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Russian/Soviet Nuclear Warhead Production

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Preface

Since the publication in 1989 of *Soviet Nuclear Weapons,* Volume IV of the *Nuclear Weapons Databook,* information from several sources has added significantly to our knowledge of Soviet nuclear weapons production. We thought it would be useful to assemble this information, which we have done here. This Working Paper has gone through many revisions (the last 12 June 1992) since it was first published in August 1990. We will continue to update it as new information becomes available though the plan is to have the next version as a book. Readers' additions and corrections are welcomed and appreciated.

We would like to thank Peter Almquist for his help with sections of this revision, and for his support over the years. The paper has been significantly improved through the work of Oleg Bukharin who drafted the section on Nuclear Fuel Cycle Activities in Russia.

The history of the U.S. Manhattan Project is extensively documented. A comprehensive bibliography would run to thousands of entries. In contrast, the Soviet program to build the atomic bomb, and later the hydrogen bomb, remains largely shrouded in secrecy, though in recent years new information has come to light. Sakharov's *Memoirs,* for example, provides new details about some aspects of the atomic and hydrogen bomb programs, and provides the names of many hitherto unknown participants. Also informative are the memoirs of V.I. Zhuchikhin, which we have borrowed from in this revision. The Khariton/Smirnov lecture of January 1993 is also an important development. Nonetheless, a comprehensive official account is needed to fill in what former President Gorbachev called the Soviet Union's "blank pages of history."

Early History

Russian and Soviet Nuclear Physics

When the time came in 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 Czarist 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 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, where Yan Danish worked.[3] In 1909 Professor P.P. Orlov was researching Siberian radioactive minerals. During the same year at the request of V.I. Vernadskiy at the Petersburg Academy of Sciences, steps were taken to organize the study of radioactive minerals on a large scale.[4] In 1912 the Physics Laboratory and the Physico-Mathematics Institute were established in the St. Petersburg Academy of Sciences.

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 Physico-Technical

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[1] Loren R. Graham, *Science in Russia and the Soviet Union: A Short History* (Cambridge: Cambridge University Press, 1993).

[2] Vasiliy S. Yemelyanov, *S Chego Nachinalos* ("How it Began"), (Moscow: 1979), p. 166.

[3] Ibid., p. 166. In the 1950's, when the International Institute for Nuclear Research was created, his son M. Danish was chosen one of the deputy directors of the institute.

[4] Ibid., p. 167.

[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.

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

In 1919, 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 Vernadskiy. The search ultimately revealed ample deposits of uranium.[9] In November 1921, the Radium Institute was created in Petrograd under the direction of Vernadskiy, and 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, technical extraction of radioactive elements from natural sources. Here also, Vernadskiy founded a school of radio-chemistry and analytical chemistry. Some of their work concerned the uses of uranium, thorium and other radioactive elements.[11]

In 1923, Dimitri V. Skobel'tsyn had begun advanced research on the measurement and detection of radioactivity; he was later to observe the flight path of cosmic rays.[12] In the late 1920s and early 1930s, Georgi Gamov, Pyotr (Peter) L. Kapitsa, and Kirill Sinel'nikov worked in Rutherford's Cavendish Laboratory in Cambridge, England, where many of the major early discoveries of nuclear physics occurred.[13]

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[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. Vernadskiy was director of the Radium Institute until his death in 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 factory and later developed the industrial processes for chemically separating plutonium from the irradiated uranium reactor fuel and fission products.

[11] Ibid., p. 170.

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

[13] 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 a series of articles between 1930 and 1934 based on his work in Rutherford's laboratory. Kapitsa spent 14 years in Cambridge, beginning in (continued...)

By the early 1930's, there were several scientific centers for research on the atomic nucleus and radioactivity, mainly in Leningrad and Kharkov.[14] In early 1931 Sinel'nikov 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, Skobel'tsyn, and other physicists from institutes around Leningrad, met five times a month, 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] 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 1934 LFTI had four laboratories working in nuclear physics, under the direction of Kurchatov, Abram I. Alikhanov, Lev A. Artsimovich,

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[13](...continued)
1921 at Cavendish Laboratory and 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, K.D. Sinel'nikov and A.I. Leipunskii did research at the Cavendish Laboratory in Cambridge; V.I. Vernadskiy and D.V. Skobel'tsyn in Marie Curie's Radium Institute in Paris; L.D. Landau in Neils 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 Center, Research Paper No. 9, 25 July 1979.

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

[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 L.D. Landau, K.D. Sinel'nikov and A.I. Leipunskii.

[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.

and Skobel'tsyn.[21] Kurchatov had invited others to work there, including several from the Radium Institute. One of the talented scientists was L.M. Mysovskii who worked on the methods and instruments for the measurement of cosmic radiation. Kurchatov and D.D. Ivanenko began intensive research into the effect of neutron irradiation on different elements.[22]

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. S.I. Vavilov, 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--the Cherenkov effect.[23] Vavilov tried unsuccessfully to concentrate nuclear physics at a single place within the Academy, in fact, 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 L.I. Mendelshtam and M.A. Leontovich worked on the theory of radioactive disintegration. Igor Ye. Tamm and D. D. 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,

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[21] Holloway, "Entering the Nuclear Arms Race."

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

[23] For which Pavel A. Cherenkov, Ilya M. Frank, and Igor Ye. Tamm shared the Nobel Prize for physics in 1958. The Cherenkov effect is the radiation emitted by a rapidly moving electron.

[24] Holloway, "Entering the Nuclear Arms Race." Skobel'tsyn, 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.

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, LEFI initiated plans for a large cyclotron. After several bureaucratic delays, including opposition from Moscow physicists who wanted their program to be second to none, construction began in earnest on 22 September 1939, but was not completed until after the war.[29]

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 and, although many were released within a year and took part in the discussion of nuclear fission in 1939-1941, the experience weakened the institute at a critical stage of the

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

[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.

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 Frenkel offered theoretical explanations of the fission process in the uranium atom at the same time that Niels Bohr and John A. Wheeler in the United States and Otto Frisch in England did the same.[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, Georgiy 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 Yuliy B. Khariton, investigated the conditions under which a chain reaction would take place in uranium and concluded that an experimental attempt to achieve a chain reaction could now be undertaken. In the same year Flerov and Konstantin A. Petrzhak, working under Kurchatov's close direction, discovered spontaneous fission of uranium. Inspired by these results, Kurchatov and his colleagues wrote to the Presidium of the Academy of Sciences, urging an expansion of work on nuclear fission.

In June 1940, the Presidium of the Academy set up a Special Committee for the Problem of Uranium, with Khlopin as chairman, to direct research on the uranium problem.[37] 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."[38] In November 1940 another Conference on the Physics of Atomic Nuclei was convened in Moscow. And on the last day of the year, an article appeared in *Izvestia*, entitled "Uranium 235," which 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

[33] Holloway, "Entering the Nuclear Arms Race."

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

[35] Ibid.

[36] Ibid.

[37] Lieberman, *Scorpion and the Tarantula*, p. 192. Other members of the Commission included Vernadskiy, Ioffe, A. Ye. Fersman (a leading Soviet geologist), Vavilov, Kapitsa, Kurchatov, and Khariton.

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

any quantity of energy he pleases and apply it to any ends he chooses."[39]

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 and as a consequence research on nuclear fission was brought to a halt, although Soviet scientists continued to publish articles in scientific journals on atomic energy developments. By this time Soviet physicists had developed the requisite strength in personnel, institutions, and material to begin research on the atomic bomb when their government called upon them to do so in 1943.[40]

Atomic Bomb Developments[41]

In early 1942, the possibility of an atomic bomb became a serious issue for the Soviet leadership, as a result of information obtained about British, American, and German work on the bomb.[42] Originally, Stalin was skeptical of the information collected by Lavrenti P. 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."[43] But as evidence of foreign progress on atomic weapons mounted from espionage efforts, it was complemented by information provided by Soviet scientists.

In the collection of the university library at Voronezh in early 1942, Flerov noticed that articles on nuclear fission were no longer being published in the West, a sign to him that secret work was under way on an atomic bomb. In May, Flerov wrote to S.V. Kaftanov, who was responsible for science in the State Defense Committee (Gosudarstvenny Komitet Oborony, GKO), and to

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

[40] Josephson, "Early Years of Soviet Nuclear Physics," p. 36.

[41] A great deal of new information is being published about the history of the Soviet bomb program. A lecture given by Yuli Khariton and Yuri Smirnov on 13 January 1993 at the Kurchatov Institute is particularly notable: "The Khariton Version," *The Bulletin of the Atomic Scientists*, May 1993, pp. 20-31. See also Yuli Khariton and Yuri Smirnov, "USSR Nuclear Arms: From America or Developed Independently?" *Izvestiya*, 9 December 1992, p. 3.

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

[43] 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, at p. 43.

Stalin that "we must build the uranium bomb without delay."[44] In November 1942, Stalin summoned four leading academicians: Ioffe, Kapitsa, Khlopin, and Vernadskiy to the Kremlin and asked them about the possibility of developing an atomic bomb in a relatively short time frame.[45] The scientists unanimously confirmed the possibility.[46] While worried about the high cost of development, Stalin nonetheless initiated a small-scale project and asked for a suitable leader for the project: preferably one neither too prominent nor too young.[47] Stalin decided that a younger man would be preferable, for whom the project would become "the main cause of his life." Ioffe suggested Kurchatov and A.I. Alikhanov.[48]

Kurchatov was selected by Stalin in late 1942 with the State Defense Committee confirming the appointment in March 1943. A month later, he was appointed director of the newly established Laboratory No. 2 in Moscow.[49] This laboratory was the Soviet equivalent to Los Alamos. By 1947, Laboratory No. 2 had been renamed "Laboratory for Measuring Instruments"(LIPAN).[50] 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."

On the Politbureau level, Vyacheslav Molotov, then Foreign Minister, was charged with overseeing the bomb program.[51] The selection of Molotov for the supervisory role is unexplained, although he had other defense industry connections such as supervising the critical tank production program in his

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[44] The letter was first published in the *Moscow News,* No. 16, 1988, and is reproduced in Appendix 2. According to Chikov, this was actually Flerov's second letter to Stalin advocating the development of a uranium weapon. The first was sent before the war. See Chikov, JPRS-UMA-91-023, pp. 43-44.

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

[46] Ibid.

[47] Ibid. The State Defense Committee established a scientific and technical research program on the use of atomic energy on 11 February 1943; "The Khariton Version," *Bulletin,* p. 24.

[48] Igor Golovin, *I.V. Kurchatov* (Moscow: 1966), excepts in *The Current Digest of the Soviet Press,* 7 September 1966, No. 33, p. 5.

[49] "Atomic Energy--The Bomb," *USSR Technology Update,* 19 April 1990, p. 1. See also, Andrei Sakharov, *Memoirs,* (New York: Alfred A. Knopf; 1990), p. 159; and A.P. Aleksandrov, ed., *Vospominaniya ob Igore Vasil'yevich Kurchatov* (Moscow: Nauka, 1988), p. 461.

