. 166.

[839] Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific Fleet,'' 27 October 1994, p. 29.

[840] White Book, p. 31. Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific,'' 27 October 1994, pp. 24-25.

Mayak for taking the spent fuel. To process each train load of spent fuel costs between one to two billion rubles, depending on its size.[841]

Several major problems have resulted from the lack of service ships and spent fuel shipping capability. Offloading of spent fuel from decommissioned submarines is proceeding very slowly. Only some third, had their fuel removed as of late 1994. In some cases, spent fuel has been sitting on decommissioned submarines for 15 years.[842] Maintaining these submarines, particularly those which still have their spent fuel on board is costly, and naval officers and local residents worry about the possibility of one sinking at dockside due to in attention of the custodian crew.

Land-based spent fuel storage sites are also are near or at capacity. As of January 1993, the White Book stated the Northern and Pacific Fleets had almost 30,000 spent fuel assemblies stored ashore and on service ships, corresponding to the contents of around 140 submarine reactor cores. At that time there was only enough room left in storage facilities for three more cores. Since the normal operation of nuclear-powered submarines requires the annual refuelling of approximately ten reactor cores in each fleet, the Commission concluded, ``the situation has already reached the critical point, precluding the continued safe operation of the fleet of atomic submarines.''[843] The situation still remains critical since so few shipments of spent nuclear fuel have taken place in 1993-1994.

Reactor Compartments. As for the submarines which have had their fuel offloaded, another problem has been the shortage of scrapping capacity at the major submarine shipyards and the lack of funds for scrapping the submarines. In the Pacific Fleet, the rate of scrapping was estimated to be 1.5 hulls a year. The process only began in the 1990 time frame. By the autumn of 1993, some six hulls had been fully scrapped. Russian naval officers noted at current rates it will take many decades to fully deal with the 60 or more nuclear submarines expected to be decommissioned in the Pacific Fleet.[844] The process has been even more delayed in the Northern Fleet, with only a few nuclear submarines had been scrapped by 1994.[845]

The lack of a land-based site for the storage of reactor compartments has lead the Russian Navy to store reactor compartments or partially dismantled submarines afloat in bays near naval facilities or in naval bases. In the Pacific Fleet, reactor compartments and the two adjoining compartments are cut-out of the submarine at the Zvezda [Star] shipyard at Bolshoi Kamen. The compartments are sealed up, and then are towed around the Shkotovo peninsula for storage a float in small Razboynik Bay across Chazhma Bay from the Chazhma Bay shipyard. (Some reactor compartments may also be stored at the near-by Pavlovsk submarine base.)[846] Six such compartments had been towed to Razboynik Bay by the autumn of 1993. In the Northern Fleet, the process may not be so ``advanced.'' There may be some similar floating reactor compartments at the Zvezdochka [Little Star] submarine repair plant at Severodvinsk. But otherwise, some eight partially stripped-down submarines had been stored at Sayda Guba near Polyarny on the Kola peninsula by the summer of 1993.[847]

---

[841] Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific,'' 27 October 1994, p. 26.

[842] Ibid., p. 50.

[843] White Book, p. 32.

[844] Joshua Handler, ``Trip Report: Greenpeace Visit to Moscow and Russian Far East July--November 1992, Subject: Russian Navy Nuclear Submarine Safety, Construction, Defense Conversion, Decommissioning, and Nuclear Waste Disposal Problems,'' (Washington, DC, Greenpeace, 15 February 1993), pp. 16-17. Joshua Handler, ``No Sleep in the Deep for Russian Subs,'' *Bulletin of the Atomic Scientists*, April 1993, p. 7. Handler, ``Russia's Pacific Fleet,'' pp. 167, 171.

[845] According to local officials, only three nuclear submarines were scrapped in 1993 at the Little Star plant. Joshua Handler, ``Trip Report on: Greenpeace Visit to Severodvinsk, Russia, 13-14 May 1994,'' (Washington, DC: Greenpeace, 3 June 1994, [revised 7 July 1994]), p. 2.

[846] Handler, ``Russia's Pacific Fleet,'' pp. 167, 171.

[847] Handler, ``The Northern Fleet's Nuclear Submarine Bases,'' p. 554.

Nuclear-powered Icebreakers of the Murmansk Shipping Company

The facilities for handling and storing nuclear waste generated by the civilian nuclear-powered fleet are located on land and aboard five icebreaker service ships. After the cessation of ocean dumping, liquid radioactive waste has been processed at a land-based facility in the Atomflot icebreaker base. Low-level solid radioactive waste is stored on land or service ships (the *Lepse* and *Volodarsky*), or is incinerated.[848] Thus compared to the Navy, the Murmansk Shipping Company does not have the same acute problems in dealing with low-level waste. However, in regards to spent nuclear fuel, the Murmansk Shipping company faces the same problem of filled-up storage.

Spent Nuclear Fuel. Spent fuel assemblies from the civilian fleet are currently stored on three floating maintenance bases anchored at the Atomflot icebreaker base--the *Lepse*, *Imandra*, and *Lotta*. The White Book calculated that around 4,500 spent fuel assemblies were stored on these three vessels as of early 1993, with ``almost no reserve storage space left.''[849]

The *Lepse* service ship is the greatest environmental concern of Atomflot at present as it contains damaged fuel assemblies which were covered by a cement sarcophagus to prevent further radioactive contamination.[850] In 1993, the radioactivity on board the ship was estimated to be 750 kCi (of which 17 kCi was contributed by long-lived and toxic transuranic elements).[851]

Proposed Land-based Solutions to Russia's
Nuclear Waste Disposal Problems

Several programs and decrees have been articulated since 1992 to address the critical radioactive waste program existing in the Navy and Murmansk shipping company. The draft ``Russian State Program for Handling, Recycling, and Disposal of RW and Spent Nuclear Materials in 1993-1995 and up to 2005'' proposed allocating over six billion rubles (1992 prices) for the construction of on-shore and shipboard complexes for the treatment of liquid and solid RW. For 1993, the planned Program included a general analysis of the formation and accumulation of RW in the Northern and Far Eastern regions of Russia, and technical and economic feasibility studies of the construction of specialized facilities for the temporary storage, treatment, and disposal of RW. The 1993-1995 Program proposed the establishment of experimental industrial burial grounds for the disposal of solid (or solidified) waste (of low- and medium-level activity).[852]

A 1993 decree by the Russian government Council of Ministers-- ``On Urgent Works in the Field of Handling Radioactive Waste and Spent Nuclear Materials,'' called for about five billion rubles (1993 prices) worth

---

[848] White Book, p. 31. Nilsen and Bohmer, ``Sources to Radioactive Contamination,'' Bellona Report, pp. 88-90.

[849] White Book, p. 30. Bellona reported that of the estimated 12,000 spent fuel assemblies emanating from the Atomflot base (by early 1993), about half were sent to Mayak and the other half were in storage on the three ships: the *Imandra* contained a total of 1,500 used fuel rods; the *Lotta* was loaded to capacity, with 5,543 used fuel rods; and the *Lepse* contained some 621 used fuel rods in two compartments (319-321 damaged rods from the *Lenin* icebreaker in compartment 1, and 303 used fuel rods in compartment 2. The damaged fuel rods were not transferred to Mayak because of the dangers involved in reprocessing them). Nilsen and Bohmer, ``Sources to Radioactive Contamination,'' Bellona Report, pp. 81, 86-87.

[850] Nilsen and Bohmer, ``Sources to Radioactive Contamination,'' Bellona Report, p. 86.

[851] White Book, p. 30.

[852] These construction projects were proposed by Section 9 of the draft Program, entitled ``The Handling of Waste Generated During the Operation and Deactivation of Nuclear Transport Assemblies.'' White Book, p. 31.

of work on numerous radioactive waste projects including those of the Navy, but only about 15 percent of these monies were allocated.[853]

A similar decree for 1994 listed the need to:
* develop the technical capability to decommission retired nuclear-propelled ships & vessels;
* decommission the training reactors at the Paldiski Naval Training Center in Estonia;
* develop special security measures for rail shipments of spent nuclear fuel;
* develop technologies for handling spent nuclear naval fuel that will not be reprocessed;
* develop a technical solution for burying the *Lepse*;
* begin the full-scale operation of the ``Special Water Cleaning Treatment Installation" at the Atomflot facility in order to begin to process some part of the Northern Fleet's liquid RW;
* develop a technical and economic plan for building an increased infrastructure for handling RW the northwest region of Russia;
* construct an experimental facility for burying radioactive waste from the Murmansk Shipping Company and the Northern Fleet at Novaya Zemlya;
* construct additional capacities for storage and processing of liquid RW;
* construction and upgrade shops for assembly, processing and storage of RW at the State Committee for Defense Industry's shipyards; and
* build a special vessel for shipment of RW containers.[854]

In 1994, beyond the removal of the spent fuel from the two training reactors in Palsiski, the exact status of the funding for the remaining proposals remains unclear.

Liquid Waste

Several programs are in place to deal with liquid radioactive waste. As of fall 1994, in the Pacific Fleet, some small scale filtering equipment has been placed on the TNT-5 to deal with its load of liquid RW. The Navy has plans to send more such equipment to the Far East.[855] In addition, in the aftermath of the October 1993 dumping scandal, Japan has promised to provide assistance for building a liquid radioactive waste processing facility. A tender for building such an facility was let in October 1994.[856] Construction is expected to begin sometime in 1995. Finally, the *Pinega* nuclear service ship may be upgraded so it too can process liquid radioactive waste. These measures are supposed to insure no further dumping of liquid RW in the Pacific occurs again.

As for the Northern Fleet, plans are being laid to expand the Atomflot liquid RW processing facility with U.S. and Norwegian help so that it can handle the Northern Fleet's waste (some waste was already processed here in 1994).[857] If the facility is expanded in a timely manner, the Northern Fleet's liquid RW problem will be solved.

---

[853] The Council of Ministers--The Government of the Russian Federation Decree from 14 August 1993, No. 824, Moscow, ``On Urgent Works in the Field of Handling Radioactive Waste and Spent Nuclear Materials." Handler, ``Trip Report on: Greenpeace Visit to Severodvinsk," p. 5.

[854] The Council of Ministers--The Government of the Russian Federation Decree from 6 July 1994, No. 805, Moscow, ``On Urgent Works in the Field of Handling Radioactive Waste and Spent Nuclear Materials."

[855] Vladimir Maryukha, ``The Retired Nuclear Ships Have Not Left Us Any Choice: Either We Bury Them, or They Bury Us," *Krasnaya Zvezda*, 14 September 1994.  Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific Fleet," pp. 48-49.

[856] On 14 October 1994, after several months of delay, Japan and Russia issued a tender offer for construction of a floating barge facility. The results of the bid are expected by late November or December; Reuters (Tokyo), ``Japan, Russia Tender for Nuclear Waste Facility," 14 October 1994.

[857] White House Press Office, ``Joint U.S.-Russian Announcement on Environmental Protection in the Arctic," 28 September 1994.  For a recent discussion of Norway's perspectives on the Russian Navy radioactive waste problem see: Bjorn Tore Godal, Foreign Minister of Norway, ``Regional Cooperation in the European High North," *NATO Review*, June 1994, pp. 8-11. Norway has also approached the United States for assistance in developing trilateral cooperation between Norway, the United States, and Russia for dealing with Arctic military-related radiation problems.

Also, there are plans for rehabilitating the *Amur* nuclear service ship.

Solid Waste

The situation with solid RW has received much less attention, and the status of solutions is much clear. As noted, the Murmansk Shipping Company already has a solid waste treatment plant at the Atomflot base, where the waste is incinerated. Naval and shipyard officials, however, seem to be mainly interested in the construction of new or expanded conventional storage facilities.

Spent Nuclear Fuel and Reactor Compartments

The offloading of spent fuel from retired submarines is supposed to be a priority, but new service ships will probably not become available in the near future, if at all. Some of the older PM-124 class ships in the North have recently been overhauled at the Little Star plant. But it still appears there is inadequate capacity. Another major problem is removing the damaged spent fuel from three submarines in the Pacific Fleet which had serious nuclear accidents, taking off damaged fuel that has been kept on two PM-124 class ships in the Pacific Fleet, and dealing with the damaged fuel in the *Lepse* icebreaker service ship. In any event, as of late 1994, the resolution of the spent fuel offloading problem remains unclear.

As for the status of land-based storage sites, the Navy has made some small steps in taking the new TUK-18 spent fuel casks into service in 1993-1994. However, the rate of shipments of spent fuel from storage sites and shipyards in the Far East and North is still very low. The Navy's preference still seems to be to continue to ship spent fuel to Mayak. However, some government officials note that this just adds to the environmental problems in the Chelyabinsk region, so a better solution might be to construct new storage in the Fleets. Once again, how these problems will be resolved beyond the steady application of small and inadequate financing is not known.

The situation with the submarine scrapping program is also not good. Lack of financing, strikes and power outages have afflicted the two shipyards in the country--Little Star in Severodvinsk in the North and Star in Bolshoi Kamen in the Pacific--engaged in this work. Some cutting equipment is arriving from the United States under the auspices of the Nunn-Lugar Cooperative Threat Reduction funding.[858] This may lead to some increase in the scrapping pace at the shipyards. But the backlog of submarines for scrapping promises to be quite large through the rest of the 1990s.

Several ideas have been considered for dealing with the reactor compartments from decommissioned submarines, including storing the reactor compartments in tunnels previously dug in hillsides at naval bases for sheltering nuclear submarines during wartime. Also, building a storage site on Novaya Zemlya has been considered. Recent reports suggest that the Novaya Zemlya project may now be pursued. However, once again, when construction of such storage sites in the North or in the Pacific may be begun or finished is not known.

---

[858] Office of Assistant Secretary of Defense (Public Affairs), ``Nunn-Lugar Assistance to NIS Accelerated,'' press release no. 495-94, 26 August 1994, p. 6. Three 700-ton scrapping machines made by Harris Waste Management Group in Cordele, Georgia, are to be shipped under a $10.7 million contract from the Defense Nuclear Agency under the Nunn-Lugar funds for destruction of strategic nuclear weapons in Russia; Associated Press, ``These Machines are Built to Chew up Russian Subs,'' *Navy Times*, 24 October 1994.

Appendix A
Profiles of Key Figures in the Soviet/Russian Nuclear Program
Revised after publication of Making the Russian Bomb

Adamsky, Viktor B.--Born 1923. A senior member of the Tamm/Sakharov theoretical department at Arzamas-16. Was in charge of what Sakharov called the ``Big Bomb,'' presumably the 150 megaton device exploded on 30 October 1961, at one-third its potential yield, and tested at least three more times during the August through December 1962 series at smaller fractions of its yield.

Aleksandrov, Anatoli Petrovich--Born 13 February 1903 in Tarashchi near Kiev. Died 1993. Graduated from Kiev University in 1930. Aleksandrov replaced Kapitsa in 1946 as director of the Institute of Physical Problems after Kapitsa refused to participate in the atomic weapons program. He directed it until 1955. In late 1948 also was named deputy director of LIPAN. Part of the Tamm group. Worked with Kurchatov on development of the first production reactors, specifically the B Plant of Combine 817. Responsible for isotope separation using thermal diffusion. Designer of early graphite production reactors and the later Chernobyl type RBMK reactors. On 15 May 1960 he became director of the I.V. Kurchatov Institute of Atomic Energy. Academician; elected on 23 October 1953; elected President of the Academy of Sciences on 25 November 1975, and served in that capacity until he was replaced by Guriy Marchuk on 16 October 1986. Lenin Prize (1959); State Prize (1942, 1949, 1951, 1953); Hero of Socialist Labor (1954, 1960, 1973).

Aleksandrov, Lt. Gen. Anatoli Sergeevich (1899-1984) From 1918 through 1924 he served in the army. From 1928-1932 was an auditor at the Military-Political Academy imeni F.E. Dzerzhinskiy. From 1932-1938 instructor at Academy of Motorization and Mechanization imeni I.V. Stalin. 1939-1945 served on the Defense Committee in various capacities, 1945-1947 assistant deputy chairman of the Soviet of People's Commissars and Council of Ministers. On 18 April 1947 named deputy to Vannikov at the First Main Directorate (PGU) assigned to provide Arzamas-16 with resources, continuing in that capacity until 1951. Was director of Arzamas-16 from 1951 to 1955. According to Sakharov, Aleksandrov was fired, ostensibly because of an affair with a woman working in a foreign embassy. The authorities claimed she was a spy, but in fact she was a double agent working for the KGB. The true cause was probably a conflict with Zernov who had been promoted and was Aleksandrov's superior.

Alfyorov, Vladimir Ivanovich--Director of a plant that produced naval mines and torpedoes. At Arzamas worked on the electrical system in the bomb. Helped prepare the first test in 1949. Was director of Arzamas-16 beginning in 1951, possibly after the dismissal of Anatoli S. Aleksandrov. Later, was director of the first nuclear warhead production plant, presumably Sverdlovsk-45. Later became director of the Sixth Main Directorate (nuclear weapons production) of the MMB. After Zernov died in 1964 became deputy minister and held post until 1967. Retired in 1968. Hero of Socialist Labor (1949).

Alikhanov, Abram Isaakovich--Born 5 March 1904 in Tbilisi; died 8 December 1970 in Moscow. Graduated from the Leningrad Polytechnical Institute in 1928 and afterwards worked at the Leningrad Physico-Technical Institute. Appointed to the weapons program at the suggestion of A.F. Ioffe. Started working in Laboratory No. 2 in 1943. In 1949 Alikhanov and his colleagues put into operation the first nuclear reactor with a heavy-water moderator in the USSR. Director of the Institute of Theoretical and Experimental Physics, 1945-1968. Principal constructor of the Serpukhov high energy accelerator. Academician; elected full member in 1943. State Prize (1941, 1948, 1953); Hero of Socialist Labor (1954).

Altshuler, Lev Vladimirovich--Born 1913. Experimental physicist at Arzamas-16 from 1947. Co-authored a report in 1949 that provided the experimental basis and calculations for a more efficient design that would be tested in 1951 as Joe 2 and Joe 3.

Antropov, Pyotr Yakovlevich--From 1945-1953 a deputy to Vannikov and also the head of the Second

Main Directorate, a special ``semi-ministry'' (like the First) of the Council of Ministers to oversee the extraction and enrichment of uranium. From 1953-1962 Minister of Geology and Resource Protection. From 1962-1979 a Deputy Minister of MMB. Hero of Socialist Labor (1954); Lenin Prize (1978); State Prize (1951).

Artsimovich, Lev Andreyevich--Born 25 February 1909 in Moscow; died 1 March 1973. Graduated from the University of Belorussia, 1928. From 1930-1944 worked at the Leningrad Physico-Technical Institute. From 1944 worked at the Institute of Atomic Energy. Responsible for isotope separation using electromagnetic separation. Leader of pioneering work on thermonuclear physics. Academician; elected 23 October 1953. Awarded Hero of Socialist Labor (1969); Lenin Prize (1958); State Prize (1953, 1971).

Averin, Aleksandr Nikitovich--Born in 1946, Averin was graduated from the Moscow Physico-Technical Institute in 1970, and has worked at Chelyabinsk-70 for the last 22 years. He holds a doctorate in Science and is deputy head of the Explosion Physics Department. His fields of expertise include: the properties of matter under high pressure and high-speed dynamic processes, such as impacts, phase transitions, cumulation, explosive techniques and technologies.

Avrorin, Evgeni Nikolaevich--Born 11 July 1932; graduated from Moscow State university in 1954; worked at Arzamas-16 from March-August 1955. Since its establishment in 1955, Avrorin has worked at Chelyabinsk-70, where he is currently the Scientific Director. Elected corresponding member of the General Physics and Astronomy Department, Academy of Sciences, 23 December 1987. Theoretical physics with interests in the fields of physical processes under high pressures and temperatures, nuclear and neutron physics, inertial confinement fusion, and disarmament.

Babayev, Yuri Nikolaevich--Born 21 May 1928; died 6 October 1986. Graduated from Moscow University in 1950 at the age of 22, went to work for Arzamas-16 in 1951 and worked on the nuclear weapons program. Was a junior member of a team that was secretly awarded the Stalin Prize in 1953. In 1959 was given Lenin Prize, in 1962 Hero of Socialist Labor. In 1962 was given rank of senior research worker at an unidentified institute. The official obituary published in *Izvestiia*, identified him as a ``major scientist, an outstanding specialist in the field of nuclear physics and atomic technology.''

Barkanov, Boris--Deputy Head of the Scientific and Design Division, Arzamas-16.

Barulin, Anatoli Yegorovich--Born in 1936 and graduated from the Moscow Physical Engineering Institute in 1960, Barulin has a doctorate in Science. He has worked at Chelyabinsk-70 since 1960 and is the Chief Designer of the Institute (for fiber optics). His experience includes work in the fields of fiber-optic networks, technology and equipment for fiber production, control systems, cryogenic machines, and laser thermonuclear experiments.

Belugin, Vladimir Aleksandrovich--Born 30 March 1931 in Leningrad (now St. Petersburg). Studied in Kazan, worked in an aviation plant in 1956. Arrived at Arzamas-16 in 1972 and Director since about 1990.

Beria, Lavrenti Pavlovich--Born 29 March 1899, Merkheuli, near Sukhumi in Georgia; arrested 26 June 1953, shot and killed 23 December 1953, Moscow. Brought to Moscow in August 1938 as first deputy to Nikolai Yezhov, the head of the People's Commissariat for Internal Affairs (NKVD; Soviet secret police). Yezhov was shot and Beria became head of the NKVD until he relinquished control in 1946. He resumed control again in 1953, renamed MVD. In 1941 he became deputy prime minister of the USSR, and during World War II, he was a member of the State Defense Committee. He was made a marshall of the USSR in July 1945. He was elected a candidate member of the Politburo in March 1939 and a full member in March 1946. Beria was director of atomic bomb program from August 1945 to 1953, as Chairman of the Special Committee and head of the NKVD. Some of his assistants that oversaw the atomic bomb program were: Nikolai I. Pavlov, Lt. Gen. Osetrov, Pavel

Yakovlevich Meshik, Col. Valery Evstafievich Rukavitsyn, Col. Vasily Ivanovich Detnyov, and Gen. V.A. Makhnev.

Blokhintsev, D.I. A physicist who died in 1979.

Bochvar, Andrei Anatolyevich--1902-1984. In June 1949 his department at Chelyabinsk-40 (now Chelyabinsk-65) was responsible for processing the plutonium and fabricating the metal hemispheres for the first bomb. Director of the All-Union Scientific Institute of Inorganic Materials. Member of the Academy of Sciences (1946); Hero of Socialist Labor (1949); State (Stalin) Prize (1941, 1949, 1951, and 1953); Lenin Prize (1961).

Bogolyubov, Nikolai Nikolaevich--Born 21 August 1909. Mathematician and theoretical physicist. Part of the Tamm group. Leading scientist at Arzamas-16. Former Academician Secretary of the Mathematics Department, from July 1963. Academician; elected to the Physical Mathematical Sciences Department (now Nuclear Physics Department) of the Academy of Sciences 23 October 1953. Former Director of the Joint Institute for Nuclear Research in Dubna, from 1965.

Boichuk, Yefim Vasilevsky--Born 1918 in the Ukraine. Head of the 12th Main Directorate, 1974 to 1985. From 1985 to his death in 1991 Inspector in Inspectorate. Hero of Socialist Labor (1984).

