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RADIOACTIVE WASTE MANAGEMENT IN THE FORMER USSR

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D. J. Bradley

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Pacific Northwest Laboratory
Richland, Washington 99352

EXECUTIVE SUMMARY

The developments expected over the next 10 years in the nuclear industry in the former Soviet Union have been described by B. V. Nikipelov, formerly Acting Minister of the new Russian Ministry of Atomic Energy (Minatom), which replaced the Ministry of Atomic Power and Industry (MAPI) in January 1992. He expects improvements in operating capacities of fuel cycle facilities to be achieved through modernization based on process automation, and a significant improvement related to environmental issues.

In the front end of the nuclear fuel cycle, the Soviets plan to decrease the number of operating uranium mines and open pits, especially low-production and high-cost operations. Some uranium processing plants will be converted to process other raw materials. After taking this into account, the former Soviet Union still will be able to supply a nuclear power capacity of up to 100 gigawatts-electrical (GWe) and maintain exports of natural uranium for a "long period of time." The Soviets plan further improvements to the gas centrifuge process and expect to enrich both domestic and foreign uranium as well as to produce high-purity ^{55}Fe and ^{85}Kr and unspecified isotopes of tungsten, sulfur, xenon and molybdenum. The existing enrichment capacity was stated to meet the needs of a nuclear power capacity of up to 100 GWe as well as enrich stored domestic supplies and provide enrichment services to foreign customers. It is estimated that the nuclear power capacity in the former Soviet Union will be about 60 GWe by the year 2000 (Nikipelov 1991). Installed new capacities of 7,000 megawatts-electrical (MWe) could be put into operation between 1991-1995, and capacities totaling 12,600 MWe could be added during the subsequent 5-year period (Konovalov 1991).

The Chernobyl accident has led to the cancellation or suspension of nuclear reactors at 39 sites having a total capacity of 109,000 MWe. However, after the year 2000, the Soviets forecast an increase in reactor growth to 150,000 to 200,000 MWe, allowing for decommissioning, by the year 2010. Near-term growth is based on the VVER-88 design, with growth after the year 2000 based on the "enhanced-safety" VVER-92 and smaller (500 to 600 MWe) versions

of this design. A reactor of even greater inherent safety, called the VPBER-600, is scheduled for design completion by 1994-1995, with a first unit possibly being built by the year 2000. With respect to reactor safety, the Soviets have stated they accept that a core-melt accident without offsite consequences should not happen more than once in 100,000 reactor years, and one with radioactive releases once in 10 million reactor years (Nucleonics Week, April 25, 1991a).

For the back end of the nuclear fuel cycle, Soviet policy continues to be the use of reprocessing of spent nuclear fuel with recycle of plutonium and uranium in fast as well as thermal reactors. The existing fuel fabrication facilities were stated to be able to satisfy a nuclear power capacity of up to 120 GWe. The Soviets plan to finish a mixed-oxide fuel fabrication plant [at Chelyabinsk-65] and the first phase of the VVER-1000 fuel reprocessing plant at Krasnoyarsk. They believe that by reprocessing VVER reactor fuel and by recycling uranium and plutonium (even in thermal reactors), they can reduce their needs for natural uranium by a factor of two over the 2000-2030 time frame, as well as reduce capital outlays per 1 GWe of installed nuclear capacity by 12 to 15% (Nikipelov 1991). In April 1991, the Soviets stated that they were ready to reprocess foreign spent nuclear fuel (Kyodo, April 15, 1991), and in July, Nikipelov suggested that international reprocessing services be offered at the Krasnoyarsk facility (Nuclear Fuel, July 8, 1991).

In waste management, the former Soviet Union will pay a great deal of attention to improving environmental conditions at existing facilities, bring high-level waste vitrification to the "commercial level," and continue field work on geologic disposal of solidified radioactive wastes (Nikipelov 1991). Also, the former MAPI drafted a state program for handling radioactive wastes. The program plan extends to the year 2001, and may cost up to 40 billion rubles, not counting for inflation (Bradley, November 11, 1991).

The Soviets continue to investigate several options for the management of long-lived nuclear wastes (Egorov et al. April 1991):

- partitioning of long-lived radionuclides
- improvement of solidification methods such as vitrification and the making of higher-melting-point materials

- transmutation of long-lived radionuclides
- disposal of radioactive wastes into outer space, as well as investigation of the more conventional geologic storage methods.

The second industrial-scale vitrification unit at Chelyabinsk-65 was operational in June 1991, and with respect to high-level waste (HLW) disposal, the Soviets stated their "first priority" is to establish an underground R&D laboratory "in the Chelyabinsk region." These points, in addition to the large amount of environmental contamination at the Chelyabinsk-65 site, have led to that site being proposed as an international research center. Currently, the Soviets have agreements with the United States, the United Kingdom, France, Japan, South Korea, Argentina, and the Commission of European Communities (CEC) in the area of radioactive waste disposal and environmental restoration (Nuclear Fuel, July 8, 1991).

The Soviets have disposed of large quantities of radioactive wastes [apparently of all types] by injecting them into geologic formations. Although past reports have indicated that this practice may be discontinued in the future, more recent statements and reports indicate the opposite. In fact, this method has been used extensively over the past 20 years in the former Soviet Union, and is indicated to have solved waste management problems at a "number of radiochemical installations" (Kedrovskii et al., May 1991b). In addition to radioactive wastes, the Soviets also use the injection method to dispose of hazardous chemical wastes from industrial operations.

Apart from injection, radioactive waste management is stated to be accomplished via several solidification and storage/disposal techniques. Vitrification technologies are being developed and used for solidification of HLW and some low-level waste (LLW) and intermediate-level waste (ILW), while cementation and bituminization are the primary solidification agents for LLW and some ILW. The solidified radioactive wastes are placed in shallow-land burial areas at nuclear power stations and at regional industrial waste disposal sites, or in the case of HLW, are stored for eventual disposal in a geologic repository. Uranium mining and ore processing wastes are becoming an increasing problem, as the former Soviet Union has extensive tailings wastes that are apparently contaminating large areas. The effects of the Chernobyl

accident are still being addressed, and the significant contamination at the Chelyabinsk-65 site is expected to garner increased attention in the future. New revelations a e also implicating significant waste management problems with respect to ocean dumping of radioactive wastes from Soviet naval operations, which may affect large regions of the arctic region oceans. In addition, evidence of significant waste management problems from nuclear testing at Semipalatinsk and Novaya Zemlya, as well as from numerous explosions of peaceful nuclear devices, is starting to surface.

It is expected that proposals for help to Russia as part of dismantlement or the redirection of Russian nuclear research will include efforts directed at nuclear waste cleanup, such as for the International Science and Technology Center, due to open in Moscow in June 1992 (The Wall Street Journal, May 5, 1992).

GLOSSARY OF ABBREVIATIONS - GENERAL TERMS

AES	Atomic Energy Station
BN	Soviet fast breeder reactor (in Russian: Reaktor na Bystrykh Neytronakh)
Bq	Becquerel, 1 nuclear disintegration/sec.
BWR	boiling water reactor
CEC	Commission of the European Communities
CIS	Commonwealth of Independent States
Ci	Curie
CMEA	Countries belonging to the Council for Mutual Economic Aid/Assistance
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FBR	fast breeder reactor
GWd	gigawatt-days
GWe	gigawatt-electrical
Gy	Gray, unit of radiation absorbed dose, equals 100 rad
HEU	high-enriched uranium
HLLW	high-level liquid waste
HLW	high-level waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILLW	intermediate-level liquid waste
ILW	intermediate-level waste
JCCEM	U.S.-U.S.S.R. Joint Coordinating Committee for Environmental Restoration and Waste Management
kWh	kilowatt-hour
LEU	low-enriched uranium
LLLW	low-level liquid waste
LLW	low-level waste
LWGR	light water-cooled, graphite moderated reactor
MAPI	Ministry of Atomic Power and Industry
Minatom	Ministry of Atomic Energy of the Russian Federation
MOX	mixed-oxide (uranium and plutonium) nuclear reactor fuel
MSWU	million separative work units
MT	metric ton
MTU	metric tons, uranium
MWe	megawatts-electrical
MWt	megawatts-thermal
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
PUREX	Plutonium/URanium EXtraction process
PWR	pressurized water reactor
R&D	research and development
REE	Rare-earth elements
RBMK	Soviet boiling water, graphite moderated reactor (in Russian: Reaktor Bol'shoi Moznosti kanalov)
Sv	Sievert, unit of radiation dose equivalent, equals 100 rem
TRU	transuranic elements

USSR	Union of Soviet Socialist Republics
VVER	Soviet pressurized water reactor (in Russian: Vodo-Vodyanoi Energeticheskii Reaktor)

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1.0 INTRODUCTION AND SCOPE

Radioactive waste materials--and the methods being used to treat, process, store, transport, and dispose of them--have come under increased scrutiny over the last decade, both nationally and internationally. Nuclear waste practices in the former Soviet Union, arguably the world's largest nuclear waste management system, are of obvious interest and may affect practices in other countries. In addition, poor waste management practices are causing increasing technical, political, and economic problems for the Soviet Union, and this will undoubtedly influence future strategies.

This report was prepared as part of a continuing effort to gain a better understanding of the radioactive waste management program in the former Soviet Union. It is the third report on this subject, updating previous reports in this series by D. J. Bradley and K. J. Schneider in March 1990 (PNL-7182) and by D. J. Bradley in March 1991 (PNL-7645). This report includes only information obtained or reported after the publication of the previous reports, and thus does not supersede the previous reports.

The scope of this study covers all publicly known radioactive waste management activities in the former Soviet Union as of April 1992, and is based on a review of a wide variety of literature sources, including documents, meeting presentations, and data base searches of worldwide press releases. The study focuses primarily on nuclear waste management activities in the former Soviet Union, but relevant background information on nuclear reactors is also provided in appendixes.

The term "former Soviet Union" is used throughout the text to describe the post-coup assemblage of the 15 republics which had constituted the Union of Soviet Socialist Republics (USSR), or Soviet Union. This is used in place of the Commonwealth of Independent States, as that alliance is still being defined.

Information is given as presented in the references, with supporting analyses or inferences by the author given in brackets [ ], when sufficient

information was available to ensure that the analyses are correct. In some cases, where it is pertinent, the same information may be given in more than one place in the report.

2.0 INSTITUTIONAL STRUCTURE

Information on the direct effects of the Soviet coup, and ensuing changes to the former Soviet Union and evolution of the new Commonwealth of Independent States (CIS), and on the Ministry of Atomic Power and Industry (MAPI) has been minimal with respect to waste management issues. MAPI was replaced by the Ministry of Atomic Energy of the Russian Federation (Minatom), on January 21, 1992, by Russian President Boris Yeltsin (Soviet Press Digest, January 23, 1992). Organizations having jurisdiction over nuclear energy matters in each Republic are either being formed or are expected to be created. With essentially all the nuclear fuel cycle facilities, as well as nuclear expertise in operations and maintenance being located in Russia, the new Minatom will most likely be the trend-setting agency. The waste management agreements that are currently in place may not be altered in the short term. Because of Boris Yeltsin's previous stance on the importance of putting in place a broad waste management plan prior to any further building of nuclear facilities, the agreements may receive greater attention.