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

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

role as senior member of the State Defense Committee (GKO).[52] (Many tank officials would subsequently be involved in the nuclear weapons program.) At its inception during the war, work on the bomb was under the direction of the secret police, then the People's Commissariat for State Security or NKGB (Narodnyy Komissariat Gosudarstvennoy Bezopasnosti), headed by Beria.[53] 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, responsible for overseeing the nuclear weapons program (renamed in 1953 the Ministry of Medium Machine Building),[54] who rose rapidly through the ranks to become an exceptional administrator.

Kurchatov at the time of Stalin's appointment was not even a full member of the Academy of Sciences, which reduced his influence among the more senior physicists.[55] Kurchatov drew up a plan of research with three main goals: to achieve a chain reaction in an experimental reactor using natural uranium; to develop methods of isotope separation; and to study the design of both U-235 and plutonium bombs. According to Khariton, Kurchatov "suggested to me that I should attend directly to the development of nuclear weapons because he knew that I had been involved to some extent with weapons development and that I was very excited by these questions."[56]

Kurchatov, assisted by V. Fursov, undertook development of an atomic pile using graphite as the moderator. Alikhanov developed a pile using heavy water as the moderator. Isotope separation technologies were divided into three sections: thermal diffusion (under Anatoliy P. Aleksandrov); gaseous diffusion (under Isaak K. Kikoin); and electromagnetic separation (under Artsimovich).[57] The Soviet bomb program was small during the war. Fifty scientists were working in Kurchatov's new laboratory by the end of 1943, a

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

[53] 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).

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

[55] Zaloga, "The Soviet Nuclear Bomb Programme," p. 175. Perhaps to rectify this problem, Kurchatov was elected a full member 29 September 1943.

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

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

figure which doubled by the end of 1944. Key administrators of the program included: Boris L. Vannikov, the chairman of the Scientific and Technical Council for the Uranium Project under the USSR Council of People's Commissars and for whom Kurchatov served as deputy; Vyacheslav A. Malyshev, a former commissar of the heavy and tank industries; and Mikhail G. Pervukhin, a former commissar of the Soviet electrical and chemical industries and deputy chairman of the Council of People's Commissars (predecessor to the Council of Ministers) from 1940 to 1946.

The search for uranium had started under the Uranium Commission in 1940, but it received added impetus from 1942 and involved several leading Soviet geologists, including Academician Vernadskiy (a deputy to Khlopin on the Uranium Commission).[58] Small scale mining operations for uranium at old radium mines in the Fergan valley area near Leninabad, Tadzhik SSR, were initiated by the NKVD's Ninth Directorate, and given the codename "Combine 6."[59] In late 1944, Kurchatov wrote to Beria, head of the NKVD (Narodnyy Kommissariat Vnutrennikh Del--People's Commissariat of Internal Affairs), complaining of the incompetence of Molotov and the desperate need for uranium. Kurchatov noted that after over a year, the surveys of the Leninabad deposits had not even been completed.[60] By the spring of 1945, Beria managed to usurp control of the program from Molotov and became the central administrator for the bomb program. Beria likewise succeeded in taking over many other high technology programs, including the ballistic missile effort.[61]

Beria's role in the program was critical. Due to his control over the GULAG, Beria was able to provide unlimited amounts of prison labor for large scale construction of the reactors.[62] 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.

The Role of Espionage

While Soviet commentators have often minimized the contribution of espionage to the development of the atomic bomb, recently revealed

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

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

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

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

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

documents and information confirm its crucial importance.[63] What is also coming to light is that the scope of the effort was larger than previously thought. 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, as well as key political decisions and developments made by the U.K. and the U.S.

Through the Cambridge spy network in Britain, Stalin probably had knowledge of British and American plans at a very early date. The key figure providing this early information was John Cairncross, who revealed in September 1991, that he was the "fifth man," of the group of British spies that included Donald Maclean, Guy Burgess, H.A.R. "Kim" Philby, and Anthony Blunt.[64] Cairncross was the private secretary (from September 1940 until March 1942) to 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 the report was likely to be first handled by Cairncross he probably passed the information to Anatoli B. Gorskiy, the control agent of the Cambridge spies from 1940 to 1944.[65]

Though Klaus Fuch's role has always been known to be important new details have recently been revealed.[66] According to Khariton, a key participant in the Soviet bomb program, the first Soviet test device, fired on August 29, 1949, was a copy of the bomb the Americans dropped on Nagasaki, based on full plans received through espionage.[67] The purpose of using the Western

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[63] Other commentators maximize the espionage contribution. The result of this is a rather heated quarrel between the scientists and the spies over who should be given proper credit. See Roald Sagdeev, "Russian Scientists Save American Secrets," *The Bulletin of the Atomic Scientists*, May 1993, pp. 32-36; Sergei Leskov, "Dividing the Glory of the Fathers," *The Bulletin of the Atomic Scientists*, May 1993, pp. 37-39.

[64] "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; and Robert Cecil, *A Divided Life: A Personal Portrait of the Spy Donald Maclean* (New York: William Morrow and Company, Inc., 1989). A second ring at Oxford could bring more surprises; see Martin Walker, "The Cloud of Treason Descends Upon Another Bastion of British Respectability," *Los Angeles Times*, 12 July 1992, p. M2.

[65] 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.

[66] Williams, *Klaus Fuchs, Atom Spy*; Ronald Radosh and Joyce Milton *The Rosenberg File: A Search for the Truth* (New York: Vintage Books, 1984).

[67] "The Khariton Version," *The Bulletin of the Atomic Scientists*, May 1993, pp. 22-23; Yuliy Khariton, "USSR Nuclear Arms: From America or Developed Independently," *Izvestiya*, 9 December 1992, p. 3; (continued...)

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."[68] The fact that there was a second spy at Los Alamos is a most significant revelation, one that is bound to alter the extensive historical record 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, there was a second spy, codenamed "Perseus," who joined the Manhattan Project in 1942, well before Fuchs arrived in America.[69]

The key figures associated with Perseus appear to be an American couple, Morris and Lona Cohen. Cohen had been recruited to work for the Soviets while recovering from a leg injury in Barcelona in 1938, fighting for the republicans in the Spanish Civil War. 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, who he married in 1941.[70] Yatskov claims Cohen was approached in New York by an "acquaintance," a physicist who had been invited to be part of the atomic bomb

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[67](...continued)
Yuriy Smirnov, "USSR Nuclear Arms: From America or Developed Independently," *Izvestiya*, 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 discover this fact.

[68] 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.

[69] Michael Dobbs, "How Soviets Stole U.S. Atom Secrets," *Washington Post*, 4 October 1992, 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.

[70] Robert J. Lamphere and Tom Shachtman, *The FBI-KGB War* (New York: Random House, 1986), pp. 276-278; Chikov, *Soviet Union Military Affairs*, JPRS-UMA-91-023, 10 September 1991, p. 49.

project. This physicist was to become Perseus.[71] With Morris fighting with the U.S. Army in Europe, Lona became the courier. According to Yatskov, Lona Cohen undertook two missions to Albuquerque to meet Perseus. Though Perseus's identity is not publicly known, according to Yatskov he is still alive.[72]

In March and April 1945, Kurchatov characterized the information passed on by Fuchs and others on U.S. nuclear weapon design as "exceptionally important" and "new and extremely important," providing guidance as to useful directions to pursue and those likely to lead only to dead ends. Kurchatov went so far as to distribute some of this material to his colleagues without Beria's authorization.[73]

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.[74] He was later joined by other German engineers, including Dr. Max Steenbeck, who was primarily involved in gas centrifuge techniques.[75] Given the low level of effort by the German scientists in developing their own bomb during the War[76] their contribution

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[71] Dobbs, "How Soviets Stole U.S. Atom Secrets," *Washington Post*, 4 October 1992, 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. Though hard to date exactly the U.S. did not firmly commit to building the bomb until mid-1942. Colonel 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 disinformation to continue to shield Perseus.

[72] As are the Cohen's, who live in Moscow. After the arrest of the Rosenbergs they apparently fled to Britain where they took new names, Peter and Helen Kroger, 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 British businessman and Secret Intelligence Service (MI6) courier Greville Wynne in 1964.

[73] Chikov, JPRS-UMA-91-023, p. 48.

[74] 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.

[75] Ibid.

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

to the Soviet program must be assessed as extremely limited.[77]

Full Speed Ahead

By the time of the Potsdam Conference, which began the day after the "Trinity" test, on 17 July 1945, the Soviet Union had a serious, albeit small (especially compared to the burgeoning Soviet missile program), 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." He also told Kurchatov to speed up his work.

The Kurchatov team at Laboratory No. 2 in Moscow learned of the successful test of the first American A-Bomb in July 1945, but this development alone did not push the program into high gear since the full implications of the successful test may not have been comprehended by the upper leadership of the Soviet Union, Beria and Stalin in particular.[78] This all changed in August 1945 when the United States employed the first two atomic bombs against Hiroshima and Nagasaki, Japan. On 7 August 1945, Stalin put his secret police chief, Beria in charge of a Soviet version of the Manhattan Project. In the middle of August, Stalin summoned Boris L. Vannikov, the People's Commissar of Munitions, and his deputies to the Kremlin. There they were met by Kurchatov. "A single demand of you, comrades," said Stalin. "Provide us with atomic weapons in the shortest possible time! You know that Hiroshima has shaken the whole world. The balance [of power] has been destroyed!"[79]

On 20 August 1945 the GKO established a Special Committee (*Spetskom*), chaired by Beria and comprised of M.G. Pervukhin, G.M. Malenkov, V.A. Makhnev, P. Kapitsa, Kurchatov, Voznesenskiy, B.L. Vannikov, and others. The Committee had a Technical Council, established 27 August 1945 and an Engineering-Technical Council established 10 December 1945.

Administration of the program was undertaken by the new First Main Directorate (PGU) of the USSR Council of Ministers, established at the end of 1945 and headed by Vannikov. In a 9 April 1946 decree of the Council of

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[77] 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." "The Khariton Version," *Bulletin*, p. 23.

[78] For a recreation of the discussions between Beria and Stalin, see Chikov, JPRS-UMA-91-023, pp. 46-47.

[79] Christopher Andrew and Oleg Gordievsky, *KGB: The Inside Story* (New York: HarperCollins, 1990), p. 376.

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 A.P. Zavenyagin, P.Y. Antropov, Ye.P. Slavskiy, Borisov, V.S. Yemelyanov, Komarovskiy. At the end of 1947 Pervukhin was appointed First Deputy Chief of the PGU until 1949 when Slavskiy 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 Administration. The NTS played an important role in providing scientific advice and was lead in the 1940s by Vannikov (1946), Pervukhin (1947-1949), and Kurchatov (1949-?).

