actually produced nine years after construction started.[281] Valeriy Lebedev, director of Krasnoyarsk-26 said in 1990 that the Minister of Atomic Power and Industry ordered the construction of RT-2 stopped for a five year period due to lack of funding.[282] Two hundred million rubles were spent on the project. Just preserving the construction would require 30 million rubles, but in 1991 only 1.5 million rubles was allocated.[283]

Waste Management Activities: Little is known about the management of radioactive effluents and waste manage practices associated with the production reactors. Combine officials claim that the gas purification efficiency is 99.9 percent, but this must apply to iodine and other particulates, and not to noble gases. The underground ventilation system reportedly changes the air volume every ten hours. Liquid radioactive waste is injected into the ground at the depth of 270 m at the "Severny"(Northern) testing ground, which is to be closed down in 2000, which is also when the last reactor is scheduled to halt operations.

Due to the discharge of coolant water from the production reactors (and presumably from laboratory operations and the chemical separation plant within the same underground tunnel complex), radioactivity is discharged into the Yenisey River. An investigation in 1990 of the radioactive contamination in the Yenisey showed that:[284]

- The contamination of the river could be traced for a distance of more than 800 km, and the contamination of the floodland for a distance of 1500 km, down the river from the discharge site.

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281 "Regular Daily Spot: Commission is Here for 1 Hour But We...", *Komsomolskaya Pravda*, June 15, 1989.

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

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

284 In August-September, 1990 specialists of the Institute of Applied Physics of the State Committee for Hydrometeorology together with scientists of the Krasnoyarsk Research Centre of the Siberian Branch of the Russia Academy of Sciences investigated into the current state of the radiation situation of the Yenisey River from Krasnoyarsk to Igarka. Some chapters of the report made by the expedition were published in "Ekologichesky Vestnik", a newspaper of Krasnoyarsk ecologists, No 3, 1991. A summary of these results were reported by Alexander Bolsunovsky, "Russian Nuclear Weapons Production and Environmental Pollution," paper presented at the Conference on "The Nonproliferation Predicament in the Former Soviet Union," Monterey Institute of International Studies, Monterey, California, April 8, 1992, from which the following is taken. Bolsunovsky also reported that the results of the investigation carried out by the scientists of the Institute of Applied Geophysics, as well as by the North Yenisey geophysical expedition, and by the Krasnoyarsk complex geophysical expedition in 1991, confirmed the fact the yenisey has been contaminated by the chemical combine.

• Discharge at the right bank causes a higher rate of contamination along the right side of the river for a distance of 250 km, and along the right bank for a distance of 50 km from the discharge site.

• The gamma dose in the water along the axis of a radioactive jet at the discharge site was 3000 μR/h.

• The density of bottom deposits contamination along the right bank at Atamanovo Village was: 35 Ci/km^2 of chromium-51, 3.3 Ci/km^2 of cobalt-60, 2.5 Ci/km^2 of zinc-65, 2.2 Ci/km^2 of cesium-136. An uniform distribution of cobalt-60 and cesium-137 was observed to the depth of 15 cm.

• Contaminated algae can be a secondary source of radioactive contamination of bottom deposits in the Yenisey River and the river-side. The coefficient of accumulation of long-lived nuclides by the algae was $(1\text{-}6)\cdot10^3$. The body of the fish caught at 700 km from the discharge site downstream contained $(3\text{-}9)\cdot10^{-10}$ Ci/kg of cesium-137 and $(5\text{-}6)\cdot10^{-9}$ Ci/kg of zinc-65. Migrating fish can carry radioactivity for long distances both downstream and upstream from the source of contamination.

• Radioactive contamination of the floodland of the Yenisey River is extremely uneven. Along the first 25 km from the sources the contamination density drops from 41 to 7 Ci/km^2. After that, for a distance of 500 km the contamination density does not depend on the distance from the source and fluctuates within the range of 3-10 Ci/km^2, this due to hydrological peculiarities of the river. For a distance from 500 to 1500 km from the source the contamination density of the floodland is up to 0.1 Ci/km^2 of cesium-137 and cobalt-60. The zone of radioactive contamination of the floodland of the Yenisey River is a narrow, 5-50 m wide, strip of land along the river.

• Of the nuclides contained in the soil the most important in terms of sanitation were plutonium-238, -239, -240; cobalt-60; cesium-137, -134; manganese-54, zinc-65, europium-152, -154, -155; cerium-144 and strontium-90.

• At some plots the contamination density of plutonium-239/240 is 47 mlCi/km^2.

Others report that the level of gamma activity in the river exceeds background by a factor of five or six.[285] More than 400 km down the Yenisey, radiation levels up to 100 μR/h have been observed (the natural background level is 10 to 15 μR/h).[286] In the region of Lesosibirsk and Yeniseisk, the radiation level exceeds background by a factor of 10 to 14. In

[285] V. Yaroslavtsev, "The Yenisey's X-Rays" from "What Troubles our Conscience: A Polar Chernobyl Syndrome," *Vozdushnyy Transport*, October 4, 1990, p. 3. The article stated that the activity levels were established by two research expeditions by specialists from the Krasnoyarsk Scientific Center and the State Committee for the Protection of Nature.

[286] Ibid.

these same regions, and lower down the river, crumbly silty radioactive deposits are being discovered in many locations.[287]

A key feature of the RT-2 reprocessing plant was the method of handling radioactive waste. According to *Moscow Trud*, liquid waste was to be injected between layers of clay at a depth of 700 meters.[288] The waste was to be piped to the injection location, called Site 27, some 10 km from the site of the reprocessing plant on the opposite side of the Yenisey River.[289] Before construction was halted a two km long tunnel had been dug some 50 meters under the river. The tunnel and the decision to inject liquid waste into the ground generated substantial controversy and undoubtedly was partially responsible for the controversy leading to cancellation of construction. Work on the tunnel has been halted. It has been damaged and water is spraying into the tunnel from the concrete arch.[290]

Military Conversion Activities: With the shutdown of the two production reactors in 1992, the combine plans to build a plant for the production of polycrystaline silicon for semiconductor technology, producing 20 tons within two or three years. The combine is also examining the production of especially pure materials such as gallium arsenide, germanium and tellurium.[291]

Plutonium and Tritium Production

The sizes and startup dates of some of the Soviet production reactors are unknown; and none of the operating power levels and capacity factors are known. Consequently, there are large uncertainties associated with estimates of the total plutonium-equivalent production[292] based on the reactor operating histories alone. However, plutonium and tritium inventory data from several independent sources are consistent with what we know about the sizes and operating periods of the reactors, and permit us to derive reasonable estimates of the missing parameters. First, the sizes of most of the graphite

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287 Ibid.

288 "Secret Site," *Moscow Trud*, July 11, 1989.

289 "Checking for Stability," *Sotsialisticheskaya Industriya*, July 23, 1989. The distance to the injection location was reported to be 20 km, but other sources say 10 km is more appropriate.

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

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

292 Plutonium-equivalent production is a measure of the total production of plutonium and other isotopes (usually tritium), where the unit of measure is the amount of plutonium alone that could have been produced. The production of one kg of tritium is equivalent to the production of 72 kg of weapon-grade plutonium.

reactors were estimated by comparing the respective number of channels to the number of channels in the original eight U.S. graphite production reactors at Hanford. The capacity factors (i.e., the average power level divided by the full power level) were then chosen so that the cumulative plutonium and tritium production was consistent with what we know from other sources.

At Chelyabinsk-65 we know the A-Reactor was upgraded from 100 to 500 Mw_t, and the IR-Reactor was 65 Mw_t. The last three reactors had 2001 channels and are assumed, therefore, to be comparable in size to the C-Reactor at Hanford. We have assumed that the AV-1 and AV-2 Reactors began operating on January 1, 1952 and April 15, 1951, respectively. The AV-3 Reactor startup was on September 15, 1952. We assume each of these three reactors began operation at a power level of 650 Mw_t, and each was upgraded over a six year period to 2000 Mw_t.[293] We further assumed that each reactor operated at an average capacity factor of 0.4 in the first year, and 0.5 thereafter. Under these assumptions, as seen in Table 10, the total production by the five graphite production reactors at Chelyabinsk-65 between 1948 and 1990 inclusive is estimated to be approximately 36 MT of weapon-grade plutonium-equivalent (6 percent Pu-240).

The heavy water reactor at Chelyabinsk was assumed to have begun operating at 250 Mw_t, and upgraded over a ten year period to 1000 My_t. It was shut down circa 1980, by which time it could have produced about 4 MT of plutonium-equivalent (See Table 11).

The five graphite reactors that make up the Siberian Atomic Power Station at Tomsk-7 are believed to have come on line about a year apart beginning in 1958. We assume the first two were upgraded from 650 Mw_t to about 2300 Mw_t (about the size of the C-Reactor at Hanford, which has about the same number of channels, after it was upgraded) over 6 years; the next two from 1300 Mw_t to 2300 Mw_t; and the last from 1950 Mw_t to 2300 Mw_t. Under these assumptions the Siberian plant would have produced some 55 MT of plutonium-equivalent (See Table 12).

The three graphite reactors at Krasnoyarsk-26 are assumed to be comparable in size to the AV-1, AV-2, and AV-3 reactors at Chelyabinsk-65. We assume each was about 2000 Mw_t. They came on line in 1957, 1961, and 1964. Together these three reactors are estimated to have produced about 30 MT of plutonium-equivalent (See Table 13).

The combined production at Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26 is estimated to be about 124 MT plutonium-equivalent. As shown in Table 14 assuming the tritium inventory gradually increased to about 37 kg

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[293] We use the Hanford C-Reactor as a model. C-Reactor had an original design power of 650 Mw_t, and was upgraded to 1740 Mw_t after 7.5 years, and to 2310 Mw_t over the next three years; see Thomas B. Cochran, et al., *Nuclear Weapons Databook*, Vol. II, p. 61.

over a 42 year period would have required some 6 MT of plutonium-equivalent production; leaving a stockpile of 118 MT. Assuming a few percent of the plutonium was lost as a consequence of weapons testing and recycling, the remaining plutonium inventory in weapons and available for weapons would be on the order of 115 MT. Of course we have selected a constant capacity factor of 0.5 over the lifetime of the reactors after the first year. We could just as easily selected an average capacity factor of 0.6, resulting in a plutonium inventory that is 20 percent higher, or about 140 MT. We have selected the lower figure to give results consistent with what we have been told by Russian sources. According to Evgeniy V. Mikerin, responsible for nuclear materials production at the Ministry of Atomic Energy, the Soviet Union, as of 1989, had produced "a little more" plutonium than the United States.[294] Another Russian source estimated the plutonium inventory in warheads at 100-120 MT.

An upper-bound estimate of plutonium-equivalent production can be made from the contribution to the buildup of krypton-85 (Kr-85) in the earth's atmosphere. Kr-85 is a gaseous fission product produced when U-235 or Pu-239 is fissioned. It is ordinarily released to the atmosphere when spent nuclear fuel is chemically processed. Chemically inert and with a radioactive half-life of 10.76 years, Kr-85 accumulates in the atmosphere. The Soviet contribution to the atmosphere's Kr-85 is estimated by subtracting the contributions from known sources outside the Soviet Union from the estimated total releases. The U.S. intelligence community monitors the atmospheric concentrations of Kr-85 and uses these data to estimate the cumulative plutonium-equivalent production over time and from that, the annual production rate. Using a similar approach, and the data on atmospheric concentrations of Kr-85 published in the open literature, von Hippel, et al. have estimated that the Soviets had released some 60 ± 10 megacuries of Kr-85 as of the end of 1983.[295] By our estimates the Soviet Union would have produced an estimated 26 MT of plutonium during the period 1983-1991, increasing the upper limit estimate to about 140 ± 20 MT.

Russia is currently producing plutonium at a rate of about 2 MT per year, and production is planned to continue for several more years.

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[294] During a 1989 visit to Chelyabinsk-40 by an NRDC/Soviet Academy of Sciences delegation, Mikerin was asked how much plutonium had the Soviet Union produced for weapons. His reply was "a little bit more than you."

[295] Frank von Hippel, David H. Albright and Barbara G. Levi, "Quantities of Fissile Materials in the U.S. and Soviet Nuclear Weapons Arsenals," Princeton University, March 27, 1986.

Uranium Enrichment

Early History

Upon entering Berlin in April 1945, the Soviets immediately began to dismantle and ship German industrial equipment to the Soviet Union. They also began to conscript leading German scientists for nuclear research.[296] German nuclear research groups were established in the Soviet Union around mid-1946, in parallel to existing Soviet research groups, to pursue uranium isotope separation. Competing German and Soviet research teams investigated each of the three enrichment technologies pursued by the United States during the Manhattan Project, namely, gaseous diffusion, electromagnetic separation, and gas centrifuge.[297]

By 1948 one of the German researchers, Professor Adolf Thiessen, had developed a laboratory-model gaseous diffusion barrier.[298] In early 1948 Thiessen's model barrier was selected by the Soviets for mass production at the Elektrostal plant south of Noginsk near Moscow.[299] Procurement of barrier material was underway by mid-1949, and by the end of the year small quantities had been delivered.[300] Though delivery of barrier material for 1949 did not meet schedules, no great concern over this was apparent until the fall of that year, at which time there was a definite increase in the priority for barrier material, together with a demand for more than double the annual

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[296] CIA, *The Problem of Uranium Isotope Separation by Means of Ultracentrifuge*, Report No. DB-0-3-633-414, October 8, 1957, p. 6. The Soviets apparently stopped short of using German scientists to assist in construction of the atomic bomb itself.

[297] Ibid., p. 8. Two groups of German scientists were located at Sinop and Agudzeri, respectively. These research centers were near Sukhumi on the Caucasian coast of the Black Sea, one about 5 km southeast of Sukhumi. A German research group also worked on the Troepfchen Method, a countercurrent diffusion technique whereby a thin vertical liquid stream enters a tube in which it breaks up into drops. These drops evaporate, and the heavy and light fractions of the fluid evaporate at different rates. The model gases that were used for this method were either chlorine or bromine; Ibid., p. 15. The competition between the Soviet and German research groups was one-sided. While the Soviets received the technical reports of their German counterparts, the Germans, with rare exceptions, received no reports from their Soviet counterparts, and no information as to their actual progress and accomplishments; Ibid., pp. 8, 9, 12.

[298] Ibid., p. 9. Thiessen's research group was working at the German research institute set up at Sinop in the Soviet Union; Ibid., p. 7.

[299] Ibid., pp. 9, 12. The location of the Elektrostal plant south of Noginsk is given in USAF, Air Intelligence Division, *A Strategic Vulnerability Study of the Soviet Atomic Energy Program*, Study No. 218, 1 February 1949. In separate tables, conflicting coordinates are given: 55°47'N 38°27'E and 54°47'25"N 38°27'37"E. The latitude of the latter is a typographical error and should read 55°47'25"N. Elektrostal is described as a large-scale uranium-smelting plant that produces uranium metal; Ibid., p. 4. "In or near the Elektrostal Steel Plant, the first large scale smelting of uranium took place in the spring of 1947 under the direction of German scientists specializing in the metallurgy of uranium"; Ibid., Annex III.