Boliatko, Viktor Anisimovich--born 1906, and joined the CPSU in 1929. General in charge of army units at Semipalatinsk test site during first test in 1949. He was killed in an automobile accident in 1965 when he was Head of a Main Directorate (probably the 12th) of the Ministry of Defense. The only industrial minister to sign his obituary was Ye.P. Slavsky.

Brish, Arkady Adamovich--Weapon designer. Began working at Arzamas-16 in the summer of 1947.

Brokhovich, Boris V.--Among the first 300 people to arrive at Chelyabinsk-40 (now Chelyabinsk-65) in 1946. Electrical Engineer; Chief Engineer at the 501-Reactor, 24 May 1952--1 July 1954; Director of Plant 156 (three reactor complex) 12 July 1963--18 May 1971; Director of Chelyabinsk-65 (formerly Chelyabinsk-40) 1971--ca. 1991. Hero of Socialist Labor; Lenin Prize (1960); State Prize (1954).

Burnazian, A.I.--1906-1981. Deputy Minister of Health and Chief of the Radiation Protection Service in 1949, responsible for studying the effect of radiation on living organisms in the first atomic test. Also in charge of the Sungal Institute.

Chernyshev, Aleksandr K.--Born 23 October 1945. In 1992 Deputy scientific director of Arzamas-16.

Davidenko, Viktor A.--(1914-1982) Worked at LFTI from 1937-1940. From 1943 to his death worked at Laboratory No. 2, LIPAN and the Kurchatov Institute. Part of the design team at Arzamas-16, responsible for the development of the neutron initiator. Hero of Socialist Labor (1954).

Dmitriev, Nikolai Alexandrovich--Born 1924. Mathematician; disciple of Academician Kolmogorov. Worked in Zeldovich's theoretical department at Arzamas-16 and later a colleague of Sakharov's. Did calculations on the ``Third Idea.'' Child prodigy.

Dollezhal, Nikolai Antonovich--Born 27 October 1899 in Omelnik, Ukraine. Graduated from the Moscow Higher Technical School in 1923. Director of All-Union Design Scientific Research Institute of Chemical Machinery (NIIKhimmash). Enlisted by Pervukhin to be Chief designer of the first atomic reactor. A chief designer of naval reactors. Academician, 1962. Member of the Physical Technical Problems of Power Engineering Department, and the Mechanics and Control Processes Department. Hero of Socialist Labor (1949); Stalin Prize

(1952); Lenin Prize (1957).

Drozhko, Evgeni Gordeevich--Candidate of Technical Sciences and Chief Engineer at Chelyabinsk-40 (now Chelyabinsk-65) in 1989.

Dudochkin, Evgeni Konstantinovich--Born 8 June 1940. Senior official with Sixth Department, under Gorobets, responsible for nuclear warhead production facilities (warhead assembly, fissile material storage, etc.) within the Department of Defense Industry, Ministry of Atomic Energy.

Dukhov, Lt. Gen. Nikolai Leonidovich--Born 26 October 1904; died 1 May 1964 (of leukemia). Was drafted in July 1948 into the atom bomb program and was Kurchatov's right hand man at Arzamas-16 as deputy scientific director and deputy chief designer. Previously from 1932-1948 he was chief designer at the Kirov Tank plant in Leningrad, where during World War II he designed the Voroshilov tank and the Stalin tank. In early 1954 he was moved to the ICBM program where he headed a design bureau. State Prize (1943); Hero of Socialist Labor (1945, 1949, 1954); Lenin Prize (1960). Corresponding member of the Academy of Sciences (1953).

Dzekun, Evgeni G.--Chief Engineer of the Radiochemical Plant, ``Mayak'' Production Association (Chelyabinsk-65) in 1991.

Faikov, Yuri Ivanovich--First deputy chief designer at Arzamas-16 in 1992; doctor of technical sciences.

Fedorov, Ye.--1910-1981. According to 3 May 1990 *Izvestiia* he once worked at the test site in Novaya Zemlya. Academician, Chief Scientific Secretary of the Academy of Sciences.

Feoktistov, Lev Petrovich--Physicist-theoretician. Part of the Tamm group. From 1955 to 1973 was in charge of a department, then a division and finally became deputy scientific director at Chelyabinsk-70. From 1973 to 1990 worked at the Kurchatov Institute of Atomic Energy (IAE)

Feoktistova, Ekaterina Alekseevna--Born c. 1920. A colleague of Sakharov's. Since September 1947 worked in A.F. Belyaev's laboratory. Sent to work at Chelyabinsk-70 in 1955 and was put in charge of a laboratory studying high explosives.

Fetisov, Viktor Ilich--In 1990 was Deputy Director of the Mayak Production Association (Chelyabinsk-65).

Fishman, David Abramovich--Head of the design department at Arzamas-16 in the period around 1961

Flerov, Georgii Nikolaevich--Born 2 March 1913 in Rostov-on-Don. Died 19 November 1990. Graduated from the Leningrad Polytechnical Institute in 1938. From 1938-1941 was on the staff of the Physico-Technical Institute. From 1941-1943 was in the Red Army. From 1943-1960 on staff of Institute of Atomic Energy. Worked at Arzamas-16. In 1960 made director of Nuclear Reactions Laboratory of the Joint Institute for Nuclear Research in Dubna, after having worked there since 1953. In 1940 Flerov together with L.I. Rusinov showed that more than two neutrons are emitted during the fission of a uranium nucleus. In the same year together with K.A. Petrzhak, Flerov discovered the spontaneous fission of heavy nuclei. Noticed articles on nuclear energy had disappeared from American, British, and German publications in the early 1940s. As a consequence he wrote letter to Stalin in April 1942 alerting him to the urgency of solving the ``uranium problem.'' This helped prompt renewed interest by Soviet officials to develop the bomb. From 1960 to 1988 he was director of the Laboratory of Nuclear Reactions (now the Flerov Laboratory of Nuclear Reactions) at the Joint Institute for Nuclear Research. Elected to the Academy of Sciences (1968); Hero of Socialist Labor (1949).

Fradkin, Efim Samoilovich--born 24 February 1924 in Shehedrin, Byelorussia. A 1948 graduate of the

University of Lvov and started work at the Institute of Physics the same year. His major works are devoted to quantum field theory, quantum statistics and hydrodynamics. State Prize (1953).

Frank-Kamenetsky, David Albertovich--A leading theoretical physicist at Arzamas-16, arriving there in 1946. Associate of Zeldovich. Left Arzamas in 1956 to work at LIPAN (Kurchatov Institute).

Fuchs, Klaus--born 29 December 1911, died 28 January 1988. A German-born physicist in the U.S. fission and fusion weapons program at Los Alamos who was convicted of being a Soviet spy. Emigrated first to Britain and then went to Los Alamos during World War II. After the war he returned to Britain and worked at Harwell, a nuclear research center near Oxford. From 1941 on he carried out espionage for the Soviet Union until his arrest in February 1950. He served nine years of a 14-year sentence and returned to East Germany where he resumed a scientific career.

Fursov, V.--Assistant to Kurchatov who helped with the design of the F-1 pile and who helped oversee the construction of Chelyabinsk-40 as Kurchatov's main representative.

Gavrilov, Viktor Yulianovich--born c. 1920; died early 1970s. Colleague of Sakharov's at Arzamas-16. Later became a molecular biologist. Headed radiobiological department.

Gerasimov, Vladimir Ivanovich--Successor to Ye.V. Boychuk as Head of the 12th Main Directorate, 1985-1992.

Ginzburg, Vitali Lazarevich--Born 4 October 1916. Graduated from Moscow University in 1938. First to propose the use of lithium deuteride in thermonuclear weapons; Sakharov said that ``The first two ideas [about the H-bomb] were those proposed by Vitali Ginzburg and myself in 1948.'' Member of the Department of Theoretical Physics of the P.N. Lebedev Institute of Physics of the Soviet Academy of Sciences (FIAN). Part of the Tamm group; became department head when Tamm died on 12 April 1971. Corresponding member of the Academy of Sciences (October 1953); elected to General Physics and Astronomy Department of the Academy of Sciences on 1 July 1966. Also a member of the Nuclear Physics Department.

Golovin, I.N. Assistant to Kurchatov from 1950-1958.

Gorobets, Boris Valentinovich--Born 1928, Samarkand. Graduated from the Central Asian Polytechnic in 1950. From 1950-1954 worked at the Mayak Production Association in Chelyabinsk-65 and then at Zlatoust-36 Instrument-Making Plant. As of late 1994 is Head of the Sixth Department, Nuclear Weapons Production, Department of Defense Industries, Ministry of Atomic Energy with current responsibilities for large-scale reductions and conversion. Address: 24/26 B. Ordynka, Moscow 101000, Russia. Tel: (095) 233-1115.

Grechishnikov, Vladimir Fyodorovich--one of the first weapon designers. Died at the age of 41 while deputy chief designer of Chelyabinsk-70. Was responsible for the design of the lenses of the first bomb. Hero of Socialist Labor.

Gurevich, Isaak Izrailevich--Born 13 July 1912 in Riga. Graduated from Leningrad University in 1934. From 1934-1945 worked at the Radium Institute. In 1941, with Zeldovich and Khariton, determined the critical mass of U-235. Since 1945 at the I.V. Kurchatov Institute of Atomic Energy. Corresponding Member of the Academy of Sciences, 1968. Main work in neutron physics, reactor theory and the properties of muonium.

Ilkayev, Rady--First Deputy Scientific Supervisor and First Deputy Chief Designer, Arzamas-16.

Ioffe, Abram Fedorovich--Born 29 October 1880; died 14 October 1960. Born in Romny, Ukraine.

Graduated from the St. Petersburg Technological Institute in 1902 and from Munich University in 1905 where he worked with Wilhelm Pontgen, the discoverer of X-rays. Director of the Physico-Technical Institute from 1923 to 1951. Recommended I.V. Kurchatov to head the Soviet atomic bomb program. Elected to Academy of Sciences (1920): Hero of Socialist Labor (1955).

Ivanov, Vitali Mikhailovich--Senior official of the Fifth Department, Nuclear Weapons Development and Testing, Department of Defense Industry, Ministry of Atomic Energy.

Izrael, Yuri Antoniyevich--Born 15 May 1930. According to 3 May 1990 *Izvestiia,* he once worked at the test site in Novaya Zemlya. Elected corresponding member of the Oceanology, Atmospheric Physics and Geography Department, Academy of Sciences on 26 November 1974.

Izraileva, Revekka--Born c. 1920. Mathematician. Colleague of Sakharov's at Arzamas-16.

Kapitsa, Peter Leonidovich--1894-1984. Born in Kronstadt. Graduated from the Petrograd Polytechnical University in 1918. Studied and worked at the Cavendish Laboratory at Cambridge University, 1921-1934. On 19 December 1945 Kapitsa was relieved of his positions on the Special Committee and its Technical Council because of differences with Beria. In 1946 he was replaced as director of the Institute of Physical Problems and in January 1955 was restored to the position. Hero of Socialist Labor (1945); Nobel Prize in Physics (1978).

Keldysh, Mstislav Vsevolodovich--Born 10 February 1911 in Riga; died 1978. Academician in 1946; President of the Academy of Sciences, 1961-1975, replacing A.N. Nesmeyanov.

Khandorin, G.--Director of the Siberian Chemical Combine (Tomsk-7) since at least 1990.

Khariton, Yuli Borisovich--Born 27 February 1904 in St. Petersburg. Graduated from the Leningrad Polytechnic Institute in 1925. From 1926-1928 studied at the Cavendish Laboratory in Cambridge, England under Rutherford and received a PhD. In 1939, with Y. B. Zeldovich, was the first to calculate the chain reaction of uranium fission. Part of the Tamm group. Scientific director of Arzamas-16 from its founding in 1946, until 1992. With Sakharov and Zeldovich one of the three principal developers of the Soviet hydrogen bomb. Elected a member of the Nuclear Physics Department, Academy of Sciences on 23 October 1953. Awarded Hero of Socialist Labor (1949, 1951, 1954). Lomonosov Medal, 1984.

Khlopin, Vitali Grigor'evich--1890-1950. Born in Perm. Graduated from Leningrad University in 1912. With Vernadski founded the Radium Institute in 1922 and became Director in 1939. The same year was elected to the Academy of Sciences. Chairman of the Uranium Commission, 1940. First scientific director of Chelyabinsk-40 (now Chelyabinsk-65). Hero of Socialist Labor (1949); State Prizes (1943, 1946, 1949).

Kikoin, Isaak Konstantinovich--Born 28 March 1908 in Malye Zhagory; died December 1984. Graduated from the Leningrad Polytechnical Institute in 1930. In 1943 worked at the Kurchatov Institute of Atomic Energy. Responsible for isotope separation using gaseous diffusion. He was head of the isotope enrichment department and involved in uranium enrichment in the Urals. Hero of Socialist Labor (1951, 1978). Elected a member of the Academy of Sciences 23 October 1953.

Koblov, Petr Ivanovich--In 1991 a deputy chief designer at Chelyabinsk-70.

Kocharyants, Samvel Grigoryevich-- born 1908, physicist, was department chairman of Moscow Energy Institute in 1945. Among the first to go to Arzamas-16. From 1959-1989 Chief Designer. Two Hero of Socialist Labor awards, four State Prizes, and a Lenin Prize.

Kolesnikov, Nikolai Vasilievich--born 1922, was a group leader at Arzamas-16 from 1947 to 1958. Helped plan first airdrop test. Worked at Chelyabinsk-70 from 1958 to 1986.

Komarovsky, Aleksandr Nikolaevich--1906-1973. State Security official, graduated from the Moscow Institute of Transport Engineering, 1928. In 1930s directed construction of the Moscow-Volga canal. Chief of the Industrial Construction Department of the NKVD which built many of the nuclear facilities. During World War II in charge of military construction resources of the Ministry of Defence. Was one of seven deputy ministers of the First Main Directorate (PGU). Deputy Minister of MMB, 1955-1963. Hero of Socialist Labour (1949). Wrote ``Zapiski stroitelya,'' (*Notes of a Builder*), published in 1973 by Voyenizdat.

Komelkov, V.S.--born 1913. Professor at Krzhizhanovstii State University, 1937-1948. Brought to Arzamas-16 in 1948 to help solve the problem of simultaneous detonation. Headed department responsible for producing krytron triggering devices.

Konovalov, Vitali Fedorovich--Born 1932, Yekaterinburg (formerly Sverdlovsk). Graduated from the Urals Kirov Polytechnic in 1956. Worked at the Ulbinsky Metallurgical Integrated Enterprise in Ust-Kamenogorsk, the Chepetsky Machine Plant in Udmurtia, and the Machine-Building Plant in Electrostal. He headed the last two enterprises. He is a specialist on the metallurgy of nonferrous and rare-earth metals. In 1986 appointed head of a main directorate of Medium Machine Building. Was Minister of the newly-named Ministry of Atomic Power and Energy (MAPI) from 1989 to August 1991. As of late 1994 he is First Deputy Minister of Atomic Energy. Two State Prizes (1970, 1976). Married, one daughter. Address: Minatom, 24/26 B. Ordynka, Moscow 101000, Russia. Tel: (095) 239-4440.

Konstantinov, Boris--at the Leningrad Physico-Technical Institute devised a chemical method of separating lithium isotopes. Awarded Hero of Socialist Labor (1954).

Kozlov, Boris Isakovich--A colleague of Sakharov's at Arzamas-16. Designed the device exploded on 27 September 1962. Acting Director of Caspian Mining and Metallurgical Complex (PGMK) ore administration, responsible for mining and refining of uranium ore; a defense plant under the MMB, 1989- .

Krupnikov, K.K.--Contributed to bomb design of improved fission devices set off in 1951.

Kryuchenkov, Vladimir Borisovich--Kryuchenkov was born in 1948 and graduated from the Moscow Physical Engineering Institute in 1972 with a doctorate in Science. In 1972, Kryuchenkov joined Chelyabinsk-70 and is currently head of the Experimental Physics Department. Kryuchenkov is an expert in diagnostics of dense high-temperature plasma, laser-plasma soft x-ray sources, plasma spectroscopy, and laser fusion.

Kurchatov, Boris V.-- Igor's brother, who joined Laboratory No. 2 in mid-1943. Isolated the first trace amounts of plutonium in October 1944 using chemical methods. Between April and August 1947 separated plutonium using the precipitation method.

Kurchatov, Igor Vasilyevich--Born 12 January 1903 in Simskii Zavod (now in Asha Region, Chelyabinsk Oblast); died 7 February 1960 in Moscow. The son of a surveyor Kurchatov graduated in 1923 from Crimean University in physics and math. In the spring of 1925 he began at the Physico-Technical Institute under A. F. Ioffe. Chosen as scientific director of the Soviet nuclear weapons program in March 1943. Elected to the Academy of Sciences in 1943. He is buried at the Kremlin Wall. The 104th element, Kurchatovium was named for him (along with a competing claim that the element should be called Rutherfordium). The element is now called Dubnium, for the Joint Institute for Nuclear Research at Dubna. Awarded Hero of Socialist Labor (1949, 1953, 1954).

Lavrentyev, Mikhail Alekseyevich--Born 1900; died 1980. A leading theoretical physicist at Arzamas-16,

arriving there in 1946. Academician (1946), vice president of the Academy of Sciences, 1957-1975, and a leading organizer of the Academy's Siberian branch. Close scientific adviser to Khrushchev. Created the science city at Novosibirsk.

Lebedev, Valeriy Aleksandrovich--born 1941, Director of the Mining and Chemical Combine (Krasnoyarsk-26) beginning in 1989 - to date.

Ledenyov, Boris Nikolaevich--From 1955 was head of gas-dynamics division at Arzamas-16. From 1959 to 1961 was chief designer at Chelyabinsk-70, and from 1961 to 1964 was Director.

Litvinov, Boris Vasilyevich--Born 12 November 1929 in Voroshilovgrad, Ukraine. The current first deputy scientific leader of Chelyabinsk-70. Chief Designer of the institute; professor; member of the Russian Academy of Sciences; graduated in 1953 from the Moscow Institute of Engineering and Physics. Winner of Lenin Prize, Hero of Socialist Labor.

Lominsky, Georgii Pavlovich--Born 1918; died 1988. Lt.-Gen. of aviation. From July 1948 to 1951 was in charge of test areas of Arzamas-16. From 1951 to 1955 he was head of the safety department. From 1955 to 1961 he was a deputy director of Chelyabinsk-70 on general issues and from 1961 to 1964 was chief engineer. From 1963 to 1986 he was director of Chelyabinsk-70.

Makarov, Aleksandr--Born 1947, Nizhny Novgorod. Graduated from the Gorky Polytechnic in 1971. Began his career as a foreman at the Assembly and Construction Administration in Aktau, Kazakhstan where he worked for 15 years rising to chief engineer. Also worked at Krasnoyarsk-26. As of late 1994 is Minatom Deputy Minister in charge of capital construction. Address 24/26 B. Ordynka, Moscow 101000, Russia. Tel: (095) 239-4390.

Malenkov, Georgii Maksimilianovich--8 January 1902-23 January 1988. Born in Orenburg. Member of the State Defence Committee, 1941-1945. Deputy Prime Minister, 1946. Prime Minister March 1953 to February 1955. Lost to Khrushchev in power struggle and removed from Politburo in 1957.

Malsky, Anatoli Yakovlevich--central participant in the 1949 and 1951 atomic tests. From 1953 was a director of the nuclear warhead production facility at Arzamas-16. Soon after was promoted to chief engineer at the Sverdlovsk-45 warhead production facility, and in 1955 became the director.

Malyshev, Vyacheslav Aleksandrovich--Born 16 December 1902 in Ust-Sysolsk, now Syktykar; died 20 February 1957 in Moscow. Graduated from the Velikie Luki Railroad Technicum in 1924. Wartime head of Soviet tank production program. Vice-chairman of the Council of People's Commissars, 1940-1944. As Minister of Ministry of Medium Machine Building from June 1953-1955, assumed responsibility for the nuclear weapons program from Beria following Stalin's death. Buried at the Kremlin Wall. Hero of Socialist Labor (1944).

Matveyev, Sergei Nikolaevich--Since September 1947 deputy head of test preparations. From 1953 to his retirement he was head of the department.

Meshcheryakov, Mikhail Grigoryevich--Born 4 September 1910. Graduated Leningrad University. Radium Institute, 1937-1947. Was one of two Soviets present at Operation Crossroads in the summer of 1946 at Bikini. Wrote a 110 page account submitted to Special Committee and PGU. Deputy Director of Institute of Atomic Energy, 1947-1948. Deputy head of the first Main Directorate, helped administer activities at Arzamas-16 from 1946 to 1953. Became member of the USSR Academy of Sciences, 1953; Professor, Moscow University, 1954, Joint Institute of Nuclear Research, Dubna. Two State Prizes (1951, 1953). Three Orders of Lenin.

Mikhailov, Viktor Nikitovich--Born 1934, Sopronovo, Moscow Region. Graduated with distinction from the Moscow Engineering and Physics Institute in 1958. Graduate student in theoretical physics under Academician Ya. B. Zeldovich at Arzamas-16. Worked at the Institute of Impulse Technology from 1969 and became Director in 1988. Deputy Director, Ministry of Atomic Power and Industry (formerly the Ministry of Medium Machine Building) from 1989 until 2 March 1992, when he was promoted to Minister of Atomic Energy. Had himself appointed Scientific Director of Arzamas-16 in 1992. Lenin Prize (1967), State Prize (1982). Married, one son. Address: Minatom, 24/26 B. Ordynka, Moscow 101000, Russia. Tel: (095) 239-4545.

Mikerin, Evgeni Ilich--Born 1928, Yaroslavl. Graduated from the Moscow Institute of Fine Chemical Technology in 1951 as a radiochemical engineer. From 1951-1979 he worked at the ministry's enterprises producing fissionable material. In 1979 was named Deputy Head of the Fourth Department and now heads it. The Directorate is responsible for isotope production and separation, reprocessing, production reactors and uranium enrichment, chemical separation, nuclear waste management, and plutonium and uranium component manufacturing--activities conducted at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26. Winner of Lenin Prize and State Prize. Address 24/26 B.Ordynka, Moscow 010000, Russia. Tel: (095) 239-4350.

Molotov, Viacheslav Mikhailovich--9 March 1890-November 1986. Became Stalin's most trusted and faithful aide. Chairman of the Council of People's Commissars (Prime Minister), 1930-1941, People's Commissar/Minister for Foreign Affairs, 1941-1949, 1953-1957. A Politburo member from 1921 to 1957 and a GKO member. Supervised the early stages of the atomic bomb program, but lost control of the program to Beria in August 1945.

Morozov, Igor Pavlovich--Born in 1939 and graduated from Kharkov Polytechnic Institute in 1961 with a degree in mechanical engineering, Morozov is the Deputy Chief Engineer of the Mining and Chemical Combine (Krasnoyarsk-26). He holds a doctorate in Science and his fields of expertise include: development of test systems, automatization of production processes and management.

Muzrukov, Boris Glebovich--Born 1904; died 1979. Defense industry official. Combine (Chelyabinsk-40) Director from 29 November 1947 to 16 November 1953; director of Arzamas-16 from 1955 to 1974. Hero of Socialist Labor (1943, 1949); Lenin Prize (1962). Sakharov calls him ``one of the great captains of industry.''