Overall control of the nuclear program at the Politbureau level remained in the hands of Beria, attesting to the importance Stalin then attached to this effort. The First Main Directorate reported directly to the Politbureau.[80] Within the secret police, Beria had previously created the Ninth Directorate to oversee the atomic project. Beria's main aide in supervising the program was Colonel General Avraami Zavenyagin, who served simultaneously as deputy to both Beria and Vannikov and whose official title was chief representative of the USSR Council of Ministers. Zavenyagin was a metallurgist by training, and his role in the Soviet programme was in some respects similar to that of General Leslie Groves in the American Manhattan Project.

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

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. He oversaw a commission that included Vernadskiy and other experts in uranium geology.[81]

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 below, would open in 1948 and become known as Chelyabinsk-40 (now Chelyabinsk-65).

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

[81] Vol'fon, et al., *Petr Yakovlevich Antropov*, pp. 30-31.

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. Beria, present at the time, continued to be skeptical about the production of an element he could not see. "And when can we see that this isn't a deception, just your fantasy?"[82]

In July 1948, Lt. Gen. Nikolai L. Dukhov of the Army Engineers was drafted into the bomb program and became the right-hand man, on the engineering side, of Kurchatov.[83]

According to Khariton the story that in 1949, Kurchatov, Khariton, and General Pavel M. Zernov, the first director of the "Arzamas-16" nuclear weapons design laboratory established at Sarova in 1946, presented Stalin with a sphere of plutonium and asked permission to test the first atomic bomb is not true.[84]

Establishment of the Test Site and the First Test[85]

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 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 intended to

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

[83] General Dukhov's previous claim to fame was as the designer of the Stalin tank. After the first thermonuclear test, Dukhov moved in early 1954 into the ICBM program where he headed a design bureau. He was a three-time recipient of Hero of Socialist Labor—in 1945, for his tank work, in 1949, for the atomic bomb, and in 1954 for the hydrogen bomb. *New York Times*, 11 November 1984, p. 14.

[84] "The Khariton Version," *Bulletin*, p. 28. The story is recounted by Steven J. Zaloga, *Target America* (Novato, CA: Presidio Press, 1993), p. 53.

[85] 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* (forthcoming).

examine the effects of the explosion on military and civilian equipment, many experiments were prepared. At 800 meters from ground zero, two three-story houses were built. At 1000 meters a section of railroad was built, 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 was erected, with two diesel generators. At 200-300 meters, to a depth of 15-30 meters, a metro tunnel was 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 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 and Kirill Shchelkin his deputy. The working groups and teams were finalized and in July Kurchatov approved the final design. We now know, as discussed above, that this first test used a device based on the American Trinity/Nagasaki design. By late July after numerous railway shipments, and some by air, almost all of the equipment had been delivered.

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 conducting tests, 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.

Throughout 26-28 August final arrangements were made in preparing the device. In the middle of the night on 29 August at 4:30 am, the device was hoisted up to the top of the tower and emplaced. The final wires were connected and the last person to leave the tower was Shchelkin at 5:40 am. The test leaders convened at Building 12, the command post. Anatoly Mal'sky announced the countdown: "-5, -4, -3, -2, -1, 0." A few seconds elapsed and then a huge roar swept over the command post. After it subsided they left the building to witness the rising mushroom cloud and the destruction that the 20 kiloton explosion wreaked.

Beria, happy about the successful test, 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.[86]

RDS-1 was not put into service. As we know now 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.[87]

Thermonuclear Weapons Developments

The initiative to create a Soviet hydrogen bomb project appeared in 1946 in a special report to the government by Isai I. Gurevich, Yakov B. Zeldovich, Isaak Y. Pomeranchuk, and Yuliy B. Khariton.[88]

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.[89] Tamm's group included Andrei Sakharov (who was Tamm's graduate student at FIAN from January 1945 until 1947 when he received his degree), Semyon Belenky, Vitaliy Ginzburg, and Yuri Romanov.[90] The group's task was to investigate the possibility of building a hydrogen bomb, and specifically, to verify and refine the calculations of Yakov Zeldovich's theoretical group at the Institute of Chemical Physics.[91] 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.[92] Sakharov left Arzamas on 14 September 1969.[93]

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[86] There is a contrary interpretation 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. Yuli Khariton and Yuri Smirnov, "The Khariton Version," *The Bulletin of the Atomic Scientists*, May 1993, p. 20.

[87] 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, "The Khariton Version," *Bulletin of the Atomic Scientists*, p. 30

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

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

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

[91] Ibid., p. 94.

[92] Ibid., p. 101.

Soviet progress on the hydrogen bomb closely parallels developments in the United States; indeed, it may have been misdirected by espionage reports of U.S. efforts that ultimately proved unsuccessful.[94] It was clear that to support a thermonuclear reaction one needed a temperature of several tens of millions of degrees. The initial Soviet concept, being pursued by Zeldovich's group, was to install a layer of liquid deuterium in an ordinary atomic bomb between the fissile material (the hollow sphere made of uranium-235 or plutonium-239) and the surrounding chemical high explosive.[95] It was noted, however, that the lack of heat and compression of the deuterium resulted in practically no thermonuclear reaction in the deuterium.[96] To increase the reaction rate, two improvements in the design were proposed in 1948, one by Sakharov and the second by Vitaliy Ginzburg.[97] 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.[98] The deuterium shell also added to the yield of the device as a result of fast fission of the uranium-238 following capture of neutrons escaping from the thermonuclear burn--the so-called fission-fusion-fission design principle. Sakharov's variant has also been described as a heterogeneous construction made of alternating layers of thermonuclear fuel, e.g., deuterium, tritium, or their chemical compounds, and a heavy substance, e.g., uranium-238.[99] Sakharov called it "sloyka," ("layer cake").[100] His colleagues referred to Sakharov's approach as "sugarization" (in English Sakharov means "of sugar").[101]

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[93](...continued)

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

[94] 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.

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

[96] 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.

[97] "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."

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

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

[100] Ibid.

[101] Ibid.

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.[102] Because tritium is not found in nature in any abundance, it must be produced in reactors by irradiating lithium-6 with neutrons, in the reaction

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

a process that is expensive. Moreover, tritium is radioactive, decaying with a 12.3 year half-life, and thus, it must be replenished on a regular basis. Soon after Sakharov proposed his "First Idea," Ginzburg proposed substituting lithium-6 for some of the deuterium, as a means of generating tritium in the weapon itself.[103] Ultimately, perhaps by Ginzburg's suggestion, the lithium-6 was incorporated in the weapons as a chemical compound lithium deuteride (^{6}LiD).

These two ideas, ^{6}LiD and "sugarization," were incorporated into the first Soviet thermonuclear test on 12 August 1953.[104] Identified as "Joe 4" by the U.S., this test was a single-stage boosted fission weapon with a yield in the 400 kiloton range.[105] Khariton puts the contribution of thermonuclear

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[102] Ibid., p. 20.

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

[104] Ibid.

[105] A new yield estimate comes from a caption on an exhibit at a museum of nuclear weapons recently opened to special visitors at Arzamas-16; "Mikhaylov Comments on Nuclear Weapons Museum," *Rossiyskaya Gazeta*, 20 October 1992, p. 4, in JPRS-UMA-92-041, 18 November 1992, p. 6. The long-standing U.S. estimate has been 200-300 Kt. It is worth quoting from the official history of the Atomic Energy Commission about Joe-4, as it has left a confusing legacy about the genealogy of the H-bomb. "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." 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). Khariton is very defensive in asserting that "Joe 4" was a *real* hydrogen bomb. "The Khariton Version," *Bulletin*, May 1993, p. 30. 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 it 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 adopted and successfully tested on 22 November 1955.

reactions to the total value of the yield in the area of 15 to 20 percent.[106]

Sakharov, Zeldovich, and Khariton are generally credited as the three principal developers of the Soviet hydrogen bomb. Khariton was the scientific director of Arzamas-16 from its beginning 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"[107]) 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.[108] Something like the Third Idea had been the subject of earlier speculation, but this two-stage approach became a serious research option in 1954.[109] The first Soviet test of a device of this type occurred on 22 November 1955.[110]

The governmental organizations and the personnel involved in the bomb program during World War II, and throughout the late 1940s until 1953, is very sketchy.[111] A special "semi-ministry" called the First Main Directorate administered the bomb program from 1945 until 1953. Its chairman was former Minister of Armaments Boris L. Vannikov, who was, in turn, overseen by secret police chief Lavrenti P. Beria. In early March 1953, Stalin died and soon after Beria was arrested (and was shot by the end of the year). With new political leaders came a reorganization of government ministries which lead to the creation of the Ministry of Medium Machine Building (MMMB). Vannikov was demoted to First Deputy Minister, and another veteran of the

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[106] Khariton and Smirnov, "The Khariton Version," *Bulletin of the Atomic Scientists*, p. 30.

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

[108] Ibid., p. 182. Khariton also includes Trutnev. Khariton and Smirnov, "The Khariton Version," *Bulletin of the Atomic Scientists*, p. 29.

[109] Ibid.

[110] The airplane crew was commanded by F.P.Golovashko. Khariton and Smirnov, "The Khariton Version," *Bulletin of the Atomic Scientists*, p. 30.

[111] Some of this will become clearer upon publication of David Holloway, *Stalin and the Bomb: Atomic Energy and Soviet Policy, 1939-1945* (New Haven, CT: Yale University Press, forthcoming).

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), his economic deputy at the Ministry of Heavy Industry (A.M. Petrosyants). Another deputy minister, A.N. Komarovskiy, 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.[112]

When Malenkov was ousted in 1955, so was Malyshev, who was replaced by A.P. Zavenyagin. Zavenyagin lived long enough to oversee establishment of a second nuclear weapons design laboratory, Chelyabinsk-70, in 1955. Zavenyagin 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. Slavskiy, ushered in an era of stability at the top, as he held the post for almost 30 years.

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;[113] and then declined more than 20 percent to 32,000 warheads by May 1993.[114] An official CIA estimate given in May 1992,

[112] Yaroslav Golovanov, *Korolev* (book chapter published in) *Poisk*, February, 1990, No. 7, 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.

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

[114] "According to Minister Viktor Mikhaylov approximately 13,000 nuclear munitions have been dismantled in this time [the last eight to 10 years], 2,000 a year on average." Sergey Ovsiyenko, "Weapons-Grade Plutonium Socks Dwindling," *Rossiyskiye Vesti*, 19 May 1993, p. 7. Viktor Mikhailov and Evgeniy Mikerin, in remarks at the International Symposium on Conversion of Nuclear Warheads for Peaceful Purposes, Rome, Italy, 15-17 June 1992, stated that the stockpiled had declined by 20 percent since it peaked in 1986. In an interview with Yevgeniy Panov, *Moscow Rossiyskaya Gazeta*, in Russian, 11 December 1992, (continued...)

placed the stockpile of the former Soviet Union at 30,000 nuclear weapons with an uncertainty of plus or minus 5000.[115] 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.[116] This implies a 17,500 to 21,000 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.[117]

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

As a consequence of the Bush/Gorbachev initiatives of September/October 1991, and the Strategic Arms Reduction Treaty (START I), the 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

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[114](...continued)
p. 7 (Translated in *Foreign Broadcast Information Service*, 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."

[115] 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.