[300] CIA, Joint Atomic Energy Intelligence Committee, op. cit., p. 3 of accompanying "Facts and Discussion." About 300,000 square feet of barrier material were ordered for 1949.

production.[301]

Thiessen's barrier was completed sometime around 1949. It was the first of the various isotope separation methods in the Soviet Union to yield satisfactory results.[302] The Soviets, who had previously regarded the isotope separation race as an open one, decided henceforth to put all available resources into the gaseous diffusion method.[303] In 1949 the Soviet's first gaseous diffusion cascade was constructed in Kefirstadt (now called Verkh-Neyvinsk).[304] Corrosion problems were encountered in the barrier, rendering the plant incapable of producing weapon-grade uranium, that is, a U-235 concentration above 90 percent.[305]

Dr. Max Steenbeck, a former Siemens Company official in Germany, was conscripted by the Soviets to lead the German gas centrifuge research effort at Sinop (a suburb of Sukhumi on the Black Sea coast). In 1949 he proposed and received permission to begin construction of a centrifuge topping plant to enrich the output of the diffusion cascade from 50 percent to 90 percent U-235.[306] During this same period Thiessen began investigating means to correct the corrosion problem in the diffusion barrier.[307] By late 1950 or early 1951 the Soviets had solved the diffusion plant corrosion problem, and the centrifuge research project ceased to be of great importance.[308] On 18 October 1951 the Soviets tested their first nuclear device utilizing highly enriched uranium (HEU). Thus, the gaseous diffusion plant at Kefirstadt was presumably producing kilogram quantities per day of HEU by early 1951.[309]

Despite the success of the gaseous diffusion technology, the Soviets continued research on the gas centrifuge method. The centrifuge topping plant project under Steenbeck was redirected to pursue development of a centrifuge

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[301] Ibid. Some 750,000 square feet of barrier material were ordered for 1950.

[302] CIA, "*Isotope Separation by Ultracentrifuge*," op. cit., p. 12.

[303] Ibid. The Smyth Report, published 12 August 1945, had confirmed that this was the method used by the United States.

[304] Ibid., pp. 12, 26. The compressors for the gaseous diffusion plant were constructed in the Kirov plant in Leningrad; Ibid., p. 36.

[305] Ibid., pp. 12, 26-27.

[306] Ibid., pp. 26-27. Steenbeck's group was formed during June 1946, when its principal members (including Steenbeck) were separated from Soviet prisoners of war.

[307] Ibid., p. 12.

[308] Ibid., p. 32.

[309] CIA, Joint Atomic Energy Intelligence Committee, *Status of the Soviet Atomic Energy Program*, NSIE-1, CIA/SI 13-52, 8 January 1953, p. 11. Joe 3 utilized a composite core design; in other words, the fissile material was a composite of plutonium and highly enriched uranium.

plant capable of taking natural uranium to 96 percent U-235, with an output of one kilogram of metal a day.[310] This research effort was shifted from Sinop to the Kirov plant in Leningrad on 15 September 1951.[311] Between 1951 and mid-1953, the Germans were gradually being eased out of the project, and by September 1953 the Soviets had assumed total control.[312] It is not known whether a centrifuge plant was ever constructed during this early period.

Enrichment Plant Sites

There are four Russian uranium enrichment plant sites: the Urals' Electromechanical Plant (Electrochemistry Combine) at Sverdlovsk-44 at Verkh-Neyvinsk (formerly Kefirstadt), near Yekaterinberg (formerly Sverdlovsk); the Siberian Chemical Combine, collocated with a production reactor site at Tomsk-7 just outside of Tomsk; the Electrochemistry Plant at Krasnoyarsk-45 on the Kan River, 90 km east of Krasnoyarsk and 75 km west of Kansk in Siberia; and the Electrolyzing Chemical Combine at Angarsk, 30 km northwest of Irkutsk, near Lake Baikal.[313] Each of these sites is near large sources of electricity, which would be needed to operate the gaseous diffusion plants that were previously used at these sites.[314] There are said to be 10 separate gas centrifuge plants (processing lines or cascades), replacing five gaseous diffusion plants, at these four sites.[315] Tomsk-7 and Angarsk are the only sites capable of converting U_3O_8 (yellowcake) to UF_6, the enrichment plant feed material. Krasnoyarsk-45 began operations in 1964. Angarsk was the last of the enrichment sites to be built.

Enrichment Technology and Production

Initially, the Soviets relied on gaseous diffusion technology, and most if not essentially all of their weapon-grade uranium production to date has been

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[310] CIA, "*Isotope Separation by Ultracentrifuge*," pp. 34, 44.

[311] Ibid., p. 34.

[312] Ibid., pp. 44, 46.

[313] These sites are identified in Table 1. Verkh-Neyvinsk is at 57° 15'N 59° 48'E; Tomsk-7 is at 56° 37'N 84° 47'E; the Electrochemistry Plant at Krasnoyarsk-45 is at 56° 08'N 94° 29'E; and the city of Angarsk is at 52° 31'N 103° 55'E. Krasnoyarsk-45 is 90 km east of the city of Krasnoyarsk (at 56° 01'N 92° 50'E) and 75 km west of Kansk (at 56° 12'N 95° 43'E).

[314] CIA, *USSR Energy Atlas*, January 1985, pp. 56-57.

[315] Christopher Paine, "Military Reactors Go on Show to American Visitors." *New Scientist*, July 22, 1989, p. 22 [condensed from "Soviets Reveal Nuclear Production Complex to visiting Americans," (unpublished)].

produced using this technology.[316] More recently, however, the Soviets have shifted to the more efficient gas centrifuge technology. Currently (early-1992) the Russians have a total of just over 14 million kilograms separative work units per year (kg SWU/y, often shortened to SWU/y) of centrifuge capacity at the four plants. The plants are currently operating at one-half capacity (about 7 m SWU/y), producing primarily low enriched product for power reactor fuel, and using as feed material, enrichment tailings (0.24-0.4 % U-235), rather than natural uranium.[317] There is still some gaseous diffusion capacity (about five percent of the total) still operating, although this is to be shut down by the end of 1992.

As noted previously the Soviet Union stopped production of highly enriched uranium for weapons in 1989. The four enrichment plant sites use to be operated as an integrated complex to provide the best use of the facilities. The Urals' Electromechanical Plant (Sverdlovsk-44) at Verkh-Neyvinsk served as the top stages to provide high enriched product for weapons. Sverdlovsk-44 has three centrifuge process lines with a total capacity of three million SWU/y. Today the four sites operate independently, all producing low enriched product.

When enriching uranium to weapon-grade, recycled uranium was sometimes used as enrichment plant feed stock. As a consequence weapon-grade uranium contains as impurities, reactor-produced uranium-236 and uranium-232 (and thallium-208, a daughter product of the radioactive decay of U-232). Only at Tomsk-7 have the gas centrifuge cascades been contaminated with U-232 and U-234 from recycled uranium.

Russian centrifuge stages are shorter and have smaller capacity than their European counterparts. The Russian machines use one-half the energy and the enrichment cost is less. Some of the centrifuge stages are now being used to provide high purity isotopes of elements other than uranium for research purposes.

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[316] See B. A. Semenov, "Nuclear Power in the Soviet Union," IAEA Bulletin, 25, June 1983, p. 55; House Committee on Energy and Commerce, Uranium Enrichment Policy, 98 Cong. 1st sess., 21 October 1983, p. 120. The Soviets assisted China in the construction of a gaseous diffusion plant in the mid-1950s. The Soviets suspended atomic aid and stopped work on the plant sometime between the summer of 1958 and August 1959; Gloria Duffy, "Soviet Nuclear Energy: Domestic and International Policies," RAND Corporation, R-2362-DOE, December 1979, p. 3.

[317] According to Russian sources, if the centrifuge cascades are forced to shut down, there are excessive centrifuge breakdowns when the cascade is placed back into operation. By using enrichment tails, rather than using natural uranium, as the cascade feed material, more separative work is required to achieve the same amount of product. By mining the tails which are free, the enrichment enterprise is able to operate at a higher capacity, preserving equipment and jobs in periods of reduced product demand.

Several alternatives to the gaseous diffusion and centrifuge methods of uranium enrichment have received attention in Russia, including experimentation with photochemical technology using lasers;[318] but these have not advanced beyond paper studies. Given the heavy reliance on low cost centrifuge technology there is no perceived need for a large laser isotope separation research and development effort.

At 0.2 percent tails assay, 235.55 SWU are required to produce one kg of HEU enriched to 93 percent U-235. Consequently, the Soviet stockpile of HEU for weapons could be comparable to, or even significantly larger than the U.S. stockpile of 500 MT.[319] The uncertainty in the estimate is large - at least 50 percent.

Civil Reactor Fuel Cycle (the Back End)

Minatom policy, at least since the mid-1970, has been to close the back end of the civil power reactor fuel cycle, that is, to reprocess the spent fuel from the power reactors, recycle the recovered plutonium and uranium, and vitrify the high level nuclear waste. The recovered plutonium was intended primarily for LMFBR reactors, although an R&D program also existed for use of MOX in VVERs. To date the overall objective has not been realized. An overview of the principal activities related to the back end of the fuel cycle is provided below. More detailed descriptions of the specific facilities are found under the site descriptions, Chelyabinsk-65, Tomsk-7, and Krasnoyarsk-26, above.

Reprocessing: In 1976 the RT-1 chemical separation plant at Chelyabinsk-65 was modified to process spent fuel from naval reactors, and in 1978, it shifted from processing military production reactor fuel, to processing spent fuel from naval (both submarine and civil icebreaker) reactors (which apparently occurred first), test reactors, and 210 Mw_e and 440 Mw_e light-water moderated and cooled power reactors (VVER-210s and VVER-440s). About 25 MT of reactor-grade plutonium have been separated and stockpiled at Chelyabinsk-65.

Construction of the RT-2 chemical separation plant at Krasnoyarsk-26 was begun in 1976 or 1978. It was designed to process VVER-1000 fuel. The spent fuel storage facility with auxiliary and service buildings was put into service in 1985, but construction of the 1500 MTHM/y chemical separation facility was halted in 1989 as a result of public opposition.

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318 CIA, *USSR Energy Atlas*, January 1985, p. 43.

319 Assuming the enrichment capacity devoted to weapon-grade uranium production increased linearly to 7 million SWU over 30 years, and operated at that level for an additional 9 years, the total HEU production would be: $(7x10^6 SWU/y)[(30y/2)+9y]/(235{,}550 SWU/MT) = 700MT$.

Mixed-Oxide (MOX) Fuel Fabrication: Russia has developed a MOX fuel technology, bur has no commercial size MOX fuel fabrication plant in operation. Construction of a MOX fuel fabrication plant, sized to make three cores for BN-800 LMFBRs per year (about 10 MT of plutonium annually), was 65-70 percent complete before construction was suspended. Construction has not resumed for lack of funding.

Table 1:
Principal Nuclear Weapon Research, Test and Production Facilities

DESIGN LABORATORIES

All-Russian Scientific Research Institute of Experimental Physics (VNIIEF)
  Arzamas-16
    at Sarova, Nizhegorod Oblast

All-Russian Scientific Research Institute of Technical Physics (VNIITF)
  Chelyabinsk-70
    20 km north of Kasli, Urals region

TEST SITES

Novaya Zemlya:
  Northern and Southern Test Areas
    two islands north of the Arctic Circle

Semiplatinsk (or Kazakh) Test Site (permanently closed in 1991):
  Semiplatinsk-21
  Shagan River, Degelen Mountain, and Konyastan test areas
    south of Semiplatinsk, Kazakhstan

WARHEAD PRODUCTION (ASSEMBLY) FACILITIES

  Sverdlovsk-45
    at Nizhnyaya Tura, Urals region

  Either **Zlatoust-36**
    near Zlatoust, Urals region
  or **Penza-19**
    near Penza

BALLISTIC MISSILE REENTRY VEHICLE ASSEMBLY PLANT

  Zlatoust-36
    near Zlatoust, Urals region

PLUTONIUM AND TRITIUM PRODUCTION REACTORS

Mayak Chemical Combine
  Chelyabinsk-65 (formerly **Chelyabinsk-40**)
    at Lake Kyzylash, near Kasli and Kyshtym, Chelyabinsk Oblast, Urals region

Siberian Chemical Combine
  Tomsk-7
    on the Tom River 15 km northwest of Tomsk in Siberia

Mining and Chemical Combine
  Krasnoyarsk-26
    on the Yenisey River 10 km north of Dodonovo near Krasnoyarsk in Siberia