Nechai, Vladimir Zinovyevich--Born 5 May 1936 in Alma Ata, Kazakh. Nuclear weapons R&D work since about 1960. Director General of Chelyabinsk-70 since 1986.

Negin, Evgeni Arkad'yevich--Born 1919. From 1955 was deputy scientific director at Arzamas-16, and since 1958 chief warhead designer. Lt. General and Academician with the Mechanics and Control Processes Department, since 15 March 1979. First came to Arzamas-16 on 19 April 1949, though worked in group with E.I. Zababakhin since August 1947. He witnessed his first nuclear test in 1953, and attended virtually all subsequent nuclear tests by Arzamas-16 afterwards, and was scientific leader at about half of them. Hero of Socialist Labor.

Nekrutkin, V.M.--one of the designers of the smaller diameter implosion device (Joe 2).

Nikipelov, Boris V.--Born 2 August 1931. Worked at Mayak Chemical Combine (Chelyabinsk-65; formerly Chelyabinsk-40) from 1955 to about 1985; Chief Engineer. First Deputy Director, Ministry of Atomic Energy and Industry (formerly Ministry of Medium Machine Building, and now Ministry of Atomic Energy) until March 1992. Advisor to the Minister of Atomic Energy for international relations, chemical separation, and nuclear waste management March 1992 to present.

Nikitin, Boris Alekandrovich--Worked with Kurchatov during the early weapon development period. Engineer responsible for developing the technology to extract plutonium from the F-1 pile. Corresponding member

of the Academy of Sciences.

Nikitin, Vladislav I.--In 1991-1992 the deputy director of Chelyabinsk-70.

Nikolsky, Boris Petrovich--Born 1900; died 1990. Worked with Kurchatov during the early weapon development period. Full member of the Academy of Sciences.

Novikov, S.A.--A leading scientist at Arzamas-16.

Ovsyannikov, L.V.--A leading scientist at Arzamas-16.

Pavlov, Nikolai Ivanovich--Born c. 1917; died ? Major-General of NKVD. Appointed in 1943 representative of the Central Committee and Council of Ministers at Laboratory No. 2 (subsequently the Kurchatov Institute of Atomic Energy). Oversaw construction at KB-11 using 10,000 prisoners. Served as Chairman of the State Testing Commission for nuclear weapons in the late 1950s. Guided work at Arzamas-16 from 1946 to 1953. In 1951 became deputy chief of the First Main Directorate and in 1953 became chief of the 5th Main Directorate of MMB.

Pavlovsky, Aleksandr Ivanovich--Born 27 June 1927. Died 12 February 1993. Physicist. After graduating from Kharkov University in 1951, went to work at Arzamas-16 the same year and worked in G.N. Flerov's group. Was a protegé of Sakharov. Just prior to his death he was Deputy Chief Scientist and Head of the Fundamental and Applied Physics Department at Arzamas-16.

Pervukhin, Mikhail Georgiyevich--(1904-1978). Born in Iuriuzan. In 1939 was People's Commissar of the Electric Power Industry and from 1940 to 1946 Deputy Chairman of the Council of People's Commissars. Minister of Chemical Industry in the early 1950s and First Deputy Chairman of the Council of Ministers from 1955 to 1957. Member of Politburo 1952 to 1957. Minister of Medium Machine Building, May-July 24, 1957. Ambassador to German Democratic Republic, 1958-1962. Hero of Socialist Labor (1949).

Petrosyants, Andronik Melkonovich--born 1906. From 1945-1954 various posts responsible for HEU and plutonium production. Was Deputy Minister with the Ministry of Medium Machine Building, 1955-1962. Chairman of the State Committee for the Use of Atomic Energy. Headed the investigation team that examined the Chernobyl disaster.

Petrzhak, Konstantin A.--In 1940 with G.N. Flerov discovered the spontaneous fission of uranium.

Pishchepov, Aleksandr Ivanovich--In 1990 was Deputy Director for Procedures at the Mayak Production Association (Chelyabinsk-65).

Pomeranchuk, Isaak Iakovlevich--Born 20 May 1913 in Warsaw, died 14 December 1966 in Moscow. Graduated from the Leningrad Polytechnic Institute in 1936. From 1940-1943 worked at the Institute of Physics and from 1943-1946 at the Institute of Atomic Energy. In 1946 he joined the staff of the Institute of Theoretical and Experimental Physics and also became a professor at the Moscow Physical Engineering Institute. Made an important contribution to the theory and development of the first nuclear reactors in the USSR. Corresponding Member of the Academy of Sciences, 1953; Academician, 1964. Awarded: State Prize, 1950, 1952; Order of Lenin; Lenin Prize

Reshetnikov, Evgeni Aleksandrovich--born 1937, Taganrog. Graduated from the Novocherkassk Polytechnic in 1959 as a mine-building engineer. Was appointed to his present post of Deputy Minister of Civil Construction in 1985. His duties cover construction of nuclear power plants in Russia and abroad. Married, one

daughter. Address 5 Kitaisky Proyezd, Moscow 103074, Russia. Tel: (095) 220-6302.

Romanov, Gennady N.--Chief of Experimental Research Station, ``Mayak'' Production Association (Chelyabinsk-65) in 1991.

Romanov, Yuri Alexandrovich--Born 1926. Theoretical physicist. A colleague of Sakharov's from 1948 to 1955. First worked at Arzamas-16, arriving there in 1950 with Sakharov; then in 1955 was sent to work at Chelyabinsk-70. Since 1970 was in charge of the theoretical division at Chelyabinsk-70. Hero of Socialist Labor.

Ryabev, Lev Dmitriyevich--Born 1933, Vologoda. In 1957 he graduated from the Moscow Engineering and Physics Institute. Worked at the Institute of Experimental Physics at Arzamas-16 and became deputy chief engineer, deputy director, and director probably from 1974 to 1978. From 1984 he was Deputy Minister of Medium Machine Building and from June 1986 First Deputy. At the end of 1986 he was appointed Minister of MMB. In 1991 he served as Deputy Prime Minister of the USSR and Chairman of the State Fuel and Energy Commission of the Cabinet of Ministers. As of late 1994 he is First Deputy Minister of the Russian Federation Ministry of Atomic Energy. Married, two children. Address: Minatom, 24/26 B. Ordynka, Moscow 101000, Russia. Tel: (095) 239-2190.

Sadovsky, Mikhail Aleksandrovich--Born 6 November 1904. In 1949 he was deputy director of the Institute of Chemical Physics and responsible for the nuclear test site at Semipalatinsk. Director of the Institute of Physics of the Earth until he retired about 1988. Academician; elected member of the Geology, Geophysics, Geochemistry, and Mining Sciences Department of the Academy of Sciences on 1 July 1966. Hero of Socialist Labor (1949); Lenin prize (1962); State Prize (1948, 1949, 1951, 1953).

Sakharov, Andrei Dmitriyevich--Born 21 May 1921 in Moscow; died 14 December 1989. Graduated from Moscow State University in 1942. Began work at the Physics Institute in 1945. Recruited into the H-bomb program in 1948 and worked at Arzamas-16 from March 1950 until his clearance was revoked in July 1968. He departed Arzamas-16 on 14 September 1969. With Khariton and Zeldovich one of the three principal developers of the Soviet hydrogen bomb, responsible for the ``First'' and ``Third Idea.'' Became Academician in the Physical and Mathematical Sciences Department on 23 October 1953. After Tamm's departure in 1954, became the head of the second theory department at Arzamas-16. Awarded Hero of Socialist Labor (1953, 1956, and 1962), Lenin Prize, USSR State Prize, and Nobel Peace Prize (1975).

Sazhnov, Vladimir K.--Director of Radiochemical Plant, ``Mayak'' Production Association (Chelyabinsk-65) in 1991.

Semenov, Nikolai Nikolayevich--Born 15 April 1896; died 1986. Born in Saratov, graduated from Petrograd University in 1917. From 1920-1931 worked at Leningrad Physico-Technical Institute. Corresponding Member of the Academy of Sciences, 1929; Academician, 1932. In 1931 became Director of the Institute of Chemical Physics. Was responsible for the ``polygon'' (the nuclear test site) at Semipalatinsk in 1949, when the Soviets tested their first atomic device. Vice President of the Academy of Sciences 1963-1971. Shared Nobel Prize in Chemistry (1956) with Sir Cyril Hinselwood for parallel research on chemical reaction kinetics. Awarded: Hero of Socialist Labor (1966); seven Orders of Lenin; State Prize (1941, 1949); Order of the Red Banner of Labor.

Semyonov, Nikolai Anatolevich--Born 1918; died 28 January 1982. First Deputy Minister of Medium Machine Building from 1971 to his death. He joined the nuclear weapon program in 1948 and rose to become director of the Mayak Combine (Chelyabinsk-40/65) before his transfer to the MMB in 1971. Received Hero of Socialist Labor, Lenin Prize, State Prize.

Senkin, Aleksandr Nikolaevich--One of the current Chief Designers at Chelyabinsk-70.

Shchelkin, Kirill Ivanovich--Born 17 May 1911; died 8 November 1968. Graduated from the Crimean Pedagogical Institute in Simferopol in 1932. Main works were devoted to the physics of combustion and explosion. From March 1947 was Khariton's deputy at Arzamas-16. Head of a department at Arzamas-16 responsible for the development of explosive shaped charges. Previously at the Institute of Chemical Physics. Served as the first scientific director of Chelyabinsk-70 from 1955 at its founding, until 1960. Corresponding member of the Academy of Sciences (1953). Hero of Socialist Labor (1949, 1954, 1956).

Sidorenko, Viktor Alekseyevich--born 1929, Donets, Ukraine. Graduated from the Moscow Mechanical (Engineering and Physical) Institute in 1952 and worked at the Kurchatov Institute from 1952 to 1984. As of late 1994 is Minatom Deputy Minister for Nuclear Power. Two State Prizes. Married, one son, one daughter. Address: 26 Staromonetny Pereulok, Moscow 109180, Russia. Tel: (095) 233-5025.

Simonenko, Vadim Aleksandrovich--Born 8 November 1939. Graduated in 1962 from Moscow Engineering Physical Institute; Head of Theoretical Physics department at Chelyabinsk-70 where he has worked since 1961.

Slavsky, Yefim Pavlovich--Born 7 November 1898 in Makeevka, Ukraine. died 1991. Graduated from the Moscow Institute of Non-Ferrous Metals and Gold as a metallurgical engineer. Was Director of Cheyabinsk-40 from 10 July to 29 November 1947, then transferred to be Chief Engineer until 3 December 1949. In charge of metallurgical extraction and processing aspects of the early bomb program. Deputy, then First Deputy Minister of Medium Machine Building, 1953-1957. Replaced Pervukhin as Minister of MMB, 1957-1963. Chairman, State Production Committee for MMB, 1963-1965. Minister of MMB, 1965-1986. Hero of Socialist Labor (1949, 1954, 1962); Lenin Prize (1980); State Prize (1949, 1951).

Tamm, Igor Evgenievich--Born 8 July 1895 in Vladivostok; died 12 April 1971 in Moscow. Graduated from Moscow University in 1918. Created a school of theoretical physics to which many well-known Soviet scientists belonged. Was influenced by Leonid Mandelstam. In June 1948 appointed head of a special nuclear bomb research group at the Physics Institute of the Soviet Academy of Sciences (FIAN), where he was head of the Theoretical department. He and Sakharov proposed in 1950 that a hot plasma in a magnetic field be used to obtain a controlled thermonuclear reaction. Left Arzamas-16 in 1954 (after the August 1953 test) to return to Moscow. Won the Nobel Prize in Physics in 1958. Elected a member of the Academy of Sciences on 23 October 1953. Hero of Socialist Labor (1953).

Terletsky, Iakov Petrovich--Physicist from Moscow University who was appointed scientific adviser to Department S in the NKGB in September 1945.

Thiessen, A.--German scientist captured by the Russians at the end of the war who succeeded in producing a suitable barrier for isotope enrichment by gaseous diffusion.

Tychkov, Yuri--born 1930, Moscow. Graduated from the All-Union Polytechnic in 1955. Worked in Novosibirsk. As of late 1994 is Minatom Deputy Minister responsible for industry economics, microelectronics, computers, and information technologies. Address: 24/26 B. Ordynka, Moscow 101000, Russia. Tel: (095) 231-7998.

Timofeev, Lt. Gen. Nikolai Ivanovich--In charge of the Ministry of Defense construction units which built the facilities at the Semipalatinsk test site (``N 2'').

Tolstikhin, Oleg T.--Deputy Director, ``Mayak'' Production Association (Chelyabinsk-65) in 1991.

Trutnev, Yuri Alekseyevich--Born 2 November 1927. First came to Arzamas-16 in 1950. Sakharov says that he made ``significant contributions'' to understanding ``the Third Idea.'' He is currently first deputy scientific director of Arzamas-16. Elected as a corresponding member of the Nuclear Physics Department of the Academy of Sciences on 26 June 1964 (now a full member), and became a full member of the Russian Academy of Sciences in 1991. Hero of Socialist Labor, Lenin Prize, State Prize.

Tsukerman, Veniamin Aronovich-- In December 1945 recruited by Khariton to work on the bomb program using his knowledge of X-rays as a diagnostic tool, and methods of neutron and gamma-radiation recording. Tsukerman was blind.

Tsyrkov, Georgi Alexandrovich--Born 1921, Moscow. Graduated from the Moscow Bauman Higher Technological School. In 1948 joined staff at Arzamas-16. From 1955 to 1960 became First Deputy Scientific Leader and Chief Designer at Chelyabinsk-70. Then chief engineer of the Fifth Main Directorate of MMB, and in 1965 became the head. This Directorate is responsible for the design laboratories, including Arzamas-16, Chelyabinsk-70, the test sites, and the warhead fabrication plants. In March 1992 appointed Head of the Fifth Department, Warhead Design and Testing in the newly created Ministry of Atomic Energy. Hero of Socialist Labor, Lenin Prize, two State Prizes. Address: 24/26 B. Ordynka, Moscow 101000, Russia. Tel: (095) 233-4642.

Turbiner, Vladimir Alexandrovich--the first leader of the design group which in 1946 designed a one-fifth size mock up of a bomb that was shown to Stalin. The actual bomb detonated in 1949 bore no relationship to this early model. In March 1948 he was dismissed.

Vannikov, Boris Lvovich--Born 7 September 1897 in Baku, Azerbajijan; died 22 February 1962 in Moscow. From 1942-1946 was People's Commissar of Munitions. From August 1945 was head of the First Main Directorate (PGU) of the Soviet Council of Ministers, the designation given the agency responsible for managing the atomic program. Also chaired the Scientific-Technical Council, an advisory body the PGU. In 1953 the PGU was renamed the Ministry of Medium Machine Building, and Vannikov was First Deputy Minister from 1953-1958. Three times Hero of Socialist Labor (1942, 1949, 1954); State Prize (1951, 1953).

Vasilyev, Dmitri Ch.-- First director of Chelyabinsk-70 from 1955 until his death in early-1961.

Vavilov, Sergei Ivanovich--born in Moscow 12 March 1891, died 25 January 1951. Graduated from Moscow University in 1914. Founder and Director of the Institute of Physics of the Soviet Academy of Sciences (FIAN) in Moscow in 1932. Elected to the Academy of Sciences the same year. In 1945 became President of the Academy of Sciences. Two Orders of Lenin; Order of the Red Banner of Lenin; State Prize (1943, 1946, posthumously 1951).

Velikhov, Evgeni Pavlovich--Born 2 February 1935. Currently (1993) Vice President (for Physical and Mathematical Sciences Section since November 1977) of the Russian (formerly Soviet) Academy of Science; and Director of Kurchatov Institute of Atomic Energy since 1988. The first President of the Soviet Nuclear Society. Formerly Chairman of the Armed Services Subcommittee of the Defense and State Security Committee of the USSR Supreme Soviet.

Veretennikov, Aleksandr Ivanovich--Born c. 1921. Specialist in electronics and its application to the measurement of fast impulse processes. Worked at Arzamas-16, then director of SNIIP (Institute of Impulse Technology) in Moscow until 1988.

Vernadsky, Vladimir Ivanovich--Born 1863 in St. Petersburg. Died 6 January 1945. Geochemist and scientific administrator. Elected to the Academy of Sciences in 1912. Founded and headed the Radium Institute from 1921-1939. In the 1930s organized and headed various commissions; heavy water (1934), isotopes (1939).

Helped set up the Uranium Commission in 1940.

Vinogradov, Hero of Socialist Labor (1949); Elected full member of Academy of Sciences (October 1953).

von Ardenne, Manfred--German nuclear scientist who went to work for the Russians after the end of the war. Headed up a team of German scientists who were working on the problem of isotope separation.

Voronin, Stanislav Nikolayevich--born 1930. Began work at Arzamas in 1954. Deputy Chief Designer 1969-1991. Became Chief Designer in 1991 following retirement of Negin. Lenin Prize and State Prize.

Yangel, Mikhail Kuzmich--Weapon designer, worked at Arzamas-16 and Chelyabinsk-70.

Yegorov, Nikolai Nikolaevich--Born 1939, Kem, Karelia. Graduated from the Leningrad Lensovet Technological Institute in 1965 and the Moscow All-Union Correspondence Polytechnic in 1976. Worked for many years at the Mining and Chemical Integrated Enterprise at Krasnoyarsk-26. As of late 1994, Deputy Minister of Atomic Energy (Minatom) responsible for uranium enrichment, production reactors, plutonium and other isotope production, chemical separation, and radioactive waste management. Married, two sons. Address: Minatom, 24/26 B. Ordynka, Moscow 101000, Russia. Tel: (095) 239-4698 or 231-6711.

Yegorov, Nikolai Pavlovich--was probably a deputy to V.A. Bolyatko in the 12th Main Directorate. Died in 1976.

Yemelyanov, Vasiliy Semenovich--Born 12 February 1901. Graduated from the Moscow Mining Academy in 1927. Joined nuclear project in September 1945, as head of the scientific-technical directorate of the PGU. Various posts between 1946 to 1957. Corresponding member of the Academy of Sciences (1953). From 1957-1960, Head, Main Board on the Use of Atomic Energy, USSR Council of Ministers. From 1957-1959 was permanent USSR representative at the International Atomic Energy Administration. 1960-1962 was Chairman, State Committee on the Use of Atomic Energy. Accompanied Khrushchev to U.S. in 1959. Died 1988. Stalin Prize (1942, 1950); Order of Lenin (1959); Hero of Socialist Labor (1954).

Zababakhin, Yevgeny Ivanovich--Born 16 January 1917; died December 1984. From March 1948 to June 1955 was leader of a group within Zeldovich's theoretical department at Arzamas-16. In 1955 became deputy scientific director of Chelyabinsk-70. In 1960 was made scientific director until his death in 1984. A classmate of Sakharov's at Moscow University. Joined Air Force Academy in 1941, graduated with rank of captain. Main works are on hydrodynamics and explosions. Corresponding Member of the Academy of Sciences, 1958; Academician, 1968. Hero of Socialist Labor (1953); Lenin Prize (1958), State Prize (1949, 1951, 1953).

Zakharenkov, Aleksandr Dmitrievich--Born 18 February 1921 in Smolensk. In 1946 was one of the first members of the group under Y.A. Khariton at Arzamas-16. Worked at Arzamas-16 from 1946-1958. Held posts as group leader, division chief, and sector chief. From 1958-1967 was sector chief, then chief designer of Design Bureau (KB-3, KB-4) at Chelyabinsk-70. From 1967-1988 Deputy Minister of Medium Machine Building, Moscow. In May 1986 was chosen as Deputy Chairman of the government commission investigating the Chernobyl accident. He was exposed to the radiation, became ill one year later, and died 25 March 1989. Hero of Socialist Labor (1962); Lenin Prize (1956), Three USSR State Prizes (Stalin Prize), Orders (two Lenin, October Revolution, four Labor Red Banner).

Zaveniagin, Avraamii Pavlovich--Born 14 April 1901 in Uzlovaia; died 31 December 1956 in Moscow. Graduated from the Mining Academy in 1930. Directed the Magnitogorsk Metallurgical Combine from 1933 to

1937, then First Deputy People's Commissar of Heavy Industry. In 1937 was sent to Norilsk, above the Arctic Circle in Siberia to establish a mining and metallurgical combine using mostly prison labor. Beginning in 1941 became Beria's deputy at the NKVD, supervising the penal camps and later an important figure in the atomic bomb program using prison labor to build many of the facilities and sites. Member of the Special Committee set up on 20 August 1945 and of the First Main Directorate. Worked at Arzamas-16, arriving there in 1946. Deputy Minister of Medium Machine Building 1953-1955. Minister of Medium Machine Building from February 1955 replacing Malyshev. In 1955-1956 organized Chelyabinsk-70. Twice Hero of Socialist Labor (1949 and 1954). Buried at the Kremlin Wall. Was project director for the research team of German scientists immediately after the war, that were located near Sukhumi on the Black Sea.

Zavoisky, E.K.--experimental physicist at Arzamas-16. Headed one of the two groups in 1949 that measured how the high explosives would compress the core, concluding that an explosion would not occur. Tsukerman headed the other group.

Zeldovich, Yakov Borisovich--Born 8 March 1914 in Minsk; died 2 December 1987. One of the founders of the modern theory of combustion, detonation, and shockwaves. His work with Khariton (1939-1941) were of great importance in solving the problem of the use of nuclear energy. An important paper with Khariton was delivered at the Conference on Questions of the Physics of the Atomic Nucleus held in Kharkov, November 15-20, 1939 and published later that year. In his *Memoirs* Sakharov said that his task, with the Tamm group, was initially to verify and refine the calculations produced by Zeldovitch's group at the Institute of Chemical Physics. Zeldovich was the first head of the theoretical department at Arzamas-16, arriving there in 1946. With Khariton and Sakharov one of the three principal developers of the Soviet hydrogen bomb. Elected full member of the Academy of Sciences in 1958. Awarded Hero of Socialist Labor (1949, 1953, 1956).

Zernov, Pavel Mikhailovich--Born 1905; died 1964. Deputy People's Commissar of the Tank Industry. First administrator (Director) of Arzamas-16 from 1946 to 1951, then deputy chairman of the First Main Directorate, 1951-1953, and Deputy Minister of the Ministry of Medium Machine Building, 1953-1964. Hero of Socialist Labor (1949).

Zhuchikhin, Viktor Ivanovich--Born c. 1924. Experimental physicist. At Arzamas-16 from 1947 to 1957 was leader of a group for nuclear bomb test measurements in K.I.Shchelkin's department. He was chief of diagnostics at the first atomic test in August 1949. From 1957 worked at Chelyabinsk-70.

Zubarev, Dmitri--Theoretical physicist who worked with Zaveniagin and with German scientists near Black Sea. Was transferred to Arzamas-16 where he remained until 1953.

Zuyevsky, Viktor Andreevich--Born 1918. Designer at Arzamas. Lenin and State Prizes.

Zysin, Yuri Aronovich--Born c. 1920; died 1987. A colleague of Sakharov's. Sent to work at Chelyabinsk-70 in the mid-1950s.