[116] Viktor Mikhailov and Evgeniy Mikerin, Rome, 15-17 June 1992.

[117] Lawrence K. Gershwin, Hearings before the House Committee on Appropriations, DOD Appropriations for 1993, Part 5, 6 May 1992, p. 499.

one of 4000-5000,[118] to a much larger one of 8000 to 10,000.[119]

Russian sources have estimated that some 55,000 nuclear warheads have been produced since 1949. If this is the case and some 32,000 warheads remained as of mid-1993, then some 23,000 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),[120] is responsible for the research, development, testing and production of nuclear warheads. Once produced, the warheads are delivered by Minatom to the Main Administration for Nuclear Weapons (the Twelfth Main Administration) of the Ministry of Defense.[121] By decree of President Yeltsin on 29 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 MAPI and MMMB, supervises the entire chain of production for nuclear weapons, from the mining of uranium ore through the fabrication of warheads, and is responsible for the production of all nuclear materials, uranium enrichment, production reactors, nuclear waste management, and warhead research, development, testing and production. Analogous to the U.S. DOE, Minatom is also responsible for research and production of civilian nuclear power technology and utilities, high-energy physics, lasers, and other civil programs

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

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

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

[121] Little is known about the history, organization, or responsibilities of the Twelfth Main Administration (or Directorate) of the Ministry of Defense. We are grateful to Peter Almquist for sharing his knowledge about the 12th Main Administration with us. The administration is apparently responsible for overseeing the development and testing 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 1 for further details): 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, Chief Nuclear Engineer.

including the production of dairy equipment.[122]

Organizational tables of Minatom, adapted from various brochures and charts, is provided in Table 2. Viktor N. Mikhailov was appointed the first minister of Atomic Energy in early-March 1992, shortly after Minatom was formed. Under Mikhailov, Vitaliy F. Konovalov (the former minister) is the first deputy minister and there are six other deputies.[123] Reporting directly to Mikhailov are two department heads responsible for central nuclear weapons activities: Boris V. Gorobets is chief of the Sixth Department,[124] responsible for nuclear weapons production; and Georgi P. Tsyrkov is chief of the Fifth Department,[125] responsible for nuclear warhead design and testing. Evgeniy I. Mikerin, chief of the Fourth Department,[126] is responsible for isotope production and separation, reprocessing, and warhead component (plutonium pit and uranium component) production and also reports directly to Mikhailov, at least with respect to the warhead component production.

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

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[122] 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, 26, b. Ordynka ul., 101000 Moscow, Russian Federation, Tel: 239-45-45; FAX: 230-24-20.

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

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

[125] Other senior officials are Boris Yuriyevich Lubovin, Vitaliy Mikhailovich Ivanov, Arkadiy Alexandrovich Kolegov, Yelena Vladimirovna Ponomareva. *Russian Government Today* (Washington, DC: Carroll Publishing Company, 1993), p. 184.

[126] Other senior officials are Stanislav Vasileyevich Malyshev, Alexander Alexandrovich Samarkin, Viktor Nikitovich Khaprenko, Arkadiy Antonovich Kuznetsov. *Russian Government Today* (Washington, DC: Carroll Publishing Company, 1993), p. 184.

Malyshev, V.A.	-	Minister, MMMB, June 1953-February 1955.
Zavenyagin, 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.
Slavskiy, 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 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 Production Complex

Since the nuclear warhead production complex and most of the arsenal were concentrated in Russia, upon the breakup of the Soviet Union in late-1991, the nuclear weapons production program was taken over by Russia, and the arsenal is in the process of being consolidated there. The research, development, and production of nuclear weapons in Russia is now administered by the Russian Ministry of Atomic Energy (Minatom), headquartered in Moscow. Minatom was created out of the Soviet Ministry of Atomic Power and Industry (MAPI) in 1992. Prior to 1989, MAPI was called the Ministry of Medium Machine Building.

The design, testing, and production of nuclear warheads and the production of fissile material for warheads takes place at 12 principal sites, now all in Russia (see Table 1). There are two nuclear weapons design laboratories, one of which also assembles nuclear warheads; one, of originally two nuclear weapons test sites; four sites at which warhead are assembled, one of which is one of the two design laboratories, one which also manufactures electronic components, and one of which may also assemble ballistic missile reentry vehicles; three plutonium (and tritium) production sites, one of which is collocated with one of the enrichment plant sites; and four uranium enrichment sites, one of which is collocated with one of the plutonium production sites.

Consistent with the traditional Soviet secrecy practices, ten of these sites (and the closed cities that support them) are not found on any Soviet maps.[127] In addition to their primary names, these closed sites are code-named after cities 50 to 100 kilometers (km) away followed by a postal zone number (e.g., Arzamas-16). Their precise locations are not always known. Beginning in 1989, several sites have been opened to limited visits by foreigners, but others sites still have not been declassified as to their specific missions and locations. Each is guarded by a special regiment of the Ministry of Internal Affairs.

The two weapon design laboratories are the All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16) at Sarova; and the All-Russian Scientific Research Institute of Technical Physics (Chelyabinsk-70) in the Urals region. 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 one of four sites with the capability to assemble and disassemble warheads, suggesting a capability greater than prototype assembly. Sverdlovsk-45 (with its closed city called Rusnoy) at Nizhnyaya Tura in the Urals is the largest of the four nuclear warhead assembly (and disassembly) plants. Zlatoust-36 (with its closed city Torifugornuy), is in the town of Yuryuzan, 85 km southwest of Zlatoust, has also been identified as a warhead assembly and disassembly facility.[128] The third facility, Penza-19 (with its closed city Zarechnoye), 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

[127] Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, 17 November 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-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)
2. Snezhinsk (Chelyabinsk-70, 46,300)
3. Ozersk (Chelyabinsk-65, 83,500)
4. Seversk (Tomsk-7, 107,700)
5. Zhelenogorsk (Krasnoyarsk-26, 90,300)
6. Zelnogorsk (Krasnoyarsk-45, 63,300)
7. Novouralsk (Sverdlovsk-44, 88,500)
8. Rusnoy (Sverdlovsk-45, 54,700)
9. Zarechnoye (Penza-19, 61,400)
10. Torifugornuy (Zlatoust-36, 29,800)

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

[128] SASC, *Threat Assessment, Military Strategy, and Defense Planning*, Senate Hearing 102-755, pp. 55-56.

Kazakhstan became independent after the failed coup earlier that month.

The three plutonium (and tritium) production sites are Mayak Chemical Combine (Chelyabinsk-65; formerly Chelyabinsk-40)) near Kyshtym in the Urals, the Siberian Chemical Combine (Tomsk-7) in Siberia, and the Mining and Chemical Combine (Krasnoyarsk-26) near Dodonovo in Siberia.[129] Plutonium (and possibly tritium) production at Chelyabinsk-65 has now ceased. Warhead pit manufacture and uranium enrichment also take place at Tomsk-7. The four operating uranium enrichment plants are the Urals Electromechanical Plant[130] at Sverdlovsk-44 (with its closed city called Novouralsk) near Verkh-Neyvinsk (formerly Kefirstadt), near Yekaterinburg (called Sverdlovsk prior to the breakup of the Soviet Union); the Siberian Chemical Combine (collocated with the production reactors) at Tomsk-7; the Electrochemistry Plant (Krasnoyarsk-45) between Krasnoyarsk and Kansk; and the Electrolyzing Chemical Combine at Angarsk near Lake Baikal.

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

According to Viktor Mikhailov, currently the Russian Minister of Atomic Energy, 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."[131] 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.[132]

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

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

[131] *Komsomol'skaya 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.

[132] 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.[133] Here the first Soviet nuclear reactor, called F-1 ("Physics-1"), was constructed and began operating on 25 December 1946.[134] In April 1946, by order of the government, design work on the atomic bomb was shifted to the newly created KB-11, now called the All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16, discussed below). The F-1 reactor and the cyclotron at Laboratory No. 2 continued to be used for physics experiments related to fission and fusion weapons research. Since the early 1960s, research at the Kurchatov Institute has been devoted primarily to civilian nuclear power and general nuclear theory. While nuclear weapons research has been shifted to other facilities, some five percent of the 3000 employees at the Kurchatov Institute are working on military weapons.[135] Upon his death in 1960, Kurchatov was succeeded as director of the institute by Academician Anatoliy P. Aleksandrov. Thrice a Hero of the Soviet Union, Aleksandrov was also the President of the Soviet Academy of Sciences until 1986. Aleksandrov was succeeded as director of Kurchatov by Academician Evgeniy P. Velikhov.

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

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

The All-Russian Scientific Research Institute of Experimental Physics (VNIIEF), the older of two principal nuclear weapons design laboratories in use today, was founded by government decree in 1946 as KB-11 [design

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[133] There was no Laboratory No. 1.

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

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

bureau 11], and apparently came into being in 1947. 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."[136] Another reference says Arzamas-16 was initially known as "Military Installation 'N,'" then "Kremlev City."[137] Prior to the dissolution of the Soviet Union its formal name was the All-Union Scientific Research Institute of Experimental Physics. It is also known informally as "Khariton's Institute," named after Academician Yuliy B. Khariton, who was the institute's scientific director from its creation until he retired in 1992.[138]

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.[139] In addition, the site was both isolated and protected. It is situated on lands of the former Sarovskiy Hermitage (Sarov monastery), destroyed in 1927, at Sarova, in the Nizhniy Novgorod oblast at the Mordvinian autonomous republic border, 75-80 km southwest of Arzamas.[140] The

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[136] 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 *Joint Publications Research Service*, 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.

[137] Moscow Teleradiokompaniya Ostankino Television First Program Network in Russian, 23 April 1992, 2000 GMT. Khariton 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. Khariton and Smirnov, *Bulletin of the Atomic Scientists*, May 1993, p. 20.

[138] 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.

[139] Mikhail Rebrov, *Krasnaya Zvezda*, in Russian, 27 October 1992, p. 2 (translated in JPRS-UMA-92-042, 25 November 1992, p. 43).

[140] "Silent People Live Here," *Komsomolskaya Pravda*, 25 November 1990, p. 2. Sarova is located at 54° 55'N/43° 19'E; Arzamas at 55° 23'N/43° 50'E. According to Serge Schmemann, *New York Times*, 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 delinquents. Just before (continued...)

closed city, which as noted above was at one time was temporarily named Kremlev, has a population of 80,300.[141] It is here that the first Soviet nuclear bomb was designed and assembled.[142]

There are about 25,000 employees at the institute. In 1990, the institute reported having two academicians, two corresponding members of the academy, 50 doctors, 500 candidate Ph.D.s, and 250 winners of Lenin and State prizes.[143]

The primary mission of Arzamas-16 is designing nuclear warheads. The institute fabricates experimental and prototype warheads.[144] 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.[145] He claimed to have assembled several thousand nuclear warheads over a fourteen year period.[146] 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

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[140](...continued)
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 Sarovskiy, canonized by the Orthodox Church in 1903.