The evolution of changes from MAPI to Minatom and information on other organizations are summarized below:

- Following the August 1991 coup attempt, Vitaliy Konovalov was removed as the Minister to MAPI, with Boris Vasil'evich Nikipelov (formerly the First Deputy Minister of MAPI for the nuclear fuel cycle) in as the acting head of MAPI, but without Ministerial status.

- In the fall of 1991, MAPI met with the "Republics" where it was agreed that "a central control organization" needs to be continued for environmental restoration activities, or alternately a self-financed inter-republic nuclear corporation could be formed to perform this function (Bradley, November 11, 1991).

- By the end of December 1991, Lev Ryabev, the Cabinet official responsible for fuel and energy matters [having broad supervisory, planning and monitoring oversight of MAPI], had been removed.

- On January 21, 1992, Boris Yeltsin met with nuclear energy officials in the Kremlin and announced the creation of Minatom. The chief functions of the Minatom would be to coordinate the enterprises of the nuclear power industry, which were to be given more independence. The Ministry will develop nuclear energy programs, control

their implementation upon Parliament approval, and have full control of all entities developing or manufacturing nuclear weapons (Soviet Press Digest, January 23, 1992). The full text of the decree, formally establishing the Ministry of Atomic Energy of the Russian Federation, is given in Appendix C (Moscow RIA, February 6, 1992).

- Following a visit to Arzamas-16 on February 28, 1992, Russian President Boris Yeltsin appointed Professor Viktor Nikitovich Mikhailov as the Minister of Minatom (Pravda, March 5, 1992).

- Further information on the emerging new structure of Minatom indicates that there will be six Deputy Ministers serving under Minister Mikhailov, effective as of April 1, 1992. Former Minister Vitaliy Konovalov has come back as a First Deputy Minister, and Boris Nikipelov has retired from Minatom. Additionally, Erik Pozdyshev, former MAPI Deputy Minister, is responsible for a consortium of Russian nuclear power plants called Rosenergoatom, which is to be a "structural unit" of Minatom. Minatom has a central staff of 850 people with about 1 million within Russia. The six Deputy Ministers are (Nucleonics Week, April 2, 1992):

  - Nikolai N. Egorov — Inherits nuclear fuel cycle business
  - Alexander Meshkov — Nuclear power plant equipment manufacturing, process equipment to include agro-industries
  - Yevgeny Reshetnikov — Civilian nuclear construction
  - Viktor Sidorenko — Civilian nuclear power
  - Yuri Tychkov — Isotope Production
  - Alexander Usanov — Engineering, to include plant backfitting, particle accelerators, and research.

Additional information on the activities of various research institutes, waste management facilities, and regulatory agencies is summarized in the following sections.

2.1 SCIENTIFIC RESEARCH INSTITUTE OF INORGANIC MATERIALS

The Scientific Research Institute of Inorganic Materials (VNIINM) in Moscow, named in honor of A. A. Bochvar, was organized in 1945. It has been intimately involved in the development of the Soviet nuclear program. VNIINM coordinates work in waste vitrification with participation by the Khlopin

Radium Institute (St. Petersburg), "Radon," [near Zagorsk], the USSR Academy of Science, the Design and Research Institute of Complex Power Technology (St. Petersburg), the Scientific Research Institute of Chemical Machine Building (Ekaterinburg, formerly Sverdlovsk), and also with the facilities at Krasnoyarsk. VNIINM was responsible for developing the technology for making phosphate glass, as well as for the design and construction of the melters. They operated the 100 liter/hr [feed rate] pilot scale melters there for at least 10 years, and developed the 500 liter/hr [feed rate] melters used at Chelyabinsk-65. Phosphate glass was selected as the high-level waste form because of the type of liquid waste that they had as well as their belief that its stability was satisfactory. About 12 years ago, VNIINM began work on a two-stage vitrification process to produce borosilicate glass, and developed the two-stage "cold-wall" induction melter concept that will be tested at Chelyabinsk-65 in 1992. They also worked with the Radon waste management facility in developing the induction melters operational there.

Dr. Polyakov, Deputy Director of VNIINM, noted the following interests of the Institute during a recent visit (Bradley, November 11, 1991):

- Reprocessing of spent fuel; the technological process was said to have been developed there, including extraction, precipitation, ion-exchange, and evaporation processes as well as gas purification and treatment of liquid wastes.
- Decontamination.
- Reprocessing of wastes from the Chernobyl accident.
- Development of equipment, such as for incineration, bituminization and cementation processes, and for vitrification of intermediate and high-level wastes. The equipment is then produced at the Scientific Research Institute of Chemical Machine Building in Ekaterinburg.
- Mixed-oxide fuel reprocessing and associated instrumentation and extraction equipment.
- Tritium research, to include blanket materials in reactors. Dr. Polyakov noted that they were the leading institute in this area.
- Reactor fuel construction materials, to include preparing powders and pellets. With respect to RBMK reactors, he noted that the Kurchatov Institute was responsible for physics, the Scientific

Research Institute of Technology (NIKIET, also in Moscow and directed by Adamov) was responsible for engineering, and VNIINM was responsible for the development of fuel elements, as well as for the VVER and BN reactors.

VNIINM also has major research interests in metallurgy, properties of matter, and other areas such as defense "conversion" work and treating wastes from the automobile industry.

2.2 VERNADSKY INSTITUTE OF GEOCHEMISTRY AND ANALYTICAL CHEMISTRY

The Vernadsky Institute of Geochemistry and Analytical Chemistry was established in 1946 following the death of V. I. Vernadsky. It has two departments, geochemistry and analytical chemistry, and about 30 different laboratories, 15 in geochemistry, 10 in analytical chemistry and 5 serving both departments. It employs 1,200 people, of which 800 are scientific staff. They have been involved with actinide chemistry since the 1940s, can work with sources of up to 100 Ci, and have separated gram quantities of americium from spent fuel. Their main activity is on extraction and sorption methods, including the use of crown ethers and dicarbolide and testing a new extractant for actinide separation at Chelyabinsk-65. This Institute is part of the USSR Academy of Sciences and was not part of MAPI, although it has played a significant role in MAPI-related activities (Bradley, November 11, 1991).

2.3 RADON

Radon, also called the Moscow Scientific and Industrial Corporation, treats, solidifies and disposes of low- and some intermediate-level radioactive wastes from a region that has a population of 40 million from which Radon derives 2000 customers. The facility is located 21 km to the north of Zagorsk, or about 90 km northeast of Moscow. Radon works for the Russian government, and was not part of MAPI (Bradley, November 11, 1991).

Dr. Igor Sobolev, Director of Radon, provided further information on the facility to a DOE delegation visiting there in October 1991. The site was started in the 1950s, with waste storage starting in 1961. The site has a surface geology of marine clay, with the first groundwater layer present at a depth of 20-45 meters, typical of this section of Russia. The overall

facility covers 0.60 km^2 and is surrounded by a safety zone of 2 km. The facility was initially designed for a 30-year life, but current plans are to double that due to the advanced waste processing techniques that are now being tested and put to use there.

Over its 30-year history, Radon has solidified and disposed of 1 million curies. It has had temporary storage of liquid wastes since 1965, used cementation for low-salt wastes since 1965 [although Radon officials mentioned the disposal of cement waste forms with "no conditioning" in 1963] and started using the bituminization process in 1978 for high-salt wastes. Radon incinerates much of the solid wastes it receives, and it combines the ash with cement to produce a solid waste form. Liquid wastes, including nitrate wastes, are used as a fuel for its incinerators; however, it does not burn PCBs. Over the last 10-15 years the facility has done testing on vitrification processes and will now start to use the induction "cold-wall" melter process as its major solidification technique, replacing the bituminization process. A new building is under construction that will house four induction melters with a total capacity of 100 kg/hr of glass or glass-ceramic product. Studies at Radon have assessed the use of broken glass from used electronic tubes, kinescope parts, and household lighting, as a frit for making radioactive waste glasses. They concluded that optimized compositions can produce an acceptable waste glass, and also save on raw materials and the expense of otherwise disposing of the commercial glass wastes (Sobolev et al. 1991). Further details of waste management at Radon, including the use of incinerators, are described by Sobolev et al. (October 25, 1991).

Radon performs fairly extensive air monitoring studies, has done in situ testing of its waste forms, and is trying to build a "geo-lab" where it can conduct a wide array of simulated in situ leach testing and environmental interaction studies. The facility has been involved with studying potential ways to prepare RBMK spent fuel for geologic storage, including encasing the fuel assemblies in lead-filled canisters. Radon does not receive power

reactor wastes as they are all handled at each particular reactor site. Radon also appears to be heavily involved with the mapping of radiation zones in the city of Moscow (Bradley, November 11, 1991).

2.4 KURCHATOV INSTITUTE

The Kurchatov Atomic Energy Institute has been renamed the Kurchatov Institute, as a Russian scientific center by Russian President Boris Yeltsin (Moscow All Union Radio, November 21, 1991).

The Kurchatov Institute and the Institute of Inorganic Materials, in Moscow, have formed a joint venture with Sierra Nuclear Corporation in the United States and with Pacific Development Services Ltd. of the United Kingdom, on spent fuel storage systems (Nuclear Waste News, October 24, 1991).

2.5 SOVIET COMMITTEE FOR STATE SUPERVISION OF SAFETY OF NUCLEAR POWER AND INDUSTRY (GPAN or CSSSINP)

According to Anatoliy Belyaev, GPAN's deputy chairman, GPAN is working out new arrangements in light of the overall restructuring of nuclear safety functions. By the end of 1992 it plans to have a new industrial research committee, with partly nuclear functions, to focus on issues involving nuclear safety and to provide help to plants like the RBMK in Lithuania. Vadim Malyshev, chairman of GPAN, noted that GPAN was formed in 1984 from a small safety group for nuclear facilities to the present organization responsible for safety in all industries. GPAN is seeking to retain a coordinating role for the new republics; Malyshev believed it was essential to have an inter-republic coordinating agency for collecting data on operating incidents, personnel training, and international republic. He noted that when the Kurchatov Institute and VNIIAES (All Union Institute for Nuclear Power Plant Operations, Moscow) reported to MAPI, he had established a 250-person science and engineering research center under GPAN to do independent safety assessments on USSR nuclear plants (Selin 1991; Nucleonics Week, September 5, 1991).

2.6 NUCLEAR SAFETY INSPECTORATE

Yu. Vishnevsky, former chief inspector for GPAN at the Balakovo nuclear power station, is now the chairman of the Russian republic's nuclear safety inspectorate. The nuclear safety inspectorate would regulate civilian and military uses of atomic energy, and include reactors, the entire fuel cycle, proliferation and international safeguards questions, radiation protection, and control of radioactive sources such as those used in medicine and industry. Vishnevsky expects it will take about 4 months for the committee to get organized and to have its funding arranged (Selin 1991).

2.7 UKRAINE COMMITTEE FOR SAFETY SUPERVISION OF NUCLEAR FACILITIES

Nikolai Shteinberg, formerly deputy director of GPAN, is now chairman of the Ukraine Committee for Safety Supervision of Nuclear Facilities. As of September 1991, he noted that his staff still technically constituted the southwest regional headquarters of GPAN but the situation was changing (Selin 1991).