The Soviet government awarded several types of prizes to citizens who made contributions to the state. The most prestigious award was the Lenin Prize (1925-1935 and 1957-1990?). Approximately 30 were awarded every two years with 25 for science and technology and the rest for literature and the arts. The recipient received 10,000 rubles. An individual could only win one.

The next most prestigious award was the State Prize, presented annually since 1967 on November 7, anniversary of the Bolshevik Revolution. Each year fifty were awarded in science and technology and ten in the arts. The Stalin Prizes that were awarded from 1940 to 1952 were converted to State Prizes. An individual could

win more than one but not within five years of each other. The recipient received 5,000 rubles. It is quite evident that some Lenin and State/Stalin Prizes were awarded in secret.

The award Hero of Socialist Labor was instituted in 1938. It was an honorific title with no cash. By 1971, 16,000 had been awarded but only 105 individuals had won it more than once. Many of the very infrequent three-time winners have been associated with the nuclear weapons program; e.g., N.L. Dukhov, Y.B. Khariton, I.V. Kurchatov, A.D. Sakharov, K.I. Shchelkin, Ye.P. Slavsky, B.L. Vannikov, and Y.B. Zeldovich.

In our research we came upon many other names associated with the bomb program, but, with either no information or too little information to include in the profile section. We will list the names and encourage readers to help us compile a fuller list: E.L. Andronikashvili; Semyon Belensky; I.V. Bogoslovsky; O.B. Bron; A.A.Chubakov; A. Dubovik; B.G. Dubovsky; V.P.Dzhelepov; Izrail Gelfand; B.M. Gokhberg; V.V. Goncharov; A.P. Grinberg; G.M. Klimenko; Yu.S. Klintsov; D.D. Kokroft; A.K. Kondratiev; V.A. Krainin; B.Ya. Krasikov; V.K. Kritskaya; Yu.Z. Lazurkin; A. Lbov; P.P. Lebedev; V.I. Lutsenko: Nikolai Vladamirovich Maslov; V.I. Merkin; A.V. Morozov; N.G. Moskvin; F. Nasyrov; L.M.Nemenov; P.E. Nemirovsky; T.I. Nikitinskaya; M.B. Pasendrik; D.S. Pereverzev; N.M. Reinov; P.N. Remorov; M.K. Romaovsky; Aleksandr Samarsky; O.I. Seman; V.D. Shafranov; Nikolai Shavrilovich Shvilkin; G.V. Siniutin; A.R. Striganov: B.D. Stsiborsky; O.K. Sursky; Andrei Tikhonov; B.A. Tkachenko; V.T Tolok: A.P. Tsitovich; N.A. Vlasov; Z.V. Yershova; O.P. Zaks; I.F. Zhezherun.

Additions after the book was published

Pishcherov, Makar Ivanovich - Chief engineer of NII-1011 (Snezhinsk)

Mikhail Vasilyevich Protsenko - First director of the penza Instrument Making plant in August 1955. Steps down in Decmber 1989.

Appendix B
Flerov Letter to Stalin, April 1942

Dear Iosif Vassarionovich:

Ten months have already elapsed since the beginning of the war, and all the time I have felt like a man trying to break through a stone wall with his head.

Where did I go wrong?

Am I overestimating the significance of the ``uranium problem''? No I am not. What makes the uranium projects fantastic are the enormous prospects that will open up if a successful solution to the problem is found. I have to make a reservation from the very beginning. Perhaps I am not right—in research there is always as element of risk, more so with uranium that anything else. Let us imagine for a minute, however, that we have ``succeeded'' with uranium. True this will not bring about a revolution in technology, as the projects of the prewar months showed but then a veritable revolution will occur in military hardware. It may take place without our participation—due simply to the fact that now, as before, the scientific world is governed by sluggishness.

Do you know, Iosif Vassarionovich, what main argument has been advanced against uranium? ``It would be too good if the problem could be solved. Nature seldom proves favorable to man.''

Perhaps being at the front, I have lost all perspective of what science should deal with at present, and the long term problems, like that of uranium, must be postponed until the after the war. I think we are making a big mistake. The greatest follies are made with the best intentions.

All of us want to do all we can to rout the nazis, but there is no need for such hurry-scurry, no need to deal only with problems that come under the term ``pressing'' military objectives.

Well and, finally, maybe I am taking too much upon myself. All letters which you, Iosif Vassarionovich, receive may be divided into two groups. In the first there are letters with proposals which can, in their authors' view, help the struggle against the nazis. In the second there are the same proposals, but the implementation of these proposals is linked to some changes in the position of the author himself.

Now, I find it very difficult to write, knowing that the ``sober'' approach can be rightfully applied to me. What is Flyorov raging about over there? He dealt with science, was called up to the army, wants to get out of it and, using uranium as a pretext, has been showering letters upon all and sundry with disapproving comments on Academicians.

Now, for the solution of the question I consider it necessary to call a conference, which should be attended by Academicians Ioffe, Fersman, Vavilov, Khlopin and Kapitsa, Academician of the Ukrainian Academy of Sciences [Alexsandr Ilich] Leipunsky, Professors Landau, Alikhanov, Artsimovich, Frenkel, Kurchatov, Khariton and Zeldovich, Doctors Migdal and Gurevich. It is also desirable to invite K. A. Petrzhak.

I ask an hour and a half for the report, and your presence, Iosif Vassarionovich, either in person or by default, is most desirable.

Generally speaking, now is not the time to arrange such scientific tournaments but personally, I see this as the only means to prove that I am right and have the right to deal with uranium—because other means—personal talks with A. F. Ioffe, letters to Comrade Kaftanov have brought about no results and are simply being passed over in silence. I have received no reply to my letter and five telegrams to Comrade Kaftanov. When discussing the

plan of the Academy of Sciences, they probably spoke about everything but uranium.

This is that wall of silence which I hope you will help me break through, because this is my last letter, whereupon I lay down arms and wait till the problem has become solved in Germany, Britain or the USA. The results will be so overriding it won't be necessary to determine who is to blame for the fact that this work has been neglected in our country, the Soviet Union.

All of this is being done in such a skilful manner that we shall not even have formal grounds against anyone. No one anywhere has ever said that the nuclear bomb is unfeasible and yet there is the opinion that this task belongs to the realm of science fiction.

Therefore my first request, on whose fulfillment I insist, is to receive from all candidates to the future conference written considerations concerning the feasibility of the uranium problem. The conclusion should include a reply concerning the figure which should be used to assess the probability of solving the problem. For those conference participants who will consider their erudition insufficient for a written conclusion, this question may be ignored, but they are not relieved of the duty of attending the conference.

Source: *Moscow News,* No. 16, 1988.

Appendix C
Plutonium and Tritium Production Estimates

The exact size and precise start up dates of some of the Soviet production reactors are unknown; and none of the operating power levels and capacity factors are known. Consequently, there are sizable uncertainties associated with estimates of the total plutonium-equivalent production[859] based on the reactor operating histories alone. However, plutonium and tritium inventory data from several independent sources are consistent with what we know about the sizes and operating periods of the reactors, and permit us to derive reasonable estimates of the missing parameters. First, the sizes of most of the graphite reactors were estimated by comparing the respective number of channels to the number of channels in the original eight U.S. graphite production reactors at Hanford. As a rough rule of thumb, each channel of an upgraded graphite production reactor can supply about one MW of thermal power. The capacity factors (i.e., the average power level divided by the full power level) were chosen to be reasonably consistent with the capacity factors achieved by the Hanford production reactors in the United States. We assumed the capacity factors of each reactor were 0.4 during the first year of operation, 0.6 during the second year, and 0.8 thereafter. We also assumed that reactors operating prior to 1955 produced 0.86 g Pu/MWd. Beginning in 1955, we assumed the reactors incorporated a spiked ring of HEU to levelize power across the core, and as a result the production rate dropped to 0.824 g Pu/MWd.

At Chelyabinsk-65 we know the A-Reactor began operation on 19 June 1948, was upgraded from 100 to 500 MW_t, and shut down in 1987. The 65 MW_t IR-Reactor began on 22 December 1951 and was shut down on 24 May 1987. The last three reactors had 2832 channels and are assumed, therefore, to be comparable in size to the C-Reactor at Hanford. The AV-1, AV-2 and AV-2 Reactors operated from 15 July 1950 to 12 August 1989, 6 April 1951 to 14 July 1990, and 15 September 1952 to 1 November 1990, respectively. We assume each of these three reactors began operation at a power level of 650 MW_t, and each was upgraded over a six year period to 2000 MW_t.[860] Under these assumptions, as seen in Table C.1, the total production by the five graphite production reactors at Chelyabinsk-65 between 1948 and 1990 inclusive is estimated to be approximately 56 t of weapon-grade plutonium-equivalent (4.6 percent Pu-240).

The first of the five plutonium production reactors at Tomsk-7, Ivan-1, operated from 20 November 1955 to 21 August 1990; and Ivan-2 operated from about September 1958 to 28 December 1990. The first of the dual purpose reactors, ADE-3 operated from 14 July 1961 to 14 August 1992. The start up dates of the remaining two dual-purpose reactors, ADE-4 and ADE-5, both of which are still operating, were in 1965 and 1968 respectively. We assume each reactor has 2832 channels; and each was upgraded from 650 MW_t to about 2000 MW_t, over six years for ADE-3 and ADE-4 and four years for ADE-3. Under these assumptions Tomsk-7 would have produced some 69 t of plutonium-equivalent (see Table C.2).

The first reactor at Krasnoyarsk-26, the AD Reactor, operated from 25 August 1958 to 30 June 1992; the second reactor, ADE-1, operated from 20 July 1961 until 29 September 1992; and the third started up in 1964 and is still operating. All three reactors have 2832 channels. We assume each operated at about 2000 MW_t. Together these three reactors are estimated to have produced about 44 t of plutonium-equivalent (see Table C.3).

The combined production at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26 is estimated to be about 169 t plutonium-equivalent (see Figure C.1).

---

[859] Plutonium-equivalent production is a measure of the total production of plutonium and other isotopes (usually tritium), where the unit of measure is the amount of plutonium alone that could have been produced. The production of one kg of tritium is equivalent to the production of 72 kg of weapon-grade plutonium.

[860] We use the Hanford C-Reactor as a model. C-Reactor had an original design power of 650 MW_t, and was upgraded to 1740 MW_t after 7.5 years, and to 2310 MW_t over the next three years; see Thomas B. Cochran, et al., *Nuclear Weapons Databook,* Vol. II, p. 61.

We have virtually no knowledge regarding tritium production or inventories in the former Soviet Union. We assume the two water-moderated reactors--one initially a heavy water and the other a light water type--at Chelyabinsk-65 were dedicated primarily to tritium production. The heavy water reactor came on line in 1950-51. Assuming that it was upgraded from 250 to 1000 MW_t, and that the light water reactor came on line about 1970 at 1000 MW_t, we estimate that these two reactors could have produced 12 t plutonium-equivalent, sufficient to build up an inventory of 90 kg of tritium by the mid-1980s (see Table C.4).

An independent upper-bound estimate of plutonium-equivalent production can be made from the contribution to the buildup of krypton-85 (Kr-85) in the earth's atmosphere. Kr-85 is a gaseous fission product produced when U-235 or Pu-239 is fissioned. It is ordinarily released to the atmosphere when spent nuclear fuel is chemically processed. Chemically inert and with a radioactive half-life of 10.76 years, Kr-85 accumulates in the atmosphere. The Soviet contribution to the atmosphere's Kr-85 is estimated by subtracting the contributions from known sources outside the Soviet Union from the estimated total releases. The U.S. intelligence community monitors the atmospheric concentrations of Kr-85 and uses these data to estimate the cumulative plutonium-equivalent production over time and from that, the annual production rate. Using a similar approach, and the data on atmospheric concentrations of Kr-85 published in the open literature, von Hippel, et al. have estimated that the Soviets had released some 44-66 MCi of Kr-85 as of the end of 1983.[861] By our estimates some 10 MCi would have come from processing VVER spent fuel at Chelyabinsk-65, leaving 34-56 MCi Kr-85 from chemical separation of production reactor fuel--producing 75-122 t of weapon-grade plutonium-equivalent. In Tables C.1, C.2, and C.3 we estimate 125 t of plutonium-equivalent production through 1983, a value consistent with the upper limit estimate of von Hippel, et al.

Russia is currently producing about 1.4 t of weapon-grade plutonium per year at Tomsk-7 and Krasnoyarsk-26 (see Tables C.3 and C.4); and in additional is separating about 1.0 t of reactor-grade plutonium per year at Chelyabinsk-65 (see Table 3.3). Weapon-grade plutonium production is planned to continue for several more years. There are no plans to cease the separation of reactor-grade plutonium.

---

[861] Frank von Hippel, David H. Albright and Barbara G. Levi, ``Quantities of Fissile Materials in the U.S. and Soviet Nuclear Weapons Arsenals,'' Princeton University, 27 March 1986. See also, Frank von Hippel and Barbara Levi, ``Controlling Nuclear Weapons at the Source: Verification of a Cutoff in the Production of Plutonium and Highly Enriched Uranium for Nuclear Weapons,'' Hearing Before the House Committee on Foreign Affairs, 20 June 1989, pp. 302-303.

Appendix D
Nuclear-powered Submarines, Surface Ships, and Icebreakers

By the beginning of 1994, the Soviet Union and (now Russia) had constructed 256 nuclear-powered vessels including: 243 nuclear-powered submarines, three nuclear-powered cruisers, one nuclear-powered communications/missile-range ship, eight nuclear-powered icebreakers, and one nuclear-powered transport ship.[862] Some 466-481 nuclear-reactors were on board these vessels[863] (see Table D.1).

Of the nuclear submarines, at least 121 have been retired, with possibly as many as 150 out of service. Taking into account three nuclear submarines which have sunk (1970, 1986, and 1989) and not been recovered, this leaves 90 to 119 operational submarines in the fleet as of 1994. As in the Soviet Navy, the Russian Navy is still keeping approximately two-thirds of its nuclear submarine force in the Northern Fleet and one-third in the Pacific Fleet.[864]

The Soviet Union produced only four nuclear-powered military surface ships of two types:[865] three Kirov-class cruisers (each with two reactors) and the *Ural* (SSV-33) Kapusta-class intelligence collection ship (with two reactors). Two cruisers are deployed with the Northern Fleet--Admiral Ushakov (ex-*Kirov*) and Admiral Nakhimov (ex-*Kalinin)*--both based at Severomorsk, and one is in the Pacific Fleet, the Admiral Lazarev (ex-*Frunze*), based at Abrek Bay). In 1994, a fourth vessel, the *Pyotr Veliky* (ex-*Yuri Andropov*) remains under construction at the Baltic shipyard in St. Petersburg, although work is proceeding slowly and its entry into the fleet is already delayed by several years. The *Ural* is based in the Far East in Abrek Bay. The nuclear cruisers may be or will shortly become unoperational due to lack of maintenance and shipyards to conduct refuellings.

---

[862] Numbers of submarines from V. Marinin and V. Dotsenko, ``90 Years of Russian Submarine Building,'' *Military Parade*, (Moscow), July-August 1994, p. 11 and author's estimates. Numbers of nuclear-powered military surface vessels from *Jane's Fighting Ships 1994-1995*, pp. 547 and 583. Numbers of nuclear-powered civilian vessels from Russian Federal Nuclear Inspectorate [Gosatomnadzor], ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993, Parts I, II,'' Approved by Order of the Gosatomnadzor, No. 61 from 13 May 1994 (Moscow), p. 48.

[863] Standard western reference works list the Alfa, Sierra, and Akula class attack submarines as having two reactors. However, it is becoming increasingly apparent these classes are powered by one reactor each. Also, such sources list the Tamyr class icebreakers as having two reactors although official Russian sources list them with only one. Taking this into account, the actual number of reactors on the nuclear-powered vessels constructed maybe as low as 466, or if other submarines are found to have one reactor, even lower. See for standard western references: *Jane's Fighting Ships 1994-1995*, Norman Polmar, *Guide to the Soviet Navy, 5th edition*, (U.S. Naval Institute Press: Annapolis, MD, 1991) and, for the official Russian information regarding icebreakers, the Russian Federal Nuclear Inspectorate [Gosatomnadzor], ``Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993, Parts I, II,'' Approved by Order of the Gosatomnadzor, No. 61 from 13 May 1994 (Moscow), p. 48.
    According to the White Book, by early 1993 the Soviet Union/ Russian Federation had a total of 235 nuclear-powered submarines, ships, and icebreakers, powered by a total of 407 reactors, including 228 in the Navy with 394 reactors and seven in the civilian Ministry of Transport (Murmansk Shipping Company) with 13 reactors. The Commission said this constituted 60 percent of the total reactors in the world. White Book, p. 30.
    These numbers seemingly include decommissioned vessels. They also imply that a greater number of submarines have one reactor than is commonly though in the west.

[864] Other western estimates give similar figures. For example, *Jane's Fighting Ships 1994-1995* (p. 528) and the International Institute of Strategic Studies *The Military Balance 1994-1995* (pp. 116-117) give the following distribution for nuclear combatant submarines in the Russian Navy in 1994:

	Northern Fleet	Pacific Fleet	
	Jane's/MB	Jane's/MB	Total
SSBN	30/30	18/16	48/46
SSGN	13/15	9/4	22/19
SSN	36/30	17/14	53/44
Total	79/75	44/34	123/109

[865] A nuclear-powered aircraft carrier, the *Ulyanovsk*, had begun construction at the Nikolayev shipyard in the Ukraine in the late 1980s. Its construction was abandoned, however, with the break up of the Soviet Union and the ship was scrapped.

In 1959, the Soviet Union launched the world's first nuclear-powered surface ship, the *Lenin* icebreaker. The Soviet Union invested heavily in civil naval nuclear-power, constructing the largest fleet of commercial nuclear-powered vessels, including eight nuclear-powered icebreakers and one nuclear-powered cargo vessel the *Sevmorput*. Today Russia is the only country operating a civil nuclear fleet, as attempts to commercially develop this technology by several western countries including the finishing of initial vessels by the United States (*Savannah*), Germany (*Otto Hahn*) and Japan (*Mutsu*) were all abandoned. All of the Russian nuclear-powered civilian ships are based out of Murmansk on the Kola peninsula. The *Lenin* icebreaker was retired in 1989. The remaining icebreakers consist of five Artika-class vessels with two reactors-each[866] and two Tamyr-class ships, powered by one reactor each.[867] A ninth vessel, the *Ural*, an Artika-class ship, is under construction at the Baltic shipyard in St. Petersburg, but work is proceeding slowly.

All Russian nuclear-powered submarines and ships are homeported in the Northern or Pacific Fleets--none are deployed with the Black Sea or Baltic Fleets, and none with the Caspian Flotilla.

---

[866] The *Arktika*, *Sibir*, *Rossiya*, *Sovietsky Soyuz*, and *Yamal* entered service between 1974 and 1992. *Jane's Fighting Ships 1994-1995*, p. 603.

[867] The *Tamyr* and *Vaygach* entered service in 1988 and 1989. *Jane's Fighting Ships 1994-1995*, p. 603.

Table D.1

	# of Reactors	Type	No. Built	Reactors in Class	Comments
Hotel	2	SSBN	8	16	First SSBN
Yankee I	2	SSBN	34	68	
Delta I	2	SSBN	18	36	
Delta II	2	SSBN	4	8	
Delta III	2	SSBN	14	28	
Delta IV	2	SSBN	7	14	
Typhoon	2	SSBN	6	12	
Papa	2	SSGN	1	2	
Charlie I	1	SSGN	11	11	
Charlie II	1	SSGN	6	6	
Echo II	2	SSGN	29	58	
Oscar I	2	SSGN	2	4	
Oscar II	2	SSGN	9	18	
November	2	SSN	13	26	
K-27	2	SSN	1	2	Modified November LMR sub
Echo I	2	SSN	5	10	
Victor I	2	SSN	16	32	
Victor II	2	SSN	7	14	
Victor III	2	SSN	26	52	
Mike	1	SSN	1	1	
Alfa	1	SSN	7	7	Second LMR subs
Sierra I	2/1	SSN	2	4/2	
Sierra II	2/1	SSN	2	4/2	
Akula	2/1	SSN	11	22/11	
Uniform	1	SSAN	3	3	
Total Subs			**243**	**458/443**	
Cruisers	2	CGN	3	6	
Surveillance	2	SSV	1	2	
Total Cruisers			**4**	**8**	
Lenin	2	Icebreaker	1	2	
Artika class	2	Icebreaker	5	10	
Tamyr class	1	Icebreaker	2	2	
Sevmorput	1	Transport	1	1	
Total Civil			**9**	**15**	
TOTAL			256	481/466	

Appendix E
The *Komsomolets* Nuclear-powered Submarine[868]

A fire broke out in the aft compartment of the *Komsomolets* Mike-class nuclear-powered attack submarine on 7 April 1989.[869] The boat surfaced, and after trying to stay afloat for a couple of hours, sank 1680 m to the ocean floor at the boundary between the Barents and Norwegian seas.[870] Forty-two of the 69 crew members perished. The reactor was shut down and there was no nuclear accident.

The total activity of the reactor was about 150 kCi (at the time of sinking), a figure which includes the activated corrosion products from the reactor coolant system and fission products from the fuel (the core contains approximately 42 kCi of strontium-90 and 55 kCi of cesium-137).[871] The radioactivity of the plutonium in the two nuclear-tipped torpedoes was approximately 700 Ci of alpha-emitters (Pu-238, Pu-239, Pu-240) and 2500-4300 Ci of beta-emitters (Pu-241).[872]

The White Book notes the accident zone is one of the most biologically productive regions in the world and is of particular economic importance. It is within the sphere of interests of Russia, Norway, Sweden, Great Britain, and Iceland. Even a minimal migration of radionuclides (fission products and transuranic elements) through the water-plankton-fish chain could have serious political and economic implications.[873]

The White Book stated the leaking of radionuclides into the marine environment is made more likely because the *Komsomolets* is equipped with a titanium hull, which would increase the speed of corrosion, due to the interaction of the sea water with the titanium hull and steel parts of the submarine and reactor.[874]

Expeditions to the Submarine

To date, five expeditions (1989, 1991, 1992, 1993, 1994) have visited the *Komsomolets* to investigate whether the nuclear reactor and the two nuclear warheads are contaminating the environment and to investigate methods for preventing leakages.

The first exploratory mission to the accident area was conducted in May 1989 by the research vessel *Academician Mstislav Keldysh* of the USSR's P.P. Shirshov Oceanology Institute. *Mir* manned deep-water submersible vehicles determined the submarine's position and obtained samples.

The second expedition was a full-scale research program, using several ships, from August to September 1991. Two *Mir* submersibles were equipped with standard dosimetric instruments and specially designed radiation

---

[868] Unless otherwise noted, the source is the White Book, pp. 21, 28-29.

[869] The *Komsomolets* was an experimental one-of-a-kind submarine, with its titanium hull giving it an operating depth of 1,000 m.

[870] The submarine is located at coordinates 73:43.27 N and 13:15.87 E, near Bear Island, and around 300 nm from the Norwegian coast. White Book, p. 28.

[871] This was based on information about the power generated by the ship-board propulsion unit. White Book, p. 28.