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

[142] "Silent People Live Here," *Komsomolskaya Pravda*, 25 November 1990, p. 2. See also, *Pravitelstvennyy Vestnik*, No. 49, December 1990, p. 12. The nearby plant where this production took place is believed to have been called "N 3."

[143] 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," *Pravitel'stvennyy 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.

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

[145] 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.

[146] Ibid.

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.[147] The testing area for the explosions department is called Area No. 19.[148]

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. The institute is interested in pursuing nonmilitary research in these fields. The average salary was approximately 40,000 rubles ($40) per month. As of 1 July 1993 it was raised to 74,000 rubles ($74) but as of mid-August due to a shortage of cash they had not yet been paid the new salaries.[149]

Today the city and "industrial zone" are separated. The 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.[150]

As is the case at other Russian weapons facilities the responsibility for managing the institute is shared by the scientific director (or scientific leader) and the director, the latter serving as the administrator. As noted above Khariton, whose 89th birthday was on 27 February 1993, was the scientific director until he retired in the fall of 1992. Khariton's successor Victor Mikhailov, who now wears two hats--scientific director of Arzamas-16 and

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[147] Mikhail Rebrov,"Three Generations of Bombs: Only Now Can We Talk About the City Where They Were Born," *Krasnaya Zvezda*, in Russian, 27 October 1992, p. 2 (translated in JPRS-UMA-92-042, 25 November 1992, p. 43).

[148] Ibid.

[149] Interview with Viktor Mikhailov in *Nezavisimaya Gazeta*, 18 August 1993, pp. 1,3, translated in FBIS-SOV-93-159, 19 August 1993, p. 36.

[150] Mikhail Rebrov, "Three Generations of Bombs: Only Now Can We Talk About the City Where They Were Born," *Krasnaya Zvezda*, in Russian, 27 October 1992, p. 2 (translated in JPRS-UMA-92-042, 25 November 1992, p. 43).

minister of the Ministry of Atomic Energy, the latter overseeing the former.[151] The first deputy scientific director is Academician Yuri A. Trutnev, a theoretical physicist who in his early years at Arzamas-16 shared an office with Andrei Sakharov.

The first director of Arzamas-16 (1946-1951) was General Pavel Zernov. The next director was General Anatoly S. Alexandrov (1951-1955), followed by Boris Muzrukov (1955-1974). The institute's current (mid-1993) director is Vladimir A. Belugin[152].

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

The second of the two existing principal nuclear weapons design laboratories, the All-Russian (formerly All-Union) Scientific Research Institute of Technical Physics (VNIITF). Also called Chelyabinsk-70, it is located between Lakes Sinara and Silach, just east of the Urals, 20 km north of Kasli and about 80 km south of Yekaterinburg.[153] Its creation in 1955 parallels that of the Lawrence Livermore National Laboratory (LLNL) in the United States.

The institute started at Site 21, which is located on a peninsula between Lake Sungul and Lake Silach--about midway between Snezhinsky, the closed city which houses most of the Chelyabinsk-70 work force today, and Kasli to the south. Site 21 was a sanitorium prior to World War II, and was converted into a hospital during the war. After the war the site housed a "Sharashka," a GULAG administered scientific research facility staffed by camp inmates. Timothy Kesovsky, a famous biophysicist who had been at the Kaiser Wilhelm Institute, and his colleagues removed from Germany immediately after the war, conducted genetic experiments with radiation at this facility, which was also called the Sungul Radiological Laboratory.[154] 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

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[151] It would appear that Mikhailov had himself appointed scientific director of Arzamas-16.

[152] 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.

[153] "Film Depicts Secret Nuclear Town: Chelyabinsk-70," Moscow Teleradiokompaniya Ostankino Television First Program Network, 1922 GMT on September 1992, 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 km to the south. A small village is located at 56° 04'N/60° 46'E.

[154] 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.

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.[155] 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 about six by thirteen kilometers that is visible in SPOT satellite images. The institute employs 16,000 people, of whom about 4000 are scientists, 3000 are production engineers, and 7000 technicians. There are 46,300 people in Snezhinsk,[156] which was previously called Semidesyatka ("Seventies town").

The primary mission of Chelyabinsk-70 is designing nuclear warheads. The institute fabricates experimental and prototype warheads, but has no factory production capability. There are extensive facilities for conducting chemical high explosive experiments (similar to Site 300 at the Lawrence Livermore National Laboratory in the U.S). The main test area is about five km to the northeast of Lake Itkul.[157]

Since 1988 Chelyabinsk-70 has been converting its research to civilian applications. In early-1992 roughly 50 percent of its research was military and 50 percent non-military, with further cuts on the military side expected.[158] The institute is pursuing nonmilitary commercial projects in fiber optic communications, nuclear medicine, and industrial diamond manufacture. About 10 percent of the institute personnel have been shifted to work on fiber optic communications.

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

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

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

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

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

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

Nuclear Warhead Test Sites

Semipalatinsk-21[159]

As mentioned above establishment of the test site near Semipalatinsk in Kazakhstan was the result of a special resolution of 21 August 1947. Since 1949 there have been a total of 467 tests, 124 in the atmosphere prior to the Limited Test Ban Treaty of 1963, and 343 underground from 1961 to 1989. Originally called "N 2," the more recent name was Semipalatinsk-21, or the "Polygon." The secret city is called Kurchatov.[160] The head of the test site (in mid-1991) was A.D. Ilyenko, and the deputy head was F.F. Safonov.[161]

With a few exceptions, just over 300 tests have been exploded within a rectangle of about 2000 square miles (49.700 to 50.125 North by 77.700 to 79.100 East). Tests have 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 Gorbachev, the president of Kazakhstan, Nursultan A. Nazarbayev formally closed the test site.

Novaya Zemlya[162]

While the first nuclear weapons were tested in Kazakhstan, the development of thermonuclear weapons led the Soviets to conclude that a new

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

[160] Interview with the Mayor of Kurchatov, Yevgeniy Chaykovskiy, *Izvestiya*, 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.

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

[162] 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 Gennadiy Y. Zolotukhin, *Izvestiya*, 3 May 1990, p. 4, translated in FBIS-SOV-90-092, 11 May 1990, pp. 58-60; Anatoliy Pavlov, *Chas Pik*, no. 20 (20 May 1991), p. 4, translated in JPRS-UMA-91-021, 7 August 1991, pp. 65-67; and V.N. Mikhailov and A. Chernyshev, "Novaya Zemlya," Report presented at the International Symposium on Underground Nuclear Tests, Ottawa, 21-26 April 1991.

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.[163]

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)--which are divided by the Matochkin Shar Strait, as well as a large number of 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 is at about the same latitude as the northernmost point of Alaska. It is a raw environment with arctic winds up 100 mph and snow, 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 are taken up by glaciers, the depth of many exceeds 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 is 4.5 meters. Complete 24-hour darkness begins near mid-November and lasts many months. The site itself is 750 km by 150 km, and it totals 90,200 square kilometers of which 55,000 are dry land.

Novaya Zemlya was discovered by Russian fishermen in the 11th century. In the sixteen and seventeenth centuries trading posts were established, and in the late nineteenth century permanent 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 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 Ye. Negin, one of the senior weapons specialists

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[163] Vitaly Adushkin and Gennady Krasilov, "Novaya Zemlya Test Site and the problem of the Radioactive Pollution of the Polar Ocean" (unpublished). The Semipalatinsk site accounted for only 26 known tests, with the remainder taking place outside the main test sites. Thomas B. Cochran, et al., *Soviet Nuclear Weapons*, Volume IV, p. 373.

from Arzamas-16, and G.P. Lominskiy, who would later direct the Chelyabinsk-70 from 1963 to 1986. In its first year, Novaya Zemlya would 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 (Ye.P. Slavskiy), Chief of the Strategic Rocket Forces (K. Moskalenko), and a Deputy Minister of Health (A. Burnazyan) arrived four days later to observe the first post-moratorium test on Novaya Zemlya. This test took place 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.[164]

The years 1961 and 1962 were the period of the most intense testing at the Novaya Zemlya test site. In a sixteen month period 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.[165]

Overseeing the annual handful of tests as chief of the test site has been a succession of naval officers: Vice-Admiral Ye. Zbritskiy, Rear Admiral V. Steshenko, Rear Admiral N. Minenko, Vice Admiral S. Kostritskiy, Vice Admiral V. Chirov, Rear Admiral Ye. Gorozhin, and Rear Admiral V. Gorev,

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[164] 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, "The Khariton Version," *Bulletin of the Atomic Scientists*, p. 30.

[165] I. Bentsa, "Novaya Zemlya: A Hush Over the Contaminated Territory," *Izvestiya*, 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, printed in FBIS-SOV-92-200, 15 October 1992, p. 18.

current chief of the site. In October 1992 the deputy commander was Capt. Valery Lepsky.[166] According to Gorev, the length of service at the site is five years.

The main settlement is called Belyushy Guba (Whale Bay). As of October 1992 about 10,000 people live on Novaya Zemlya, half military, half civilian.[167] The site has been under the authority of the Navy's Sixth Main Administration, 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, M. Sadovskiy, Ye. Fedorov, G. Tsyrkov (currently responsible for nuclear weapons research and development), Yu. Izrael, N. Semenov, S. Kristianovich, and V. Chuganov.[168] Admiral V. Vyskrebentsev was identified as head of the testing commission in 1990.[169]

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.[170] 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 until 1 July 1993. On 3 July 1993 President Clinton extended the moratorium through September 1994 and as a consequence no nuclear testing by Russia or the United States is anticipated.

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[166] Fred Hiatt, "Russian Test Site Displays Pride, Perils of a Superpower," *Washington Post*, 18 October 1992, pp. A1.

[167] Ibid.

[168] See Kudryavtsev and *Rabochaya tribuna*, 3 October 1990, p. 3, translated in FBIS 12 October 1990, pp. 94-96.

[169] *Rabochaya tribuna*, 3 October 1990, p. 3, translated in FBIS 12 October 1990, p. 94-96; *Trud*, 7 November 1990, p. 3.

[170] *Nezavisimaya gazeta*, 24 March 1992, p. 6, in FBIS-SOV-92-060, 27 March 1992, p. 1; "Poka 'zelenyye' ishchut lysogo olenya," *Komsomol'skaya pravda*, 27 May 1992, p. 1; and Viktor Makarov, "Komi Region Views Draft Law on Nuclear Testing," *Moscow ITAR-Tass*, in English, 29 July 1992, 0853 GMT.

Nuclear Warhead Production Facilities

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

In mid-1992 Minatom Minister Mikhailov identified four facilities for the assembly and dismantlement of nuclear warheads: Sverdlovsk-45, Zlatoust-36, Penza-19, and Arzamas-16.[171] In addition, fissile material component fabrication takes place at Tomsk-7.

Sverdlovsk-45 (with its closed city called Rusnoy with a population of 54,700) is at Nizhnyaya Tura, on the eastern edge of the Urals, 200 km north of Yekaterinburg.[172] It has been identified by the U.S. Defense Intelligence Agency (DIA) as one of three Russian nuclear warhead production facilities (DIA excluded Arzamas-16 and Tomsk-7), and characterized as "[a] very large plant."[173] It serves as one of the larger weapon storage sites in the former Soviet Union.