2.8 INSTITUTE OF NUCLEAR SAFETY OF THE USSR ACADEMY OF SCIENCES

The Director of the Institute of Nuclear Safety of the former USSR Academy of Sciences is Leonid Bolshov, who notes that his institute had a good, non-competitive relationship with GPAN and the Kurchatov Institute, and served as an independent source of safety advice in the former USSR. Created in 1988, the Institute has a number of departments and laboratories working in areas such as severe accident modeling, behavior of radionuclides in nature, human health and environmental safety, computer science, risk and safety analysis, seismic safety, comparative economics of different energy sources (including nuclear), waste disposal, theoretical physics, advanced nuclear reactor studies, information analysis (such as consequences of the Chernobyl accident) and sociological studies, including polling public opinion on the use of nuclear energy. The Institute's budget is obtained partly from the former USSR Academy of Sciences and partly from sponsors of Institute projects. With the uncertainty about the future of that organization, Bolshov is

actively looking for support from new Republic safety organizations, and he anticipates being better funded at the Russian Republic level (Selin 1991).

2.9 ALL-UNION INSTITUTE FOR NUCLEAR POWER PLANT OPERATIONS (VNIIAES)

Armen Abagyan is the Director of VNIIAES, which functions like a combination of the U.S. Institute for Nuclear Power Operations and the Electric Power Research Institute, using facilities at various locations. VNIIAES does research and tests nuclear plant equipment to come up with recommendations for equipment development, plant operator training, and safety diagnostic systems. Maintenance and equipment failure data on all former USSR plants are being analyzed by VNIIAES to assess reliability and to help improve safety, and analyses of operating events are performed to determine root causes of problems (Selin 1991).

2.10 OTHER WASTE MANAGEMENT ORGANIZATIONS

Other waste management organizations are being created in the former Soviet Union. For example, an Association for Disposal of Radioactive Waste has been reported to have been formed, headed by Academician Ye. Shemyanin (Izvestia, June 29, 1991).

In addition, an association called "Green Lawn" was formed in September 1991. It is being staffed with former members of MAPI and MAPI institutes, the Academy of Sciences Institutes, and others. This self-financing organization is trying to do work in the environmental restoration and waste management field (Bradley, November 11, 1991).

3.0 INTERNATIONAL EXCHANGES AND AGREEMENTS

The Soviets have stated that as of July 1991, they have radioactive waste management agreements with the United States, the United Kingdom, France, Japan, South Korea, Argentina, and the Commission of the European Communities (CEC) (Nuclear Fuel, July 8, 1991). Additional international exchange information is given in this section.

3.1 FRANCE

A commercial agreement has been reported where the Siberian Chemical Combine (Tomsk) would enrich uranium recovered from reprocessed French power reactor fuel. The deal was said to be worth $50 million a year for at least 10 years (Izvestia, January 25, 1991). It was further reported that the consortium of the "combine" and Eurodif was enriching uranium ore up to 4%, and that 150 tons have already been processed (Moscow Russian Television Network, June 3, 1991).

3.2 SOUTH KOREA

An agreement has been "initialed" between the Korea Trade Leader Co. and an unnamed Soviet research institute to transfer Soviet technology for disposal of nuclear and industrial wastes in underground chambers. The institute was not named pending review by the Soviet Ministry of Science and Technology. The agreement provides for the transfer of knowledge to prepare about 2,000 chambers, formed at a depth of 350 to 500 meters in geologic structures containing sand, using a "controlled explosion." The explosion would create a cavity with hardened, leak-proof walls and a volume of 1 cubic meter (Yonhap, March 28, 1991).

3.3 UNITED STATES

A memorandum on environmental (nature) conservation was signed between the U.S. Environmental Protection Agency's William K. Reilly and the USSR Minister of Nature Management and Nature Conservation, Nikolay Vorontsov, in Moscow on April 22, 1991. The agreement was reported to contain provisions

for 55 joint projects that included a center for energy efficiency and a joint park in the Bering Strait area (Moscow World Service, April 22, 1991).

A U.S. Department of Energy (DOE) delegation visited Russia from October 21-25, 1991, to conduct technology exchange workshops in two of the areas set forth by the Memorandum of Cooperation (MOC) signed by W. Henson Moore for the DOE and Vitaliy Konavalov for the USSR Ministry of Atomic Power and Industry (MAPI) on September 18, 1990, in Vienna, Austria. Preceding this, fact-finding visits were conducted by a Soviet MAPI Delegation to the United States, led by Boris V. Nikipelov, from March 26 to April 3, 1990, and by a U.S. DOE Delegation to the Soviet Union led by Leo P. Duffy on June 18-27, 1990. The specific areas for technology exchanges were then further defined during a U.S. DOE delegation visit to the Soviet Union from November 12-16, 1990, led by Clyde Frank, where the first meeting of the U.S./USSR Joint Coordinating Committee on Environmental Restoration and Waste Management (JCCEM) was conducted. The JCCEM serves as the governing body for workshops and technical exchanges with the former Soviet Union on Environmental Restoration and Waste Management. The visit to the former Soviet Union to conduct workshops in vitrification and radionuclide migration in October 1991 was then agreed to during a DOE delegation visit to the Soviet Union, led by W. Henson Moore, in July 1991 (Bradley, November 11, 1991).

4.0 WASTE MANAGEMENT IN THE FRONT END OF THE FUEL CYCLE

4.1 URANIUM MINING, MILLING AND CONVERSION

The total uranium reserves in the former Soviet Union are stated to be 2 million MT, with reserves and associated production costs broken down as follows: 735,000 MT - less than 60 $/kgU; 465,000 MT - from 60 to 90 $/kgU; and 800,000 MT - more than 90 $/kgU. Based upon the estimated reserves, processing plants are expected to meet the needs of a nuclear industry with a capacity of up to 100 GWe (Nikipelov 1991). Soviet uranium reserves also include about 700,000 metric tons of tails (Nuclear Fuel, November 11, 1991) and about 95,000 tons of uranium concentrate (Moscow Television Network, January 14, 1992). It was stated that Soviet uranium processing plants use "filterless sorption-extraction" processes to produce uranium oxides and other elemental byproducts (Nikipelov 1991).

The current Soviet uranium production capacity was recently reported to be 16,800 tons per year, of which Tenex (Techsnabexport) claims that 5,000 MT is for export and 6,800 MT is for domestic use. Tenex, the Soviet marketing organization for nuclear services, is 30 years old, and from 1963 to 1988 was a part of the Ministry of Foreign Economic Affairs, after which it became associated with MAPI. Tenex has annual revenues of $1 billion, employs 1,500 people, and has two main "Departments," according to the General Director, Albert Shishkin: Uranservis and a Fuel Elements Department. Uranservis was limited to selling enrichment services up until 1988, after which they were permitted to sell natural uranium as well. It was estimated from geological data presented to members of a OECD/NEA delegation visiting the Ministry of Geology that cumulative uranium production could be considerably higher than the commonly used estimate of 190,000 MT (Geidl, November 6, 1991). Apparently Uranservis has been recently replaced with an inter-republic uranium mining enterprise, called Atomredmet. Uranium production associations in Bishkek, Khodzhent, Navoi, Aktau, Lormontov, Zheltyye Vody, Ekaterinburg, and Krasnokamensk have joined the enterprise, and Albert Shishkin is its deputy director (Nuclear Waste News, January 2, 1992b).

Uranservis was involved with mining and processing or uranium ores and ore processing equipment, handling 800,000 MT annually. As a byproduct they produce 25% of the Soviet gold production, as well as other materials, since it is Soviet mining policy to recover all metals when mining a deposit. There are 92 uranium deposits located in eight mining centers; three in Tajikistan, two in Kazakhstan, and one each in Ukraine, Uzbekistan, and Turkmenia. Each region has its own ore processing facility and ore is not transported between regions. The uranium product contains 99.8% U_3O_8 [equivalent to 84.6%] which is then delivered to facilities for conversion into UF_6. Due to this high purity level, the Soviets claim to have eliminated a step in the refining process. The capacities of the eight production centers range from 400 to 4,000 MT annually [alternately reported as from 500 to 5,000 MT annually (Nikipelov 1991)], with the Tajikistan capacity being 2,000 MT annually (Geidl, November 6, 1991). Uranium mining and milling facilities include U_3O_8 plants at Kara-Balta in Kyrgyzstan, two mills at Navoi and Chkalovsk in Uzbekistan, and one near Narva in Estonia (Nuclear Fuel, November 11, 1991). The Soviets have indicated that some of their uranium mining facilities will be shut down, especially "unviable" deep mines and other high cost operations. The Chalgi and Tassbulak mines in Kazakhstan are being closed, and a rundown in production is scheduled for the deep Mangishlak Peninsula mines (Nuclear Fuel, December 23, 1991).

Uranium exploration began in 1945 in the Soviet Union, and some details of the geology of Soviet uranium mining have been made available by the Ministry of Geology. A brief history of the uranium mining industry was given as follows (Geidl, November 6, 1991, except where noted):

- The first uranium mining deposit was discovered in 1928 at Taboschary near Tashkent.
- A plant was built for radium production in 1932.
- No further development from 1932 through 1944.
- A major uranium exploration program started in 1944; the first domestic deposits were discovered in Tajikistan in 1952, Kyrgyzstan and Lamotta in 1954, Zhettyye Vodi (Ukraine) in 1959, Navoi in 1964, Kazakhstan in 1968, and Russia in 1969.

- The Chkalovsk uranium processing plant, located 17 km from Khodzhent (Leninabad), along with similar operations at Taboshar and Adrasman, were the USSR's first producers of natural uranium. The Taboshar plant produced an oxide concentrate up to 1967, and an "enriched" uranium ore up to 1971. The Adrasman plant was shut down in 1959 and now produces metals such as lead, zinc, copper, and bismuth (Nezavisimaya gazeta, February 27, 1992).

- Until 1954 all processing plants used absorption technology with ion exchange columns to extract uranium.

- In 1961, at the Zhettyye Vodi plant, a high absorption processing using charged catenates was developed, similar to the American IRA-400 process.

- In 1970, the autoclave method was developed for simultaneous recovery of uranium and molybdenum, considered economic for ores having a molybdenum content greater than 0.02%.

- The Chkalovsk plant, now known as the Eastern Rare Metals Association (Vostokredmet), was reported to be Tajikstan's only facility for processing natural uranium, having an annual output of at least 10,000 tons. Its General Director, Yuriy Nesterov, has noted that a new corporate structure has been created since the formation of Minatom (Nezavisimaya gazeta, February 27, 1992).

At present, 38% of Soviet uranium production is from in situ leaching operations, which Tenex plans to increase to 45% by 1995 (Geidl, November 6, 1991). Underground mining of uranium ores produces from 1.3 to 1.6 tons of solid wastes per ton of ore mined and processed, whereas 10 to 15 tons of waste are similarly produced per ton of ore from strip-mining operations. Up to 2,000 m^3/day of liquid wastes are produced in the form of underground drain waters, with another 100 to 300 m^3/day of low-activity waste waters from ore washing and rinsing. Processing 1 ton of ore yields more than 4 tons of liquid wastes. Radionuclides such as U, ^{226}Ra, ^{222}Ra, ^{230}Th, ^{210}Po, and ^{210}Pb are reported to have accumulated up to 10 to 50 Bq/liter in soils and "muds," as a result of untreated discharges of waste-waters from ore processing facilities (hydrometallurgical plants). The permissible concentration level for aquifers is only 0.111 Bq/liter (Mosinets 1991) and for "unmonitored" use of mining waters, the uranium content should not be above 0.1 mg/liter (Shatalov et al. 1990).