[872] Based on the U.S. claim that the torpedoes contained 10 kg of weapon-grade plutonium-239/240 (U.S. Government position paper, ``Sunken Russian Nuclear Submarine Komsomolets,'' 29 October 1993), while ABC News reported a figure of 20 kg. We also assume the Pu-240 content is between 4.6 percent and 6.0 percent, and have ignored any Pu-241 decay into Am-241 as the warhead ages.

[873] The White Book said The Russian Polar Scientific Research Institute of Marine Fishing and Oceanography assessed the possible economic losses resulting from the contamination of commercial fish, by plutonium-239, as high as 2.5 billion rubles (1991 prices). White Book, pp. 28-29.

[874] White Book, p. 28.

measuring equipment. The submersibles carried special cassettes (containing selective sorbents attracting certain radionuclides) to and from the submarine. Between August 23 and 31, the two vehicles made six trips to the *Komsomolets*, collecting 32 water and soil samples.[875]

The third expedition to the submarine took place between 7 May and 18 June 1992, aboard the *Academician Mstislav Keldysh* and the Navy oceanographic vessel *Ivan Kruzenshtern.* The *Mir* submersibles were again specially equipped, and dove six times to the submarine and to the escape chamber (which was found at a distance of 300 meters from the submarine).[876]

The fourth expedition was the first joint effort with western scientists. A team of Russian scientists (including the submarine's designers), along with their American, Norwegian, and Dutch counterparts, departed Copenhagen at the end of July 1993 for a month long expedition aboard the Russian research ship *Academician Mstislav Keldysh* (once again with the *Mir 1* and *Mir 2*).

The fifth expedition worked in the Norwegian Sea around the wreck between 2 and 28 July 1994. The major aim of the expedition was to place plugs over the opened torpedo tube doors in order to reduce the water flow through the torpedo compartment so as the plutonium corrodes out of the warheads it would not be carried away. Several smaller holes in the forward end of the submarine were also plugged. Further investigation of the status of the submarine and biological activity in the area was also conducted.

What the Expeditions Found

Reactor

The soil and water samples from the second expedition were analyzed, and the results, released in January 1992, showed the primary circuit was leaking, but radionuclide emissions were extremely low (cesium-137 concentrations of no more than 10 pCi/l).[877] The small quantities of cesium-137 leaking into the sea, first noted in 1991, were recorded again in the third expedition, in line with forecasts.[878]

On the fifth expedition, based on preliminary analysis, the measured concentrations of cesium-137 in the immediate surrounding of the submarine did not exceed 2mBq/m^3, which showed there was no substantial changes in the radiation situation around the submarine from previous expedition. However, concentrations of cesium-137 measured inside the reactor compartment's emergency ventilation pipe (where measurements on previous expeditions had detected cesium-137) are some 100 times higher than it has been measured in the previous years, having a magnitude of one   Bq/m^3. The leaders of the 1994 expedition concluded this means there needs to be a careful analysis of the data obtained on the expedition to insure its accuracy and there may be a need for some reassessment of the reactor plant's status.[879]

---

[875] White Book, p. 28. Adm. V. Samoylov (Ret.), deputy head of the expedition and N. Nosov, technical director of the expedition, ``Depth 1,700 Meters. Aboard the 'Komsomolets,''' *Morskoi Sbornik*, No. 4, April 1992, pp. 34-35.

[876] White Book, p. 28. Adm. V. Samoylov (Ret.) and N. Nosov, ``Results of New Expedition,'' *Morskoi Sbornik*, No. 4, April 1993, (translated in JPRS-UMA-93-028, 11 August 1993, p. 30).

[877] White Book, p. 28.

[878] The maximum concentration of cesium-137 near the submarine was 180 Bq/m^3, while the average concentration was 29.6 Bq/m^3 (the permissible concentration of cesium-137 for drinking water is 550,000 Bq/m^3). White Book, p. 29.
   According to an official U.S. source, ``Russian fuel design results in normally operating with some fission products in the reactor coolant. Thus, the presence of Cs-137 in the sediment does not necessarily indicate core damage.''  U.S. Government position paper, ``Sunken Russian Nuclear Submarine Komsomolets,'' 29 October 1993.

[879] A.M.Sagalevich, Head of the expedition, M.Ye.Vinogradov, Scientific supervisor of the expedition, N.A.Nosov, Deputy head of the expedition from the Rubin submarine design bureau and, L.I.Yakushev, deputy head of the expedition from the Ministry of Emergency Situations, ``Brief

Nuclear Torpedoes

Rather than the reactor, the White Book's major concern was the possible environmental contamination arising from the plutonium in the nuclear torpedoes.[880] It noted the torpedo tubes were partially open and water was in contact with the torpedoes. The safety casing of the nuclear warheads had lost their seal, and materials in the warheads were in contact with the sea water. The White Book predicted that the plutonium could start leaking in 1995 or 1996, and that ``This uncontrollable process could gather momentum and could go on for several years.''[881]

Two major opinions exist about what would happen to the plutonium as it corroded off the warheads. Some contend that the plutonium would settle on to the ocean floor near the submarine.[882] Others note the particular nature of the plutonium corrosion as influenced by the presence of titanium could result in flakes which could be taken up by biota and then transported to the upper water layers. Also, there is the possibility currents could transport the plutonium much farther from the submarine.[883] As of 1994, expeditions as of yet have not been able to detect plutonium from the warheads leaking outside the submarine hull.

What to Do About It

After the first expedition in 1989 which did not discover such extensive structural damage, it was thought the submarine might be able to be salvaged in its entirety. The second expedition, however, uncovered greater than expected damage, leading experts to discount the possibility of raising the whole submarine.[884] Since 1991, increasing focus has been put on dealing with the nuclear torpedoes rather than with the submarine as a whole.

Several options have been considered, including separating and raising the front end of the submarine; somehow extracting and raising individual torpedoes; encasing parts of the submarine in concrete; injecting a gel, which once polymerized by the calcium in the sea water, would form a vitreous-like substance unlikely to be washed away even by a strong current;[885] and sealing the holes around the bow section to stop or reduce water current flows through the bow section, and thus reduce the chances any corroding plutonium will be swept outside the submarine.

The first two options are not seriously being considered at the moment due to costs, technical difficulties,

---

Information On the Preliminary Results of the 1994 Expedition to the Sunken Nuclear-Powered Submarine *Komsomolets*,'' 2 August 1994.

[880] The White Book predicted that prospects were ``quite favorable'' for the reactor radionuclides and that no perceptible migration into the surrounding waters were expected in the near future. White Book, p. 29.

[881] White Book, p. 29.

[882] So concludes Dr. Charles Hollister of the Woods Hole Oceanographic Institute. See: William J. Broad, ``Hazard is Doubted from Sunken Sub,'' *New York Times*, 5 September 1993.

[883] Presentation by V.I. Filippovsky, Chief of Sector of Research Center of Nuclear Safety, Russian Ministry of Defense, at ``International Symposium on the Discussion of Results of 1993 Expedition to SSN 'Komsomolets' and on the Working Out of a Common Concept for Further Research,'' at Central Design Bureau for Marine Engineering Rubin, St. Petersburg, Russia, 31 January - 2 February 1994. Debrora MacKenzie, ``Row Surfaces over Sunken Nuclear Sub,'' *New Scientist*, 18 September 1993, p. 7. Rolf L. Larsen, ``Radioactive Emissions Threaten Norwegian Sea,'' *Aftenposten* (Norway) (translated in JPRS-TEN-93-019, 28 July 1993, pp. 71-72).

[884] Samoylov and Nosov, ``Results of New Expedition,'' p. 31.

[885] With a 1-2 percent content of chitosan, an active absorbent of heavy metal, such as plutonium. Chitosan and chitin are complex organic substances found in the shells of crustaceans and insects. White Book, p. 29.

and possible adverse ecological consequences if the operations fail in the middle of their implementation.[886] Placing concrete around parts of the submarine is also not being pursued. The last two options were more technologically appealing by comparison and also pouring concrete inside or outside the submarine may foreclose further remediation or retrieval efforts as well as complicate further monitoring of the submarine. In 1993-1994, the promoters of the gel option lost their influence in the Russian government apparatus, and as a result of this and the technological solutions being pursued at the Rubin Design Bureau[887], in 1993, it was decided the next step in the work to prevent radiation contamination outside the torpedo room would involve placing metal plugs or plates over the torpedo tube doors and several smaller holes in the bow of the submarine during the 1994 expedition.

The 1994 expedition successfully covered six of the torpedo tubes and three smaller holes in the bow section. Expedition leaders concluded currents inside the front section had been cut substantially or eliminated. Concerns remain, however, about the possibility of plutonium leakage outside the submarine. A large amount of biological activity was found around the submarine during the expedition raising concerns about biological transport of leaking radionuclides. Thus in 1995, attempts may be made to plug more of the holes in the hull. In addition, pouring materials into the holes to cover the compartments or putting substances which may absorb radionuclides may be pursued.[888]

---

[886] The Commission estimated that the cost of such an operation would exceed U.S. $250 million. However, the Commission concluded the damage to the hull and the ongoing corrosion could have made this operation impossible, and could have resulted in further damage and loss of containment around the reactor and nuclear weapons. White Book, p. 29.

[887] The *Komsomolets* was designed by the Rubin submarine design bureau in St. Petersburg.

[888] A.M.Sagalevich, Head of the expedition, M.Ye.Vinogradov, Scientific supervisor of the expedition, N.A.Nosov, Deputy head of the expedition from the Rubin submarine design bureau and, L.I.Yakushev, deputy head of the expedition from the Ministry of Emergency Situations, ``Brief Information On the Preliminary Results of the 1994 Expedition to the Sunken Nuclear-Powered Submarine Komsomolets,'' 2 August 1994. Interview at the Rubin Central Design Bureau, 25 November 1994 by author. Boris Konovlov, interview with M.G. Tolokonnikov, Chief of Russian Federation Ministry of Emergency Situations Administration for Work at Sea and in the Bodies of Water, ``Nuclear Komsomolets Still a Threat to World's Oceans,'' *Izvestiya*, 9 August 1994, (translated in JPRS-TEN-94-021, 29 August 1994, p. 36).

Appendix F
Accidents Involving Soviet/Russian Submarines, 1956-1994[889]

During 1956-1994, Soviet/Russian submarines suffered a total of about 144 accidents, of which 110 involved nuclear-powered submarines.[890] The worst accidents include reactor meltdowns and explosions, submarine sinkings, nuclear weapons accidents, undersea collisions, and fires.

Although accidents involving the reactors and nuclear weapons create an immediate possibility of radioactive contamination, all serious accidents involving nuclear-powered or armed submarines can affect the nuclear reactor or nuclear weapons aboard and have possible consequences for the environment.[891] The most serious accidents are summarized below.

Out of 30 radiation incidents involving the reactors of Soviet nuclear submarines, at least 14 incidents were so severe--involving reactor meltdowns, major reactor accidents, or reactor explosions-- that the submarine was retired or withdrawn from service while its reactors were cut-out and replaced with new ones:

* 4 July 1961, the K-19 Hotel class SSBN had a severe reactor accident while in the north Atlantic. The reactors were removed and dumped off Novaya Zemlya.

* 12 February 1965, the K-11 submarine suffered a fire while the core was being prepared for unloading at Severodvinsk. The reactors were removed and dumped off Novaya Zemlya.

* 24 May 1968, the K-27, a modified November class SSN with liquid-metal cooled reactors (the first such Soviet submarine) suffered a severe reactor accident in the north Atlantic. The submarine with its two reactors was dumped off Novaya Zemlya in 1981.

* 23 August 1968, the K-140, possibly a Yankee I class SSBN, suffered a serious reactor accident. One of its reactors may have been dumped off Novaya Zemlya.
* In the 1960s, the K-3 November class SSN *Leninsky Komsomol*, the K-5, and the K-22 all had severe reactor accidents which lead to their reactors being removed and dumped off Novaya Zemlya.[892]

* 1972, the first Alfa class SSN was dismantled after suffering a reactor accident in the Atlantic.

* July 1979, the K-116 Echo I class SSN (order no. 541), suffered a meltdown in one reactor while at sea near Russia in the Pacific. The submarine was removed from service. The fuel could not be removed from the reactor. It is currently at the Pavlovsk submarine base.[893]

---

[889] Unless otherwise indicated, all data on submarine accidents comes from an ongoing database project on Soviet/Russian submarine accidents maintained by Joshua Handler, Greenpeace International. The latest version is: Joshua Handler, ``Soviet/Russian Submarine Accidents: 1956-1994,'' (Moscow/Washington, DC: Greenpeace, 6 December 1994).

[890] The actual amount of accidents is uncertain. The 144 number is derived from a large number of western and Russian official and unofficial sources. Thus some accidents listed by different sources may be the same accident. However, since Russian authorities have not provided a comprehensive list of major submarine accidents, the actual number of serious accidents may be higher.

[891] For example, flooding and most likely a weapons explosion, respectively, were the precipitating causes for the sinking of the two U.S. nuclear-powered submarines that were lost at sea--the *USS Thresher* in 1963 off Massachusetts and the *USS Scorpion* in 1968 in the mid-Atlantic.

[892] Joshua Handler, ``Trip Report: Greenpeace Visit to Moscow and Russian Far East July--November 1992, Subject: Russian Navy Nuclear Submarine Safety, Construction, Defense Conversion, Decommissioning, and Nuclear Waste Disposal Problems,'' (Washington, DC: Greenpeace, 15 February 1993), p. 21.

[893] Some reports say it was and Echo II class SSGN and happened in 1978. Joshua Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific Fleet, Nuclear Waste Disposal Problems, Submarine Decommissioning, Submarine Safety, and Security of Naval

* 8 April 1982, the K-123 Alfa class SSN's primary circuit was destroyed. The submarine was dismantled or underwent protracted repairs.

     * 10 August 1985, the K-431 Echo II class SSGN (order no. 175) suffered a reactor explosion at the end of a refuelling operation at the Chazhma Bay shipyard. The submarine was withdrawn from service and currently is at the Pavlovsk submarine base (see below).

     * December 1985, the K-314 Charlie class SSGN (order number 610) suffered a reactor meltdown in the Pacific as the submarine was returning to base. The submarine was withdrawn from service.[894]

     * Summer 1986, the K-175 Echo II class SSGN suffered a reactor accident in Cam Ranh Bay, Vietnam, when the wrong chemicals were put into the primary circuit. The submarine was withdrawn from service.

     * 26 June 1989, an Echo II class SSGN suffered a leak in the primary coolant while in the Norwegian Sea, leading to the retirement of the submarine.

     A total of nine Soviet submarines--five diesel-powered and four nuclear-powered--sank following accidents. Five of the vessels were later recovered--four diesel-powered and one nuclear-powered--and four are still on the ocean floor. In total these unrecovered submarines contained five nuclear reactors and an estimated 43 nuclear warheads.[895] The Russian White Book for the first time provided official estimates of the radioactive inventory of the reactors and lost warheads. In total, the five reactors were estimated to contain 650 kCi of activity, and the undisclosed number of warheads, 6.03 kCi at the time of sinking:[896]

     * 8-10 March 1968, the K-129 Golf II class SSB sank about 700 miles north-northwest of Midway Island in the Pacific in some 6,000 m of water 1968.[897] The White Book estimated that the nuclear weapons contained some 1.0 kCi at the time of sinking. The bow section of the boat containing the nuclear torpedoes with an activity of 0.4 kCi was raised by the CIA (using the ship *Glomar Explorer*) in the summer of 1974 under the code-name Operation Jennifer.[898]

     * 12 April 1970, the K-8 November class SSN with two reactors and two nuclear torpedoes was lost in the Bay of Biscay in 4,000 m of water after a fire broke out on 8 April while the submarine was submerged. The White Book estimated the reactors contained 250 kCi of activity and the two nuclear torpedoes, 0.8 kCi.

Fuel," (Moscow/Washington, DC: Greenpeace 27 October 1994), p. 44.

[894] Some reports say it was a Victor class SSN and the meltdown occurred while the submarine was in the Pavlovsk submarine base. Joshua Handler, ``Greenpeace Trip Report. Subject: Radioactive Waste Situation in the Russian Pacific Fleet, Nuclear Waste Disposal Problems, Submarine Decommissioning, Submarine Safety, and Security of Naval Fuel," (Moscow/Washington, DC: Greenpeace 27 October 1994), p. 44.

[895] Some fifty nuclear warheads are estimated to be lost at sea due to military operations. Forty-three were on sunken Soviet submarines, and the rest were from U.S. military activities, including two nuclear torpedoes on the submarine *USS Scorpion* when it sank in the Atlantic in 1968. William Arkin and Joshua Handler, *Neptune Paper No. 3, Naval Accidents 1945-1988* (Washington, DC: Greenpeace, June 1989). Joshua Handler, Amy Wickenheiser and, William M. Arkin, *Neptune Paper No. 4, Naval Safety 1989: The Year of the Accident*, (Washington, DC: Greenpeace, April 1990).

[896] White Book, Table 7, p. 21 (due to a typographical error, the table column lists the amounts of activity in the weapons in curies rather than kilocuries). All estimates of radioactivity totals from the White Book, Table 7, p. 21.

[897] For many years, western sources (and the White Book, Table 7, p. 21) inaccurately listed the submarine as sinking in April 1968. New information shows K-129 disappeared during 8-10 March after its last communication and before its next scheduled one.

[898] The Golf II class SSBs could carry up to three SS-N-5 SLBMs (in the sail) and up to six 21-inch nuclear torpedoes (bow). Cochran et al., *Nuclear Weapons Databook*, Volume IV, *Soviet Nuclear Weapons* (New York: Harper & Row, 1989), p. 206.

* 6 October 1986, the K-219 Yankee I class SSBN with two reactors and estimated 34 nuclear warheads on 16 ballistic missiles and two nuclear torpedoes[899] sank in 5,500 m of water after an explosion in a missile tube on 3 October. The White Book estimated the reactors contained 250 kCi of activity and the nuclear weapons, 3.8 kCi.[900]

* 7 April 1989, the K-278 *Komsomolets* Mike class SSN with one reactor and two nuclear torpedoes was lost in Norwegian Sea in 1,685 m of water after suffering a fire. The White Book estimated that the reactor contained 150 kCi of activity, and the two torpedoes, 0.43 kCi.

The Chazhma Bay Accident of 10 August 1985[901]

On 10 August 1985, the port side reactor of a nuclear-powered submarine (an Echo II-class SSGN, the K-431, order no. 175) suffered an ``uncontrollable spontaneous chain reaction of uranium nuclear fission'' during the final stage of reactor refuelling at the naval shipyard on Chazhma Bay near the town of Dunay (Shkotovo-22) located near Vladivostok in the Far East.

The explosion killed 10 people in the reactor room. Around 290 people were exposed to radiation during the accident and the subsequent cleanup (10 people suffered from acute radiation sickness and 39 had a ``severe'' reaction to the radiation).

The thermal explosion of the reactor destroyed the fore and aft instrument bulkheads and the fore control and safety system. One compartment with a newly installed core was blown out of the reactor. The hull of the submarine was damaged in the aft section of the reactor compartment. The explosion was followed by a fire in the reactor compartment, which was brought under control within four hours. The combustion products--along with the fission and activation products and particles of fresh fuel--fell back to earth within a radius of 50-100 meters around the damaged submarine.

According to official estimates, the amount of radioactive materials discharged into the atmosphere was approximately 185,000 TBq (5 MCi).[902] The greatest concentration of contamination was recorded at the epicenter of the explosion[903] and on the axis of the radioactive plume, especially the land areas.[904]

While large areas of water around the submarine became contaminated immediately following the

---

[899] Yankee I SSBNs could carry up to 16 SS-N-6 SLBMs, with two major modifications: Mod1/2 with one warhead and Mod 3 with two-three MRV warheads. Cochran et al., *Nuclear Weapons Databook*, Volume IV, *Soviet Nuclear Weapons* (New York: Harper & Row, 1989), p. 143. The 34 warhead estimate from: William Arkin and Joshua Handler, *Neptune Paper No. 3, Naval Accidents 1945-1988* (Washington, DC: Greenpeace, June 1989).

[900] There was one report in the western press that, according to conversations by a Woods Hole Oceanographic Institute scientist with the designers of the submarine at the Rubin submarine design bureau in St. Petersburg, the missiles and warheads were ``badly damaged and scattered on the sea floor.''  William J. Broad, ``Sunken Soviet Sub Leaks Radioactivity in Atlantic,'' *New York Times*, 8 February 1994.
    Subsequent conversations with representatives from Rubin by the author indicate such conclusions were based on casual conversations and logical speculation, but not any first-hand knowledge of the situation.

[901] Unless otherwise noted, all data on this explosion was obtained from the White Book, pp. 27-28.

[902] This figure does not include the radioactive noble gases emitted, which account for an additional 81,000 TBq (2 MCi).

[903] Within 7.5 hours, the exposure dose rate in the epicenter had reached 250-500 mR/h, and the contamination of the surface by beta-emitting nuclides was $0.5\text{-}4.0 \times 10^6$ dpm/cm^2 x min (dpm = disintegrations per minute).

[904] The axis of the radioactive band intersected the Dunay peninsula in a north-westerly direction (the length of the band on the peninsula was 5.5 km) and extended out to sea (the Ussuriysk Bay). Fallout was detected on the water surface as far away as 30 km from the damaged submarine.

explosion (from fallout and from radioactive water from the damaged reactor compartment, which entered the bay through a hole in the hull),[905] the vast majority of the radioactive debris either dispersed in ocean currents or sank to the bottom. Currently all the radioactivity in the marine environment is concentrated in the seabed sediments.

The region of maximum contamination of the seabed (where gamma-radiation is over 240 R/h) is located, not surprisingly, in the accident zone, and covers an area of approximately 100,000 m^2 (0.1 km^2). At the center of the zone, the exposure dose is 20-40 mR/h (maximum of 117 mR/h as of 1992). The contamination is caused by the concentration of radionuclides in the bottom sediment, primarily Cobalt-60 (96-99 percent) but also Cesium-137.[906]

Ocean currents have spread the radioactive sediments from the accident site throughout the southeastern portion of the Chazhma Bay, and they are gradually moving towards the western entrance of Strelok Bay.[907] However, the White Book predicted that the migration of the radioactive contamination along the bottom of Chazhma Bay ``will not have any serious ecological consequences'' since the total activity of the radionuclides in the bottom sediment is comparatively low (approximately 5 Ci), and the main radionuclide is Cobalt-60, which has a half-life of 5.26 years. The only way to completely eliminate the radioactive contamination would be to remove this seabed sediment.

This reactor accident was so severe the nuclear fuel could not be removed, and this caused the submarine to be permanently withdrawn from service. Following the accident, the reactor compartment was filled with concrete to prevent further radioactive contamination, and the hole in the hull was welded shut. The submarine is currently at Pavlovsk, floating alongside other decommissioned submarines, including two with seriously damaged reactors.

As of 1991, local residents were still very concerned about a temporary burial site created in the fall-out trace several kilometers from the shipyard where some of the materials cleaned upped after the accident were dumped in hastily prepared trenches. Warning signs and fences around the burial site were inadequate. Also, some contamination had spread to the village of Dunay as contaminated building materials had been brought into the town.