URANIUM ENRICHMENT FACILITIES

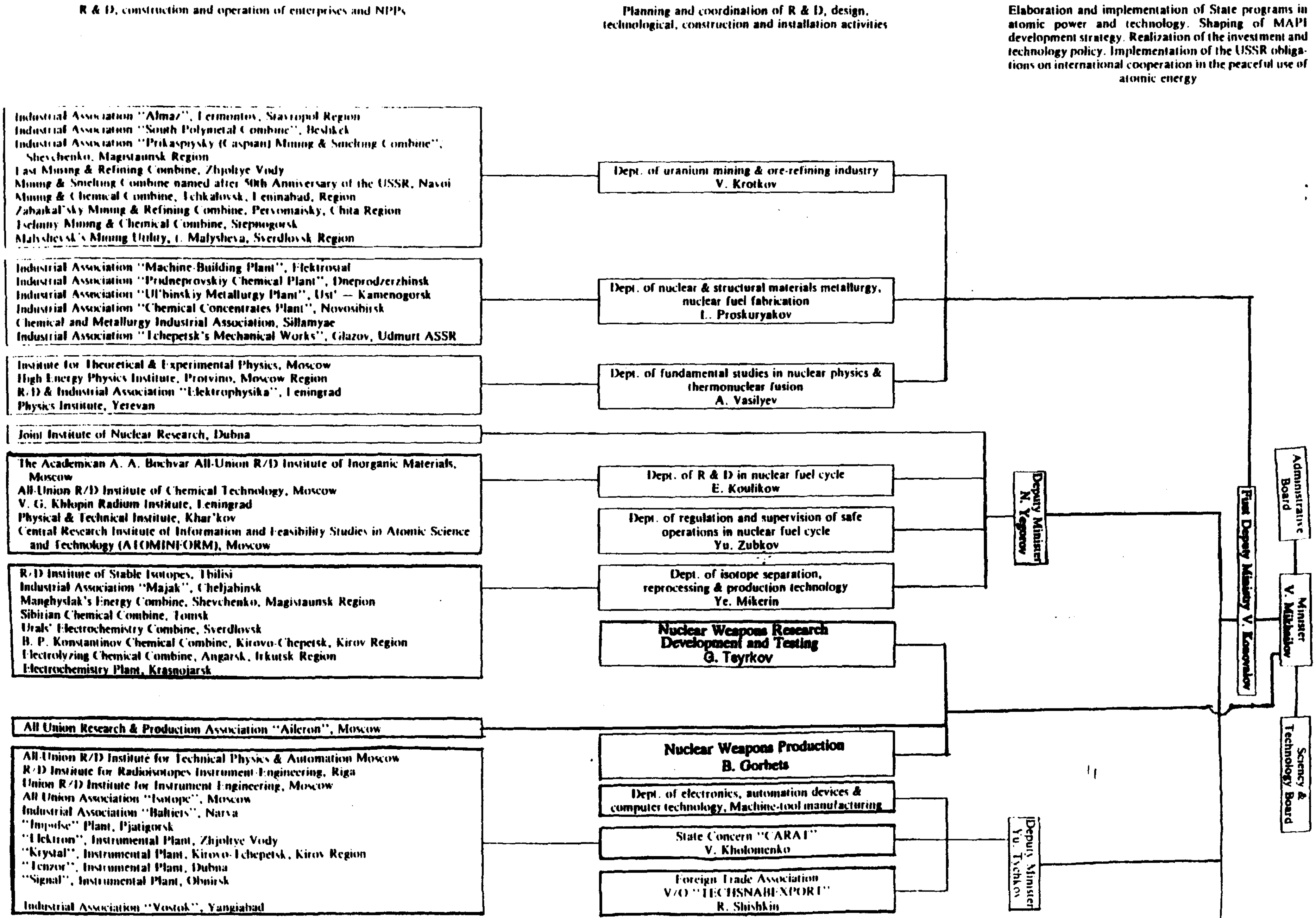
Urals' Electromechanical Plant (Urals' Electrochemical Combine)
  Sverdlovsk-44
    at Verkh-Neyvinsk, near Yakaterinburg (formerly Sverdlovsk), Urals region

Siberian Chemical Combine
  Tomsk-7
    on the Tom River 15 km northwest of Tomsk in Siberia

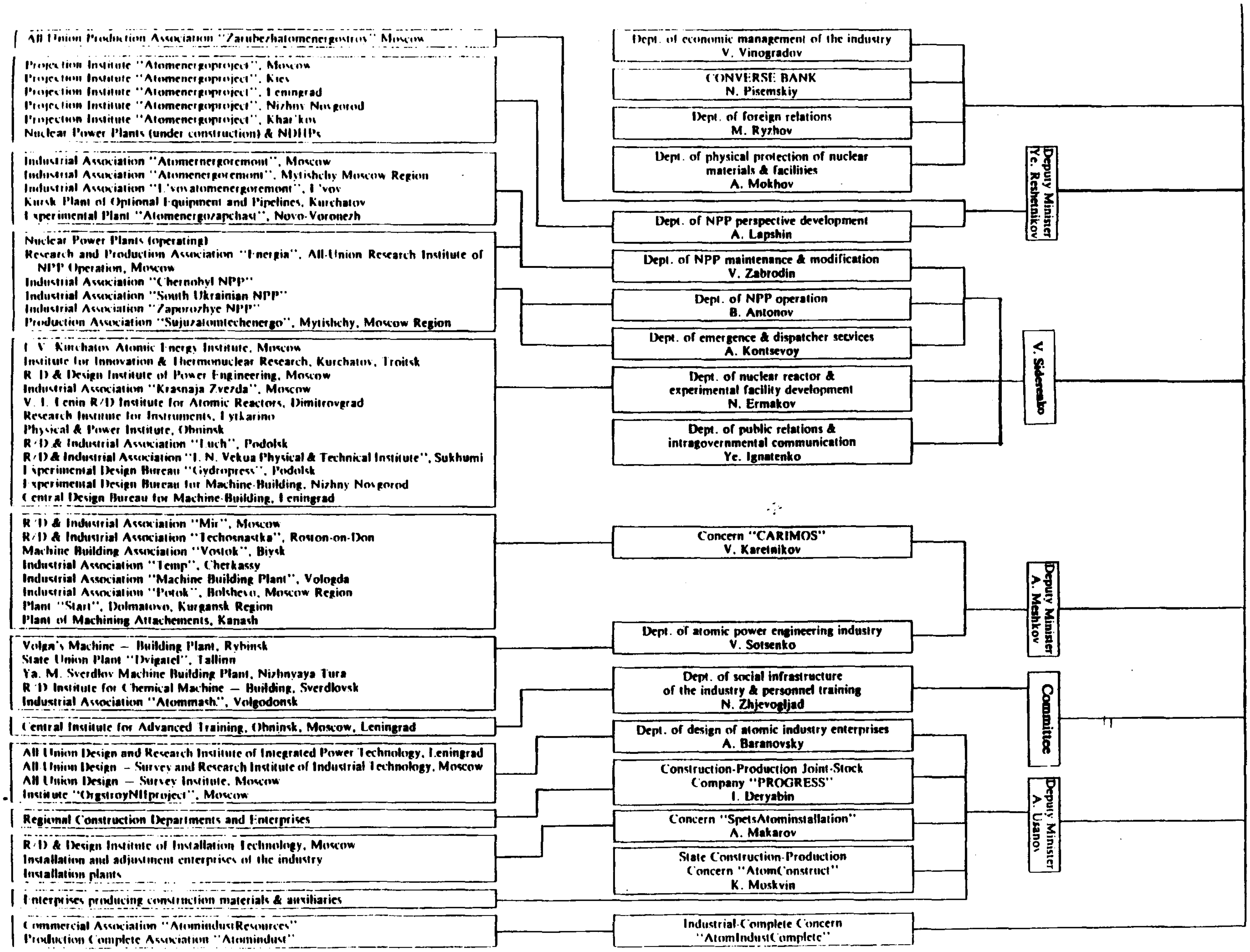
Electrochemistry Plant
  Krasnoyarsk-45
    on the Kan River between Krasnoyarsk and Kansk, Siberia

Electrolyzing Chemical Combine
    at Angarsk, 30 km northwest of Irkutsk in Siberia

Table 2
Organizational Chart of the Ministry of Atomic Energy
(overleaf)



R & D, construction and operation of enterprises and NPPs
Planning and coordination of R & D, design, technological, construction and installation activities
Elaboration and implementation of State programs in atomic power and technology. Shaping of MAPI development strategy. Realization of the investment and technology policy. Implementation of the USSR obligations on international cooperation in the peaceful use of atomic energy
Industrial Association "Almaz", Lermontov, Stavropol Region
Industrial Association "South Polymetal Combine", Beshkek
Industrial Association "Prikaspiysky (Caspian) Mining & Smelting Combine", Shevchenko, Magistaunsk Region
East Mining & Refining Combine, Zhjoltye Vody
Mining & Smelting Combine named after 50th Anniversary of the USSR, Navoi
Mining & Chemical Combine, Tchkalovsk, Leninabad, Region
Zabaikal'sky Mining & Refining Combine, Pervomaisky, Chita Region
Tselinny Mining & Chemical Combine, Stepnogorsk
Malyshevsk's Mining Utility, t. Malysheva, Sverdlovsk Region
Industrial Association "Machine-Building Plant", Elektrostal
Industrial Association "Pridneprovskiy Chemical Plant", Dneprodzerzhinsk
Industrial Association "Ul'binskiy Metallurgy Plant", Ust' — Kamenogorsk
Industrial Association "Chemical Concentrates Plant", Novosibirsk
Chemical and Metallurgy Industrial Association, Sillamyae
Industrial Association "Tchepetsk's Mechanical Works", Glazov, Udmurt ASSR
Institute for Theoretical & Experimental Physics, Moscow
High Energy Physics Institute, Protvino, Moscow Region
R/D & Industrial Association "Elektrophysika", Leningrad
Physics Institute, Yerevan
Joint Institute of Nuclear Research, Dubna
The Academican A. A. Bochvar All-Union R/D Institute of Inorganic Materials, Moscow
All-Union R/D Institute of Chemical Technology, Moscow
V. G. Khlopin Radium Institute, Leningrad
Physical & Technical Institute, Khar'kov
Central Research Institute of Information and Feasibility Studies in Atomic Science and Technology (ATOMINFORM), Moscow
R/D Institute of Stable Isotopes, Tbilisi
Industrial Association "Majak", Cheljabinsk
Manghyslak's Energy Combine, Shevchenko, Magistaunsk Region
Sibirian Chemical Combine, Tomsk
Urals' Electrochemistry Combine, Sverdlovsk
B. P. Konstantinov Chemical Combine, Kirovo-Chepetsk, Kirov Region
Electrolyzing Chemical Combine, Angarsk, Irkutsk Region
Electrochemistry Plant, Krasnojarsk
All Union Research & Production Association "Aileron", Moscow
All-Union R/D Institute for Technical Physics & Automation Moscow
R/D Institute for Radioisotopes Instrument-Engineering, Riga
Union R/D Institute for Instrument Engineering, Moscow
All Union Association "Isotope", Moscow
Industrial Association "Baltiets", Narva
"Impulse" Plant, Pjatigorsk
"Elektron", Instrumental Plant, Zhjoltye Vody
"Krystal", Instrumental Plant, Kirovo-Tchepetsk, Kirov Region
"Tenzor", Instrumental Plant, Dubna
"Signal", Instrumental Plant, Obninsk
Industrial Association "Vostok", Yangiabad
Dept. of uranium mining & ore-refining industry V. Krotkov
Dept. of nuclear & structural materials metallurgy, nuclear fuel fabrication L. Proskuryakov
Dept. of fundamental studies in nuclear physics & thermonuclear fusion A. Vasilyev
Dept. of R & D in nuclear fuel cycle E. Koulikow
Dept. of regulation and supervision of safe operations in nuclear fuel cycle Yu. Zubkov
Dept. of isotope separation, reprocessing & production technology Ye. Mikerin
Nuclear Weapons Research Development and Testing G. Tsyrkov
Nuclear Weapons Production B. Gorbets
Dept. of electronics, automation devices & computer technology, Machine-tool manufacturing
State Concern "CARAT" V. Kholomenko
Foreign Trade Association V/O "TECHSNABEXPORT" R. Shishkin
Deputy Minister N. Yegorov
Deputy Minister Yu. Tychkov
First Deputy Ministry V. Konovalov
Minister V. Mikhailov
Administrative Board
Sciency & Technology Board



All Union Production Association "Zarubezhatomenergostroy" Moscow
Projection Institute "Atomenergoproject", Moscow
Projection Institute "Atomenergoproject", Kiev
Projection Institute "Atomenergoproject", Leningrad
Projection Institute "Atomenergoproject", Nizhny Novgorod
Projection Institute "Atomenergoproject", Khar'kov
Nuclear Power Plants (under construction) & NDHPs
Industrial Association "Atomernergoremont", Moscow
Industrial Association "Atomenergoremont", Mytishchy Moscow Region
Industrial Association "L'vovatomenergoremont", L'vov
Kursk Plant of Optional Equipment and Pipelines, Kurchatov
Experimental Plant "Atomenergozapchast", Novo-Voronezh
Nuclear Power Plants (operating)
Research and Production Association "Energia", All-Union Research Institute of NPP Operation, Moscow
Industrial Association "Chernobyl NPP"
Industrial Association "South Ukrainian NPP"
Industrial Association "Zaporozhye NPP"
Production Association "Sujuzatomtechenergo", Mytishchy, Moscow Region
I. V. Kurchatov Atomic Energy Institute, Moscow
Institute for Innovation & Thermonuclear Research, Kurchatov, Troitsk
R/D & Design Institute of Power Engineering, Moscow
Industrial Association "Krasnaja Zvezda", Moscow
V. I. Lenin R/D Institute for Atomic Reactors, Dimitrovgrad
Research Institute for Instruments, Lytkarino
Physical & Power Institute, Obninsk
R/D & Industrial Association "Luch", Podolsk
R/D & Industrial Association "I. N. Vekua Physical & Technical Institute", Sukhumi
Experimental Design Bureau "Gydropress", Podolsk
Experimental Design Bureau for Machine-Building, Nizhny Novgorod
Central Design Bureau for Machine-Building, Leningrad
R/D & Industrial Association "Mir", Moscow
R/D & Industrial Association "Techosnastka", Roston-on-Don
Machine Building Association "Vostok", Biysk
Industrial Association "Temp", Cherkassy
Industrial Association "Machine Building Plant", Vologda
Industrial Association "Potok", Bolshevo, Moscow Region
Plant "Start", Dolmatovo, Kurgansk Region
Plant of Machining Attachements, Kanash
Volga's Machine — Building Plant, Rybinsk
State Union Plant "Dvigatel", Tallinn
Ya. M. Sverdlov Machine Building Plant, Nizhnyaya Tura
R/D Institute for Chemical Machine — Building, Sverdlovsk
Industrial Association "Atommash", Volgodonsk
Central Institute for Advanced Training, Obninsk, Moscow, Leningrad
All Union Design and Research Institute of Integrated Power Technology, Leningrad
All Union Design — Survey and Research Institute of Industrial Technology, Moscow
All Union Design — Survey Institute, Moscow
Institute "OrgstroyNIIproject", Moscow
Regional Construction Departments and Enterprises
R/D & Design Institute of Installation Technology, Moscow
Installation and adjustment enterprises of the industry
Installation plants
Enterprises producing construction materials & auxiliaries
Commercial Association "AtomindustResources"
Production Complete Association "Atomindust"
Dept. of economic management of the industry V. Vinogradov
CONVERSE BANK N. Pisemskiy
Dept. of foreign relations M. Ryzhov
Dept. of physical protection of nuclear materials & facilities A. Mokhov
Dept. of NPP perspective development A. Lapshin
Dept. of NPP maintenance & modification V. Zabrodin
Dept. of NPP operation B. Antonov
Dept. of emergence & dispatcher services A. Kontsevoy
Dept. of nuclear reactor & experimental facility development N. Ermakov
Dept. of public relations & intragovernmental communication Ye. Ignatenko
Concern "CARIMOS" V. Karetnikov
Dept. of atomic power engineering industry V. Sotsenko
Dept. of social infrastructure of the industry & personnel training N. Zhjevogljad
Dept. of design of atomic industry enterprises A. Baranovsky
Construction-Production Joint-Stock Company "PROGRESS" I. Deryabin
Concern "SpetsAtominstallation" A. Makarov
State Construction-Production Concern "AtomConstruct" K. Moskvin
Industrial-Complete Concern "AtomIndustComplete"
Deputy Minister Ye. Reshetnikov
V. Siderenko
Deputy Minister A. Meshkov
Committee
Deputy Minister A. Usanov

Table 3
Facilities at the Mayak Chemical Combine (Chelyabinsk-65)

REACTORS

Graphite Moderated (all shut down)

A-Reactor
IR-Reactor
AV-1 Reactor
AV-2 Reactor
AV-3 Reactor

Heavy Water Moderated (shut down)

Apparently, a **reactor of unknown type** used for isotope production (e.g., Pu-238)

CHEMICAL SEPARATION PLANTS

RT-1 (400-600 MT/y capacity used for reprocessing naval and power reactor fuel))

Isotope separation facility ("The Vatican") used for special isotope production

Plutonium Storage Facility (contains about 25 MT of plutonium from naval and power reactors)

"Tech 300" Mixed-Oxide (MOX) Fuel Fabrication Plant (construction suspended after 70 percent complete)

South Urals AES (site for three BN-800 LMFBR Reactors)
Construction of all three units halted; two units abandoned; construction of the third unit, still in an early construction stage, may be resumed.