The principal radioactive contamination around ore processing facilities is stated to be from aerosols. For a processing capacity of 2,000 tons of ore per day and a U_3O_8 content of 0.2%, 1 Ci of ^{226}Ra is released to the atmosphere per day. Aerosol "fallout" at the ore processing plants is reported to be up to 40 $Bq/m^2 \cdot$ day. The Soviets feel that the most dangerous environmental contamination, however, comes from tailings piles at processing facilities and dusts derived from the shores of contaminated water bodies, and is largely attributed to ^{222}Ra. The amount of ^{222}Ra released from the surface of operating tailings piles is from 1,700 to 7,000 Ci/year. The specific activity of tailings with a uranium content of 0.011% is 13,700 Bq/kg, and the release of radon is stated to be 1 $Bq/m^2 \cdot$ sec for a specific activity of 1 Bq/g of tailings, the latter figure being the USSR safety standard. At this specific activity level, the total release of ^{222}Ra from all the tailings piles accumulated in the former USSR (assuming 30% of the shores are dry) is from 320,000 to 410,000 curies per year (Mosinets 1991).

Soviet-East German processing facilities, used to produce uranium "yellowcake" from ore, have been cited as the cause of an environmental disaster in the East German towns of Oberrothenbach and Seelingstaedt. Artificial lakes were constructed there in the 1950s to hold the tailings from the uranium ore processing plants built in Crossen (neighboring Oberrothenbach) and Seelingstaedt after World War II. Wismut, a Soviet-East German corporation, built a 150-foot-high earthen dam in Oberrothenbach in the 1950s to contain the uranium-bearing "slag" from the Crossen plant. The resulting man-made lake is stated to contain 50 million tons of uranium sludges, and more than 20,000 tons of arsenic. In addition to seepage into the groundwater, the shores of the lake dried during hot weather and winds evidently have distributed uranium-bearing dust throughout the town and surrounding area. A study, completed by the Office of Energy and Environment in Munich, revealed 750 locations in the area of Oberrothenbach and Crossen that have abnormally high radiation readings of up to 7,000 Bq/m^3. Apparently, 500 million tons of radioactive residues lay exposed from the operations at Crossen and Seelingstaedt as well as from 3,600 other small sites in Saxony and Thuringa. About 1 million tons of this material has been used in construction.

Wismut, which was founded in 1947 and closed its last mine in 1990, produced 200,000 tons of uranium for the Soviet Union. It was reported that records show that 5,237 miners died of radiation poisoning from these mining operations (The Baltimore Sun, June 23, 1991).

4.2 URANIUM ENRICHMENT

Although specific waste management information with respect to uranium enrichment in the former Soviet Union is not available, the sites have at least been recently identified. According to Evgeniy Mikerin, MAPI operates four uranium enrichment plants, all equipped with gas centrifuges. A "few" gaseous diffusion plants were operating, but only to purify UF_6 for centrifuge enrichment, evidently due to past quality control problems in UF_6 conversion. These four facilities have a total capacity of at least 14 MWSU/year, of which about 10 MSWU/year are available for the world market for production on low-enriched uranium (LEU), said to have been available since 1987. According to Mikerin, the Soviets at that time abandoned the production of high-enriched uranium (HEU) for defense purposes. He noted that the stockpile of HEU was "well over 500 MT." The four uranium enrichment plants, all located in the Russian Republic, are as follows (Nuclear Fuel, November 11, 1991):

- Verkhniy-Nivinsk near Sverdlovsk (now called Ekaterinburg), called the Ural Electrochemistry Combine
- Angarsk near Lake Baikal, called the Electrolyzing Chemical Combine
- Krasnoyarsk, called the Electrochemistry Combine
- Tomsk, called the Siberian Chemical Combine.

4.3 FUEL FABRICATION

The Soviets state that they are building a new facility at Chelyabinsk-65 for the manufacturing of uranium/plutonium mixed-oxide nuclear fuels (MOX) for fast reactors as well as for VVER-1000 reactors. Mikhail Troyanov of the Institute of Physics and Power Engineering in Obninsk has also reported that while the BOR-60 pilot fast reactor at Dimitrovgrad is the only Soviet reactor to use MOX fuel on a significant scale, the BN-350 reactor at Shevchenko has

some plutonium fuel in its core, and the BN-600 reactor at Beloyarsk has been testing experimental MOX assemblies. The facility in Dimitrovgrad is currently the only place manufacturing MOX fuel for fast reactors in the former Soviet Union, which is done using vibrocompaction technology (Nuclear Fuel, May 27, 1991). After 11 years of experience at the R&D Institute for Atomic Reactors (NIIAR) at Dimitrovgrad in developing this technology, a new fabrication facility was built 2.5 years ago. Testing of the fuel has been previously done in the BOR-60 reactor at the site, where fuel assemblies have achieved up to 18% burnup with the average being 12%. This process is competing with the widely used pelletizing technology, which is the basis for the half-completed MOX fuel fabrication facility at Chelyabinsk-65 (Nuclear Fuel, August 5, 1991).

MOX fuel, produced by the vibropack process, is being tested in the BN-600 reactor at Beloyarsk for 3 to 4 years to determine whether large-scale fuel fabrication using this technique is warranted. A total of eight fuel elements were produced, but only four were put into the BN-600 for testing. The vibropack process produces a crust of fuel crystals by electrolysis on a cathode within a graphite capsule. The material is then placed into fuel rods vibrated at three different frequencies to achieve the desired fuel density. The fuel rod is topped with a depleted "uranium dioxide matrix" and placed into a fuel assembly. The remote-controlled process being used is said to be able to handle a wide range of plutonium isotopic contents as well as up to 0.5% americium. The NIIAR is also developing a dry reprocessing method, using electrolysis, that has a capacity of 30 kg of MOX fuel a year. When combined with this dry reprocessing operation, the vibropack process is said to offer significant advantages due to a reduction of costs and production of radioactive wastes. It is also said to lower health risks from inhalation since it uses fuel granules instead of powders (Nuclear Fuel, August 5, 1991).

The MOX fuel plant at Chelyabinsk-65, about half-completed, is known as the "300 Mayak" facility. Its construction was begun in 1984, and it has a design capacity of 60 MTHM/yr, including about 5 to 6 MT of plutonium. Smaller facilities at Chelyabinsk-65 have produced 400 kg of MOX fuel that has been used to make over 2,000 fuel elements for the BN-350 and -600 reactors.

The Soviets have also produced 10 fuel assemblies using weapons-grade plutonium that were tested in the BN-350 reactor and then reprocessed. They also plan to build a 300-400 MTHM/yr MOX plant at Krasnoyarsk (Nuclear Fuel, April 13, 1992). The MOX facility was started simultaneously with the start of construction of the South Urals BN-800 reactors (Bukharin 1991). The MOX fuel fabrication plant [at Chelyabinsk-65] will use conventional pelletizing technology. While the Dimitrovgrad plant can handle plutonium containing significant quantities of plutonium-240 and -241 isotopes, the Chelyabinsk-65 plant will use "pure" plutonium [mainly ^{239}Pu] as the feed material. Although the schedule for the plant was not specified, last year it was stated that the Soviets planned to have it operational by 1995 (Nuclear Fuel, May 27, 1991).

The Soviets are developing several production processes for fast and thermal reactor mixed U-Pu fuel: granular oxides made from ammonia precipitation, sol-gel spheres, and oxides made from carbonate precipitation. The ammonia process appears to be preferred since it is simple and produces low amounts of waste; however, it does require a very pure feed material. The sol-gel process, which produces a high-density product, comes next, although it has the disadvantage of being a complex process and produces complex waste streams that require special processing. The carbonate process, although it can produce a low impurity product with good properties that allow a wide range of granule sizes to be used to manufacture fuel, requires a sophisticated oxidation process, has high uranium and plutonium solution concentrations, produces incrustations on process equipment, develops unstable U/Pu ratios due to the incomplete oxidation of plutonium and insolubility of metals in carbonate media, and produces a relatively large fraction of oxide particles of less than 100 μm, which will be a large source of alpha-bearing aerosols, compared with the other processes. The development of the ammonia and sol-gel processes has reached the level of semi-commercial testing, in the course of which large batches of mixed fuel containing 25% Pu (by mass) have been produced; pilot fuel assemblies have been fabricated for the BN-600 fast reactor (Andryushin et al. 1991).

Members of an OECD/NEA delegation recently visited the Electrostal nuclear fuel fabrication plant, which dates from 1917 when it served as a

World War I bomb factory. It was stated that the current facility produces fuel assemblies for VVER-440, BN-350, BN-600, and RBMK-1000 and -1500 reactors. The plant has a capacity of 1 million fuel rods per year, although it has been operated at 50% capacity since the Chernobyl accident. No automated processes were observed in the part of the plant that was visited. The plant also produces 3,000 MT of calcium magnets per year, and appears to be rapidly undertaking diversification activities such as production of electric irons, heaters and lamps, and a joint venture has been signed with Argentina to produce fur coats (Geidl, November 6, 1991).

5.0 NUCLEAR REACTOR OPERATIONS WASTE MANAGEMENT

In the former Soviet Union, management of nuclear reactor operations wastes, primarily low-level wastes, is handled by evaporation followed by incorporation into bitumen or cement; the wastes are then stored onsite in shallow-land burial facilities. Although several nuclear power stations have such solidification facilities (Bradley 1991), 135,000 m^3 of low-level wastes, containing 35,000 curies, are still being stored as liquids at reactor stations in the former Soviet Union. Although only 8,000 m^3 of solidified wastes have been produced, it is planned to have LLW solidification equipment at all nuclear stations by 1995 (Nuclear Fuel, July 8, 1991).

The radioactive waste handling process at the Zaporozhye VVER-1000 power station was recently described as follows (Pravda Ukrainy, February 19, 1991):

- Radioactive wastes are transported in special shielded vehicles, from reactors to a decontamination shop located nearby, where the wastes are sorted.
- Combustible wastes are burned in a "special furnace" at a temperature of 1,100°C, and the off-gases are "cleaned" and monitored.
- Metals are compacted and packed in shielded carbon steel drums reducing their volume by four to 100 times. The drums are then lowered into "wells" inside a storage facility for radioactive wastes. These storage wells are set in concrete and covered with concrete lids 900 to 1,200 millimeters thick, weighing from 1.0 to 4.5 tons and are periodically monitored. The three storage facilities at Zaporozhye are stated to be capable of storing all wastes produced over the plant lifetime.

The former Soviet Union has stopped the construction and designing of about 60 nuclear power stations since the Chernobyl accident. However, due to serious power shortages in a number of regions of Ukraine and Russia, local authorities are considering resuming the construction of nuclear power plants (Moscow World Service, April 3, 1991). It was stated that construction of the Yuzhno-Uralsk [South Urals] and the Kostroma reactors will be resumed, while expansion of the Kola, Kursk and Novovoronezh nuclear power stations is planned (Izvestia, March 23, 1991).