In 1991, levels of several hundred to over a 1,000 micro-roentgens/hour were measured around the burial site. In the spring of 1992, the Pacific Fleet dug up the temporary burial site and removed most of the radioactive materials to the permanent naval radioactive waste storage site at the tip of the Shkotovo peninsula. Prior to the clean-up operation, the Pacific Fleet measured spots of radiation in the burial site with levels as high as 5,300 to 40,000 micro-roentgens/hour. In fall 1992, levels of 80 micro-roentgens/hour were measured on top of the dug-up area. However, higher levels ranging from several hundred micro-roentgens/hour to over a 1,000 micro-roentgens/hour were measured in some spots in the fallout trace. Although, further remediation measures are planned (e.g. repaving or paving roads to reduce levels of radiation or prevent further spread of contaminated soils have been planned for several years), as of spring 1994 they had not been carried out. The Pacific Fleet's preference is to not do much more remediation, since the primary contamination comes from cobalt-60, the radiation background levels will return to normal in some 50 years.[908]

---

[905] The activity of short-lived radionuclides in the seawater reached 74 kBq/l (2 μCi/l) within an hour of the explosion. Two months after the accident, the activity of radionuclides in the sea water had decreased to the original levels (i.e. similar to other regions of the Pacific coast).

[906] The maximum specific activity of Cobalt-60 in the seabed sediment in the accident zone is 78 kBq/kg (2.1 μCi/kg), and in marine water life--670 Bq/kg (18 μCi/kg). The total cobalt-60 activity in the bottom sediments of Chazhma Bay was approximately 185 GBq (5 Ci) in 1992. Contamination of bottom sediments by Cesium-137 is seen in local areas and in concentrations at or slightly above background values.

[907] Radioactive sediments were also deposited along a 6-10 km-wide swath in the eastern part of the Ussuriysk Bay, mirroring the path of the original radioactive plume.

[908] Joshua Handler, ``Preliminary Report on: Greenpeace Visit to Vladivostok and Areas Around the Chazhma Bay and Bolshoi Kamen Submarine Repair and Refuelling Facilities, 9-19 October 1991,'' (Washington, DC: Greenpeace, 6 November 1991), pp. 2-7. Joshua Handler, ``Trip Report:

Thomas B. Cochran

Dr. Thomas B. Cochran is Senior Staff Scientist with the Natural Resources Defense Council, and Director of NRDC's Nuclear Program. He initiated NRDC's Nuclear Weapons Databook Project. He also initiated a series of joint nuclear weapons verification projects with the Soviet Academy of Sciences. These include the Nuclear Test Ban Verification Project, which demonstrated the feasibility of utilizing seismic monitoring to verify a low-threshold test ban, and the Black Sea Experiment, which examined the utility of passive radiation detectors for verifying limits on sea-launched cruise missiles. He has served as a consultant to numerous government and non-government agencies on energy, nuclear nonproliferation and nuclear reactor matters. He is currently a member of the Department of Energy's Fusion Energy Advisory Board and Environmental Management Advisory Board. Previously he served as a member of DOE's Energy Research Advisory Board, the Nuclear Regulatory Commission's Advisory Committee on the Clean Up of Three Mile Island and the TMI Public Health Advisory Board.

Dr. Cochran is the author of *The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique* (Washington, DC: Resources for the Future, 1974); and co-editor/author of the *Nuclear Weapons Databook, Volume I: U.S. Nuclear Forces and Capabilities* (Cambridge, MA: Ballinger Press, 1984); *Volume II: U.S. Nuclear Warhead Production* (1987); *Volume III: U.S. Nuclear Warhead Facility Profiles* (1987); and *Volume IV: Soviet Nuclear Weapons* (1989). In addition, he has published numerous articles and working papers, including those in *SIPRI Yearbook* chapters, *Arms Control Today,* and the *Bulletin of the Atomic Scientists.* He has co-authored (with Dr. Norris) the article on ``Nuclear Weapons'' in the 1990 printing of *The New Encyclopedia Britannica* (15th edition).

Dr. Cochran received his Ph.D. in Physics from Vanderbilt University in 1967. He was assistant Professor of Physics at the Naval Postgraduate School, Monterey, California, from 1969 to 1971, and from 1971 to 1973, he was a Senior Research Associate at Resources for the Future. Dr. Cochran has been with NRDC since 1973. He is the recipient of the American Physical Society's Szilard Award and the Federation of American Scientists' Public Service Award, both in 1987. As a consequence of his work, NRDC received the 1989 Scientific Freedom and Responsibility Award by the American Association for the Advancement of Science.

Robert S. Norris

Dr. Robert S. Norris is Senior Staff Analyst with the Natural Resources Defense Council and Director of the Nuclear Weapons Databook Project. His principal areas of expertise include writing and research in the areas of nuclear weapons research and production, arms control, and nuclear weapons testing. He is co-editor of NRDC's *Nuclear Weapons Databook* series and is a

---

Greenpeace Visit to Moscow and Russian Far East July- November 1992, Subject: Russian Navy Nuclear Submarine Safety, Construction, Defense Conversion, Decommissioning, and Nuclear Waste Disposal Problems,'' (Washington, DC: Greenpeace, 15 February 1993), pp. 10-11. Handler site visits--October 1991, Fall 1992, May 1994.

co-author of *U.S. Nuclear Warhead Production,* Vol. II (1987); *U.S. Nuclear Warhead Facility Profiles,* Vol. III (1987); *Soviet Nuclear Weapons,* Vol. IV (1989); and *British, French and Chinese Nuclear Weapons*, Vol. V (1994). He has co-authored (with Dr. Cochran) the chapter on nuclear weapons in the 1985, 1986, 1987, 1988, 1989, 1990, 1991 and 1992 editions of the *SIPRI Yearbook.* Dr. Norris is an author of six recent NRDC Working Papers. He has written articles for *Arms Control Today,* and contributes a column for each issue of the *Bulletin of the Atomic Scientists.* He has co-authored (with Dr. Cochran) the article on ``Nuclear Weapons'' in the 1990 printing of *The New Encyclopedia Britannica* (15th edition).

Dr. Norris received his Ph.D. in Political Science from New York University in 1976, and taught at New York University, Miami University in Ohio, Miami University, Luxembourg, and American University. He was a senior research analyst for the Center for Defense Information before coming to the Natural Resources Defense Council in September 1984.

TABLES for the MAKING THE RUSSIAN BOMB

Table 2.1

```
                        ┌─────────────────────────┐
                        │   Alexander G. Meshkov   │
                        │     Deputy Minister      │
                        └────────────┬────────────┘
          ┌──────────────────────────┼──────────────────────────┐
┌──────────────────┐    ┌────────────────────────┐   ┌────────────────────────────┐
│ Atommash         │    │ Karimos Concern        │   │ Karat Concern              │
│ Production       │    │ President V.V.         │   │ President V.G. Kholoneuko  │
│ Association,     │    │ Karetnikov             │   │ Manufacturing of Tools     │
│ Valgodonsk       │    │ Equipment for Dairy    │   │ and Equipment for Nuclear  │
│                  │    │ Industry               │   │ Power Station              │
└──────────────────┘    └───────────┬────────────┘   └─────────────┬──────────────┘
                        ┌────────────────────────┐   ┌────────────────────────────┐
                        │ Production Associations:│   │ SNIIP Engineering Center   │
                        │ Potok, Vostok,          │   │ Plants: Impulse, Tenzor,   │
                        │ Tekhosnastka, Mir,      │   │ Signal, Electron, Crystal  │
                        │ TESMO, Temp, Plant      │   │ Association Baltiets,      │
                        │ Start, Design Bureau    │   │ Institute of Technical     │
                        │ Kontur, Komito Center,  │   │ Physics, Automation        │
                        │ Milk Stock Utilization  │   │ Association Izotop         │
                        │ Institute               │   │                            │
                        └────────────────────────┘   └────────────────────────────┘
```

Lev Ryabev
First Deputy Minister

Viktor A. Sidorenko
Deputy Minister
Nuclear Power

Main Directorate for Development of Nuclear Reactors and Special Nuclear Power Plants

Rosenergoatom Concern
President Erik Pozdyshev

Institutes: technological, innovation and thermonuclear research, power engineering, physics and power, atomic reactors, instruments. Production Association Krasnaya Zvezda Design Bureaus: Hydropress, machine building. Plants: electromechanical equipment, Vektor, Luch

Nuclear Power Plants: Balakovo (4), Beloyarsk (1), Bilibino, Kalinen (2), Kola (4), Kursk (4), Leningrad (4), Novo Voronezh (3), Smolensk (3)
Production Associations: Soyuzatomtekhenergo, Atomenergoremont, Rosatomremont, Spetsatom
Energiya Plants: Atomenerogozapchast, Atomremmash
Enterprises: NovoVoronezhatomtekhenergo, Kalininatomtekhenergo

```
                    ┌─────────────────────────┐
                    │   Nikolai N. Yegorov     │
                    │    Deputy Minister       │
                    └─────────────────────────┘
```

Nikolai N. Yegorov
Deputy Minister

| Main Scientific-Technological and Nuclear-Chemical Directorate

Evgeni Mikerin, Head | Committee for Ecology, Nuclear and Radiation Safety, Emergency Situations and Radioactive Waste Management | Department of Information and Public Relations |

Mayak Chemical Combine (Chelyabinsk-65): Siberian Chemical Combine (Tomsk-7), Mining Chemical Combine (Krasnoyarsk-26), Ural Electrochemical Combine (Sverdlovsk-44), Electrochemistry Combine (Krasnoyarsk-45), Electrolyzing Chemical Combine (Angarsk), B.P. Konstantinov Chemical Combine (Kirovo-Chepetsk, Kirov Region); Stable Isotopes Institute; Nuklid Center

```
                        ┌──────────────────────┐
                        │   Yuri I. Tychkov     │
                        │   Deputy Minister     │
                        └──────────────────────┘
```

Yuri I. Tychkov
Deputy Minister

Main Accounting and Reporting Directorate	Main Financial Directorate	Main Directorate of Labor Relations and Forms of Property

Economics and Forecasting Committee	Convers ion Bank	Techsnabexport Joint Stock Company *President A. H. Shishkin* Export of Equipment and Materials for Nuclear Power Stations

```
                    ┌─────────────────────────┐
                    │  Evgeni A. Reshetnikov  │
                    │   Deputy Minister for   │
                    │    Civil Construction   │
                    └─────────────────────────┘
```

Evgeni A. Reshetnikov
*Deputy Minister for
Civil Construction*

Main Directorate of
Nuclear Power Development

Rosatominvest Concern
President A.S. Zenkov
Investments in Nuclear
Power Industry

Zarubezhatomstrol
Production Association

Nuclear District Heating Plants:
Arkhangelsk, Voronezh, Gorky
Nuclear Power Plants: Bashkir,
Far East, Kostroma, Primorsk,
Tatar, Novo Voronezh-2, Kola-2
Leningrad Design and
Development Institute Nizhnii
Novgorod Atomenergoproekt
Institute

Alexander Makarov
Deputy Minister

Central Department of Military Construction Units

Spetsstrolmaterialy Joint Stock Company
President V.A. Barkov
Production of Construction Materials for Nuclear Power Stations

Combines: Solikamsk, Chunsky, Vikhorevka, Strolmashpolymer, Iskitin. Dustlik Joint Stock Company. Orgtekhstrol-13. Technological Institute Plants: Ramushlov, Nizhnyaya Tura, Perm, Tomsk, Potaninsk, Zykovo. Associations: Strolplastpolymer, Volzhsky Pilot and Experimental Plant

Spetsatommontazh Concern
President Viktor Shilenko
Construction of Nuclear Power Stations

NIKIMT Production Association Associations: Elektron, Hudromontazh, Energospets montazh, Promelektromontazh. Trusts: Mospromtekhmontazh, Prommekhano-montazh, Uralprommontazh. Plant Prom-stalkonstruktslya. Pilot Production Plants, Installation & Construction Directorates

Atomstroi Concern
President K.N. Moskvin
Construction of Nuclear Power Stations in European Russia

Construction Directorates: Dimitrovgrad, nrs. 606 and 909, Don, Northern. Joint Stock Company Obninsk Construction Directorate. Trusts: Gorky, Kaluga, Dimitrovgrad, Orgtekhstroi-II. Souyzantiseptik Enterprise
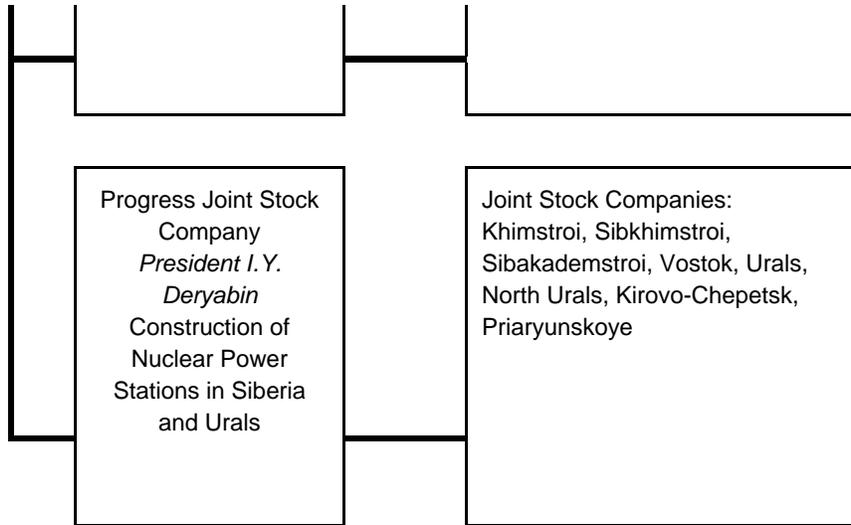
| Progress Joint Stock Company *President I.Y. Deryabin* Construction of Nuclear Power Stations in Siberia and Urals | Joint Stock Companies: Khimstroi, Sibkhimstroi, Sibakademstroi, Vostok, Urals, North Urals, Kirovo-Chepetsk, Priaryunskoye |

Vitali F. Konovalov *First Deputy Minister*	Legal Directorate
	Transport Directorate

Main Directorate of Design and Investments	Planning & Design; Research and Technological Association; Planning & Surveying Institute of Production Technology; Institutes Orgstroyniiproekt; Vibrotekhnika; Design Institute; Krasnoyarsk; Tomsk; Novosibirsk; Uralian and Siberian branches of the Institute of Production Technology

Main Scientific and Technical Directorate	Institutes of Inorganic Materials, Chemical Technology, Chemical Engineering, Physics and Power (Obninsk) Polytechnical (Urals, Tomsk). Associations: Radium Institute, Tsentr, Polytekh Enterprise, Main Computing Center

Atomredmetzoloto Concern *President Vyacheslay V. Krotkov* Extraction & Processing of Rare Metals & Gold	Production Associations: Almaz (Lermontov, Stavropol Region), Southern Polymetal Combine (Beshkek), Prikaspiyski (Shevchenko Magistaunsk Region), Navoi Mining and Smelting Combines (Tchkalovsk, Leningrad Region), Priagunski, Krasnokamensk (uranium ore mining and reprocessing), Tselinny Mining and Chemical Combine (Stepnogorsk), East Mining and Refining Combine (Zhjoltye Vody), Erdes Mining Plant, Kauchuk Plant, Malyshevsk Mining Utility

TVEL Concern *President Leonid O. Proskuryakov* Production of Fuel Sources & Strategic Metals	Production Associations: Machine Building Plant, Novosibirsk Chemical Concentrates Plant, Chepetsk Mechanical Plant (Glazov, Udmurt), Moscow Polymetals Plant, Voiznsk Machine Building Plant. Zabaikalredmet, Building Structure Plant, Energiya Foreign Trade Company

Atompromcompleks Concern	Blagoveznensk; Simferopol Fittings Plant; Novgorod Kontur

President V. M. Bednyakov Construction of Enterprises for Equipment and Materials for Nuclear Power Stations	Association; Zaporozne Association of Fittings Engineering
	Commercial and Production Enterprises: Atompromcompleks, Kontrakt, Chelyabinsk, Gorky, Central-Urals, Yaroslavl, Rostov, North-West, Novosibirsk and Tver enterprises, Spetsavtomatika Plant

Sredmashinvest Concern
President Y. P. Averiyanov

Viktor N. Mikhailov *Minister*		

Ministerial Board	Second Directorate Physical Protection of Nuclear Materials & Facilities *Vladamir Bogdanov, Head*	Atomzashitainform Centre
First Deputy Minister (2) Deputy Minister (5)	Fifth Main Directorate of Nuclear Warhead Design & Testing *Georgi A. Tsyrkov, Head*	Research Institutes: Arzamas-16 Chelyabinsk-70 Automation Impulse Technology Measurement Systems Design Bureau of Motor Transport Equipment
Scientific & Technical Council	Sixth Main Directorate of Nuclear Warheads Production *Boris V. Gorobets, Head*	Elektrokhimpribor Combine: Production Associations: Start, Molniya, Sever, Avangard Electromechanical Plant. Kuznetsk and Nizhnyaya Tura Machine Building Plants
Secretariat *Valery V. Bogdan, Head*	Eighteenth Directorate Fundamental Studies in Nuclear Physics and Thermonuclear Fusion *Atlant A. Vasilyev, Head*	Institute for Theoretical & Experimental Physics (Moscow); High Energy Physics Institute (Protvino, Moscow Region); R & D and Industrial Association ``Elektrophysika,'' Leningrad Physics Institute (Yerevan)
Administration Department	Eleron Research and Production Association (Moscow) *Yevgeny Mishin, Head*	Institutes: physics instruments. Eleron radioelectronic engineering
International Relations Committee	Committee Chairman	Department of Social Policy

	Committee for Social and Personal Policy	Polyanka Trading and Industrial Joint Stock Company (Export and Import of Equipment for Nuclear Power Stations)
Central Research Institute of Management, Economics and Information (ATOMINFORM)	Main Directorate of Personnel and Educational Institutions	

```
                        ┌─────────────────────────┐
                        │   Viktor N. Mikhailov    │
                        │        Minister          │
                        └─────────────────────────┘
```

Viktor N. Mikhailov
Minister

Vitali Konovalov
First Deputy Minister

Uranium Mining
  and Milling
Fuel Cycle Research
Fuel Fabrication

Nikolai Yegorov
Deputy Minister

Evgeni Mikerin
Head, Fourth Directorate

Reprocessing Uranium
Enrichment
Isotope Production

Georgi Tsyrkov
Head, Fifth Directorate

Nuclear Warhead R&D
and Weapons
Laboratories

Boris Gorobets
Head, Sixth Directorate

Warhead Production
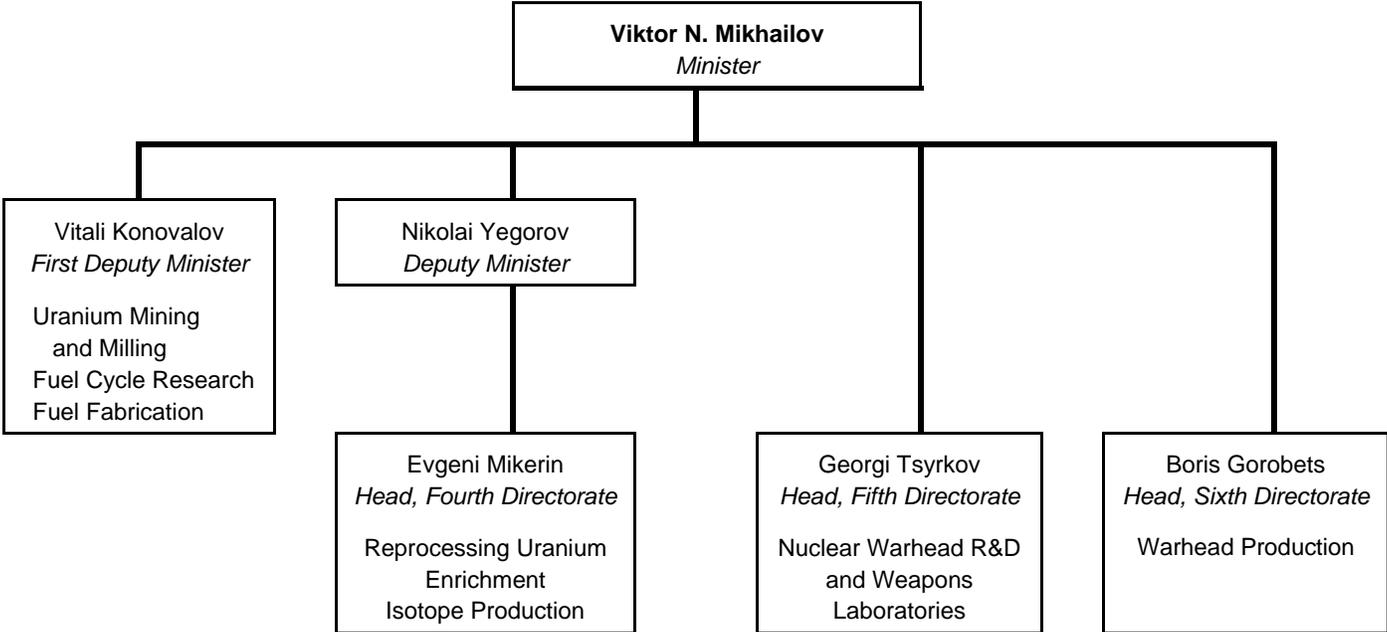
```
Table 2.2
```

Principal Nuclear Weapon Research, Test and Production Facilities

DESIGN LABORATORIES

All-Russian Scientific Research Institute of Experimental Physics (VNIIEF)

Arzamas-16 (*Kremlev*)   55° 23'N 43° 50'E
at Sarova, Nizhni Novgorod Oblast

All-Russian Scientific Research Institute of Technical Physics (VNIITF)

Chelyabinsk-70 (*Snezhinsk*) 56° 05'N 60° 44'E
20 km north of Kasli, Urals region

TEST SITES

Central Test Site

Novaya Zemlya

Northern and Southern Test Areas
two islands north of the Arctic Circle

Semipalatinsk (or Kazakh) Test Site (permanently closed in 1991)

Semipalatinsk-21

Shagan River, Degelen Mountain, and Konyastan test areas
south of Semipalatinsk, Kazakhstan

WARHEAD PRODUCTION (ASSEMBLY) FACILITIES

Final Assembly

Sverdlovsk-45 (*Lesnoy*)   58° 40'N 59° 48'E
at Nizhnyaya Tura, 200 km north of Yekaterinburg, Urals region

Zlatoust-36 (*Trekhgornyy*) 54° 42'N 58° 25'E
at Yuryuzan, 85 km southeast of Zlatoust, Urals region

Arzamas-16 (*Kremlev*) Avangard   see above
at Sarova, Nizhniy Novgorod Oblast

Components

Penza-19 (*Zarechnyy*)   53° 08'N 46° 35'E
at Kuznetsk, 115 km east of Penza

PLUTONIUM AND TRITIUM PRODUCTION REACTORS

Mayak Chemical Combine

Chelyabinsk-65 (formerly **Chelyabinsk-40**) (*Ozersk*) 55° 44'N 60° 54'E
at Lake Kyzyltash, near Kasli and Kyshtym, Chelyabinsk Oblast, Urals region

Siberian Chemical Combine (SKhK)

Tomsk-7 (*Seversk*)   56° 37'N 84° 47'E
on the Tom River 15 km northwest of Tomsk in Siberia

Mining-Chemical Combine (GKhK)

Krasnoyarsk-26 (*Zheleznogorsk*) 56° 20'N 93° 36'E
on the Yenisey River 10 km north of Dodonovo near Krasnoyarsk in Siberia