Nuclear Waste Facilities

Waste Storage Tanks (for High and Intermediate Level Waste)
Pilot Waste Vitrification Plant (500 l/h)
Installation for "cleaning low-level waste

Facilities for manufacturing manipulators and other equipment

Facilities for manufacturing defense industry equipment

Radiological Research Facility

Table 4
Occupational Radiation Exposures at Chelyabinsk-65(-40)
(Distribution of Employees According to Their Dose)[1]

	Installation A					Installation B				
	Percent of Employees				**Average dose (rem)**	**Percent of Employees**				**Average doses (rem)**
	<25	**25-100**	**100-400**	**>400**		**<25**	**25-100**	**100-400**	**>400**	
1948	84.1	11.1	4.8	-	19.6	-	-	-	-	-
1949	10.7	57.7	31.1	0.5	93.6	26.9	66.2	6.9	-	48.0
1950	52.2	47.2	0.6	-	30.7	21.5	42.0	36.0	0.5	94.0
1951	74.9	25.1	-	-	18.1	13.8	41.6	42.8	1.8	113.3
1952	83.9	16.1	-	-	14.9	21.8	57.0	21.2	-	66.0

	Percent of Employees				**Average dose (rem)**	**Percent of Employees**				**Average dose (rem)**
	<10	**10-25**	**25-100**	**>100**		**<10**	**10-25**	**25-100**	**>100**	
1953	37.8	41.5	18.4	2.3	19.6	25.3	25.4	47.3	2.0	30.7
1954	64.0	33.0	3.0	-	8.9	34.7	36.1	29.1	0.1	20.0
1955	61.8	33.7	4.5	-	9.5	29.8	36.7	33.2	0.3	21.3
1956	92.3	6.4	0.6	0.7	5.1	45.0	31.9	23.1	-	16.2
1957	98.1	1.9	-	-	4.2	37.5	36.9	25.5	0.1	17.5
1958	95.3	4.7	-	-	4.4	59.6	31.3	9.1	-	10.8
1959	99.7	0.3	-	-	3.3	75.7	21.1	3.2	-	14.7

	Percent of Employees			**Average dose (rem)**	**Percent of Employees**			**Average dose (rem)**
	<2.5	**2.5-5.0**	**>5.0**		**<2.5**	**2.5-5.0**	**>5.0**	
1960	57.5	29.3	13.2	2.7	14.2	25.8	60.0	15.2
1961	73.9	22.4	3.7	2.0	13.8	49.1	37.1	11.0
1962	65.0	31.4	4.0	2.3	16.6	32.5	50.9	7.6
1963	64.3	29.8	5.9	2.4	41.4	37.3	21.3	3.8
1964	55.7	27.8	16.5	3.0	66.4	29.3	4.3	4.1
1965	24.5	49.1	26.4	4.0	67.0	31.4	1.6	2.1
1966	25.5	52.4	22.1	1.7	56.7	41.3	2.0	2.4
1967	45.5	41.4	13.1	1.3	76.7	23.2	0.1	1.8
1968	55.0	38.7	6.3	1.1	76.3	23.7	-	1.8
1969	56.2	39.5	4.3	1.0	91.9	8.1	-	1.4
1970	36.9	49.7	13.4	1.4	85.6	14.4	-	1.6
1971	25.7	36.5	37.8	1.3	95.1	4.9	-	1.4
1972	69.7	26.8	3.5	1.1	97.9	2.1	-	1.3
1973	45.5	44.8	9.7	1.0	97.4	2.6	-	1.3
1974	95.1	4.9	-	1.0	98.9	1.1	-	0.6

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

Table 5
Organ Dose Estimates (External and Internal) for Inhabitants in Some Villages Along the Techa River[1]

Villages	Distance from point of release, km	Mean doses, Gy			
		red bone marrow	bone surfaces	large intestine	other tissues
Metlino	7	1.64	2.28	1.40	1.27
Muslyumovo	78	0.61	1.43	0.29	0.12
Russkaya Techa	138	0.22	0.53	0.10	0.04
Zatecha	237	0.17	0.40	0.08	0.03

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

Table 6
Radioactive Contamination in the Chelyabinsk-65 Reservoirs[1]

Composition of Radionuclides										Accumulation, Ci		
Reservoir Number	Area of the Reservoir (sq km)	Capacity of the Reservoir (million cubic m)	Concentration in Water, ci/l					Ground Deposits, Ci/kg		In the Reservoir	In Ground Deposits	Overall
			Sr-90	Cs-137	HTO	$\Sigma\alpha$	$\Sigma\beta$	Sr-90	Cs-137			
9	0.25	0.4	$1.7x10^{-3}$	$1.2x10^{-2}$	$5.3x10^{-5}$	$57x10^{-6}$	$1.9x10^{-2}$	0.3	1.4	$8.4x10^{6}$	$110x10^{6}$	$120x10^{6}$
3	0.5	0.75	$1.6x10^{-6}$	$2.0x10^{-7}$	$1.4x10^{-6}$	$3x10^{-10}$	--	$1.4x10^{-4}$	$1x10^{-3}$	$2.6x10^{3}$	$15.4x10^{3}$	$18x10^{3}$
4	1.3	4.1	$1.7x10^{-7}$	$7.3x10^{-8}$	$5.2x10^{-7}$	$4.5x10^{-9}$	--	$4x10^{-6}$	$6x10^{-5}$	$1.7x10^{3}$	$4.2x10^{3}$	$6x10^{3}$
10	19	76	$3.5x10^{-7}$	$8.6x10^{-9}$	$3.2x10^{-7}$	$1x10^{-11}$	--	$3.5x10^{-6}$	$1.5x10^{-4}$	$50x10^{3}$	$60x10^{3}$	$110x10^{3}$
11	44	230	$5.1x10^{-8}$	$2x10^{-2}$	$4.5x10^{-8}$	$2x10^{-12}$	--	$1.3x10^{-6}$	$1.3x10^{-7}$	$24x10^{3}$	$15x10^{3}$	$39x10^{3}$
2	19	83	$1.1x10^{-6}$	$4.5x10^{-9}$	$2.5x10^{-7}$	?	--	$1.3x10^{-6}$	$3x10^{-5}$	$2x10^{3}$	$18x10^{3}$	$20x10^{3}$
17	0.17	0.43	$1x10^{-4}$	$4x10^{-6}$	$1x10^{-4}$	$1.2x10^{-3}$	--	0.12	$3.3x10^{-2}$	$45x10^{3}$	$2x10^{6}$	$2x10^{6}$
6	3.6	17.5	$3.7x10^{-10}$	$2x10^{-11}$	$1x10^{-6}$	$39x10^{-6}$	--	$3.3x10^{-7}$	--	2	300	300

1 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); Table given to Thomas B. Cochran by Victor N. Chukanov, USSR Academy of Sciences, Ural Department, Ecological Security Center, Sverdlosk, private communication, April 13, 1991. This table gives the capacity of reservoir 11 as 217 m cubic m.

Table 7
Characteristics of the Radioactivity Released in the 1957 Accident[1]

Radionuclide	Contribution to total activity of the mixture, %	Half-life	Type of radiation emitted
^{89}Sr	traces	51 d	β, γ
^{90}Sr + ^{90}Y	5.4	28.6 y	β
^{95}Zr + ^{95}Nb	24.9	65 d	β, γ
^{106}Ru + ^{106}Rh	3.7	1 y	β, γ
^{137}Cs	0.036	30 y	β, γ
^{144}Ce + ^{144}Pr	66	284 d	β, γ
^{147}Pm	traces	2.6 y	β, γ
^{155}Eu	traces	5 y	β, γ
$^{239,240}Pu$	traces	-	α

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

Table 8
Land Contaminated by the 1957 Accident at Chelyabinsk-65[1]

Contamination Level (Ci/km^2)	Area (km^2)
0.1 - 2	15,000 - 23,000
2 - 20	600
20 - 100	280
100 - 1000	100
1000 - 4000	17

Table 9
Solid Waste Burial Sites at Chelyabinsk-652[2]

KIND OF WASTE	NUMBER OF BURIAL SITES	VOLUME OF WASTE (1000 m^3)	WASTE ACTIVITY (Ci)	TOTAL AREA (ha)
Low- and Medium-level Waste	203	685.1	31.6x10^3	20.2
High-level Waste	24	41.3	12 x10^6	1.1
Total	227	726.4	12 x10^6	21.3

1 G.N. Romanov and A.S. Vorovov, "The Radiation Situation After the Explosion," *Prirода*, May 1990, p. 50.

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

Table 10
Estimated Plutonium-Equivalent Production by the Five Graphite Reactors at Chelyabinsk-65

YEAR	CAPACITY	THERMAL ENERGY		PLUTONIUM EQUIVALENT	
		ANNUAL	CUMULATIVE	ANNUAL	CUMULATIVE
	(MWt)	(1000 Mwd)	(1000 Mwd)	(kg)	(MT)
1948	100	8	8	7	0.0
1949	100	17	24	14	0.0
1950	100	18	43	16	0.0
1951	965	100	143	86	0.1
1952	2265	289	432	249	0.4
1953	2265	397	829	341	0.7
1954	3165	522	1350	449	1.2
1955	4465	731	2081	629	1.8
1956	4465	815	2896	701	2.5
1957	5165	905	3801	779	3.3
1958	6565	1108	4909	953	4.2
1959	6565	1198	6107	1030	5.3
1960	6565	1198	7305	1030	6.3
1961	6565	1198	8503	1030	7.3
1962	6565	1198	9701	1030	8.3
1963	6565	1198	10900	1030	9.4
1964	6565	1198	12098	1030	10.4
1965	6565	1198	13296	1030	11.4
1966	6565	1198	14494	1030	12.5
1967	6565	1198	15692	1030	13.5
1968	6565	1198	16890	1030	14.5
1969	6565	1198	18088	1030	15.6
1970	6565	1198	19286	1030	16.6
1971	6565	1198	20484	1030	17.6
1972	6565	1198	21683	1030	18.6
1973	6565	1198	22881	1030	19.7
1974	6565	1198	24079	1030	20.7
1975	6565	1198	25277	1030	21.7
1976	6565	1198	26475	1030	22.8
1977	6565	1198	27673	1030	23.8
1978	6565	1198	28871	1030	24.8
1979	6565	1198	30069	1030	25.9
1980	6565	1198	31268	1030	26.9
1981	6565	1198	32466	1030	27.9
1982	6565	1198	33664	1030	29.0
1983	6565	1198	34862	1030	30.0
1984	6565	1198	36060	1030	31.0
1985	6565	1198	37258	1030	32.0
1986	6565	1198	38456	1030	33.1
1987	6000	1145	39601	985	34.1
1988	6000	1095	40696	942	35.0
1989	4000	954	41650	820	35.8
1990	0	484	42134	416	36.2

Table 11
Estimated Plutonium-Equivalent Production by the Heavy Water Reactor at Chelyabinsk-65

YEAR	CAPACITY	THERMAL ENERGY		PLUTONIUM EQUIVALENT	
		ANNUAL	CUMULATIVE	ANNUAL	CUMULATIVE
	(MWt)	(1000 Mwd)	(1000 Mwd)	(kg)	(MT)
1950	250	37	37	35	0.0
1951	250	46	82	43	0.1
1952	250	46	128	43	0.1
1953	250	46	173	43	0.2
1954	250	46	219	43	0.2
1955	500	91	310	87	0.3
1956	500	91	402	87	0.4
1957	500	91	493	87	0.5
1958	500	91	584	87	0.6
1959	500	91	675	87	0.6
1960	1000	183	858	173	0.8
1961	1000	183	1040	173	1.0
1962	1000	183	1223	173	1.2
1963	1000	183	1405	173	1.3
1964	1000	183	1588	173	1.5
1965	1000	183	1770	173	1.7
1966	1000	183	1953	173	1.9
1967	1000	183	2135	173	2.0
1968	1000	183	2318	173	2.2
1969	1000	183	2500	173	2.4
1970	1000	183	2683	173	2.5
1971	1000	183	2865	173	2.7
1972	1000	183	3048	173	2.9
1973	1000	183	3230	173	3.1
1974	1000	183	3413	173	3.2
1975	1000	183	3595	173	3.4
1976	1000	183	3778	173	3.6
1977	1000	183	3960	173	3.8
1978	1000	183	4143	173	3.9
1979	1000	183	4325	173	4.1
1980	1000	183	4508	173	4.3

Table 12
Estimated Plutonium-Equivalent Production by the Five Graphite Reactors at Tomsk-7

YEAR	CAPACITY (MWt)	THERMAL ENERGY ANNUAL (1000 Mwd)	THERMAL ENERGY CUMULATIVE (1000 Mwd)	PLUTONIUM EQUIVALENT ANNUAL (kg)	PLUTONIUM EQUIVALENT CUMULATIVE (MT)
1958	650	20	20	17	0.0
1959	1300	104	124	89	0.1
1960	3250	385	508	331	0.4
1961	4550	783	1291	673	1.1
1962	8450	1377	2668	1184	2.3
1963	9100	1661	4329	1428	3.7
1964	10800	1920	6249	1652	5.4
1965	11150	1971	8220	1695	7.1
1966	11500	2035	10255	1750	8.8
1967	11500	2099	12354	1805	10.6
1968	11500	2099	14453	1805	12.4
1969	11500	2099	16551	1805	14.2
1970	11500	2099	18650	1805	16.0
1971	11500	2099	20749	1805	17.8
1972	11500	2099	22848	1805	19.6
1973	11500	2099	24946	1805	21.5
1974	11500	2099	27045	1805	23.3
1975	11500	2099	29144	1805	25.1
1976	11500	2099	31243	1805	26.9
1977	11500	2099	33341	1805	28.7
1978	11500	2099	35440	1805	30.5
1979	11500	2099	37539	1805	32.3
1980	11500	2099	39638	1805	34.1
1981	11500	2099	41736	1805	35.9
1982	11500	2099	43835	1805	37.7
1983	11500	2099	45934	1805	39.5
1984	11500	2099	48033	1805	41.3
1985	11500	2099	50131	1805	43.1
1986	11500	2099	52230	1805	44.9
1987	11500	2099	54329	1805	46.7
1988	11500	2099	56428	1805	48.5
1989	11500	2099	58526	1805	50.3
1990	6900	1931	60457	1661	52.0
1991	6900	1469	61926	1263	53.3