Zlatoust-36, with its closed city of Torifugornuy (population 29,800), is at Yuryuzan, 85 km southeast of Zlatoust, which is in the Urals in Chelyabinsk Oblast, 110 km due west of Chelyabinsk.[174] Zlatoust-36 is characterized by DIA as "a much smaller facility" than Sverdlovsk-45.[175] U.S. satellite imagery evidence indicates that Zlatoust-36 has done most of the work on dismantlement of warheads so far.[176] Assembly of ballistic missile reentry vehicles may

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[171] Earlier, during the 1992 Summit between Presidents Bush and Yeltsin, a Russian spokesman indicated that warheads would be dismantled at three sites: Arzamas-16, Chelyabinsk-70, and Sverdlovsk-45.

[172] Nizhnyaya Tura is located at 58° 40'N/59° 48'E. 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. "Elektrochimpribor" sounds like another name for the Urals Electromechanical Plant (or Electrochemical Combine), but this enrichment facility is at Sverdlovsk-44, as opposed to Sverdlovsk-45.

[173] Lt. Gen. James R. Clapper, Jr., USAF, Director of the U.S. Defense Intelligence Agency, Hearings Before the Senate Committee on Armed Services, S. Hrg. 102-755, 22 January 1992, pp. 55-56.

[174] Ibid.; and Akira Furumoto, *Tokyo Yomiuri Shimbun*, in Japanese, 17 November 1991, Morning Edition, p. 1 (translated in *Foreign Broadcast Information Service-SOV-91-225-A*, 21 November 1991, p.3.). Yuryuzan is located at 54° 42'N/58° 25'E.

[175] Lt. Gen. James R. Clapper, Jr., USAF, Director of the U.S. Defense Intelligence Agency, Hearings Before the Senate Committee on Armed Services, S. Hrg. 102-755, 22 January 1992, 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.

[176] 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. 498.

take place at Zlatoust-36. It is not clear whether Zlatoust-36 receives preassembled physics packages for installation in the reentry vehicles, or whether it assembles both. A separate facility referred to in the START Treaty as the Zlatoust Machine Building Plant, presumably in Zlatoust, is a submarine-launched ballistic missile production facility.

Penza-19, with its closed city of Zarechnoye (population 61,400) is at Kuznetsk, 115 km east of Penza and 300 km southeast of Sarova where Arzamas-16 is located.[177] The site is characterized by DIA as, "a small component fabrication and assembly plant."[178] It is said to manufacture electronic warhead components perhaps like those manufactured at the Kansas City Plant for U.S. nuclear warheads.

Arzamas-16 is identified as a warhead fabrication plant by Minister Mikhailov, but not by DIA or the CIA. Its capacity is therefore thought to be small. Dismantlement of tactical nuclear warheads removed from Ukraine has already started at Arzamas-16, according to the Russian press.[179]

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.[180] It was explained that the process of dismantling warheads takes more time than the assembly process.[181] Previously Russian officials have

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

[178] Lt. Gen. James R. Clapper, Jr., USAF, Director of the U.S. Defense Intelligence Agency, Hearings Before the Senate Committee on Armed Services, S. Hrg. 102-755, 22 January 1992, pp. 55-56. Gershwin, CIA, Hearings before the House Committee on Appropriations, DOD Appropriations for 1993, Part 5, 6 May 1992, p. 498, said the Russians have two disassembly facilities, at Nizhnyaya Tura and Yuryuzan. 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.

[179] "Unichtozhayetsya ukrainskoye yadernoye oruzhiye," *Izvestiya*, 23 August 1992, p. 1.

[180] 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.

[181] 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

(continued...)

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, "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 dome 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."[182]

Plutonium and uranium components for weapons, including plutonium pits and highly enriched uranium components for thermonuclear secondaries, are manufactured at Tomsk-7, which is also the site of a uranium enrichment plant and plutonium production reactors and the proposed site for a large warhead fissile component storage facility.

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 (formerly All-Union) Automatics Research Institute is a Minatom institute that manufactures commercial pulsed neutron generators and portable X-ray devices. It probably makes the neutron generators for nuclear warheads. The A.A. Bochvar All-Russian Scientific Research Institute of Inorganic Materials (VNIINM), founded in 1945 in Moscow, conducts research in several areas, including chemical separation and nuclear waste management processes and technologies. 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).

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[181](...continued)
("gravel gerties") and can assemble (or disassemble) 1500 warheads per year when operating one shift per day. If the Pantex plant were operated three shifts per day it could handled close to 4500 warheads per year.

[182] Gershwin, CIA, Hearings before the House Committee on Appropriations, DOD Appropriations for 1993, Part 5, 6 May 1992, p. 498.

Nuclear Weapon Materials Production

Russian data suggests that the Soviets had about 140 metric tons (MT) of weapon-grade plutonium in weapons when the stockpile peaked in 1986 at about 45,000 warheads.[183] We estimate that through 1992, the 13 graphite production reactors produced some 176 MT of plutonium-equivalent. A Soviet tritium inventory growing to about 90 kilograms (kg) by 1986, when the 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 170 MT of plutonium is in, or available for, weapons.[184] Allowing 30 MT for what is in the production pipeline, in scrap, and any reserve -- this represents less than 20 percent of the total inventory -- the remaining 140 MT would appear to be a good estimate of what was in weapons when the stockpile peaked in 1986.

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 produced about 500 MT of HEU for a weapons stockpile that peaked at about 32,000 warheads. If the Soviet HEU requirement was comparable on a per warhead basis, their stockpile of 45,000 warheads would have entailed on the order of 700 MT of HEU in and available for warheads. Russia has agreed in principle to sell 500 MT of HEU from weapons to the United States. If they intend to retain an HEU inventory comparable to that of the United States, their total inventory today is closer to 1000 MT. We take as our best estimate the mid-point between these two values, namely, an HEU stockpile of about 850 ± 150 MT.

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 development of gaseous diffusion technology for the enrichment of uranium. More recently, Russia relied on graphite reactors for plutonium production, and heavy water, and since the 1980s light water

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[183] According to Academician Yuri Trutnev, discussing an Arzamas-16 proposal to destroy plutonium pits with underground nuclear explosives, there are about 62 MT of plutonium in 20,000 pits. this implies 3.1 kg per warhead, or about 140 MT 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 MT of weapon-grade plutonium.

[184] We assume one percent losses (1.8 MT) at the chemical separation plants, 2.2 MT used in 715 nuclear tests, and about 1.5 MT used for making breeder reactor fuel.

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 they had adopted a program to close down all plutonium-producing reactors by the year 2000, three by 1996 and the last three by 2000.[185] 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."

As of the end of 1992, three of 13 graphite moderated plutonium production reactors remained operational. These last three are dual purpose reactors producing heat and/or electricity. The year 2000 production cut-off apparently was chosen as the date by which a new power plant could brought on line to replace the dual purpose reactor at Krasnoyarsk-26, the last production reactor to be shut down.

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."[186] 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 tons of weapon-grade plutonium (perhaps as much as 120 MT) and several hundreds of tons of HEU (at least 500 MT and perhaps as much as 800 MT) will be removed from warheads committed to be

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[185] 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 is blended with freshly produced plutonium to meet impurity specifications. In the U.S. weapons program the plutonium recovered from retired warheads used to be sent to the Rocky Flats plant, where a pyrochemical process was used to remove the americium-241. This and other operations associated with plutonium pit manufacture at the Rocky Flats plant have now ceased.

[186] Statement by Evgeny 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.

eliminated by Presidents Gorbachev and Yeltsin. Current government policy is to store all the plutonium from dismantled warheads for at least a decade, most likely at Tomsk-7. How Russia will ultimately dispose of the plutonium may not be decided for several years. Senior Minatom officials want to complete the construction of the mixed-oxide (MOX) fuel plant at Chelyabinsk-65, and use the plutonium as MOX fuel in civil reactors.[187] In this case the plutonium fuel could be used in Russia's seven VVER-1000 [vodavodyanoi energeticheskiy reaktor-1000] light water reactors at a concentration of 0.3 MT per reactor (one-third core loading), with an annual consumption of 2 MT for all seven reactors.[188] The plutonium makeup requirement for the BN-600 is 0.6 MT/y; and for the BN-800, none of which have been biult, is 1.6 MT/y. Clearly it would 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.[189] 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 MT of HEU from weapons to the United States for this purpose.

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

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

[188] Assuming a capacity of 3000 MW_t, a burnup of 40,000 MWd/MT, 4.4% enriched fuel, and a capcaity 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 MT; or 1.9 MT for seven reactors. At a burnup of 36,000 MWd/MT, and capacity factor of 0.8 (assumptions used in Table 20), the consumption increases to 0.35 Mt per reactor. As of mid-1993 there were an additional two VVER-1000 reactors in Russia in advanced stages of construction, which could bring the total annual consumption to 2.4 MT. In addition, there are 15 VVER-1000 operating and in advanced stages of construction in Ukraine and Bulgaria, but the chances of loading them with Russian plutonium is remote.

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 MT/y for seven VVER-1000s.

[189] According to Arzamas-16 experts, as a rule of thumb, each kiloton of nuclear explosive yield could produce about 1000 MT of "melted substance." Thus, a 100 kiloton explosion would melt 100,000 MT of plutonium and rock. If 62 MT of plutonium from 20,000 warhead pits were eliminated in this manner the resulting plutonium would be uniformly distributed in vitrified rock at a concentration of 6×10^{-4} grams of plutonium in each gram of vitrified rock.

Plutonium and Tritium Production Sites

Plutonium production for weapons in Russia has taken place at three locations: Chelyabinsk-65 (previously Chelyabinsk-40, and for many years known in the West as the "Kyshtym Complex"), near Kyshtym in Chelyabinsk Oblast; at the Siberian Atomic Power Station, located at the Siberian Chemical Combine (Tomsk-7) on the Tom River 15 km northwest of Tomsk; and at The Mining and Chemical Combine (Krasnoyarsk-26) on the Yenisey River, 10 km north of Dodonovo, and 64 km northeast of Krasnoyarsk in Siberia. Prior to 1987, there were 13 operational plutonium production reactors at these three sites — five at Chelyabinsk-65, five at Tomsk-7, and three at Krasnoyarsk-26.[190] 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, steam for district heating, and/or electricity.

At Chelyabinsk-65 there are currently the two light water production reactors that are used for the production of tritium (if it is still being produced) 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. It is not known whether tritium production and processing have ever taken place at Tomsk-7.

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

A closed city until 1989, Chelyabinsk-65 was not on maps of the former Soviet Union. Prior to about 1990, it was called Chelyabinsk-40. It is about 15 km east of the city of Kyshtym on the east side of the southern Urals in Chelyabinsk Oblast.[191] It is located in the area around Lake Kyzyltash, in the upper Techa River drainage basin among numerous other lakes with intercon-

[190] 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.