URANIUM ENRICHMENT FACILITIES

Ural Electrochemical Combine (UEKhK)

Sverdlovsk-44 (*Novouralsk*) 57° 15'N 59° 48'E
near Verkh-Neyvinsk, near Yekaterinburg, Urals region

Siberian Chemical Combine

Tomsk-7 (*Seversk*)   see above
on the Tom River 15 km northwest of Tomsk in Siberia

Electrochemistry Combine

Krasnoyarsk-45 (*Zelenogorsk*)   56° 08'N 94° 29'E
on the Kan River between Krasnoyarsk and Kansk, Siberia

Electrolyzing Chemical Combine (AEKhK)   52° 31'N 103° 55'E
at Angarsk, 30 km northwest of Irkutsk in Siberia

Table 2.3
Design Laboratory Leaders 1946-1995

Arzamas-16 Directors

1946-1951	General Pavel M. Zernov
1951-1955	General Anatoli S. Aleksandrov
1955-1974	Boris G. Muzrukov
1974-1994	Evgeni A. Negin
1994-date	Vladimir A. Belugin

Arzamas-16 Scientific Directors

1946-1992	Yuli B. Khariton
1992-to date	Viktor N. Mikhailov

Arzamas-16 Chief Designers

1959-1989	Samvel G. Kocharyants
?	Evgeni A. Negin
?	Stanislav N. Voronin

Chelyabinsk-70 Directors

1955-1961	Dmitri Ch. Vasilyev
1961-1963	Boris N. Ledenyov
1963-1986	Lt. Gen. Georgi P. Lominskiy
1986-date	Vladimir Z. Nechai

Chelyabinsk-70 Scientific Directors

1955-1960	Kirill I. Shchelkin
1960-1984	Evgeni I. Zababakhin
1984-to date	Evgeni N. Avrorin

Chelyabinsk-70 Chief Designers

1955-?	
1959-1961	Boris N. Ledenyov
1961-?	
?-to date	Boris V. Litvinov

Table 3.1

Facilities at the Mayak Chemical Combine (Chelyabinsk-65)

Production Reactors:
   Graphite Moderated (for plutonium production; all shut down)
         A-Reactor
         IR-Reactor
         AV-1 Reactor
         AV-2 Reactor
         AV-3 Reactor

   Light Water Moderated (for tritium and special isotope production)
   Lyudmila (initially a heavy water reactor; rebuilt in late-1980s)
         Ruslan

Chemical Separation Plants:
   B Plant For recovery of plutonium from production reactor fuel: shut down
   BB Plant For recovery of plutonium from production reactor fuel: shut down
   RT-1 400 MT/y capacity; in use for reprocessing naval and power reactor fuel
   Radioisotope Plant (``The Vatican'') in use for special isotope recovery

Tritium Handling Facilities

Plant 20 For plutonium processing, finishing and component manufacturing

Mixed-Oxide (MOX) Fuel Fabrication Plants:
   Pilot Bay 1 MT plutonium alloys and PuO_2 fuel manufactured in the 1960s and 1970s
   Zhemchug operated from 1986-1987 with a capacity of 35 kg
         Pu/y (for 5 fuel assembles/y) to produce fuel
         assemblies for fast reactors.
   Granat has operated since 1988 with as capacity of 70-80 kg
         Pu/y (for 10 fuel assemblies/y) to produce fuel for
         testing in fast reactors.
   Paket has operated since 1988 with a capacity of 70-80 kg
         Pu/y (for 10 fuel assemblies/y) to manufacture MOX
         pellets, and fabricate fuel elements for testing in
         fast reactors.

Complex 300 Plant (construction suspended after 50-70 percent complete) has a capacity of 5-6 MT Pu/y to manufacture fuel for BN-800 fast reactors.

Spent Fuel Storage Facility Interim pool storage for 2000 MT of VVER-440 spent fuel; construction suspended after 70 percent complete

Plutonium Storage Facility contains about 25 MT of plutonium from naval and power reactors

South Urals AES (site for three BN-800 LMFBR Reactors)
Construction of all three units halted; two units abandoned; construction of the third unit, still in an early construction stage, may be resumed

Nuclear Waste Facilities
Waste Storage Tanks (for High and Intermediate Level Waste)
Pilot Waste Vitrification Plant (500 l/h)
Installation for ``cleaning low-level waste''

Instrument Engineering Plant
Designs and manufactures a wide variety of instruments for on site use, and for defense and civilian industries

Experimental Scientific Research Center

Central Research Laboratory
Works on problems associated with radiochemical processing, safety and environmental monitoring

Repair and Machine Shop

Table 3.2

Occupational Radiation Exposures at Chelyabinsk-65(-40)
(Distribution of Employees According to Their Dose)[909]

	Installation A					Installation B				
	Percent of Employees				Average dose (rem)	Percent of Employees				Average doses (rem)
	<25	25-100	100-400	>400		<25	25-100	100-400	>400	
1948	84.1	11.1	4.8	-	19.6	-	-	-	-	-
1949	10.7	57.7	31.1	0.5	93.6	26.9	66.2	6.9	-	48.0
1950	52.2	47.2	0.6	-	30.7	21.5	42.0	36.0	0.5	94.0
1951	74.9	25.1	-	-	18.1	13.8	41.6	42.8	1.8	113.3
1952	83.9	16.1	-	-	14.9	21.8	57.0	21.2	-	66.0
	Percent of Employees				Average dose (rem)	Percent of Employees				Average dose (rem)
	<10	10-25	25-100	>100		<10	10-25	25-100	>100	
1953	37.8	41.5	18.4	2.3	19.6	25.3	25.4	47.3	2.0	30.7
1954	64.0	33.0	3.0	-	8.9	34.7	36.1	29.1	0.1	20.0
1955	61.8	33.7	4.5	-	9.5	29.8	36.7	33.2	0.3	21.3
1956	92.3	6.4	0.6	0.7	5.1	45.0	31.9	23.1	-	16.2
1957	98.1	1.9	-	-	4.2	37.5	36.9	25.5	0.1	17.5
1958	95.3	4.7	-	-	4.4	59.6	31.3	9.1	-	10.8
1959	99.7	0.3	-	-	3.3	75.7	21.1	3.2	-	14.7
	Percent of Employees				Average dose (rem)	Percent of Employees				Average dose (rem)
	<2.5	2.5-5.0	>5.0			<2.5	2.5-5.0	>5.0		
1960	57.5	29.3	13.2		2.7	14.2	25.8	60.0		15.2
1961	73.9	22.4	3.7		2.0	13.8	49.1	37.1		11.0
1962	65.0	31.4	4.0		2.3	16.6	32.5	50.9		7.6
1963	64.3	29.8	5.9		2.4	41.4	37.3	21.3		3.8
1964	55.7	27.8	16.5		3.0	66.4	29.3	4.3		4.1
1965	24.5	49.1	26.4		4.0	67.0	31.4	1.6		2.1
1966	25.5	52.4	22.1		1.7	56.7	41.3	2.0		2.4
1967	45.5	41.4	13.1		1.3	76.7	23.2	0.1		1.8
1968	55.0	38.7	6.3		1.1	76.3	23.7	-		1.8
1969	56.2	39.5	4.3		1.0	91.9	8.1	-		1.4
1970	36.9	49.7	13.4		1.4	85.6	14.4	-		1.6
1971	25.7	36.5	37.8		1.3	95.1	4.9	-		1.4
1972	69.7	26.8	3.5		1.1	97.9	2.1	-		1.3
1973	45.5	44.8	9.7		1.0	97.4	2.6	-		1.3
1974	95.1	4.9	-		1.0	98.9	1.1	-		0.6

---

[909] 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).

Table 3.3
Estimated Plutonium Production, High-Level Radioactive Waste Generation, and Atmospheric Radioactive Releases by the Chemical Separation Plants at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26 in Russia (1992).

Isotope	Half-life (years)	RT-1 Chelyab'k-65 (Curies/y)	Tomsk-7 (Curies/y)	Kras'k-26 (Curies/y)
Atmospheric Releases:				
H-3	12.26	660	210	100
C-14	5730	40	23	12
Kr-85	10.72	810,000	450,000	230,000
I-131	0.022	-	3	2
Xe-131m	0.033	-	250	130
Xe-133	0.014	-	730	360
Remaining in High-Level Waste:				
Sr-90	29.3	7,700,000	3,300,000	1,600,000
Y-90m		7,700,000	3,300,000	1,600,000
Zr-95	0.18	2,700	95,000,000	47,000,000
Nb-95m		2,700	95,000,000	47,000,000
Tc-99	213,000	1,600	450	230
Ru-106	1.02	8,400,000	12,000,000	5,800,000
Rh-106m		8,400,000	12,000,000	5,800,000
I-129	1.6xE07	4.5	1.0	0.5
Ce-144	0.78	18,000,000	88,000,000	44,000,000
Pr-144m		18,000,000	88,000,000	44,000,000
Cs-137	30.17	10,000,000	3,600,000	1,800,000
Ba-137m		10,000,000	3,600,000	1,800,000
Np-237		4.5	1.5	0.78
Am-241	432.2	76,000	150	75
Am-242m	141	640	0.110	0.057
Am-243	7,370	830	0.024	0.012
Am(total)		77,000	150	75
Cm-242	162.9	32,000	170	340
Cm-243	28.5	1,100	0.003	0.001
Cm-244	18.11	85,000	0.051	0.025
Cm-245	8,500	9.0	-	-
Cm-246	4,780	0.97	-	-
Cm(total)		120,000	170	340

Recovered from processed fuel elements:

	MT/y	MT/y	MT/y
Np-237	0.035	-	-
U(Total)	114.[*]	2,310.[#]	1,155.[#]
Pu(Total)	1.04[**]	0.997[##]	0.498[##]

[*] 98.27% U-238; 1.254% U-235; 0.4499% U-236; 0.02417% U-234.
[**] 64.24% Pu-239; 20.11% Pu-240; 11.28% Pu-241; 2.952% Pu-242;
   1.427% Pu-238.
[#] 99.33% U-238; 0.6566% U-235; 0.00919% U-236.
[##] 95.15% Pu-239; 4.605% Pu-240; 0.2395% Pu-241;
   0.004406% Pu-242; 0.002958% Pu-238.

Table 4 Notes.

The data in Table 4 was calculated using a one group burnup code and the fission product spectra for U-235 and Pu-239 fission by thermal neutrons. The fission product spectra were taken from K.A. Varteressian and Leslie Burris, "Fission-Product Spectra From Fast and Thermal Fission of ^{235}U and ^{239}Pu," Argonne National Laboratory, ANL-7678, March 1970. The following additional assumptions were made:

Chelyabinsk-65:

(a) Fuel type: VVER;
(b) Initial fuel enrichment: 3.6 percent U-235, 0.0337 percent U-234, and 96.3663 percent U-238;
(c) Fuel burnup: 30,000 Mwd/MT;
(d)   Fuel irradiation period: 3 years;
(e) Spent fuel cooling period prior to reprocessing: 3 years;
(f) Spent fuel processed: 120 MTHM;
(f) Recovery: 99 percent of the uranium and plutonium,[910] and 85 percent of the neptunium; and periodic recovery of other elements.
(g) No capture of Krypton-85, Carbon-14, or tritium (it is all release up the stack at the chemical separation plant);

---

[910] Based on ``Report by the Commission for Investigation of Environmental Situation in Chelyabinsk Region.'' (Decree by the President of the USSR, #RP 1283, 3 January 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.

Tomsk-7 and Krasnoyarsk-26:

(a)Reactor characteristics: Similar to Hanford B-Reactor;
(b)Number of reactors operating: 2 at Tomsk-7 and 1 at Krasnoyarsk-26;
(c)Reactor power level: 2000 Mw (thermal) each;
(d)Average Capacity factor: 0.8 each reactor
(e)Fuel: natural U (99.289 percent U-238; 0.711 percent U-235);
(f)Fuel burnup: 500 Mwd/MT;
(g)   Fuel irradiation period: 62.5 full power days;
(h)Spent fuel cooling period prior to reprocessing: 120 days;
(i)Spent fuel processed: 2336 MTHM at Tomsk-7; 1168 MTHM at Krasnoyarsk-26;
(j)Recovery: 99 percent of the uranium and plutonium,[911] no neptunium;
(k)No capture of Krypton-85, Carbon-14, or tritium (it is all released up the stack at the chemical separation plant);
(l)Atmospheric releases of I-131, Xe-131m and Xe-133 were estimated from the Kr-85 release using the average release fractions for the Savannah River Site during the 8 year period 1971-1978.

---

[911] Ibid.

<div align="center">

Table 3.4

Non-radioactive Chemical Waste Constituents From Chemical Separations[912]

</div>

Solvent

Trichloroethylene
Tri-n-butylphosphate
n-Undecane
n-Dodecane
n-Tridecane
n-Tetradecane
n-Pentadecane
$n-C_{22}H_{46}--nC_{34}H_{70}$
Kerosene
Carbon tetrachloride
Butylbenzylphthalate
Dicotylphthalate
Unknown phthalates

Volatile Solvents

Acetone
Methylene chloride
Chloroform

Carboxylic Acids

Docos-13en-oic acid
Hexanedioic acid
Hexadecanoic acid
Phthalic acid
Nonanedioic acid
Tetradecanoic acid
Pentanedioic acid
Octadecanoic acid
Hydroxybutanedioic acid
Butanedioic acid

Alkanes

$nC_{23}-nC_{35}$

Phthalate Esters

Dibutylphthalate
Dioctylphthalate

Chelating/complexing Agents

Citric acid
N-(2-Hydroxyethyl)ethylenediaminetriacetic acid (HEDTA)
Ethlyenediaminetetraacetic acid
Methane Tricarboxylic acid
Nitrilotriacetic acid (NTA)

Chelator Fragments

Ethylenediaminetriacetic acid (ED3A)
N-(2-Hydroxyethly)ethylenediamine-N'N'-diacetic acid (HEDDA)
N-(ethylene)ethylenediaminetriacetic acid (E_2DTA)
N-(2-Hydroxyethyl)iminodiacetic acid (HEIDA)
N-(2-Hydroxyethyl)-N'-(methyl)ethylenediamine-'N,N'-diacetic acid (MeHEDDA'A)
N-(methyl)ethylenediamine-N,N'-diacetic acid (MeEDD'A)
Imnodiacetic acid (IDA)

[912] DOE, "Final Environmental Impact Statement on Disposal of High-Level, Transuranic and Tank Wastes, Hanford Site," DOE/EIS-0113, December 1987, p. A11.

Table 3.5
Population Centers Along the Techa River[913]

Population Center	Distance (km)	Radiation Dose (rems) to those	
		Evacuated	Remaining
Metlino*	7	160	
Techa-Brod*	18	130	
Novo Asanovo*	27	110	
Staro Asanovo*		110	
Nazarovo*		110	
N. Taskino*		90	
GP*		75	
Nadirovo*		60	
Nadirov*		55	
Most*		20	
Ibragimovo*	48	51	
Isaevo*		33	
Ferma (Farm) # 2*		31	
Muslyumovo	78		26
Kurmanovo*		16	
Karpino*		20	
Zamanila*		14	
Vetroduika*		18	
Brodokalmak	109		6.5
Panovo*			
Osolodka*			
Cherepanovo*			
Russkaya Techa	138		9.0
Baklanovo*			
Nizhnepetropavlovsk	152		11
Lobanovo			9.0
Anchugovo			10
Verkhnyaya Techa			11
Skiyagino			16
Bugaevo			10
Shutikhinskoye			4.0
Pershinskoe			6.0
Klyuchevskoye	202		3.5
Zatechenskoye	237		7.0
Dalmatovo			

* Population centers that were evacuated; only 21 (of 22 cited in the literature) could be identified on the chart.

[913] Data from a photograph of a chart on the wall at Mayak (ca. 1991). Population centers are identified in the order of their distance from the discharge point. Radiation doses for some villages could not be read from the photograph.

Table 3.6
**Organ Dose Estimates (External and Internal) for
Inhabitants in Some Villages Along the Techa River**[914]

Village	Distance from point of release, km	Effective dose equiva- lent, rem	Mean doses, Rem			
			red bone marrow	bone surfaces	large intes- tine	other tissues
Metlino	7*	140	164	226	140	127
Techa-Brod	18*	119	127	148	119	115
N. Asanovo	27*	100	127	190	104	90
Ibragimovo	48*	56	95	180	62	44
Muslyumovo	78	24	61	143	29	12
Brodokalmak	109	5.8	14	31	7	3.3
Russkaya Techa	138	8.2	22	53	10	3.7
Nizhnepetropavlovsk	152	10	28	68	13	4.3
Klyuchevskoye	202	3.6	8	18	2.6	2.2
Zatechenskoye	237	6.6	17	40	8.4	3.2

* Villagers were evacuated.

---

[914] G.I. Romanov, ``Radioecological Conditions Accounted for the 1957 and 1967 Accidents and Production Activities of the Industrial Complex ``Mayak,'' paper presented at the International Radiological Conference, Chelyabinsk, Russia, 20-25 May 1992; and M.M. Kossenko, M.O. Degteva, and M.A. Petrushova, ``Estimate of the Risk of Leukemia to the Residents Exposed to Radiation as a Result of a Nuclear Accident in the Southern Urals,'' *The PSR Quarterly*, Vol. 2, Number 4, December 1992, p. 192.

Table 3.7
Radioactive Contamination in the Chelyabinsk-65 Reservoirs[915]

			Composition of Radionuclides							
Reservoir Number	Area of the Reservoir (sq km)	Capacity of the Reservoir (million cubic m)	Concentration in Water, ci/l					Ground Deposits, Ci/kg		R
			Sr-90	Cs-137	HTO	$\Sigma\alpha$	$\Sigma\beta$	Sr-90	Cs-137	
2	19	83	1.1×10^{-8}	4.5×10^{-8}	2.5×10^{-7}	?	--	1.3×10^{-6}	3×10^{-5}	
3	0.5	0.75	1.6×10^{-6}	2.0×10^{-7}	1.4×10^{-6}	3×10^{-10}	--	1.4×10^{-4}	1×10^{-3}	
4	1.3	4.1	1.7×10^{-7}	1.3×10^{-8}	5.2×10^{-7}	4.5×10^{-9}	--	4×10^{-6}	6×10^{-5}	
6	3.6	17.5	3.7×10^{-10}	2×10^{-11}	1×10^{-8}	3.9×10^{-5}	--	3×10^{-7}	3.9×10^{-7}	
9	0.25	0.4	1.7×10^{-3}	1.2×10^{-2}	5.3×10^{-5}	5.7×10^{-6}	1.9×10^{-2}	0.3	1.4	
10	16.6	76	3.5×10^{-7}	8.6×10^{-9}	3.2×10^{-7}	1×10^{-11}	--	3.5×10^{-6}	1.5×10^{-1}	
11	44	217	5.1×10^{-8}	2×10^{-11}	4.5×10^{-8}	2×10^{-12}	--	1.3×10^{-6}	1.3×10^{-7}	
17	0.17	0.8	7×10^{-4}	4×10^{-6}	1×10^{-4}	1.2×10^{-3}	--	3.3×10^{-7}	3.3×10^{-2}	

[915] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' (Ordered by President M. Gorbachev, Presidential Decree # RP-1283, 3 January 1991), ca. April 1991 [translated into English], Vol. I, p. 37 (of the English translation); 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); and tables given to Thomas B. Cochran by Victor N. Chukanov, USSR Academy of Sciences, Ural Department, Ecological Security Center, Sverdlosk, private communication, 13 April 1991.

<div align="center">

Table 3.8
**The Average Annual Sr-90 and Cs-137
Concentration in the Techa River
at the Myslyumovo Settlement**[916]

</div>

Observation year	Sr-90 content (pCi/l)	Cs-137 content (pCi/l)
1951	40,000	510,000
1962	10,000	4,000
1964	3,000	250
1973	2,000	40
1978	1,500	36
1983	350	24
1988	420	40

[916] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' (Ordered by President M. Gorbachev, Presidential Decree # RP-1283, 3 January 1991), ca. April 1991 [translated into English], Vol. II, p. 51 (of the English translation).

Table 3.9
Dose Rates along the Techa River Measured in July 1990.[917]

LOCATION	WATER SURFACE (µGy/h)	BOTTOM (µGy/h)	RIVERBANK (µGy/h)
Nadirov Bridge	5	28-30	0.90-24
Muslumovo	6.5-16	0.20-15	0.60-28
Verknaja Techa	0.19	0.13	0.15
Zatechenskoje	0.10	0.1	0.2

---

[917] A.V. Trapeznikov et al., ``Radioactive Contamination of the Techa River, the Urals,'' *Health Physics*, 5 (November 1993): 487. One µGy = 100 µrem.

Table 3.10

**Radionuclide Content of Lake Karachay and a Water
Sampling Well 130 Meters to the South**

Component	in Lake Karachay (MBq/l)[*]	in groundwater (MBq/l)[*]
β-emitters	589 ± 2.7	19.1
Cerium-144	22.9 ± 2.3	
Cesium-137	370 ± 2.6	0.59 ± 0.148
Cesium-134	16.2 ± 1.0	0.0055 ± 0.0026
Antimony-125	3.8 ± 0.5	0.037 ± 0.011
Ruthenium-106	111 ± 10	17.4 ± 4.2
Ruthenium-103	4.9 ± 0.6	
Zirconium-95	1.3 ± 0.2	
Niobium-95	2.4 ± 0.3	
Strontium-90	55.4 ± 13.3	0.89 ± 0.15
Cobalt-60	0.538 ± 0.049	0.215 ± 0.063
Tritium	1.2 ± 0.5	1.1 ± 0.4
α-emitters	0.0703 ± 0.0299	0.0074 ± 0.003
Pu-239	0.0212 ± 0.0104	0.0011 ± 0.0004
Pu-238 + Am-241	0.0193 ± 0.013	0.0017 ± 0.0004
U-isotopes	0.0196 ± 0.0111	0.0044 ± 0.001
Nitrates		50 g/l

[*] Data are averages over many years. 1 curie = 3,700 megabecquerel (MBq)

Table 3.11
**Characteristics of the Radioactivity Released
in the 1957 Accident**[918]

Radionuclide	Contribution to total activity of the mixture, %	Half-life	Type of radiation emitted
^{89}Sr	traces	51 d	β, γ
^{90}Sr + ^{90}Y	5.4	28.6 y	β
^{95}Zr + ^{95}Nb	24.9	65 d	β, γ
^{106}Ru + ^{106}Rh	3.7	1 y	β, γ
^{137}Cs	0.036	30 y	β, γ
^{144}Ce + ^{144}Pr	66	284 d	β, γ
^{147}Pm	traces	2.6 y	β, γ
^{155}Eu	traces	5 y	β, γ
^{239,240}Pu	traces	–	α

[918] 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, 28 May 1989.

Table 3.12
Land Contaminated by the 1957 Accident at Chelyabinsk-65[919]

Contamination Level (Ci Sr-90/km^2)	Area (km^2)
0.1 - 2	15,000 - 23,000
2 - 20	600
20 - 100	280
100 - 1000	100
1000 - 4000	17

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

Table 3.13
Solid Waste Burial Sites at Chelyabinsk-65[920]

KIND OF WASTE	NUMBER OF BURIAL AREA SITES	VOLUME OF WASTE (1000 m^3)	WASTE ACTIVITY (Ci)	TOTAL (ha)
Low- and Medium-level Waste	203	685.1	31.6×10^3	20.2
High-level Waste	24	41.3	12×10^6	1.1
Total	227	726.4	12×10^6	21.3

[920] ``Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast,'' Vol. II, p. 27.