Table 13
Estimated Plutonium-Equivalent Production by the Three Graphite Reactors at Krasnoyarsk-26

YEAR	CAPACITY	THERMAL ENERGY		PLUTONIUM EQUIVALENT	
		ANNUAL	CUMULATIVE	ANNUAL	CUMULATIVE
	(MWt)	(1000 Mwd)	(1000 Mwd)	(kg)	(MT)
1957	2000	146	146	126	0.1
1958	2000	329	475	283	0.4
1959	2000	365	840	314	0.7
1960	2000	365	1205	314	1.0
1961	4000	511	1716	439	1.5
1962	4000	694	2409	596	2.1
1963	4000	730	3139	628	2.7
1964	6000	876	4015	753	3.5
1965	6000	1059	5074	910	4.4
1966	6000	1095	6169	942	5.3
1967	6000	1095	7264	942	6.2
1968	6000	1095	8359	942	7.2
1969	6000	1095	9454	942	8.1
1970	6000	1095	10549	942	9.1
1971	6000	1095	11644	942	10.0
1972	6000	1095	12739	942	11.0
1973	6000	1095	13834	942	11.9
1974	6000	1095	14929	942	12.8
1975	6000	1095	16024	942	13.8
1976	6000	1095	17119	942	14.7
1977	6000	1095	18214	942	15.7
1978	6000	1095	19309	942	16.6
1979	6000	1095	20404	942	17.5
1980	6000	1095	21499	942	18.5
1981	6000	1095	22594	942	19.4
1982	6000	1095	23689	942	20.4
1983	6000	1095	24784	942	21.3
1984	6000	1095	25879	942	22.3
1985	6000	1095	26974	942	23.2
1986	6000	1095	28069	942	24.1
1987	6000	1095	29164	942	25.1
1988	6000	1095	30259	942	26.0
1989	6000	1095	31354	942	27.0
1990	6000	1095	32449	942	27.9
1991	4800	876	33325	753	28.7

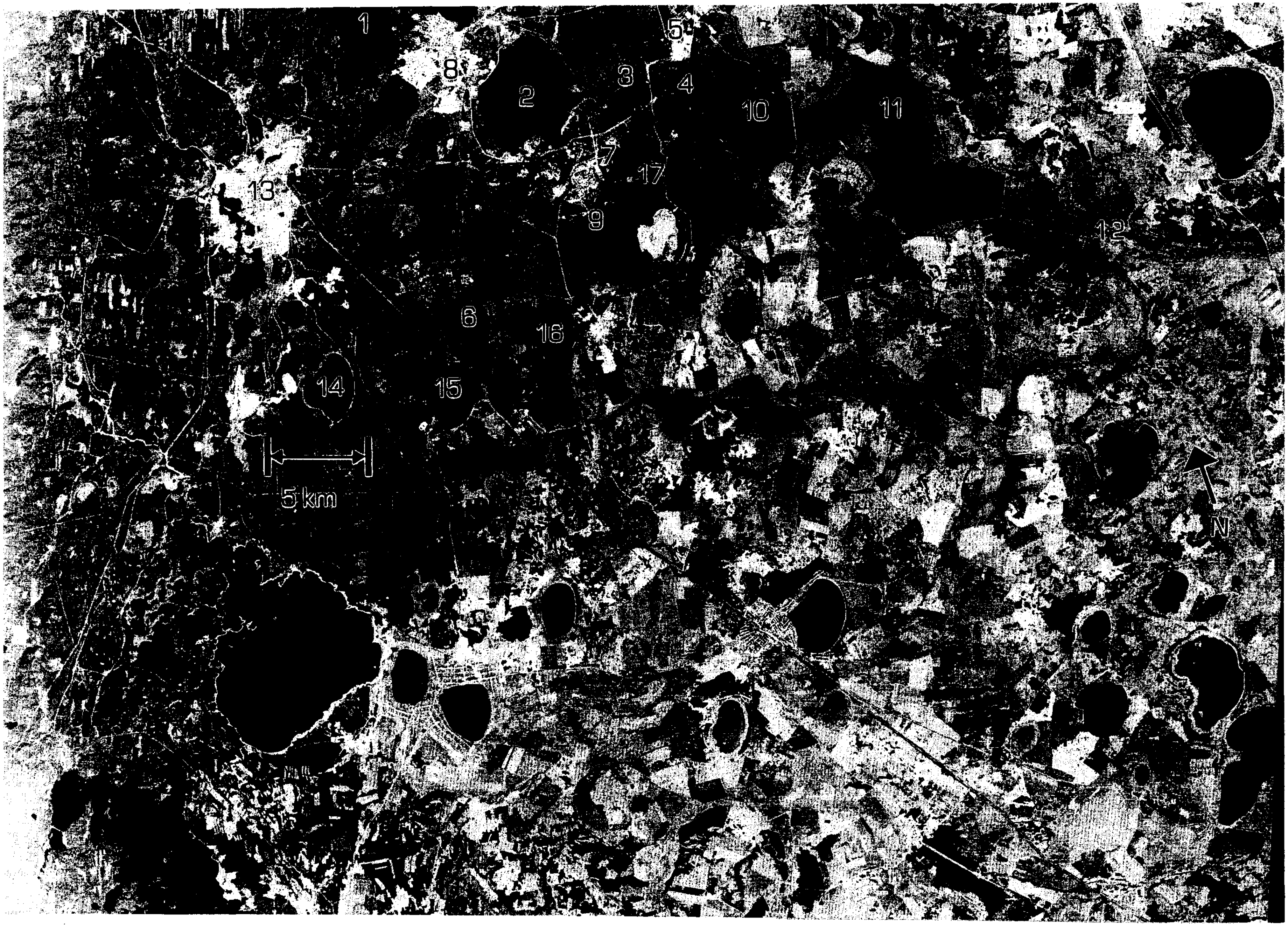
Table 14
Estimated Tritium Production

YEAR	TRITIUM			PLUTONIUM EQUIVALENT		
	INVENTORY (kg)	DECAY (kg)	PRODUCTION (kg)	INVENTORY (kg)	PRODUCTION (kg)	CUMULATIVE (MT)
1950	0.0	0.0	0.1	0	7	0.0
1951	0.1	0.0	0.2	7	14	0.0
1952	0.3	0.0	0.3	21	22	0.0
1953	0.6	0.0	0.4	42	29	0.1
1954	0.9	0.1	0.5	68	36	0.1
1955	1.4	0.1	0.7	100	50	0.2
1956	2.0	0.1	0.9	145	65	0.2
1957	2.8	0.2	1.1	202	79	0.3
1958	3.8	0.2	1.3	270	94	0.4
1959	4.8	0.3	1.5	349	108	0.5
1960	6.1	0.3	1.9	438	137	0.6
1961	7.7	0.4	2.3	551	166	0.8
1962	9.5	0.5	2.3	686	166	1.0
1963	11.3	0.6	2.3	814	166	1.1
1964	13.0	0.7	2.3	936	166	1.3
1965	14.6	0.8	2.3	1050	166	1.5
1966	16.1	0.9	2.3	1158	166	1.6
1967	17.5	1.0	2.3	1261	166	1.8
1968	18.9	1.0	2.3	1357	166	2.0
1969	20.1	1.1	2.3	1449	166	2.1
1970	21.3	1.2	2.3	1535	166	2.3
1971	22.5	1.2	2.3	1617	166	2.5
1972	23.5	1.3	2.3	1694	166	2.6
1973	24.5	1.3	2.3	1767	166	2.8
1974	25.5	1.4	2.3	1836	166	3.0
1975	26.4	1.4	2.3	1901	166	3.1
1976	27.3	1.5	2.3	1963	166	3.3
1977	28.1	1.5	2.3	2021	166	3.5
1978	28.8	1.6	2.3	2076	166	3.6
1979	29.6	1.6	2.3	2128	166	3.8
1980	30.2	1.7	2.3	2178	166	4.0
1981	30.9	1.7	2.3	2224	166	4.1
1982	31.5	1.7	2.3	2268	166	4.3
1983	32.1	1.8	2.3	2310	166	4.4
1984	32.6	1.8	2.3	2349	166	4.6
1985	33.1	1.8	2.3	2386	166	4.8
1986	33.6	1.8	2.3	2421	166	4.9
1987	34.1	1.9	2.3	2455	166	5.1
1988	34.5	1.9	2.3	2486	166	5.3
1989	34.9	1.9	2.3	2516	166	5.4
1990	35.3	1.9	2.3	2544	166	5.6
1991	35.7	2.0	2.3	2570	166	5.8

Figure 1
Reservoirs and Lakes at Chelyabinsk-65
(overleaf)

Legend

1. Lake Irtyash (Reservoir Number 1)
2. Lake Kyzyltash (Reservoir Number 2)
3. Reservoir Number 3
4. Reservoir Number 4
5. South Urals Project (Construction of 3 BN-800 reactors)
6. Lake Number 6
7. Chelyabinsk-65 Reactor Area
8. Ozhorsk (Chelyabinsk-65 Residential Area)
9. Lake Karachay (Reservoir Number 9)
10. Reservoir Number 10
11. Reservoir Number 11
12. Techa River
13. Kyshtym
14. Lake Bol'shaya Akulya
15. Lake Akakul'
16. Lake Ulagach
17. Lake Staroe Boloto (Old Swamp)