Concerns have been raised about the safety of nuclear reactors operating in Moscow. A 6-month inspection of the Kurchatov Institute by the State Industrial Atomic Energy Inspectorate, the Ministry of Public Health, and the International Atomic Energy Agency (IAEA) resulted in specific dates for the removal of certain reactors. The MR reactor is scheduled to be taken out of operation in 1996, the Gamma reactor in 1993, and the IR-8 reactor in 1999. (USSR Technology Update, March 21, 1991). It was further reported that the Moscow Soviet Presidium decided to shut down all the nuclear reactors in Moscow, of which there are currently nine (Moscow Central Television, March 12, 1991). Seven of these are at the Kurchatov Institute, one at an enterprise near Sokolniki, and one at the Moscow Engineering and Physics Institute (Moscow Teleradiokompania Ostankino, April 11, 1992).

The overhaul of the St. Petersburg unit #1 RBMK reactor has been completed, and all "technological lines" have been replaced and new monitoring and accident-prevention equipment has been installed. The Soviets expect the life of the plant to exceed 10 years, and they indicate that similar operations may be conducted at the other St. Petersburg reactors, as well as those at the Kursk and Chernobyl stations in Ukraine (Moscow Central Television April 15, 1991). It was further noted that the Soviets plan to complete reconstruction of the other St. Petersburg units by 1995, as well as the early units of the Kola and Bilibino reactors [no date specified] (Nucleonics Week, April 25, 1991a).

AEA Technology is to participate with the Soviet Research & Development Institute of Power Engineering (RDIPE) in a joint probabilistic safety assessment (PSA) of the recently backfitted St. Petersburg RBMK nuclear unit. The year-long PSA effort was stated to be starting in June 1991 (Nucleonics Week, June 6, 1991a).

At the Beloyarsk nuclear site, wastes from plant operations discharged to the Olkhovka marshes are being studied due to their potential migration into the Tura and Tobol river systems (Nuclear Waste News, October 10, 1991a). There appears to be no immediate danger from migration of these wastes, although about 60 Ci of ^{137}Cs, 20 Ci of ^{60}Co, and 2 Ci of ^{90}Sr have been discharged to the marshes (Atomnaya Energiya, September 1991).

It has been reported that an underground nuclear power station is being planned in the Primorsky Kray at Vladivostok. The station, which would be located 60-100 m underground, would consist of four submarine-type reactors and have a design life of 30 to 40 years. After that, the reactors would be "filled in with concrete." Work at the site is expected to start in 1993 (The European, January 6, 1992).

There were three cases reported during 1991 where incidents at nuclear power plants in the former Soviet Union led to a release of radioactivity (Izvestia, March 11, 1992):

- Due to a violation in startup and adjustment work on the second reactor unit at Ignalina in Lithuania on May 4, 1991, three workers received external radiation doses in excess of the maximum permissible annual dose.
- On July 10, 1991, due to a violation of procedures for working with radioactive materials, the Bilibino reactor area and part of the surrounding site in Siberia were contaminated.
- In the process of making repairs to the Chernobyl unit #2 reactor in Ukraine, about 100 m^3 of radioactive water spilled onto the facility on August 10, 1991.

The fire at the Chernobyl unit #2 reactor power generator on October 11, 1991, apparently had no radioactive material releases associated with it (TASS, October 13, 1991).

A release of radioactive noble gases was associated with an automatic shut down of the unit #3 reactor at Sosnoviy Bor near St. Petersburg early in the morning on March 24, 1992. The shutdown was actuated by a pressure rise caused by the failure of a fuel channel. The radioactive release for the day slightly exceeded one-half of the daily permissible value, and three personnel were exposed to a maximum dose of 200 mR. By the end of the day, radioactivity levels were at background all over the reactor site (Adamov, March 25, 1992). The events at the Sosnoviy Bor reactor have focused new attention on the general safety of Soviet nuclear reactors, as well as on radioactive waste management practices at the reactor sites. At the Zaporozhye reactor site, for instance, discharges from the reactor into reservoirs and possible heavy

metal contamination are drawing renewed public interest (Moscow Teleradio-kompania Ostankino Television, March 27, 1992).

6.0 SPENT FUEL MANAGEMENT

Spent fuel from VVER-440 reactors is being reprocessed at the Chelyabinsk-65 site, but its capacity to reprocess this fuel is being "severely stretched." Four years ago, the Soviets put restrictions on the amount of foreign spent fuel they would accept. Although it is reported that that policy was modified, the Soviets still reprocess only in exchange for hard currency. Since the East European countries are unable to meet the high reprocessing costs, said to be about $160 million for Czechoslovakia alone, spent fuel is building up in these countries. Bulgaria, for example, has requested assistance from the European Community for building additional spent fuel storage capacity (Nuclear Waste News, September 12, 1991). The Soviets also have indicated that they intend to increase the size of their away-from-reactor spent fuel storage capacity, possibly doubling their current size. They are also considering dry storage of spent fuel (Bradley, April 30, 1991). At present, VVER-1000 fuel is being stored pending completion of a new reprocessing facility at Krasnoyarsk. It has been reported that the Krasnoyarsk site may accept spent fuel from South Korea for storage at the rate of $1 million per ton of fuel (Moscow Postfactum, January 24, 1992). RBMK fuel is also being stored, pending a decision on direct disposal in geologic repositories, as the Soviets have no plans to reprocess this fuel in the near future.

Spent nuclear fuel is stored either at the bottom of storage pools in baskets and racks for VVER and BN reactor fuel, or suspended from the metal ceiling beams, in the case of RBMK reactor spent fuel.

At VVER-440 reactors, a "wet" reloading method is performed using a reloading machine that removes fuel assemblies from the reactor core under water and transfers them into the nearby "at-reactor" storage pool. VVER-1000 at-reactor spent fuel storage is essentially the same as that for VVER-440 reactors, except that boron stainless steel tubes are used for racks that increase the storage capacity. Figure 6.1 (Kondratyev et al., April 1991), Figure 6.2 (Kritsky 1991), and Figure 6.3 (Kondratyev et al., March 1991) depict spent fuel storage facilities for VVER reactors.