[191] Chelyabinsk-65 is located at 55° 44'N/060° 54'E, near the cities of Kyshtym (population about 40,000) and Kasli (population about 20,000), and about 70 km north of Chelyabinsk (population 1.2 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.

necting watercourses. Chelyabinsk-65 is run by the production association Mayak[192] (translated "Lighthouse" or "Beacon"), and the defense enterprise is referred to as the Mayak Chemical Combine.[193] In 1989, an American delegation was told that there were some 10,000 employees and 40,000 dependents at Chelyabinsk-65. Between Lake Kyzyltash and Lake Irtyash, about 10 km from the reactor area, is Ozersk, the military-industrial city built to house the Chelyabinsk-65 work force, and whose population is 83,500.[194] Once the city bore the name of Beria. Today, local inhabitants call it Sorokovka ("Forties Town").[195]

Probably fashioned after the U.S. Hanford Reservation, Chelyabinsk-65 was the Soviet Union's first plutonium production complex. Construction was started on the first buildings of the new city in November 1945 and in June 1948 the first production reactor was brought on line.[196] To construct the complex reportedly some 70,000 inmates of 12 labor camps were used.[197] The Chelyabinsk-65 site occupies an area on the order of 200 km^2.[198] The industrial area bordering the southeast shore of Lake Kyzyltash, where the reactors and chemical separation plant are located, is about 90 square kilometers (km^2).[199]

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

[193] In a 1957 CPSU Centeral Committee document it was referred to as Combine No. 817; Ye. Slavskiy, "Whose Sins Are We Paying for Today?," *Moscow Rossiyskiye Vesti*, 27 January 1993, p. 1 [translated into English in *Joint Publications Research Service*-TEN-93-004, 8 March 1993, pp. 51-52].

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

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

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

[197] 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.

[198] 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).

[199] 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).

It was at this site that Kurchatov, working under Beria, built the Soviet Union's first plutonium production reactor.[200] Fursov, who with Kurchatov had designed the F-1 pile at Laboratory No. 2, oversaw Chelyabinsk-65 as Kurchatov's main representative.[201] Academician Khlopin was the first scientific director of Chelyabinsk-40. Khlopin and workers from the Radium Institute completed the first chemical plant for the separation of plutonium from irradiated uranium. Boris A. Nikitin was the engineer responsible for developing the technology for extracting the plutonium from the uranium and fission products.[202] A. Bochvar was responsible for processing the plutonium and fabricating the two sub-critical fissile masses for the bomb.[203]

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 for plutonium and uranium recovery. In 1990 the combine was also producing special (read "military") instruments.[204] No longer producing weapon-grade plutonium, the complex in recent years has begun to produce a variety of equipment for civilian use.[205]

The known facilities at Chelyabinsk-65 are listed in Table 3. There are seven production reactors--five graphite-moderated water-cooled reactors and two light water-moderated and cooled reactors, one of which was a heavy water-moderated production reactor before being rebuilt in the late-1980s. The graphite reactors, which had a combined capacity of 6565 megawatts thermal (MW_t),[206] were used for plutonium production before being shut down between 1987 and 1992. The two light water reactors, each with a capacity of about 1000 MW_t, are used for the production of tritium and other

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

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

[202] Ibid.

[203] Ibid.

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

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

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

isotopes.[207] Mayak produces isotopes for special applications, such as plutonium-238 (Pu-238) for thermo-electric power sources. At least 5 kg of Pu-238, and as much as 40 kg over the next 5 years, will be sold to the United States to be used by NASA to power unmanned space missions.

At Chelyabinsk-65 there are two chemical separation areas. One houses a 400 metric ton of heavy metal per year (MTHM/y) chemical separation plant, called RT-1, which was formerly used to recover plutonium for weapons, but is now used to reprocess civil power reactor (VVER), naval reactor, and research reactor fuel. RT-1 may also be used to reprocess the enriched uranium spent fuel elements from the two light water production reactors, since RT-1 also handles the spent naval fuel which is also highly-enriched. A separate chemical separation area houses facilities for recovering tritium and special isotopes produced in target elements irradiated in the light water production reactors. Plutonium-238 is recovered at Plant 45 in this area. 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.[208] 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. There are also some 60 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.

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.[209] Viktor Ilich Fetisov was identified as the director of the Mayak Production Association in 1990-1992; Aleksandr I. Pishchepov was identified as the deputy director for procedures in 1990.[210]

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

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

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

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

[210] Colonel L. Nechayuk, "In the City Without a Name,"*Krasnaya Zvezda*, 19 October 1990, First Edition, p. 2 (translated into English in *FBIS*-SOV-90-208, 26 October 1990, p. 56); and S. Sergeyev, "Novosti" newscast, *Moscow Teleradiokompaniya Ostankino Television First Program Network*, in Russian, 31 July 1992, 1700 GMT (translated in *Joint Publications Research Service*, JPRS-TND-92-027, 5 August 1992, p. 26).

and AV-3 Reactors are located in a separate area of the complex.

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

A-Reactor: The first reactor, "A" reactor, was graphite-moderated with 1168 channels. It was originally designed to operate at 100 megawatts thermal (MW_t), but was later upgraded to 500 MW_t.[211] Called "Anotchka" ("Little Anna" in English), A-Reactor was designed by Nikolai Dollezhal, and constructed in only 18 months.[212] It is located in Building 1 in the Plant 156 area. A-Reactor was loaded with all the uranium then available in the country, and began operation on 19 June 1948. It was shut down 39 years later in 1987. Its plutonium was used to fabricate a ball almost 10 cm in diameter which was used in the first Soviet atomic bomb tested 29 August 1949.[213]

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

A confinement system was used to control radioactive releases in the event of an accident. Accidental fission product releases were vented into a 100 cubic meter (m^3) tank. Gas and particulates would enter from one side and travel through a "labyrinth," gas holdup allowing short-lived activity to decay. Filters made from special textiles were designed to capture cesium and strontium isotopes. For iodine-131 there were absorber columns of activated carbon.

The A-Reactor is being dismantled in three stages. The first stage was shutdown and fuel unloading. The second stage, in progress, will take up to five years and involves dismantling of the control and operating system and filling the empty spaces with concrete. During the third stage, which will last

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[211] "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].

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

[213] 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.

20 to 25 years, there will be no activity, after which a decision will be made to bury the reactor on site or remove it.

IR-Reactor: Housed in Building 701, a separate building adjacent to the A-Reactor, is a small 65 MW_t dual-purpose graphite-moderated reactor with 248 channels, used for plutonium production and (1) fuel rod research, (including strengthening fuel elements for the A-Reactor, permitting an increase in its power level to 500 MW_t), and (2) testing the fuel assemblies for the RBMK power reactors. The IR-Reactor was the third production reactor (the second graphite-moderated reactor) constructed at Chelyabinsk-65. Construction began on 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.

AV-1 Reactor: There are three large reactors, AV-1, AV-2 and AV-3, that appear to be of similar, if not the same design. Each has 2001 channels. Characteristics of the AV-2, the only one of the three which has been described in the open literature, are given below. The AV-1 was decommissioned on 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 April 1951, Shut down [14] July 1990."[214] 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."[215] 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

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

[215] Ibid.

among five shifts per day with 28 people per shift.[216]

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.[217]

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. Yefrim P. Slavskiy, then complex chief engineer and later Minister of Medium Machine Building, claims he had to enter the radiation area and place his hand on one of the heat exchangers to convince the designers that the heavy water had frozen.[218]

Lyudmila: Originally a heavy water reactor and presumably the one just described, "Lyudmila" was rebuilt in the late-1980s as a light water-moderated and cooled production reactor. Still operational with a capacity of about 1000 MW_t, it is used for the production of tritium (if tritium is still being produced) and special isotopes, e.g. Pu-238.

Ruslan: A second light water-moderated production reactor, called "Ruslan," also nominally powered at 1000 MW_t, is also currently being used for the same purpose.[219]

Chemical Separation Facilities: Chemical separation (radiochemical, or reprocessing) plants are used to separate chemically the plutonium and uranium from the highly radioactive fission products contained in the irradiated reactor fuel elements. There have been at least two or three such plants at Chelyabinsk-65 at two separate chemical separation areas. The first chemical separation plant went into operation in December 1948, six months after the startup of the A-Reactor, was not used after 1961, and was decommissioned at a later date.[220] Currently operating are the RT-1 plant,

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[216] Ibid.

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

[218] "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.

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

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

described in more detail below, and separate facilities process the target elements irradiated in the two light water isotope production reactors.

The initial chemical separation technology used at Chelyabinsk-65 was based on a precipitation processes developed at the Radium Institute in St. Petersburg (then Leningrad) under the guidance of Academician V.G. Khlopin. During the 40 year period of radiochemical plant operation the chemical separation and waste management technologies have changed substantially several times.[221] The precipitation process was changed as a consequence of the waste tank explosion in 1957 (discussed below).

The initial technology was based on slightly soluble sodium uranyl acetate ($NaUO_2(CH_3COO)_3$) precipitation from nitric acid solutions of irradiated uranium. Plutonium, when in the six valence state in the form of sodium plutonyl acetate, 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. The resulting HLW had a sodium nitrate concentration exceeding 100 grams per liter (g/l) and sodium acetate concentration of 60-80 g/l.[222]

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. This waste processing technology may have been put into use about 1953, when the intermediate waste storage facility was placed into operation. It was impossible to achieve high concentration of the waste due to its high salinity. Moreover, the solutions contained a large quantity of deficient reagent - sodium acetate. Consequently, radionuclides were concentrated by 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

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[220](...continued)
"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.

[221] 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).

[222] Ibid.

with alkali. From distillation residue containing 1100-1150 g/l of sodium nitrate, its crystallization and even recrystallization were realized.[223]

Today the Russians rely on the PUREX (Plutonium-URanium-EXtraction) process, or a variant of PUREX, at their chemical separation plants, as evidenced by the descriptions of the RT-1 plant (below) and the chemical separation plant at Tomsk-7 that experienced a processing tank explosion on 6 April 1993. In the PUREX process, first used in the United States in 1954, fuel elements are 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 tributyl phosphate in a kerosene carrier). Sucessive 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.

RT-1 Radiochemical Plant: One of the combine's currently operating chemical separation plant, designated RT-1 and located in Area 235, started processing spent fuel from the production reactors in 1956. It was modified to handle stainless steel and zircaloy clad spent fuel; and in 1976 shifted from processing military production reactor fuel, to processing spent fuel from naval (both submarine and civil icebreaker) reactors (which apparently occurred first), test reactors, two demonstration LMFBRs (the BN-350 on the east coast of the Caspian Sea in Kazakhstan and BN-600 at Belyarskiy in the Urals), and the first generation light-water reactors--the 440 MW_e light-water moderated and cooled power reactors (VVER-440s).[224] It is the only facility for power and naval reactor fuel reprocessing. The plant in 1992 employed about 2500 people.[225]

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

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[223] Ibid.

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

[225] 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.

below).