Table 4.1
General Characteristics of Dual-Purpose Production Reactors
at Tomsk-7 and Krasnoyarsk-26

Initial Power	about 2000 MW
Ultimate Power	about 2000 MW
Electrical Outlet	150 MWe - 200MWe
Steam Heating	300 GCal (350 GCal at Krasnoyarsk-26)

Type

Dual Purpose		
Moderator		Granite
Coolant		Water
Number of Lattice Positions		2832
Control/Safety Rods		about 125 (in process tube positions)
Automatic Regulation Rods		about 10 (in reflector)

Number of Channels		2832
Channel Orientation		Vertical
Channel Inner Diameter (mm)	42	
Channel Thickness (mm)		1.65
Number of Fuel Elements in Channel	66-67	

Distance between Centers of Channels (cm)	20	
Total Weight of Natural Uranium (t)	300	
Total Weight of 90% Enriched Uranium (kg)	75	
Void Coefficient		several $

Natural Uranium Fuel Elements:

Uranium Composition	U	
Uranium Rod Diamter (mm)		35
Cladding Material		Al Si Alloy
Minimum Thickness of Cladding (mm)	1	
Irradiation Level at Discharge (MWd)	600-1000	
Annual Fuel Discharge/Reactor	500-800	

Highly Enriched Uranium Fuel Elements:

Uranium Composition		8.5 wt% UO_2 in Al
Uranium Rod Diameter (mm)	35	
Enrichment (%)	90	
Cladding Material		Al Alloy
Minimum Thickness of Cladding (mm)	1	

Primary System:

Coolant		H_2O
Temperature at Installed Power (°C)		
Reactor Outlet	185	
Reactor Inlet		90

Fuel Storage:
Type   Water Filled Pool
Typical Storage Time (months)   6
Maximum Storage Time (months)   18 (Limited by Corrosion)

<div align="center">

Table 5.1
Uranium Mining Areas[921]

</div>

District	Type of deposit	Known uranium resources, MTU	Mined at $80/kg or less, percent

<div align="center">

Uranium ore areas

<u>Russia</u>

</div>

District	Type of deposit	Known uranium resources, MTU	Mined at $80/kg or less, percent
Strelitsa	vein/stockwork in volcanic complexes	183,200	91
Stavropol	vein/stockwork	exhausted	

<div align="center">

<u>Ukraine</u>

</div>

District	Type of deposit	Known uranium resources, MTU	Mined at $80/kg or less, percent
Kirovograd	metasomatic stockwork in albatites	82,400[922]	87
Krivoi Rog	metasomatic stockwork in albatites	exhausted	

<div align="center">

<u>Kazakhstan</u>

</div>

District	Type of deposit	Known uranium resources, MTU	Mined at $80/kg or less, percent
Chu-Saryisk	roll-front deposits in sandstone	221,000	100
Syrdarya	roll-front deposits in sandstone	77,300	100
Iliysk	uranium-coal deposits in sedimentary basins	92,900	31
Pricaspiysk	fish-bone detritus	64,400	0
Pribalkhash	vein/stock in volcanic complexes	21,900	82
Kokchetavsk	vein/stock in folded regions	99,200	73

<div align="center">

<u>Uzbekistan</u>

</div>

District	Type of deposit	Known uranium resources, MTU	Mined at $80/kg or less, percent
Kyzylkum	sandstone, black shales	230,000	74
Karamazar	vein/stock in volcanic complexes	exhausted	

<div align="center">

Uranium bearing areas (all in Russia)

</div>

---

[921] *Uranium Raw Material Base*, JPRS-UEQ-93-002; ``Uranium In The New World Market: Supply And Demand 1993,'' Uranium Institute, 1993; A. Mazurkevich ``Uranium Mining in Uzbekistan'', *Nukem Market Report*; Yazikov ``Kazakhstan's Uranium Resources'', Uranium Institute Symposium, 8-10 September 1993, London.

[922] According to NEA OECD estimates, the total resources in Ukraine is 140,900 MT, 62,200 MT of them recovered at less than $80/kg. ``Uranium resources, production and demand'', OECD, 1993.

Zauralsk	sandstone	16,400	0
Yeniseysk	vein-stockwork, sandstone	7600	0
Vitimsk	sandstone	75,500	69
Onezhsk	black shales	2000	0
Far Eastern	vein/stockwork	3900	
Central Trans-Baikalian (Chita)	vein/stockwork, sandstone	20,700	0

Table 5.2
Principal Uranium Production Centers

Production facility and location	Deposits (uranium ore area)	Mill capacity, MTU/yr [923]	Production 1993, MTU
Russia			
Priargunsky Mining and Chemical Combine (Krasnokamensk, Chita area)	Streltsovskoye Tulukuevskoye (Strelitsa area)	4000	2400
Kazakhstan			
Kaskor Joint Stock Co (Actau, Mangiztau)	Melovoye Tomak (Prikaspiysk area)	1000	Total uranium from Kazahstan ore, 2700
Tselinny Mining and Chemical Combine (Krasnogorsk, Kokchetav)	Kamyshovoye Shokpack Grachevskoye Vostok Zvezdnoye Zaozernoye (all Kokchetavsk area) North Karamurun (Syrdarya area)	3000	
Kyrgyzstan			
Kara Balta Ore Mining Combine (Bishkek)	Uvanas Mynkuduk Kanzhugan Moinkum (all Chy-Saryisk area, Kazakhstan)	2000	1100
Uzbekistan			
Navoi Mining and Metallurgy Combine (Navoi)	Uchkuduk Vostok Zafarabad Nurabad (Kyzylkum area)	4000	Combined total of 2600
Ukraine			

923 Mill capacities and 1993 production data are from C.Grey ``Up front in the CIS,'' *Nuclear Engineering International*, May 1994, pp. 16-20.

| Eastern Mining and Processing Combine (Zheltye Vody) | Vatutinsky (Kirovograd area) | 2000 | 500 |

Table 5.3

Estimated Natural Uranium and

SWU Requirements per Reactor for Soviet-built Power Reactors

Type	Enrichment, %	Amount of fuel, MT/yr[924]	SWU requirements, x 10^6 SWU/y[925]	Equivalent of natural uranium requirements, MTU/y[926]
RBMK -1000	2.4	37.8[927]	0.154	144
VVER-440	3.6	12.7[928]	0.095	73.8
VVER-1000	4.4	18.5	0.181	132.1
BN-350/600 (1/1)	20-25	6.2/7.4	0.359/0.428	205/244
Pu-production reactors	0.7		0	1200

---

[924] Assuming burn-up of 20 MWday/kgU and the average load factor of 0.66, a 1000-MWe RBMK reactor consumes about 36 MT 2.4% enriched uranium per year. With burn-ups of 40 MWday/kgU, VVER-440 and VVER-1000 reactors consume 18.1 and 10.6 MTU per year.

[925] Assuming 0.11 percent tail assay.

[926] Neglecting conversion and enrichment losses, which are on the order of 0.5 percent.

[927] Assuming burn-up of 20 Mwd/kgU and the average load factor of 65.3%, a 1000-MWe RBMK reactor consumes slightly more than 36 MT 2.4 percent enriched uranium per year.

[928] Assuming burn-up of 30 MWd/kgU and average load factor of 0.653, a VVER-440 consumes about 10.6 MTU per year. Currently, VVER-440s are being transferred from a 3 to a 4 year-fuel life with increase in burn-up to 40 MWd/kg.

Table 5.4
Natural Uranium and SWU Requirements
for Countries Operating Soviet Designed Reactors

Countries	Uranium requirements (MT/y)	Enrichment requirements (million SWU/y)
Russia (power reactors)	3196	3.959
Pu-production reactors in Russia	3600	
Ukraine	1757	2.308
Kazakhstan	205	0.359
Lithuania	360	0.385
Outside former USSR	1460	1.891
Total:		
-- Without Pu-production reactors	6978	8.875
-- With Pu-production reactors	10,578	8.875

<div align="center">

Table 5.5
Fuel Fabrication Complex[929]

</div>

Facility (location)	Principal products	Capacity, MT/y	1993 production, MT
Ulbinsky Metallurgical Plant (Ust-Kamenogorsk, Kazakhstan)	-- beryllium -- tantalum -- UO2 powder and pellets for VVER-440/1000 and RBMK reactors	-- 2650	-- 220 (VVER) and 570 (RBMK)
Machine-Building Factory (MSZ), Elektrostal, Moscow area (founded 1945) State Scientific-Production Enterprise Politekh (GNPP Politekh) Elektrostal (founded 1974)	-- UO2 powder and pellets for VVER-440 reactors -- fuel rods and assemblies for VVER-440 reactors -- fuel rods and assemblies for RBMK reactors -- fuel for naval reactors -- fuel for BN-350/600 reactors	-- 700 -- 700 -- 570 -- 20 (reactor core) and 15 (blanket)	-- 230 -- 230 -- 570
Novosibirsk Factory of Chemical Concentrates (NZKhK), Novosibirsk (founded 1949)	-- fuel rods and assemblies for VVER-1000 reactors -- fuel for military materials production reactors -- fuel for research reactors -- lithium production	-- 1000	210
Production Association Chepetsk Mechanical Plant (ChMZ), Glazov (founded 1951)	-- zirconium -- zircalloy tubing for VVER and RBMK reactors -- calcium	-- 6000 and 2000 km of tubing for RBMK and VVER reactors	
Moscow Plant of Polymetals	-- reactor control rods		

---

[929] The capacity and 1993 production data are from Yu.Babilashvilli, F.Reshetnikov ``Russia's Nuclear Fuel Cycle: An Industrial Perspective'', *IAEA Bulletin*, 3/1993, pp. 28-31.

Table 5.6
Soviet Designed Power Reactors Operating and Under Construction[930]

	VVER-440	VVER-1000	RBMK	Others	Under construction[931] (% complete)
Russia					
Novovoronezh	2	1			
Kola Peninsula	4				
Balakovo		4			
Tver		2			1 VVER-1000 (80)
Kursk			4		1 RBMK-1000 (60)
St.Petersburg			4		
Smolensk			3		
Beloyarskaya				BN-600	
Bilibino				4 x 12 MWe[932]	
Ukraine					
Rovno	2	1			1 VVER-1000 (80)
Zaporozhye		5			1 VVER-1000 (80)
South Ukraine		3			

---

[930] The acronyms, Russian names and English translation of the reactor names are as follows:

VVER -- Vodo-Vodyanoy Energetichesky Reactor (water-water power reactor);

RBMK -- Reactor Bolshoy Moschnosti Kipyaschiy (high power boiling reactor);

AST -- Atomnaya Stantcia Teplovaya (heat atomic station);

BN -- [reactor na] Bystrykh Neitronakh (fast neutrons reactor).

[931] Construction of some reactors (not included in the table) has been stopped. Among them are about 30 percent-complete Tver' 4 unit (the local government voted to allow operation of Tver' 3 unit but to stop construction of Tver' 4); Rostov 1 and Rostov 2 units; Voronezh 1 and 2 AST-500 units; and the fast reactor South Ural project. The prospects for completion of these reactors are uncertain.

[932] Heat and electricity graphite-moderated pressurized-water reactors.

Khmelnitsky		1			1 VVER-1000 (95)
Chernobyl			2		
Ignalina, Lithuania			2x1,250 MWe		
Actau, Kazakhstan				BN-350	

Outside the Former Soviet Union

Bulgaria	4	1			1 VVER-1000
Hungary	4				
Czechoslovakia	8				6 VVER-440 and 2 VVER-1000
Finland	2				

TABLE 5.7 – see final page

Table 5.8
Research and Commercial Reactor Tests of Pu-Containing Fuel

REACTOR	TIME OF TESTING	FUEL TYPE AND PRODUCTION PROCESS	
BR-2	1956	Pu metal	
BR-5 (BR-10)	from 1959	PuO_2	
IBR-2	1965	PuO_2	
IBR-30	from 1957	Pu metal	
Crit. facility BFS (Ph.En.Inst.)	from 1960s	Pu metal	
BOR-60	from 1975	1.$(U,Pu)O_2$:electrochemical granulation & vibrocompaction of fuels	
	from 1973	2.$(U,Pu)O_2$:mechanical strirring of individua oxides & pelletizing	
	from mid-1980s	3.$(U,Pu)O_2$:co-precipiatation by carbonate an ammonia processes and pelletizing	
BN-350	from 1980	1.$(U,Pu)O_2$:mechanical coprecipitation, granulatation and pelletizi	
	1990-1992	2.$(U,Pu)O_2$:ammonia coprecipitation, granulation, pelletizing	
BN-600	from 1990	$(U,Pu)O_2$:ammonia co-precipita-tion, granulation, pelletizing	
MIR	from 1992	$(U,Pu)O_2$:co-precipitation by carbonate & ammonia & pelletizing (Thermal reactor fuel containing 5% mass Pu)	

* FAs: fuel assemblies

Table 5.9
Pilot and Semi-Commercial U-Pu Fuel Production Bays

BAYS (PRODUCTION)	LOCATION	OPERATION TIME	PURPOSE	FUEL COMPOSITION & ITS PRODUCTION PROCESS	TYPE OF Pu USED
Laboratory lines, bays	Sci. Res. Inst. for non-organic Materials, Moscow	Early 1950s to present day	Preparation of experimental fuel specimens, fabrication of individual fuel elements	Delta-Pu alloys; PuO_2; $(U,Pu)O_2$ & other different methods	Militar
Pilot bay	Mayak, Chelya-binsk-65	1960s to 1970s	Manufacture of pellets and pilot fuel elements for fast research reactors	Pu alloys; PuO_2	Militar
Pilot complex	Sci. Res. Inst. for Nuclear Reactors, Dimi-trovgrad	1985 to present day	U-Pu fuel production, fabrication of fuel elements & assemblies for fast reactor testing	$(U,Pu)O_2$;Elec-trochemical granulation & vibrocompaction of fuels	Militar & energ produci
Semi-commercial plant Zhemchug	Mayak, Chelya-binsk-65	1986-1987	U-Pu fuel production for fast reactor testing	$(U,Pu)O_2$; sol-gel process	Militar (from E reactor
Semi-commercial Granat	Mayak, Chelya-binsk-65	1988 to present day	U-Pu fuel production for fast reactor testing	$(U,Pu)O_2$;ammonia granulation of coprecipitated U & Pu compounds	Militar

Semi-commercial plant Pakat	Mayak, Chelya-binsk-65	1988 to present day	U & Pu dioxide pellet manufacture, fabrication of fuel elements for fast reactor testing	$(U,Pu)O_2$ produced by both mec-anical stirring of individual U & Pu oxides & sol-gel process, ammonia granu-lation, carbonate	Militar
Semi-commercial complex for mixed fuel production (1 line)	Mayak, Chelya-binsk-65	50% ready produc-tion	U-Pu fuel production, pellet manufacture, fuel element & assembly fabrication for use in commercial fast reactors	$(U,Pu)O_2$ produced by U and Pu coprecipitatio n	Energy produci and militar
Semi-Commercial complex for mixed fuel production (2 line)	Mayak, Chelya-binsk-65	Project develop-ments	U-Pu fuel production, pellet manufacture, fuel element and assembly fabrication for use in VVER type reactors	$(U,Pu)O_2$ produced by U and Pu coprecipitatio n	Miltary & energ produci

* FAs: fuel assemblies

Table 5.10
**Principal Organizations Involved in
Research On Utilization of Plutonium**

NAME	LOCATION	RESEARCH AREA
A.A. Bochvar Scientific Research Institute of Non-norganic Materials (VNIINM), founded 1945	Moscow	-- Research on MOX powders. -- Technology of fabrication of pelletized MOX fuel. -- Radiochemical research.
Institute of Physics and Power (FEI), founded 1946	Obninsk	-- Basic research. -- Concept of a reactor core with MOX fuel. -- Thorium nuclear fuel cycle. -- Actinide transmutation.
V.I. Lenin Scientific-Reaserch Institute of Nuclear Reactors (NIIAR), founded 1956	Dimitrovgrad	-- Pyroreprocessing. -- Fabrication of MOX fuel by vibrocompaction.
Scientific-Production Association (NPO) (V. G. Khlopin Radium Institute), founded 1922	St.Petersburg	-- Radiochemical research. -- Coordination of research on MOX fuel in VVER reactors.
Production Association Mayak, founded 1948	Chelyabinsk-65	-- Fabrication of MOX fuel.

Table 5.11
Versions of Pu Utilization in the Nuclear Fuel Cycle

REACTOR TYPE	Pu UTILIZATION SCHEDULE	Pu INVENTORY, MT	
		Initial Inventory (MT/reactor)	Makeup (MT/y)
BN-350	Loading of whole core	~1.5	0.6
BN-600	50% loading of core*	1.1-1.2	0.6
BN-800	Loading of whole core	2.3	1.6
VVER-1000	1/3 loading of core	1.0	0.35
	Loading of core	3.0	1.0

* On condition the reactor core is updated.

TABLE 5.7 Research Reactors, Critical and Subcritical Assemblies

Operator	Facility	Comments
Kurchatov Institute (Moscow)	8 research reactors, including:	
	MR	Channel, water-pool 50 MW reactor.
	WWR-2	Vessel-type, 3 MW reactor.
	IR-8	Pool-type, 8 MW reactor.
	INN-3M Hydra	Uranil nitrate solution, 10 MW reactor. Used for development of low-power passive safety reactors.
	Gamma	Vessel-type, thermal, 0.125 MW reactor.
	Argus	Uranil sulphate solution, graphite reflector, 20-50 kW reactor. Used for neutron activation and radiographic analysis, production of nuclear filters, non-destructive testing, and production of short-lived isotopes.
	F-1	Uranium-graphite, 5-24 kW reactor.
	OR	Pool-type, water cooled and moderated, 0.3 MW reactor.
	16 critical assemblies, including:	
	UG	Uranium-graphite reactor research.
	RBMK	RBMK reactor research.
	Mayak	Uranium-water reactor research.
	SF-1, SF-3, SF-5, SF-7 Kvant, Delta	
	Astra	Uranium-graphite core, graphite reflector
	V-1000	VVER 1000 reactor research.
	Grog	Uranium-graphite core, uranium reflector.
	P	VVER-fuel research.
	Efir-2M	Uranium-water reactor research.
	Narciss M2	Space reactor research.
	Model of MR reactor	
	2 subcritical assemblies:	
	Garanty RM-50	
Institute of Physics and Power Engineering, Minatom (Obninsk)	5 research reactors, including:	
	BR-10	Sodium-cooled fast reactor, 10 MW. Used for testing of fuel rods of fast reactor, neutron experiments, radio-therapy for cancer treatment.
	AM-1	First power reactor (start-up 1954).
	MPR	Pool-type reactor.
	18 critical assemblies, including: FS-1M, FG-5, SGO, Strela, PS-2, T-2, AMBF-2-1600, RF-GS, BR-1, Cobra, MATR-2, Grot-2, V-1M, K-1	
	BFS-1	Simulation of research and small power reactors, including BOR-60, BN-350.
	BFS-2	Simulation of cores and blankets of BN-600, BN-800, and BN-1600 reactors.
Institute of Atomic Reactors, Minatom (NIIAR, Dimitrovgrad)	8 research reactors, including:	
	SM-2	100 MW reactor. Used for irradiation of reactor materials, production of trans-plutonium isotopes, neutron-activation analysis.
	MIR-M1	Water-cooled and moderated, beryllium reflector, 100 MW. Used for testing fuel rods and assemblies, validation of reactor core designs for power, propulsion, and research reactors.
	VK-50	Vessel-type, boiling water reactor, 50 MW.
	RBT-10/1	RBT reactors (10, 10 and 6 MW) are
	RBT-10/2	used for research of reactor
	RBT-6	materials.
	BOR-60	Sodium-cooled fast reactor, 60 MW. Used for power production, for research on and test of fuels, safety of fast reactors, sodium technology, and steam generators.
	Prima	Pool-type reactor, 100 MW.
	3 critical assemblies	
Institute of Energy Technologies, Minatom (NIKIET, Moscow)	Research reactor IR-50	Pool-type, 50 kW reactor.
	3 subcritical assemblies (SO-2M, PS-2, FS-4)	
Branch of the Institute of Energy Technologies, Minatom (Zarechny, Yekaterinburg region)	2 research reactors, including	
	IVV-2M	Pool-type, 15 MW reactor.

TABLE 5.7 *(continued)*

Operator	Facility	Comments
NIIP, Minatom (Lytcarino, Moscow area)	6 research reactors, including: TIBR-1M BARS-2 BARS-3M BARS-4 IRV	Reactors are designed and managed by VNIIEF (Arzamas-16).
Machine-Building Plant, Minatom (Electrostal)	7 critical assemblies	
Experimental Design Bureau for Machine-Building, Minatom (OKBM, Nizhny Novgorod)	4 critical assemblies	
Institute of Theoretical and Experimental Physics, Minatom (ITEF, Moscow)	Research reactor TVR	Heavy water, 2.5 MW. Start-up 1949.
	One critical assembly: Maket	Heavy water reactor research.
Institute of Chemical Technologies, Minatom (VNIIKhT, Moscow)	One subcritical assembly	
Gidropress, Minatom (Moscow)	One subcritical assembly	
Institute of Experimental Physics, Minatom (VNIIEF, Arzamas-16)	Research reactors BIGR BR-1 VIR-2M	Reactors are used for research on resistance of materials to effects of radiation, safety, solid-state physics, radiobiology, for development of radiation-resistant radioelectronic components.
Institute of Nuclear Physics, Ministry of Science (at Tomsk Polytechnical Institute)	Research reactor IRT-T	Tank type reactor, 6 MW.
Moscow Power Institute (MEI), Ministry of Science	One subcritical assembly	
Moscow Institute of Physics and Engineering (MIFI), Ministry of Science	Research reactor IRT-MIFI	Pool-type, 2.5 MW reactor.
	7 subcritical assemblies, including VVER, RBMK, VTGR, UV-1, UV-2, UG	UV-1 and UV-2 are uranium water assemblies. Used for training.
Machinstitute, Ministry of Science	One subcritical assembly	
Krylov Institute, Roscomoboronprom (St. Petersburg)	Research reactor U-3	Pool-type, 0.5 MW reactor.
	Two critical and one subcritical assemblies	
Physical-Chemical Institute, Roscomkhimnefteprom (NIFKhI) (Obninsk branch)	Research reactor VVR-C	Used for isotope production.
Centrgeologia, Roscomnedra (Belgorod)	One subcritical assembly	
Mining Combine "Norilsk Nikel"	Research reactor RG-1M	Pool-type, 0.1 MW reactor. Used for activation analysis.
Medical-Biological Institute, Minzdrav (Moscow)	Research reactor SW-1	Pool-type, 0.5 MW reactor.
Institute of Nuclear Physics, Rosacademnauki (Gatchina)	Two research reactors: PIK, BIOR One critical assembly	
Joint Institute of Nuclear Research (Dubna)	Research reactors IBR-2, IBR-30	