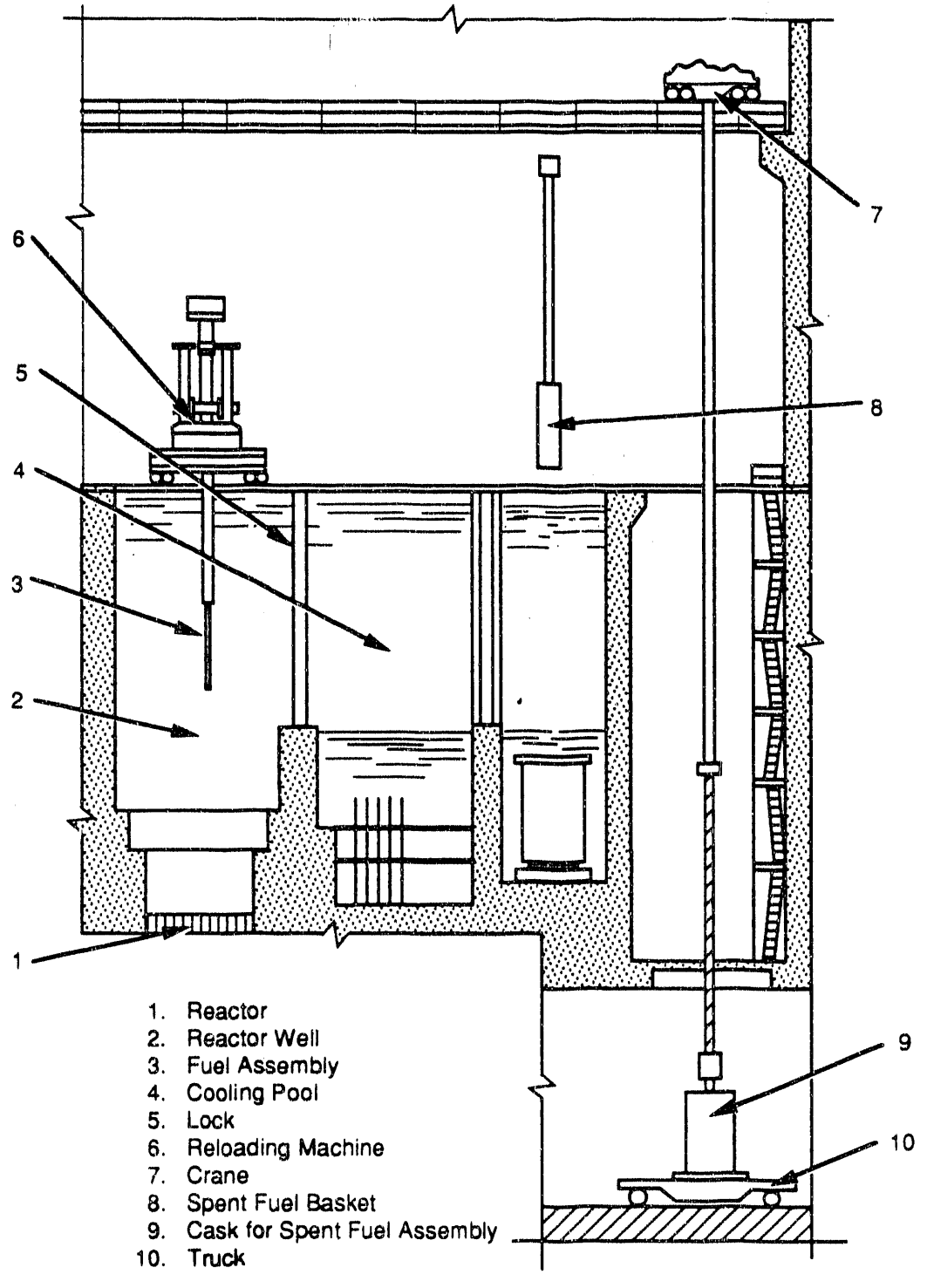
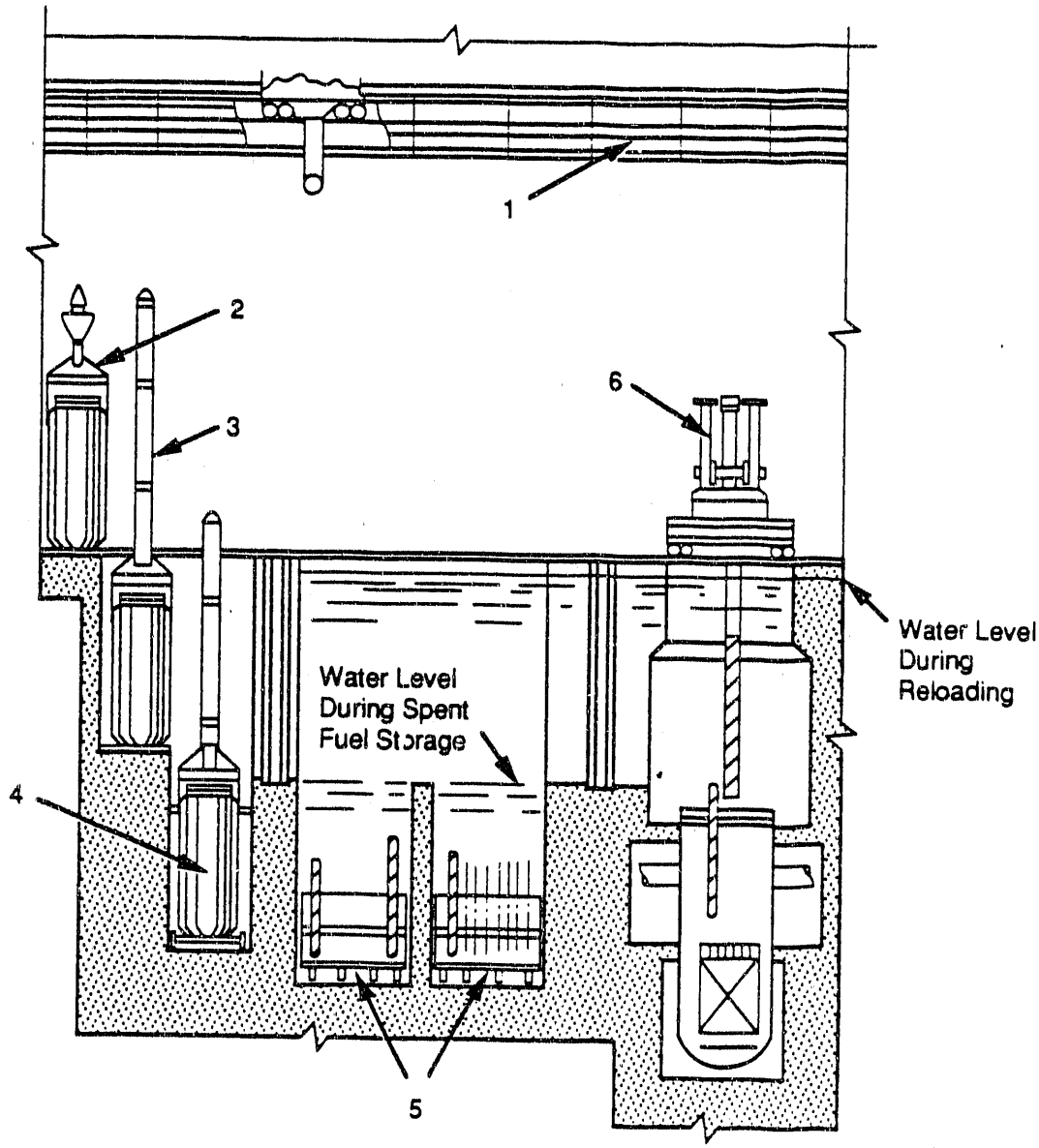
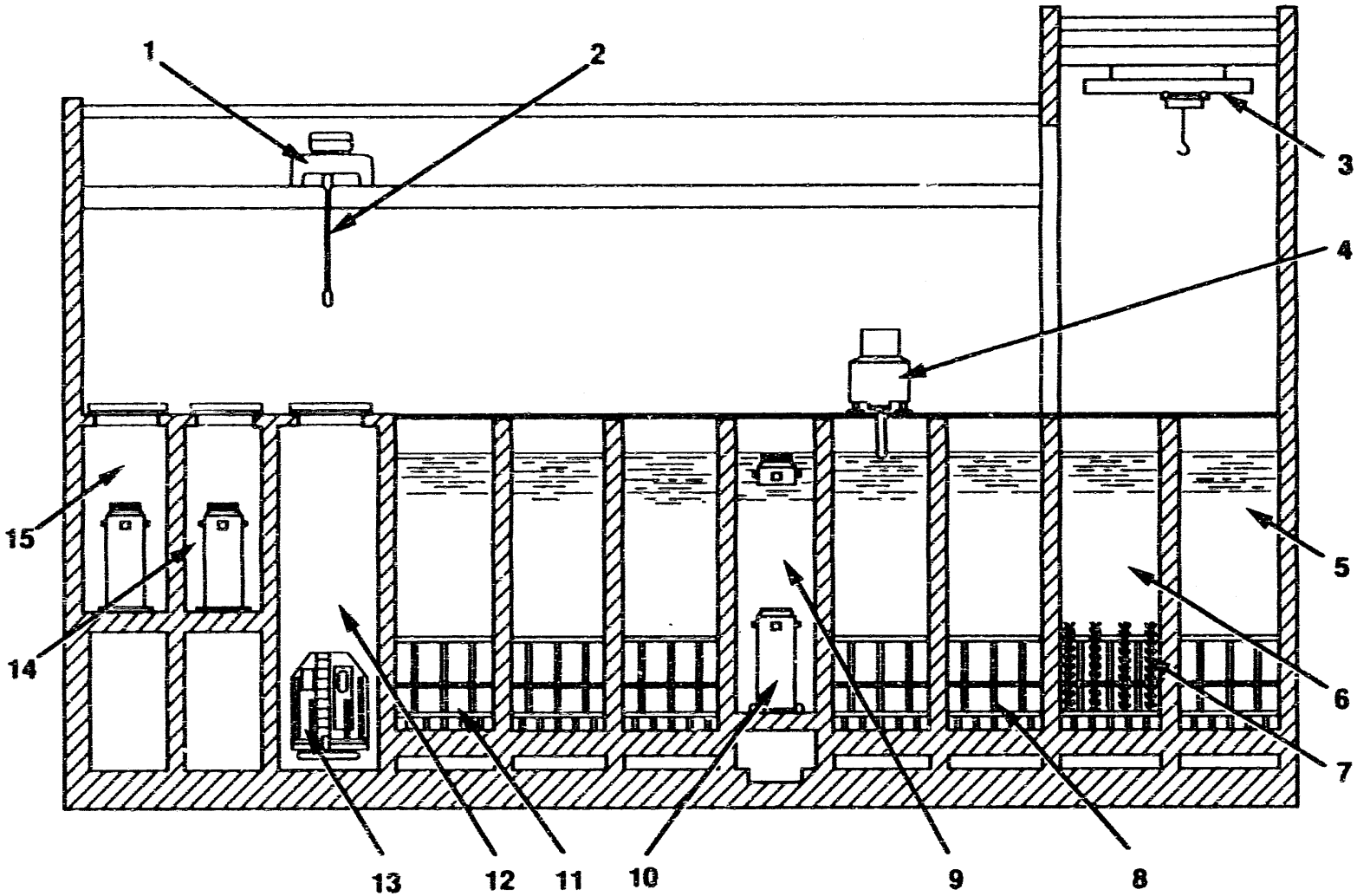


FIGURE 6.1. At-Reactor Cooling Pool for VVER-440 Spent Fuel (Kondratyev et al., April 1991)



1. Circular Electric Crane
2. Traverse for Spent Fuel Container
3. Rod for Container
4. Shipping Cask
5. Cooling Pool Racks
6. Loading Machine

FIGURE 6.2. VVER-1000 At-Reactor Spent Fuel Storage Facility (Kritsky 1991)



1. Crane (32 MT)
2. Traverse
3. Crane (10 MT)
4. Reloading Machine
5. Burnable Absorber Rod Storage Bay
6. Spent Fuel Cassette Storage Bay
7. Spent Fuel Assemblies
8. Rack
9. Reception Bay
10. TK-10 Container (TK-13)
11. Stand-By Bay
12. Transport Corridor
13. Transport Mechanism
14. Decontamination Shaft
15. Decontamination Stand

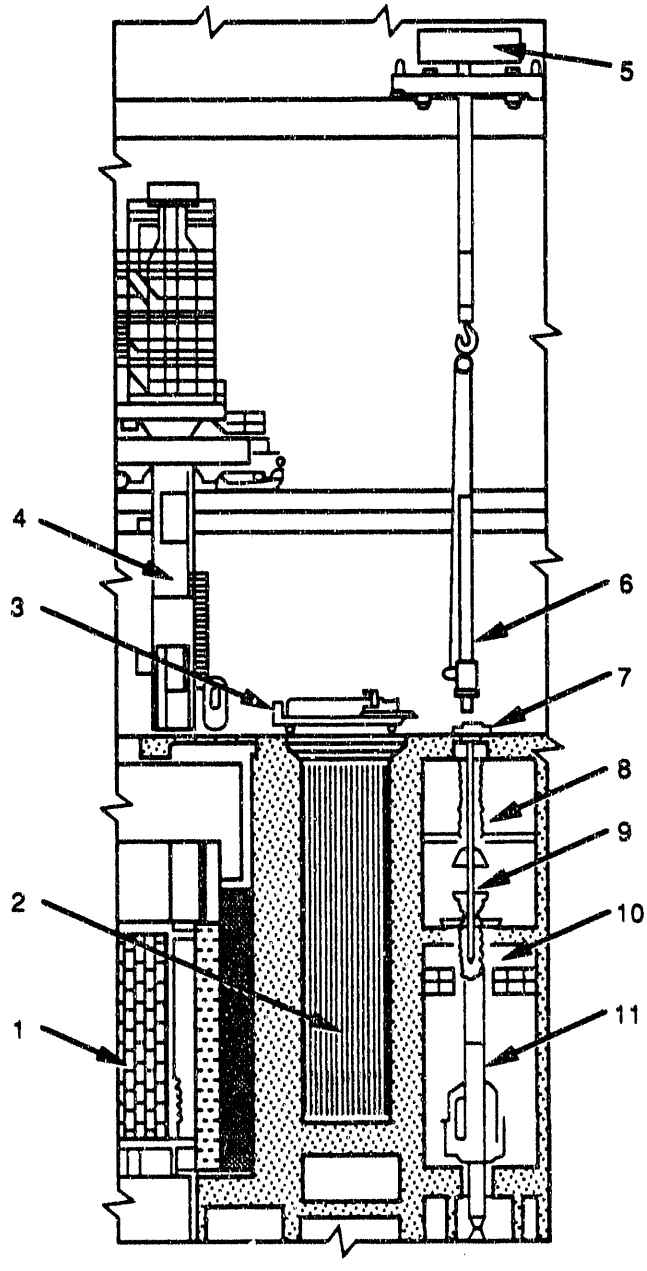
FIGURE 6.3. Away-From-Reactor Storage Facility for VVER-1000 Spent Fuel (Kondryatev et al., March 1991)

The at-reactor storage pool for RBMK reactor fuel is located in the reactor unit central hall near the reactor. The Soviets are developing a method to increase the storage density for this fuel by a factor of two. Away-from-reactor spent fuel storage facilities at each RBMK-1000 reactor station have been built to contain 10-years' worth of spent fuel discharge from four reactors. Spent fuel assemblies are stored in water-filled stainless steel canisters suspended from ceiling beams. Figures 6.4 through 6.8 show RBMK spent fuel storage facilities and dry storage concepts (Kritsky 1991; Kondratyev et al., March 1991). RBMK fuel is to be stored for 3 years at the reactor storage pools, then for another 10 years at an away-from-reactor storage facility (Independent Spent Fuel Storage Installation) and then for another 30 to 40 years in "regional storage facilities." The design of the regional facilities (shown in Figure 6.6) is still being studied. Following this storage period, the fuel is to be "conditioned" and then disposed of in geological formations (Strakhov et al., April 1991).

Spent fuel from BN reactors is also stored in water-filled pools. Fuel reloading is performed with the reactor shut down and is combined with scheduled repairs. For BN-350 and BN-600 reactors, a "dry" method of spent fuel reloading is used with the help of reloading equipment located in the reactor vessel and in reloading containers. An inert gas atmosphere in these containers allows for reloading of spent fuel having sodium coolant residues. Figure 6.9 illustrates a BN-600 reactor and associated spent fuel storage pool (Kondratyev et al., March 1991).