1
8
2
3
5
4
10
11
7
17
13
9
12
6
16
14
15
5 km
N

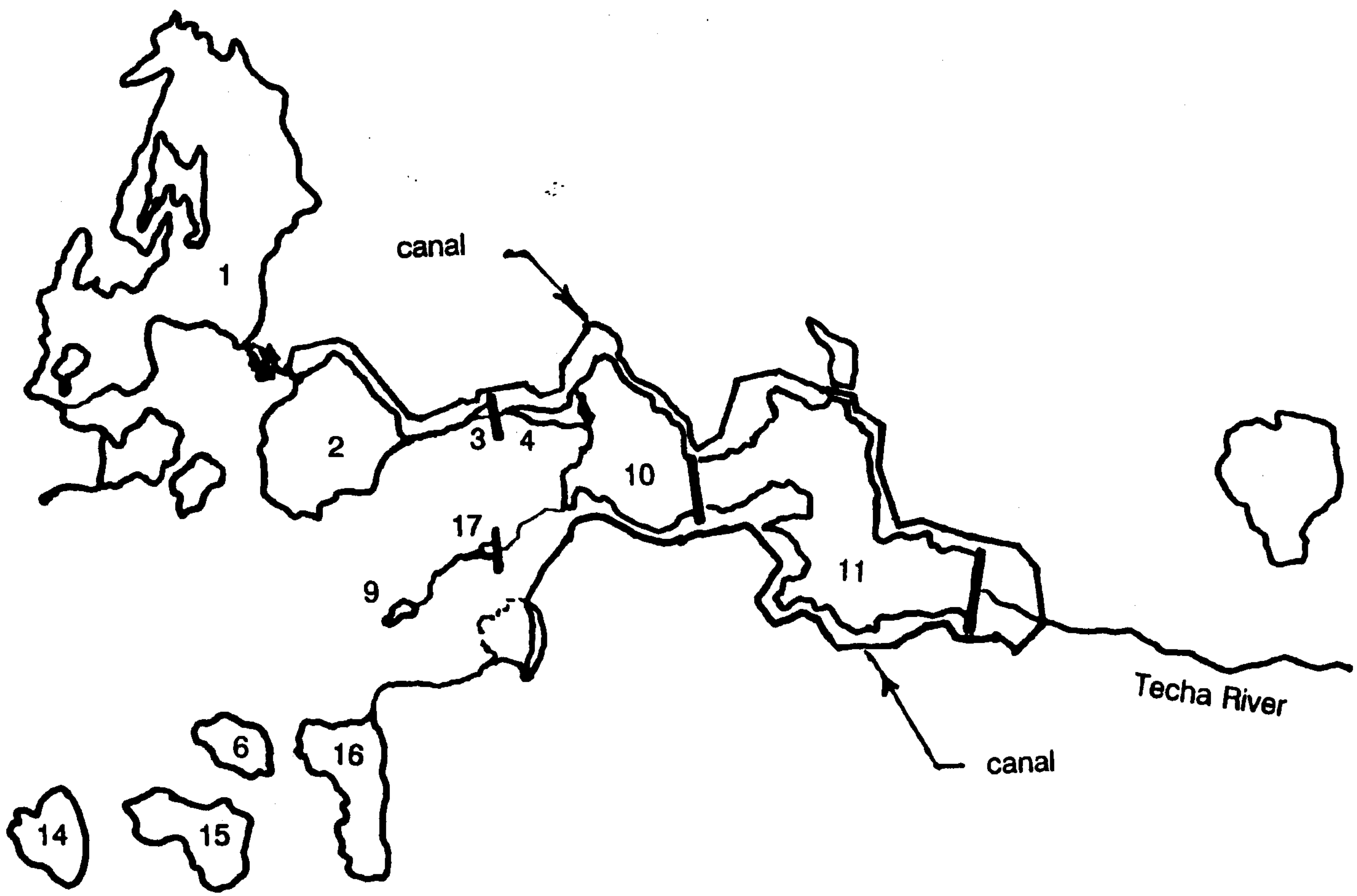
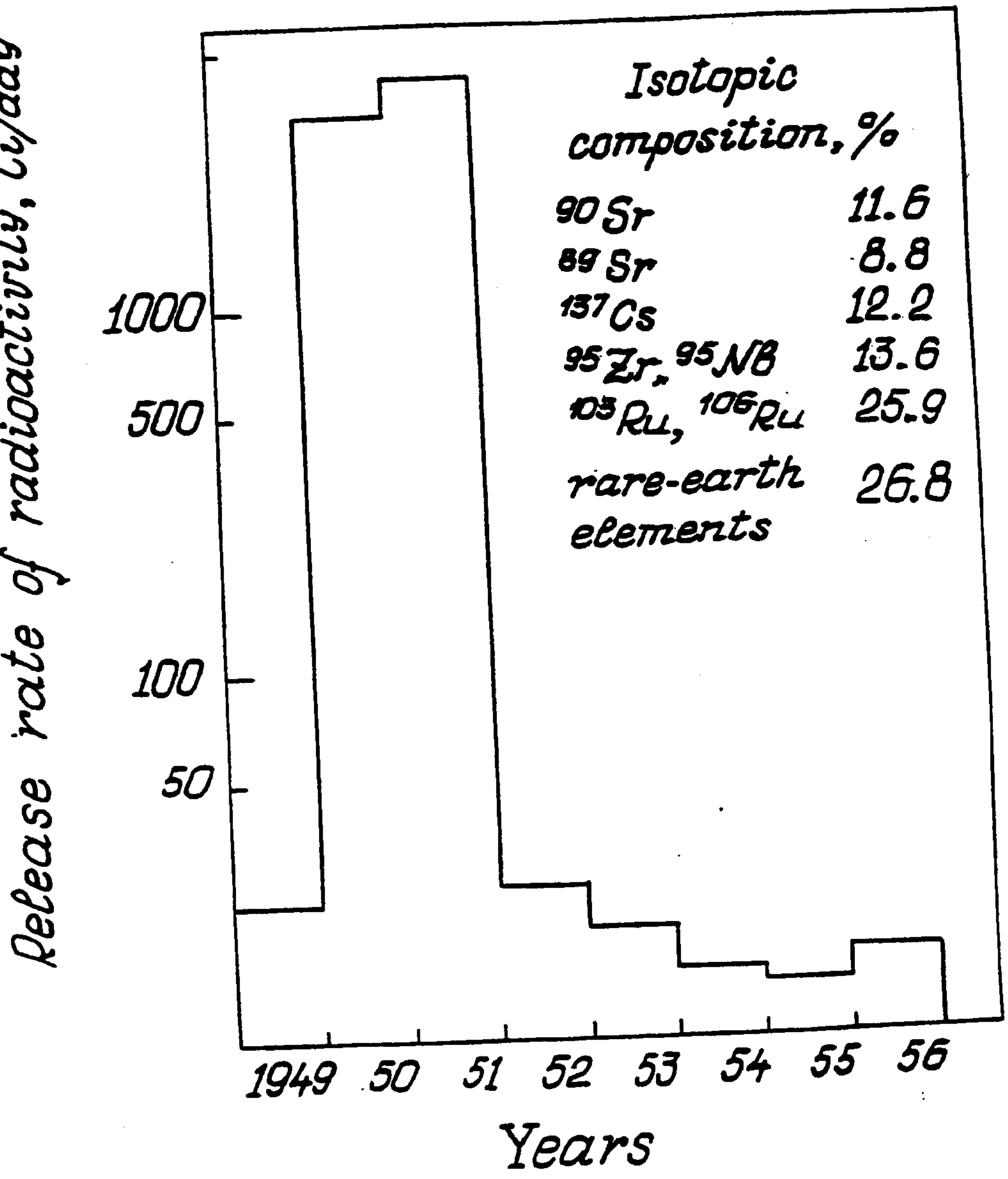
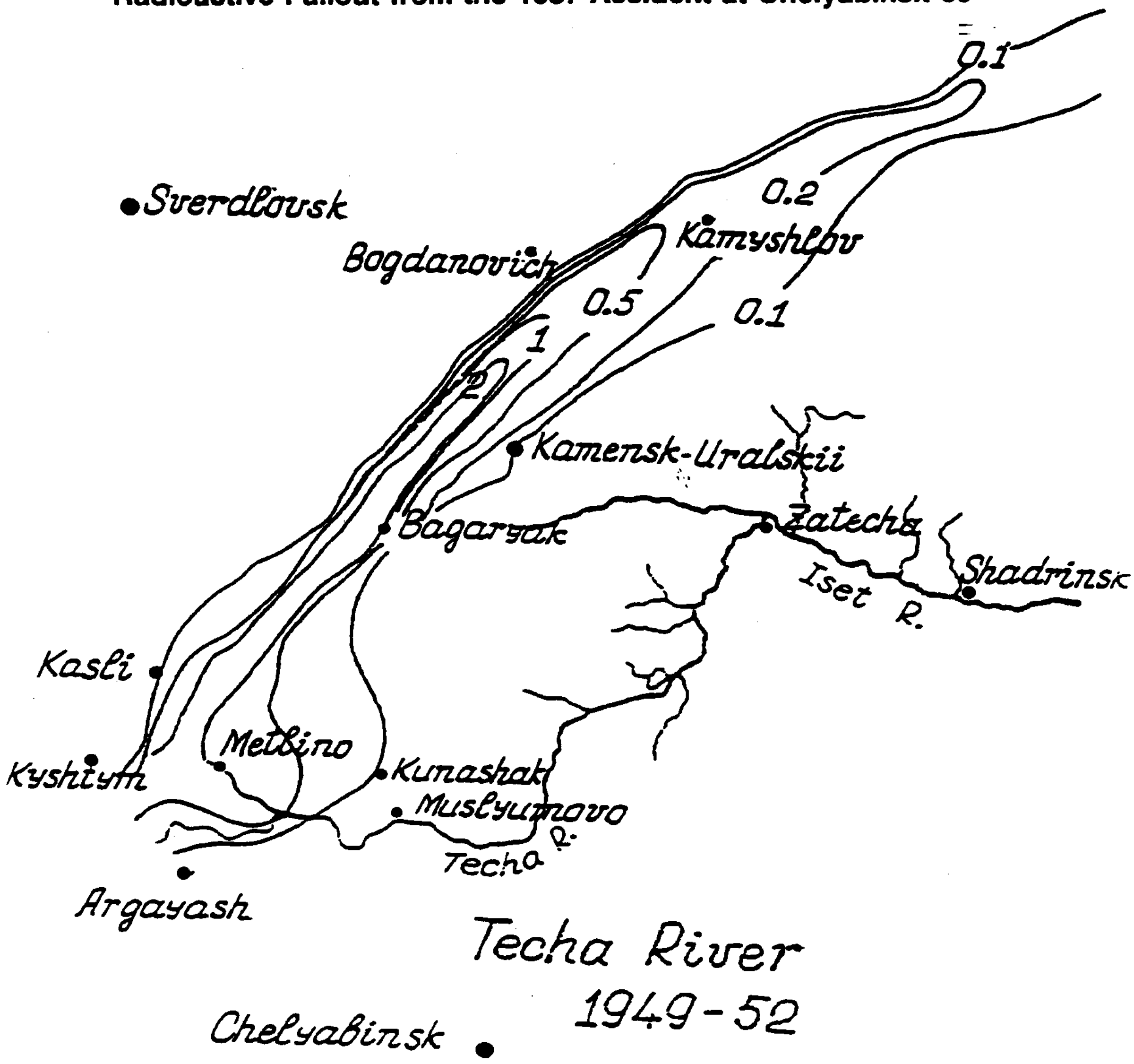

1
canal
2
3
4
10
17
9
11
Techa River
canal
6
16
14
15

Figure 2
Radioactivity Discharged into the Techa River, 1949-1956[1]



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

Figure 3
Radioactive Fallout from the 1957 Accident at Chelyabinsk-65[1]



[1] G.N. Romanov and A.S. Vorovov, "The Radiation Situation After the Explosion," *Priroda*, May 1990, p. 50; also in M.M. Kosenko, M.O. Degtava, and M.A. Petrushova, "Leukemia Risk Estimate on the Base of Nuclear Incidents in Southern Urals," Chelyabinsk Branch Office of the Institute of Biophysics of the USSR Ministry of Health, Chelyabinsk, USSR (undated, ca. 1991), submitted to *PSR Quarterly* for publication.

Appendix 1. Glossary of Key Figures in the Soviet Nuclear Program

Adamsky, Viktor - Born c. 1920. A senior member of the theoretical department at the All-Russian (formerly All-Union) Scientific Research Institute of Experimental Physics (Arzamas-16). Was in charge of what Sakharov calls the "Big Bomb," presumably the 58 megaton device exploded on October 28, 1961.

Aleksandrov, Anatoliy Petrovich - Born February 13, 1903 in Tarashchi. From 1946-1955 directed the Institute of Physical Problems. Part of the Tamm group. Worked with Kurchatov on development of the first production reactors (see *Pravda,* March 4, 1989). Responsible for isotope separation using thermal diffusion. Designer of early graphite production reactors and the later Chernobyl type RBMK reactors. On May 15, 1960 he became director of the I.V. Kurchatov Institute of Atomic Energy. Academician; elected a member of the Academy of Sciences on October 23, 1953; elected President of the Academy on November 25, 1975, and served in that capacity until he was replaced by Guriy Marchuk on October 16, 1986.

Alikhanov, Abram Isaakovich - Born March 5, 1904 in Tbilisi; died December 8, 1970 in Moscow. Appointed to the weapons program at the suggestion of A. F. Ioffe. In 1949 Alikhanov and his colleagues put into operation the first nuclear reactor with a heavy-water moderator in the USSR. Director of the Thermodynamic Laboratory, 1945-1968. Principal constructor of the Serpukhov high energy accelerator. Academician; elected full member of the Academy of Sciences in 1943 (won over Kurchatov).

Anuchina, Nina Nikolayevna - Anuchina was born in 1930 and was graduated from Gorky State University in 1953. She worked at Keldysh Applied Mathematics Research Institute from 1953-55 and at Steklov Mathematical Institute from 1955-57. She joined the Institute in 1957 and is now Head of the Mathematics Division. Her fields of expertise include: finite difference schemes theory, numerical simulation of nonstationary hydrodynamic processes, high-speed impacts, hydrodynamic instabilities, turbulent mixing, and cumulative jets.

Artsimovich, Lev Andreyevich - Born February 25, 1909 in Moscow; died March 1, 1973. From 1930-1944 worked at the Physicotechnical Institute. From 1944 worked at the Institute of Atomic Energy. Responsible for isotope separation using electromagnetic separation. Leader of pioneering work on thermonuclear physics. Academician; elected a member of the

Academy of Sciences on October 23, 1953. Awarded Hero of Socialist Labor, 1969; Lenin Prize 1958; State Prizes 1953 and 1971.

Averin, Alexander Nikitovich - Born in 1946, Averin was graduated from the Moscow Physical-Technical Institute in 1970, and has worked at the All-Russian Scientific Research Institute of Technical Physics for the last 22 years. He holds a doctorate in Science and is deputy head of the Explosion Physics Department. His fields of expertise include: the properties of matter under high pressure and high-speed dynamic processes, such as impacts, phase transitions, cumulation, explosive techniques and technologies.

Avrorin, Evgeniy Nikolaevich - Born July 11, 1932; graduated from Moscow State university in 1954; worked at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16) from March-August 1955. Since its establishment in 1955, Avrorin worked at the All-Union (now All-Russian) Scientific Research Institute for Technical Physics (Chelyabinsk-70), where he is currently the Scientific Leader. Elected corresponding member of the General Physics and Astronomy Department, Academy of Sciences, December 23, 1987. Theoretical physics with interests in the fields of physical processes under high pressures and temperatures, nuclear and neutron physics, inertial confinement fusion, and disarmament.

Babayev, Yuri Nikolayevich - Born May 21, 1928; died October 6, 1986. Graduated from Moscow University in 1950 at the age of 22, went to work for an unidentified research institute in 1951. Is believed to have worked on the nuclear weapons program. Was a junior member of a team that was secretly awarded the Stalin Prize in 1953. In 1959 was given Lenin Prize, in 1962 Hero of Socialist Labor. In 1962 was given rank of senior research worker at an unidentified institute; see *New York Times*, October 29, 1986, p. B8.

Barulin, Anatoly Yegorovich - Born in 1936 and graduated from the Moscow Physical Engineering Institute in 1960, Barulin has a doctorate in Science. He has worked at the All-Russian Scientific Research Institute of Technical Physics since 1960 and is the Chief Designer of the Institute (for fiber optics). His experience includes work in the fields of fiber-optic networks, technology and equipment for fiber production, control systems, cyrogenic machines, and laser thermonuclear experiments.

Belugin, Vladimir Aleksandrovich - Born March 30, 1931 in Leningrad (now St. Petersburg). Current (1990-1992) director of the All-Russian (formerly All-Union) Scientific Research Institute of Experimental Physics (Arzamas-16).

Beria, Lavrenti Pavlovich - Born March 29, 1899, Merkheuli, Russia; died December 23, 1953, Moscow. Brought to Moscow as deputy to Nikolay Yezov, the head of the People's Commissariat for Internal Affairs (NKVD; Soviet secret police). Yezov was shot and Beria became head of the secret police, retaining the position from 1938 to 1953. In 1941 he became deputy prime minister of the USSR, and during World War II, he was a member of the State Defense Committee. He was made a marshall of the USSR in 1945. He was also a member of the Central Committee of the Communist Party from 1934, and of the executive policy-making committee, the Politburo from 1946. Beria was director of atomic bomb program from 1943 to 1953.

Bochvar, A. - Headed a department at Chelyabinsk-40 (now Chelyabinsk-65), responsible for processing plutonium and fabricating the sub-critical fissile masses for a bomb.

Bogolyubov, Nikoay Nikolayevich - Born August 21, 1909. Mathematician and theoretical physicist. Part of the Tamm group. Leading scientist at the All-Union Scientific Research Institute for Experimental Physics (Arzamas-16). Former Academician Secretary of the Mathematics Department, from July 1963. Academician; elected to the Physical Mathematical Sciences Department (now Nuclear Physics Department) of the Academy of Sciences on October 23, 1953. Former Director of the Joint Institute for Nuclear Research in Dubna, from 1965.

Brokhovich, Boris V. - Among the first 300 people to arrive at Chelyabinsk-40 (now Chelyabinsk-65) in 1946. Electrical Engineer; Chief Engineer at the 501-Reactor, May 24, 1952 - July 1, 1954; Director of Plant 156 (three reactor complex) July 12, 1963 - May 18, 1971; Director of Chelyabinsk-65 (formerly Chelyabinsk-40) 1971 - ca. 1991. Hero of Socialist Labor; Lenin Prize, 1960; State Prize laureate, 1954.

Davidenko, V. - Part of the design team at KB-11 (Arzamas-16), responsible for the development of the neutron generator.

Dmitriev, Nikolai - Born c. 1925. Mathematician. Colleague of Sakharov's at the All-Russian (formerly All-Union) Scientific Research Institute of Experimental Physics (Arzamas-16). Did calculations on the "Third Idea." Child prodigy.

Dodochkin, Evgeniy K. - Born June 8, 1940. Currently (1992) responsible for nuclear warhead production facilities (warhead assembly, fissile material storage, etc.) within the Department of Defense Industry, Ministry of Atomic Energy.

Dollezhal', Nikolai Antonovich - Born October 27, 1899. Head designer of the first atomic reactor. A chief designer of naval reactors. Academician. Member of the Physical Technical Problems of Power Engineering Department, and the Mechanics and Control Processes Department.

Drozhko, Evgeny Gordeevich - Candidate of Technical Sciences and Chief Engineer at Chelyabinsk-40 (now Chelyabinsk-65) in 1989.