The RT-1 reprocessing plant capacity is 400 MTHM/y, comparable to the UP2-400 (oxide) plant that was operated by Cogema at La Hague in France.[226] In 1989 it was reported that over the plants 10-year "civilian" lifetime, throughput has averaged 200 MTHM/y.[227] In 1991 it processed 160 MTHM of spent fuel; about 120 MTHM in 1992, and in 1993 it is not expected to exceed the 1992 throughput. The recent decline in the rate of spent fuel proceeding is a consequence of 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 Chech and Slovenia), Germany and Hungary awaiting legal clarification whether spent fuel should be regarded as a nuclear waste.

The spent fuel from the power stations arrives 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 is no backlog of spent fuel awaiting reprocessing. An interim wet storage facility for 2000 MT of spent VVER-440 fuel is about 70 percent complete.[228] According to Evgeniy Dzekun, chief engineer of the RT-1 reprocessing plant, ". . . as long as we keep reprocessing, we won't need it."[229]

From pool-storage the spent fuel is transferred to the preparation and chopping area at the head end. There the 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% and 0.06% of their content in spent fuel, respectively.[230]

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[226] Oleg Bukharin, notes taken at meeting with Evgeny 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 MTHM in 349 fuel elements. Therefore, RT-1 capacity is on the order of 3300 assembles/y.

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

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

[229] Ibid.

[230] 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.

The produced nitrate solutions are the suspension of high dispersity 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.[231]

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% solution of tributilphosphate (TBP) in n-paraffine dilutor (C_{11}-C_{14}).[232]

After the second extraction cycle the factors of purification of uranium and plutonium from fission products are (1-1.5) x 10^7 and 3 x 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.[233]

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, macroimpurities 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).[234] 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.

The RT-1 reprocessing technology, currently provides recovery of 99 percent of the uranium and plutonium, and 85 percent of the neptunium.[235] Americium and curium are not extracted at present and remain with the fission products. From one MT of VVER spent fuel with a burnup of 30,000

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[231] Ibid.

[232] Ibid.

[233] Ibid.

[234] Ibid.

[235] "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).

MWd/MT (corresponding to a reduction in the uranium enrichment from 3.6 to 1.25 percent) one extracts:[236]

	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 MTHM/y, RT-1 is recovering 114 MT low-enriched uranium (LEU) (1.25% U-235) and 1 MT 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% U-235) is now blended with higher enriched uranium to produced the desired RBMK fuel enrichment (2.4 % U-235).[237]

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 plutonium-dioxide (PuO_2) is being placed into temporary storage at Chelyabinsk-65. Most of the Np-dioxide is also sent to storage. Part of it has been used for Pu-238 production and research purposes.[238]

At RT-1 the PuO_2 is loaded into the transport cannisters, each with a capacity of 1930 cm^3 (not greater than 3 kg PuO_2). The cannister 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 cannister is placed into a sealed container, both made of X18H10T stainless steel. This package is intended for transport to and store

[236] Currently VVER-440s are being shifted from a three to four year fuel life with increase in burnup to 40,000 MWd/MT; 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.

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

[238] Ibid.

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 MT.[239] By the end of 1992 the inventory would have grown to an estimated 25.4 MT; and as noted previously, it is expected to continue to grow at a rate of about 1 MT/y as long as the RT-1 throughput remains at the 1992 rate of 120 MTHM/y. Through the beginning of 1992 approximately 4 MT of plutonium had been recovered from processing BN-350 asnd BN-600 spent fuel, but some of this plutonium has been used to produce new MOX fuel.[240]

We do not know what fractions of the spent fuel processed and the 25.4 MT of separated plutonium are from naval fuel, and what fractions are from VVER 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 4, for the year 1992, when 120 MTHM 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 light water 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 4.

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 5). These

[239] 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.

[240] 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.

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 fuel.[241] Nitric acid ($HN0_3$) is used most commonly, but other types of acid are also used (see Carboxylic Acids in Table 5).[242] 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.[243]

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 5). 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 5). 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.[244] 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.

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[241] Acids are generated primarily from the first cycle raffinate wastes.

[242] 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.

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

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

Special Isotope Separation Facilities: 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 for medical use and radioisotope thermo-electric generators (RTG).[245] The RTGs typically use energetic beta emitters, e.g., Sr-90 or Ce-144, or alpha emitters, e.g., Pu-238 or Pm-147.

Mayak Production Association has advertized its capability to produce isotopes for special applications. Under a series of agreements signed in December 1992, the U.S. Department of Energy (DOE) will purchase Pu-238 from Mayak for use in unmanned space missions conducted by the U.S. National Aeronautics and Space Administration (NASA). The terms of the agreement call for the DOE 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.[246]

The plutonium-238 is recovered at Plant 45. At 1645 hours on 17 July 1993, there was an accidental release of radioactivity to the atmosphere from Plant 45. According to preliminary data, the accident was due to a seal failure in sorption column, a 25 liter tank, 1.5 m high and 16 cm in diameter, in a cell covered by a layer of concrete and steel. About 20 liters of plutonium solution leaked into the cell. The ventilation system of the building successfolly 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.[247]

MOX Fuel Fabrication Facilities: At Chelybinsk-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 1 MT of "military," probably weapon-grade, plutonium was used. The fuel composition was plutonium alloys and PuO_2 fuel.[248]

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[245] 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.

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

[247] Andrey Illesh and Valeriy Yakov, "Discharge of Radioactive Substances at Chelyabinsk-65 Not as Harmless as the Ministry of Atomic Energy States," *Moscow Izvestiya*, in Russian 21 July 1993, First Edition, p. 2 (Translated into English in *Foreign Broadcast Information Service*, FBIS-SOV-93-138, 21 July 1993, p. 35); Yevgeniy Tkachenko, *Moscow ITAR-TASS*, in English, 0852 GMT 22 July 1993, (Reproduced in *Foreign Broadcast Information Service*, FBIS-SOV-93-139, 22 July 1993, p. 45); and *NucleaR nEWS*, aUGUST 1993, P. 88.

[248] V.N. Solonin, "Utilization of Nuclear Materials Released as a Result of Nuclear Disarmament."

"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 5 fuel assembles/y) and used "military," presumably weapon-grade, plutonium from BN type reactors (fast reactors).[249]

"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 10 fuel assemblies/y) and has been using "military" plutonium.[250]

"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 10 fuel assemblies/y) and has been using "military" plutonium.[251]

"Complex 300" MOX Fuel Fabrication Plant: This MOX fuel fabrication plant was designed to manufacture the fast breeder reactor fuel assemblies for the three BN-800 South Urals Project, handling 5-6 MT of plutonium annually.[252] Construction of the MOX plant (and the South Urals Project) was started in 1984,[253] and then suspended after expending 71.3 million rubles through 1989.[254] The MOX plant has been variously reported as being 50 to 70 percent complete.[255] 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 MT Pu/y, for the production of MOX fuel for VVERs,[256] but more recently Krasnoyarsk-26 has been named as the site for a new VVER MOX fuel plant.

South Urals Project: Construction of the South Urals Nuclear Power Station, which originally was intended to consist of three 800 MW_e liquid metal fast breeder reactors,[257] was begun in 1984.[258] Only the concrete footings for

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[249] Ibid.

[250] Ibid.

[251] Ibid.

[252] 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 MT, this would amount to about 7 MT annually.

[253] "Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. I, p. 10.

[254] "Proceedings of the Commission on Studying the Ecological Situation in Chelyabinsk Oblast," Vol. II, p. 22.

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

[256] Ibid.

[257] The BN-800s may actually be rated at 750 MW_e each.

first two reactors were put in place before construction was suspended in 1987.[259] The third reactor did not advance beyond the planning stage.

The reactor complex is clearly shown in French SPOT (Satellite Pour l'Observation de la Terre) satellite photographs of the Kyshtym area taken in 1987 (See Figure 1 and *Nuclear Weapons Databook, Vol. IV, Soviet Nuclear Weapons,* pp. 82-83). It is located on the northwestern edge of Reservoir No. 10 (See Figure 3). At the construction site the soil contamination ranges from 1.0-1.5 Curies/square kilometer (Ci/km^2) for strontium-90 (Sr-90) and 4.0-4.5 Ci/km^2 for cesium-157 (Cs-137).[260]

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.[261]

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.[262] 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.[263] 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 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

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[258](...continued)
[258] "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.

[259] Ibid.

[260] "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 Zhizn*, 1 November 1989.

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

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

[263] "South Urals construction to resume in 1993," *Nuclear News*, December 1992, p. 44.

arguments have been challenged, and neither supports the construction of a breeder over a VVER. For an extensive critique of the South Urals project, which cites numerous examples where the project justification or supporting data is incorrect or incomplete, see "Resonance," Chelyabinsk, 1991.

The breeder program is plagued by safety concerns — leaks in the sodium-water heat exchangers and the possibility of a runaway chain reaction during an overheating accident — and by problems encountered in the development of "mixed-oxide" (MOX) plutonium fuel. The BN-600 breeder at Beloyarskiy continues to operate at half power, and until recently operated with highly-enriched uranium rather than plutonium. The Soviet breeder is increasingly vulnerable to charges that it is uneconomical. Even its backers cheerfully admit that breeder generated electricity is "2.5 times more expensive" than power from conventional power plants.[264] 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.

Radiation Exposure to Workers: Nikipelov, et al., in 1990 published an analysis of the radiation doses to workers at A-Reactor and the chemical separation plant at Chelyabinsk-40.[265] The distributions of worker exposures at these two facilities are reproduced in Table 6. The period 1948-1952 is characterized by exceedingly high exposures. At A-Reactor the *average* annual worker dose peaked at 93.6 rem in 1949, the first full year of operation; and at the chemical separation plant the average annual dose peaked at 113.3 rem in 1951. From 1949 to 1951, 0.5 or 1.8 percent of the workers at either A-Reactor or the chemical separation plant were receiving doses in excess of 400 rem annually, more than 80 times the current occupational exposure standard. Because plutonium production was a higher priority than worker safety many workers received doses exceeding the administrative limits established by the Ministry of Medium Machine Building, which were:

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[264] "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].

[265] 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).

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.

The sum of the average annual dose for the first decade of operation was 226 rem at A-Reactor, and 438 rem at the chemical separation plant. Assuming a risk of 0.6×10^{-3} cancer fatalities/man-rem,[266] 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.[267]

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; and
high-level - >1 Ci/l.

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

[266] 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.

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

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 amoung 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.

We estimate some 780 million curies (MCi) of the Sr-90 and Cs-137, were produced through 1992, of which, following radioactive decay, some 560 MCi remained as of end-1992.[268] When the activity of the daughter products, Y-90 and Ba-137m, are included these figures are doubled, i.e, some 1550 MCi produced and some 1100 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.[269] This is presumed to be measured in terms of the Sr-90 + Y-90 + Cs-137 content.

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 insoluable 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.

[268] 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/MT); 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/MT). We estimate that 350 MCi of Sr-90 were produced through 1992, and 250 MCi remained after radioactive decay; and 430 MCi of Cs-137 were produced, decaying to 310 MCi. In 1992 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.

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