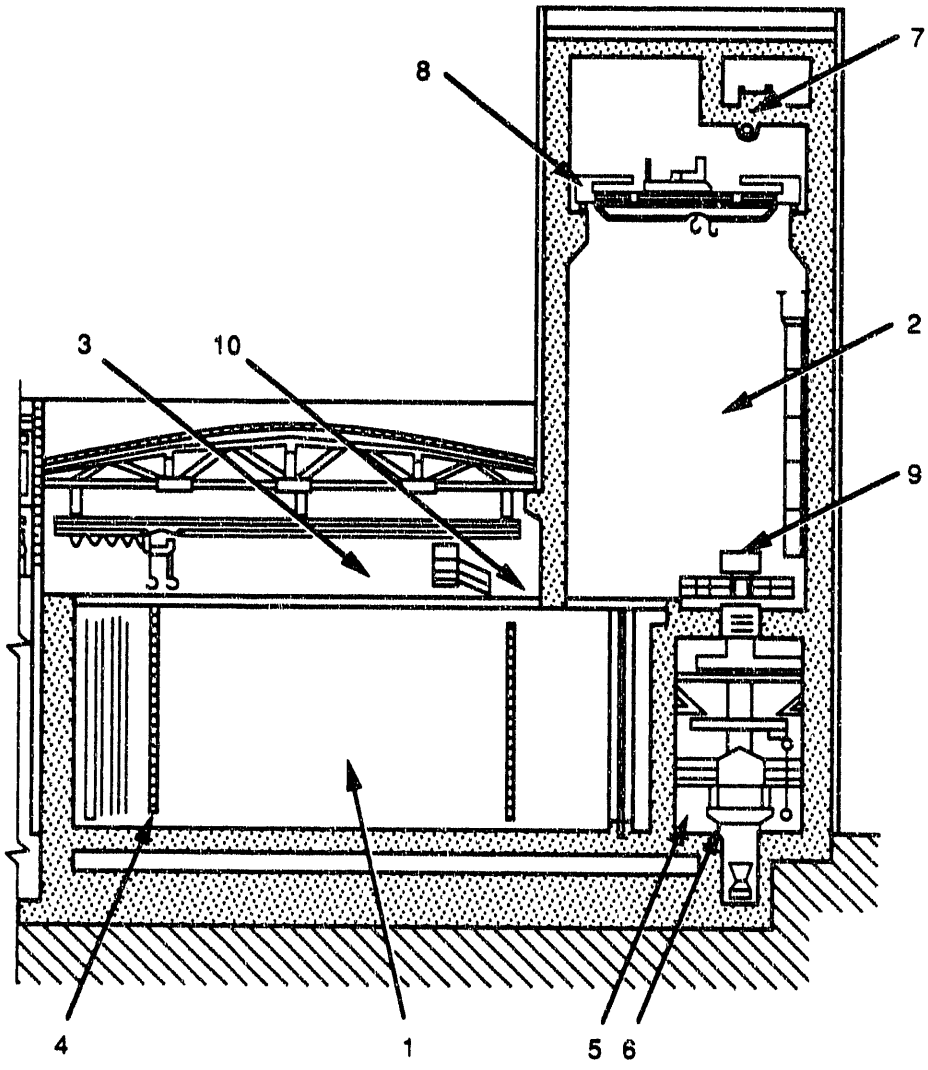
The interim spent fuel storage at Chelyabinsk-65 is reported to be "robustly built." A railway wagon can be driven into the reception hall, where a basket containing 30 spent fuel assemblies can be lifted out of the wagon. While it is in the air without any shielding, the room is unoccupied. The basket is then lowered into a fuel pool through an inclined shaft. The fuel pools can hold 500 baskets, which equals about 1800 MT of uranium (NEI, January 1991).

Table 6.1 provides information on spent fuel storage facilities for Soviet reactors (Kondratyev et al., March 1991).



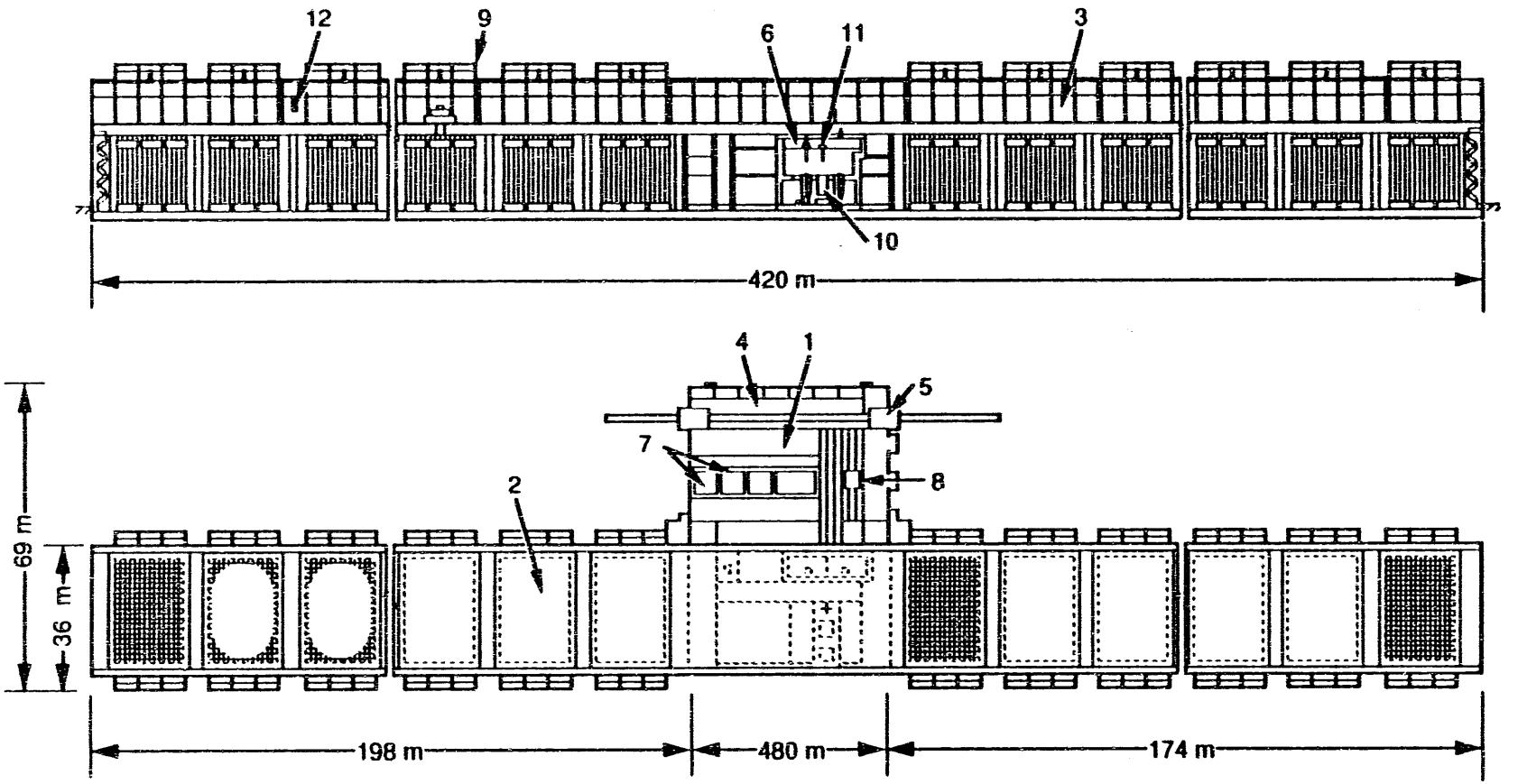
1. Reactor
2. Cooling Pool
3. Floor Beam-Crane
4. Loading Machine
5. Traveling Crane
6. Reloading Container
7. Charge Device
8. Guide Shaft
9. Spent Fuel Basket
10. Guiding Device
11. Transport Container

FIGURE 6.4. RBMK At-Reactor Spent Fuel Storage Facility (Kritsky 1991)



1. Storage Pool
2. Main Hall
3. Storage Section
4. Cans with Spent Fuel
5. Transport Entrance
6. Transport Container
7. Cable Trolley (15 MT)
8. Traveling Crane (5 MT)
9. Guiding Device
10. Transfer Device

FIGURE 6.5. Away-From Reactor Storage Facility for RBMK Spent Fuel (Kritsky 1991)



1. Reception Area
2. Storage Area
3. Transport Hall
4. Cask-Car Arrival Area
5. Cask Discharge Preparation Area
6. Canning Area
7. Washing Area
8. Cask Dispatch Preparation Area
9. Reloading Machine
10. Cask
11. Manipulator
12. Suspended Crane

FIGURE 6.6. Away-From-Reactor or Regional Spent Fuel Storage Facility for RBMK Reactors (Kondratyev et al., March 1991)

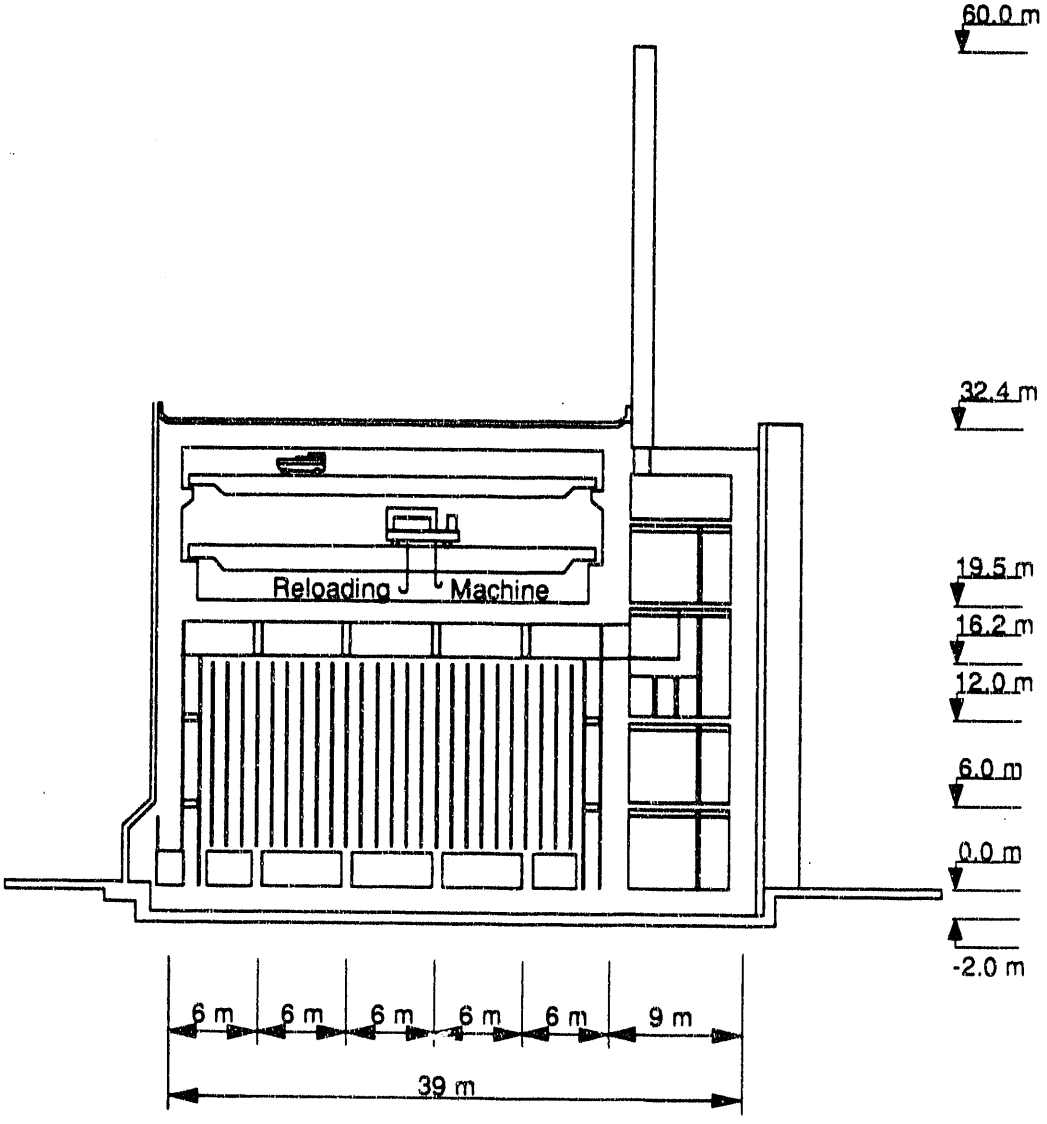


FIGURE 6.7. Cross Section of Dry Storage Facility for RBMK Fuel (Kondratyev et al., March 1991)