Dukhov, Lt. Gen. Nikolai Leonidovich - Born October 26, 1904; died May 1, 1964. Was drafted in July 1948 into the atom bomb program and was the right hand man on the engineering side to Kurchatov. Deputy head of the scientific effort at KB-11 (Arzamas-16). In 1932-1948 he was chief designer at the Kirov plant in Leningrad (now St. Petersburg), where during World War II he designed the Stalin tank. In early 1954 he was moved to the ICBM program where he headed a design bureau. Three times a Hero of Socialist Labor in 1945, 1949 and 1954; Lenin Prize in 1960; see *New York Times*, November 11, 1984, p. 14.

Dzekun, Evgeniy G. - Chief Engineer of the Radiochemical Plant, "Mayak" Production Association (Chelyabinsk-65) in 1991.

Fedorov, Ye - Born 1910; died ? According to May 3, 1990 *Izvestiya* he once worked at the test site in Novaya Zemlya. Academician; Chief Scientific Secretary of the Academy of Sciences.

Feoktistova, Ekaterina - Born c. 1920. A colleague of Sakharov's. Sent to work at the All-Russian (formerly All-Union) Institute Technical Physics (Chelyabinsk-70) in the mid-1950s.

Fetisov, Victor Ilich - Currently (1990) Director of the Mayak Production Association (Chelyabinsk-65).

Flerov, Georgii Nikolaevich - Born March 2, 1913 in Rostov-on-Don. From 1938-1941 was on the staff of the Physicotechnical Institute. From 1941-1943 was in Soviet Army. From 1943-1960 on staff of Institute of Atomic Energy. Worked at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16). In 1960 made director of Nuclear Reactions Laboratory of the Joint Institute for Nuclear Research in Dubna. In 1940

Flerov together with L.I. Rusinov showed that more than two neutrons are emitted during the fission of a uranium nucleus. In the same year together with K.A. Petrzhak, Flerov discovered the spontaneous fission of heavy nuclei. Noticed articles on nuclear energy had disappeared from American, British, and German publications in the early 1940s. As a consequence he wrote letter to Stalin in April 1942 alerting him to the urgency of solving the "uranium problem." This prompted renewed interest by the Soviets in developing an atomic bomb.

Frank-Kamenetskiy, D.A. - A leading theoretical physicist at the All-Russian (formerly All-Union) Scientific Research Institute of Experimental Physics (Arzamas-16), arriving there in 1946.

Fuchs, Klaus - (December 29, 1911 - January 28, 1988) A German-born physicist in the U.S. fission and fusion weapons program at Los Alamos who was convicted of being a Soviet spy. Emigrated first to Britain and then went to Los Alamos during World War II. After the war he returned to Britain and worked at Harwell, a nuclear research center near Oxford. From 1941 on he carried out espionage for the Soviet Union until his arrest in February 1950. He served nine years of a 14-year sentence and returned to East Germany where he resumed a scientific career.

Fursov, V. - Assistant to Kurchatov who helped with the design of the F-1 pile and who helped oversee the construction of Chelyabinsk-40 as Kurchatov's main representative.

Gavrilov, Viktor Yulianovich - Born c. 1920; died early 1970s. Colleague of Sakharov's at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16). Later became a molecular biologist. Headed radiobiological department.

Ginzburg, Vitaly Lazarevich - Born October 4, 1916. First to propose the use of lithium deuteride in thermonuclear weapons; Sakharov said that "The first two ideas [about the H-bomb] were those proposed by Vitaly Ginzburg and myself in 1948." Member of the Physics Institute of the Soviet Academy of Sciences (FIAN). Part of the Tamm group. Academician; elected to General Physics and Astronomy Department of the Academy of Sciences on July 1, 1966. Also a member of the Nuclear Physics Department.

Gorbets, Boris V. - Currently (1991-1992) Deputy Head of Department for Nuclear Weapons Production, Department of Defense Industries, Ministry of Atomic Energy.

Gurevich, Isai Izrailevich - Born July 13, 1912 in Riga. Graduated from Leningrad University in 1934. From 1934-1945 worked at the Radium Institute. Since 1945 at the I.V. Kurchatov Institute of Atomic Energy. Corresponding Member of the Academy of Sciences, 1968. Main work in neutron physics, reactor theory and the properties of muonium.

Ioffe, A.F. - Head of the Physics Institute of the Soviet Academy of Sciences (FIAN) who recommended I.V. Kurchatov as the man to head the Soviet Union's atomic bomb development program.

Ivanov, Victor - Currently (1991-1992) Deputy Head of Department, Nuclear Weapons Development and Testing, Department of Defense Industry, Ministry of Atomic Energy.

Izrael, Yuriy Antoniyevich - Born May 15, 1930. According to May 3, 1990 *Izvestiya,* he once worked at the test site in Novaya Zemlya. Elected corresponding member of the Oceanology, Atmospheric Physics and Geography Department, Academy of Sciences on November 26, 1974.

Izraileva, Revekka - Born c. 1920. Mathematician. Colleague of Sakharov's at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16).

Keldysh, Mstislav Vsevolodovich - Born February 10, 1911; died 1978. Academician; President of the Academy of Sciences, 1961-1975.

Khandorin, G. - Director of the Siberian Chemical Combine (Tomsk-7) in 1991.

Khariton, Yuliy Borisovich - Born February 27, 1904 in St. Petersburg. Graduated from the Leningrad Polytechnic Institute in 1925. From 1926-28 studied at the Cavendish Laboratory in England under Rutherford and received a PhD. In 1939, with Y. B. Zeldovich, was the first to calculate the chain reaction of uranium fission. Part of the Tamm group. Scientific director of the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16) from its beginning in 1946, until the present. With Sakharov and Zeldovich one of the three principal developers of the Soviet hydrogen bomb. Academician; elected a member of the Nuclear Physics Department, Academy of Sciences on October 23, 1953. Awarded the title of Hero of Socialist Labor three times, in 1949, 1953, and 1956.

Khlopin, V.G. - Director of the Radium Institute in Leningrad from 1939. First scientific director of Chelyabinsk-40 (now Chelyabinsk-65).

Kikoin, Isaak Konstantinovich - Born March 28, 1908 in Malye Zhagory; died December 1984. In 1943 worked at the Kurchatov Institute of Atomic Energy. Responsible for isotope separation using gaseous diffusion. He was head of the isotope enrichment department and involved in uranium enrichment in the Urals. Hero of Socialist Labor 1951. Academician; elected a member of the Academy of Sciences, October 23, 1953.

Koblov, Petr Ivanovich - Currently (1991) deputy chief designer at the All-Russian (formerly All-Union) Scientific Research Institute of Technical Physics (Chelyabinsk-70).

Komelkov, V. - Head of the department at KB-11 (Arzamas-16) responsible for producing kryton triggering devices.

Konovalov, Vitaliy Fedorovich - Born 1932. Minister of the Ministry of Atomic Power and Industry (now the Ministry of Atomic Energy (formerly the Ministry of Medium Machine Building) until August 1991; First Deputy Minister of Atomic Energy, March 1992-present.

Kozlov, Boris Isakovich - A colleague of Sakharov's at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16). Designed the device exploded on September 27, 1962. Acting Director of Caspian Mining and Metallurgical Complex (PGMK) ore administration, responsible for mining and refining of uranium ore; a defense plant under the MMB, 1989- .

Kryuchenkov, Vladimir Borisovich - Kryuchenkov was born in 1948 and was graduated from the Moscow Physical Engineering Institute in 1972 with a doctorate in Science. In 1972, Kryuchenkov joined the All-Russian Scientific Research Institute of Technical Physics and is currently head of the Experimental Physics Department. Kryuchenkov is an expert in diagnostics of dense high-temperature plasma, laser-plasma soft x-ray sources, plasma spectroscopy, and laser fusion.

Kurchatov, Igor Vasilyevich - Born January 12, 1903 in Sim (now in Asha Region, Chelyabinsk Oblast); died February 7, 1960 in Moscow. The son of a surveyor Kurchatov graduated in 1923 from Crimean University in physics and math. In 1925 he began at the Physicotechnical Institute under A. F. Ioffe. He was head of the Soviet nuclear weapons program. In 1943 he founded and was head of what later became known as the Institute of Atomic Energy. Since 1960 it has been known as the Kurchatov Institute of Atomic Energy. He is buried at the Kremlin Wall. The 104th element, Kurchatovium is named for him, though there is a competing claim that the element should be called Rutherfordium. Awarded the title of Hero of Socialist Labor three times, in 1949, 1953, and 1954.

Lavrentyev, M.A. - A leading theoretical physicist at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16), arriving there in 1946.

Lebedev, Valeriy - Director of the Mining and Chemical Combine (Krasnoyarsk-26) in 1991.

Ledenyov, Boris N. - Director of the at All-Union Scientific Research Institute of Technical Physics (Chelyabinsk-70) from 1961 to 1963.

Litvinov, Boris Vasilyevich - Born November 12, 1929 in Voroshilovgrad, Ukraine. The current (1992) first deputy scientific leader of the All-Russian (formerly All-Union) Scientific Research Institute of Technical Physics (Chelyabinsk-70). Chief designer of the institute; professor; member of the Russian Academy of Sciences; graduated in 1953 from the Moscow Institute of Engineering and Physics.

Lominskiy, Georgii P. - Director of the All-Union Scientific Research Institute of Technical Physics (Chelyabinsk-70) from 1963 to 1986.

Malyshev, Vyacheslav Aleksandrovich - Born December 16, 1902 in Ust'-Sysol'sk, now Syktykar; died February 20, 1957 in Moscow. Warhead head of Soviet tank production program. Vice-chairman of the Council of People's Commissars, 1940-1944. As Minister of Ministry of Medium Machine Building from June 1953-1955, assumed responsibility for the nuclear weapons program from Beria following Stalin's death. Buried at the Kremlin Wall.

Mikhailov, Victor Nikitovich - Born 1934. Graduated with distinction from the Moscow Engineering Physics Institute. Graduate student in theoretical physics under Academician Ya. B. Zeldovich at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16). Director of the Institute of Impulse Technology. Deputy Director, Ministry of Atomic Power and Industry (formerly the Ministry of Medium Machine Building) until March 1992, when he was promoted to Minister of Atomic Energy.

Mikerin, Evgeniy I. - Deputy Minister and Head of Directorate in charge of fuel cycle activities, Ministry of atomic Energy, March 1992 to present. Head of Department of Isotope Separation, Reprocessing, and Production Technology, Ministry of Atomic Power and Industry until 1992; in charge of isotope production, i.e., production reactors and uranium enrichment. program.

Molotov, V.M. - Supervised the early stages of the atomic bomb program, but lost control of the program to Beria in 1945.

Morozov, Igor Pavlovich - Born in 1939 and graduated from Kharkov Polytechnic Institute in 1961 with a degree in mechanical engineering, Morozov is the Deputy Chief Engineer of the Institute. He holds a doctorate in Science and his fields of expertise include: development of test systems, automatization of production processes, management of developments.

Muzrukov, Boris Glebovich - Born 1904; died 1979. Defense official, Combine (Chelyabinsk-40) director during its construction in 1946 and until 1955; director of the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16) from 1955 to 1974. Awarded the title of Hero of Socialist Labor twice, in 1943 and 1949; Lenin Prize in 1962.

Nechai, Vladimir Zinovyevich - Born May 5, 1936 in Alma Ata, Kazakh. Director of the All-Russian Scientific Research Institute of Technical Physics (Chelyabinsk-70) since 1986.

Negin, Yevgeniy Arkad'yevich - Born 1921. General and Academician with the Mechanics and Control Processes Department, since March 15, 1979. Worked at the All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16) He witnessed his first nuclear test in 1953, and attended virtually all subsequent nuclear test by Arzamas-16 since then, and was scientific leader at about half of them (*Pravda*, April 16,1992, p. 4). According to May 3, 1990 *Izvestiya,* he once worked at the test site in Novaya Zemlya.

Nikipelov, Boris V. - Born August 2, 1931. Worked at Mayak Chemical Combine (Chelyabinsk-65; formerly Chelyabinsk-40) from 1955 to about 1985; Chief Engineer. First Deputy Director, Ministry of Atomic Energy and Industry (formerly Ministry of Medium Machine Building, and now Ministry of Atomic Energy) until March 1992. Advisor to the Minister of Atomic Energy for international relations, chemical separation, and nuclear waste management March 1992 to present.

Nikitin, Boris Alekandrovich - Worked with Kurchatov during the early weapon development period (see *Pravda,* March 4, 1989). Engineer responsible for developing the technology to extract plutonium from the F-1 pile. Corresponding member of the Academy of Sciences.

Nikitin, Vladislav I., - Currently (1991-1992) the deputy director of the All-Russian Scientific Institute of Technical Physics (Chelyabinsk-70).

Nikolskii, Boris Petrovich - Born 1900; died 1990. Worked with Kurchatov during the early weapon development period (see *Pravda*, March 4, 1989). Academician, full member of the Academy of Sciences.

Ovsyannikov, L.V. - Leading scientist at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16).

Pavolovsky, Aleksandr Ivanovich - Born June 27, 1927. Currently (1992) head of the Department of Fundamental and Applied Research at the All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16).

Pavlov, Nikolai - Born c. 1917; died ? Appointed in 1943 representative of the Central Committee and Council of Ministers at Laboratory No. 2 (subsequently the Kurchatov Institute of Atomic Energy).

Pervukhin, Mikhail Georgiyevich - Born 1904. Minister of Medium Machine Building, May-July 24, 1957. Ambassador to GDR, 1958-1962.

Pishchepov, Aleksandr Ivanovich - Current (1990) Deputy Director for Procedures at the Mayak Production Association (Chelyabinsk-65).

Pomeranchuk, Isaak Iakovlevich - Born May 20, 1913 in Warsaw, died December 14, 1966 in Moscow. Graduated from the Leningrad Polytechnic Institute in 1936. From 1940-1943 worked at the Institute of Physics and from 1943-1946 at the Institute of Atomic Energy. In 1946 he joined the staff of the Institute of Theoretical and Experimental Physics and also became a professor at the Moscow Physical Engineering Institute. Made an important contribution to the theory and development of the first nuclear reactors in the USSR. Corresponding Member of the Academy of Sciences, 1953; Academician, 1964. Awarded: State Prize, 1950, 1952; Order of Lenin; Lenin Prize

Romanov, Gennady N. - Chief of Experimental Research Station, "Mayak" Production Association (Chelyabinsk-65) in 1991.

Romanov, Yuri - Born c. 1920. A colleague of Sakharov's from 1948 to 1955. Sent to work at the All-Russian (formerly All-Union) Scientific Research Institute of Technical Physics (Chelyabinsk-70) in the mid-1950s.

Ryabev, Lev Dmitriyevich - Born 1928. In 1957 he graduated from the Moscow Engineering and Physics Institute. Was deputy chief engineer, deputy director, and director of the Scientific and Research Institute of the Ministry of Medium Machine Building. From 1984 he was deputy and from June 1986 first deputy of the Ministry. At the end of 1986 he was appointed Minister of Medium Machine Building.

Sadovskiy, Mikhail Aleksandrovich - Born November 6, 1904. In 1949 he was deputy director of the Institute of Chemical Physics and responsible for the nuclear test site at Semipalatinsk. According to May 3, 1990 *Izvestiya,* he once worked at the test site in Novaya Zemlya. Director of the Institute of Physics of the Earth until he retired about 1988. Academician; elected member of the Geology, Geophysics, Geochemistry, and Mining Sciences Department of the Academy of Sciences in July 1, 1966.

Sakharov, Andrei Dmitriyevich - Born May 21, 1921; died December 15, 1989. Lived and worked at the All-Russian (formerly All-Union) Scientific Research Institute of Experimental Physics (Arzamas-16) from 1950 to 1968. With Khariton and Zeldovich one of the three principal developers of the Soviet hydrogen bomb, responsible for the "First" and "Third Idea." Became Academician in the Physical and Mathematical Sciences Department on October 23, 1953. Awarded the title of Hero of Socialist Labor three times (1953, 1956, and 1962), and won the Lenin Prize, the USSR State Prize, and the 1975 Nobel Prize for Peace.

Sazhnov, Vladimir K. - Director of Radiochemical Plant, "Mayak" Production Association (Chelyabinsk-65) in 1991.

Semenov, Nikolai Nikolayevich - Born April 15, 1896; died 1986. Born in Saratov, graduated from Petrograd University in 1917. From 1920-1931 worked at Leningrad Physicotechnical Institute. Corresponding Member of the Academy of Sciences, 1929; Academician, 1932. In 1931 became Director of the Institute of Chemical Physics. Was responsible for the "polygon" (the nuclear test site) at Semipalatinsk in 1949, when the Soviets tested their first atomic device. Vice President of the Academy of Sciences 1963-1971. Shared Nobel Prize in Chemistry (1956) with Sir Cyril Hinselwood for parallel research on chemical reaction kinetics. Awarded: Hero of Socialist Labor, 1966; seven Orders of Lenin; State Prize, 1941, 1949; Order of the Red Banner of Labor.

Semyonov, Nikolai Anatol'evich - Born 1918; died January 28, 1982. First Deputy Minister of Medium Machine Building from 1971 to his death. He joined the nuclear weapon program in 1948 and rose to become director of a secret warhead manufacturing plant before his transfer to MMB in 1971. Received Hero of Socialist Labor.

Shchelkin, Kirill Ivanovich - Born May 17, 1911; died November 8, 1968. Graduated from the Crimean Pedagogical Institute in Simferopol in 1932. Main works were devoted to the physics of combustion and explosion. Was Khariton's deputy at the All-Russian (formerly All-Union) Scientific Research Institute of Experimental Physics (Arzamas-16). Head of a department at KB-11 (the earlier name for Arzamas-16) responsible for the development of explosive shaped charges. Previously at the Institute of Chemical Physics. Served as the first scientific director of the All-Union Scientific Research Institute of Technical Physics (Chelyabinsk-70) from 1955 until 1960. Corresponding member of the Academy of Sciences. Three times a Hero of Socialist Labor, in 1949, 1953, and 1956.

Simonenko, Vadim Aleksandrovich - Born November 8, 1939. Graduated in 1962 from Moscow Engineering Physical Institute; Head of Theoretical physics department, All-Russian (formerly All-Union) Scientific Research Institute of Technical Physics (Chelyabinsk-70) where he has worked since 1961.

Slavsky, Yefim Pavlovich - Born November 7, 1898 in Makeevka, Ukraine. Trained as a metallurgical engineer. The first Chief Engineer at Chelyabinsk-40 (now Chelyabinsk-65) - 1946. In charge of metallurgical extraction and processing aspects of the early bomb program. Deputy, then First Deputy Minister of Medium Machine Building, 1953-1957. Replaced Pervukhin as Minister of MMB, 1957-1963. Chairman, State Production Committee for MMB, 1963-1965. Minister of MMB, 1965-1986. Received Hero of Socialist Labor, 1949, 1954 and 1962; Lenin prize 1980; State Prizes 1949 and 1951.

Tamm, Igor Evgen'evich - Born July 8, 1895 in Vladivostok; died April 12, 1971 in Moscow. Created a school of theoretical physics to which many well-known Soviet scientists belonged. In June 1948 appointed head of a special nuclear bomb research group at the Physics Institute of the Soviet Academy of Sciences (FIAN). He and Sakharov proposed in 1950 that a hot plasma in a magnetic field be used to obtain a controlled thermonuclear reaction. Left the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16) after the August 1953 test to return to Moscow.

Won the Nobel Prize in Physics in 1958. Elected a member of the Academy of Sciences on October 23, 1953.

Tchernyshev, Alexander K. - Born October 23, 1945. Currently (1992) Deputy scientific director All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16).

Thiessen, A. - German scientist captured by the Russians at the end of the war who succeeded in producing a suitable barrier for isotope enrichment by gaseous diffusion.

Tolstikhin, Oleg T. - Deputy Director, "Mayak" Production Association (Chelyabinsk-65) in 1991.

Trutnev, Yuri Alekseyevich - Born November 2, 1927. Sakharov says that he made "significant contributions" to understanding "the Third Idea." He is currently first scientific deputy director of the All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16). Elected as a corresponding member of the Nuclear Physics Department of the Academy of Sciences on June 26, 1964 (now a full member), and became a full member of the Russian Academy of Sciences in 1991. A Hero of Socialist Labor.

Tsyrkov, Georgi Pavlovich - Head of the department defense industry within the Ministry of Atomic Power and Industry (formerly the Ministry of Medium Machine Building). This department is responsible for the design laboratories, including the All-Russian Scientific Research Institute of Experimental Physics (Arzamas-16), the All-Russian Scientific Research Institute of Technical Physics (Chelyabinsk-70), the test sites, and the warhead fabrication plants. In March 1992 appointed Head of the Department responsible for nuclear weapons research (at Arzamas-16 and Chelyabinsk-70), and nuclear weapons testing (at the Central Test Site) in the newly created Ministry of Atomic Energy. According to May 3, 1990 *Izvestiya,* he once worked at the test site in Novaya Zemlya.

Vannikov, Boris L'vovich - Born September 7, 1897 in Baku; died February 22, 1962 in Moscow. From 1942-1946 was People's Commissar of Munitions. In 1949 he was head of the First Main Directorate of the Soviet Council of Ministers, the provisional designation given the agency responsible for the entire atomic program. It was subsequently renamed the Ministry of Medium Machine Building, and Vannikov was First Deputy Minister from 1953-1958. Three times Hero of Socialist Labor, 1942, 1949, 1954; State Prize 1951, 1953.

Vasilyev, Dmitri Ch. - Died early-1961. First director of the All-Union Scientific Research Institute of Technical Physics (Chelyabinsk-70) from 1955 until his death in early-1961.

Velikhov, Evgeniy Pavlovich - Born February 2, 1935. Currently (1992) Vice President (for Physical and Mathematical Sciences Section since November 1977) of the Russian (formerly Soviet) Academy of Science; and Director of Kurchatov Institute of Atomic Energy since 1988. The first President of the Soviet Nuclear Society. Formerly Chairman of the Armed Services Subcommittee of the Defense and State Security Committee of the USSR Supreme Soviet.

von Ardenne, M. - German nuclear scientist who went to work for the Russians after the end of the war. Headed up a team of German scientists who were working on the problem of isotope separation.

Yangel, M. - Worked at All-Union Scientific Research Institute of Technical Physics (Chelyabinsk-70).

Yegorov, Nikolay Nikolaevich - Physicist, Deputy Minister of Atomic Energy (Minatom) responsible for uranium enrichment, production reactors, plutonium and other isotope production, chemical separation, and radioactive waste management, March 1992- present. From 1965-1992, worked at Krasnoyarsk-45.

Yemelyanov, Vasiliy Semenovich - Born 1901. Joined nuclear project in September 1945, as deputy to Boris L. Vannikov. Various unknown posts between 1946 to 1957. From 1957-1960, Head, Main Board on the Use of Atomic Energy, USSR Council of Ministers. From 1957-1959 was permanent USSR representative at the International Atomic Energy Administration. 1960-1962 was Chairman, State Committee on the Use of Atomic Energy. Accompanied Khruschev to U.S. in 1959. Awarded: Stalin Prize, 1942, 1950; Order of Lenin; Hero of Socialist Labor, 1954.

Zababakhin, Yevgeny Ivanovich - Born January 16, 1917; died December 1984. Director of the All-Russian (formerly All-Union) Scientific Research Institute of Technical Physics (Chelyabinsk-70) from 1960 until his death about 1984. A colleagues of Sakharov's. Main works are on hydrodynamics and explosions. Corresponding Member of the Academy of Sciences, 1958; Academician, 1968. Hero of Socialist Labor, 1953; Lenin Prize, 1958, State Prize, 1949, 1951, 1953.

Zavenyagin, Avraamii Pavlovich - Born April 14, 1901 in Uzlovaia; died December 31, 1956 in Moscow. Colonel general in the army and main aide to Beria in supervising the postwar nuclear weapons program. Worked with Kurchatov during the early weapon development period (see *Pravda,* March 4, 1989). Worked at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16), arriving there in 1946. Deputy Minister of Medium Machine Building 1953-1954. Minister of Medium Machine Building 1955 replacing Malyshev. In 1955-56 organized the All-Union Scientific Research Institute of Technical Physics (Chelyabinsk-70). Twice Hero of Socialist labor, 1949 and 1954. Buried at the Kremlin Wall. Was project director for the research team of German scientists immediately after the war, that were located near Sukhumi on the Black Sea.

Zeldovich, Yakov Borisovich - Born March 8, 1914 in Minsk; died December 2, 1987. One of the founders of the modern theory of combustion, detonation, and shockwaves. His work with Khariton (1939-1941) were of great importance in solving the problem of the use of nuclear energy. An important paper with Khariton was delivered at the Conference on Questions of the Physics of the Atomic Nucleus held in Kharkov, November 15-20, 1939 and published later that year. In his *Memoirs* Sakharov said that h is task, with the Tamm group, was initially to verify and refine the calculations produced by Zeldovitch's group at the Institute of Chemical Physics. Sakharov said that he now believes that the design developed by the Zeldovich group for the hydrogen bomb was directly inspired by information acquired through espionage, though he has no proof. Zeldovich was initially responsible for theoretical research at the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16), arriving there in 1946. With Khariton and Sakharov one of the three principal developers of the Soviet hydrogen bomb. Academician; elected full member of the Academy of Sciences in 1958. Awarded the title of Hero of Socialist Labor three times, in 1949, 1953, and 1956.

Zernov, P.M. - Administrator of KB-11 (Arzamas-16).

Zubarev, Dmitri - Theoretical physicist who worked with Zavenyagin and with German scientists near Black Sea. Was transferred to the All-Union Scientific Research Institute of Experimental Physics (Arzamas-16) where he remained until 1953.

Zysin, Yuri - Born c. 1920; died 1987. A colleague of Sakharov's. Sent to work at the All-Union Scientific Research Institute of Technical Physics (Chelyabinsk-70) in the mid-1950s.

Appendix 2. Flerov Letter to Stalin, April 1942

Dear Iosif Vassarionovich:

Ten months have already elapsed since the beginning of the war, and all the time I have felt like a man trying to break through a stone wall with his head.

Where did I go wrong?

Am I overestimating the significance of the "uranium problem"? No I am not. What makes the uranium projects fantastic are the enormous prospects that will open up if a successful solution to the problem is found. I have to make a reservation from the very beginning. Perhaps I am not right—in research there is always as element of risk, more so with uranium that anything else. Let us imagine for a minute, however, that we have "succeeded" with uranium. True this will not bring about a revolution in technology, as the projects of the prewar months showed but then a veritable revolution will occur in military hardware. It may take place without our participation—due simply to the fact that now, as before, the scientific world is governed by sluggishness.

Do you know, Iosif Vassarionovich, what main argument has been advanced against uranium? "It would be too good if the problem could be solved. Nature seldom proves favorable to man."

Perhaps being at the front, I have lost all perspective of what science should deal with at present, and the long term problems, like that of uranium, must be postponed until the after the war. I think we are making a big mistake. The greatest follies are made with the best intentions.

All of us want to do all we can to rout the nazis, but there is no need for such hurry-scurry, no need to deal only with problems that come under the term "pressing" military objectives.

Well and, finally, maybe I am taking too much upon myself. All letters which you, Iosif Vassarionovich, receive may be divided into two groups. In the first there are letters with proposals which can, in their authors' view, help the struggle against the nazis. In the second there are the same proposals, but the implementation of these proposals is linked to some changes in the position of the author himself.

Now, I find it very difficult to write, knowing that the "sober" approach can be rightfully applied to me. What is Flyorov raging about over there? He dealt with science, was called up to the army, wants to get out of it and, using uranium as a pretext, has been showering letters upon all and sundry with disapproving comments on Academicians.

Now, for the solution of the question I consider it necessary to call a conference, which should be attended by Academicians Ioffe, Fersman, Vavilov, Khlopin and Kapitsa, Academician of the Ukrainian Academy of Sciences [Alexsandr Il'ich] Leipunsky, Professors Landau, Alikhanov, Artsimovich, Frenkel, Kurchatov, Khariton and Zeldovich, Doctors Migdal and Gurevich. It is also desirable to invite K. A. Petrzhak.

I ask an hour and a half for the report, and your presence, Iosif Vissarionovich, either in person or by default, is most desirable.

Generally speaking, now is not the time to arrange such scientific tournaments but personally, I see this as the only means to prove that I am right and have the right to deal with uranium—because other means—personal talks with A. F. Ioffe, letters to Comrade Kaftanov have brought about no results and are simply being passed over in silence. I have received no reply to my letter and five telegrams to Comrade Kaftanov. When discussing the plan of the Academy of Sciences, they probably spoke about everything but uranium.

This is that wall of silence which I hope you will help me break through, because this is my last letter, whereupon I lay down arms and wait till the problem has become solved in Germany, Britain or the USA. The results will be so overriding it won't be necessary to determine who is to blame for the fact that this work has been neglected in our country, the Soviet Union.

All of this is being done in such a skilful manner that we shall not even have formal grounds against anyone. No one anywhere has ever said that the nuclear bomb is unfeasible and yet there is the opinion that this task belongs to the realm of science fiction.

Therefore my first request, on whose fulfillment I insist, is to receive from all candidates to the future conference written considerations concerning the feasibility of the uranium problem. The conclusion should include a reply concerning the figure which should be used to assess the probability of solving the problem. For those conference participants who will consider their erudition insufficient for a written conclusion, this question may be ignored, but they are not relieved of the duty of attending the conference.

Source: *Moscow News,* No. 16, 1988.

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