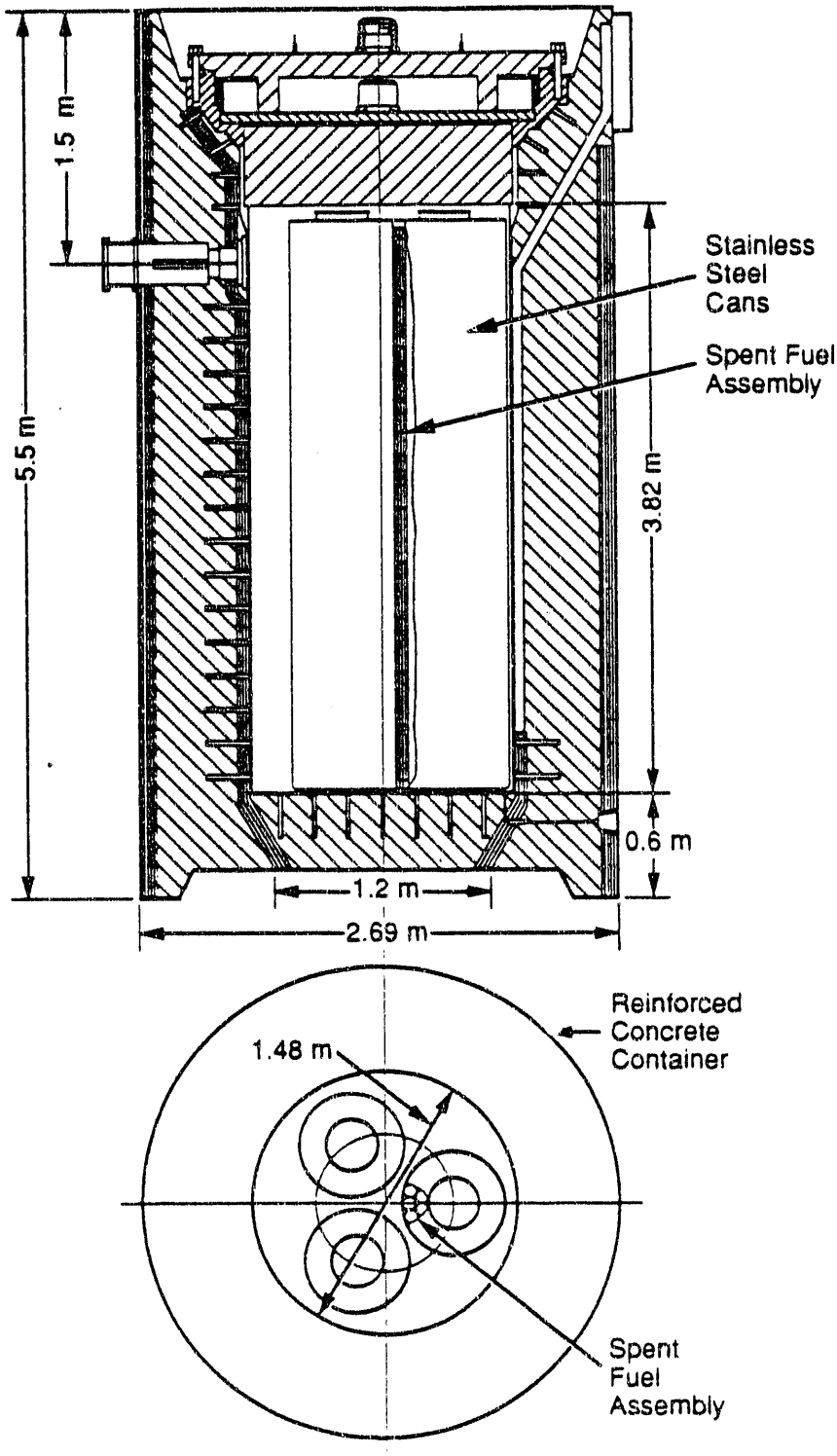
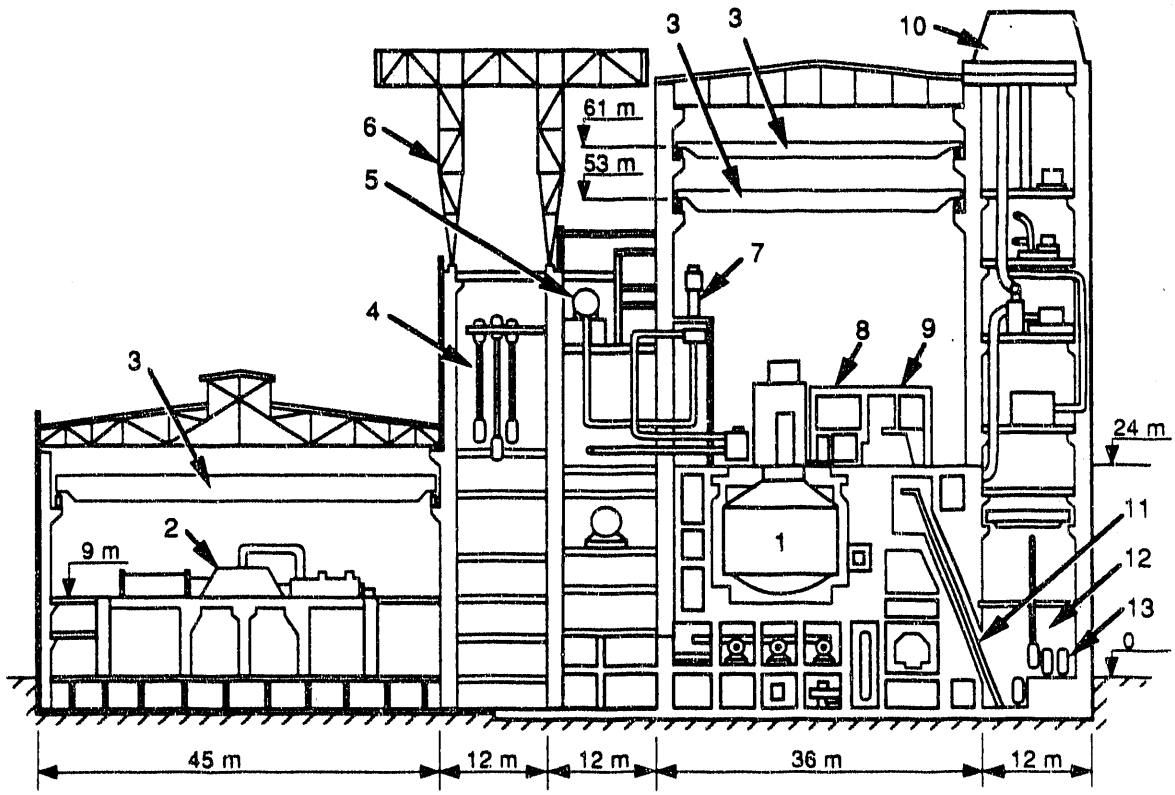


FIGURE 6.8. Long-Term Dry Storage Concrete Casks for RBMK Spent Fuel (at reactor site) (Kondratyev et al., March 1991)



1. Reactor Vessel
2. Turbogenerators
3. Overhead Cranes
4. Steam Generator
5. Buffer Tank
6. Traveling Gantry Crane
7. Secondary Circuit Circulation Pump
8. Transfer Box
9. Washing Box
10. Ventilation Stack
11. Inclined Lift
12. Cooling Pool
13. Spent Fuel Baskets

FIGURE 6.9. BN-600 Reactor Building and Spent Fuel Storage Facility (Kondratyev et al., March 1991)

TABLE 6.1. Main Spent Fuel Storage Features of Soviet Reactors

Features	At-Reactor Storage				Away From Reactor Storage	
	VVER-440	VVER-1,000	RBMK-1,000	BN-600	VVER-1,000	RBMK-1,000
Storage Capacity						
Fuel Assemblies, pcs.	600	400	1,700	3,885	770	17,520
Fuel, MT	72	165	190	80	330	1,900
Number of Sections, pcs.	2	2	2	3	8	5
Section Dimensions, mm						
length	10,700	13,250	10,700	13,945-21,475	6,200	26,600
width	4,200	6,210	4,200	10,000	4,400	5,600
depth	17,520	16,200	17,520	7,000	16,400	11,300
Construction Volume, m^3	30,000	45,000	15,926	24,000	65,100	64,600

The port of Murmansk has been stated as the home for naval vessels having a total of 220 nuclear reactors (Nuclear Waste News, October 10, 1991a). Murmansk is home for four ships, two of which have been phased out of use, for the storage and transport of spent fuel from 11 reactors on Soviet ice-breakers (Nuclear Waste News, October 10, 1991a), and from two reactors on a nuclear container ship (Oslo Aftenposten, November 26, 1991). The fuel is stored for 1 year on the Imandra, transferred for another 2 years storage on the Lotta, and then shipped by rail for reprocessing (Nuclear Waste News, October 10, 1991b) at the Chelyabinsk-65 complex in the southern Urals (Nucleonics Week, April 18, 1991). Another storage ship, the Senebryanka, has also been reported. The ships are anchored 2 km from Murmansk and on-board radiation detectors are said to read 700 μR/hr (Moscow Teleradiokompaniya, January 27, 1992). Public concerns are being raised since Atomflot's storage facilities will reach maximum capacity by 1993 (USSR Technology Update, March 21, 1991). The first Soviet icebreaker, the Lenin, started service in 1959. Since then, the Arktika, Sibir, Rossiya, Sovyetskiy Soyuz, Taymyr, and Vaygach have been added. Two more, the Oktyabrskaya Revolyutsiya and the Ural, are reported near completion. A nuclear-powered light carrier, the Sevmorput, may be joined by a sister ship in the future (IAEA Bulletin, January 1991a).

The Netherlands will operate a "consortium" to raise the submarine Komsomolets, which sank in April 1989 in the Sea of Norway at a depth of 1500 meters. They plan to raise the submarine in the summer of 1992 (Moscow All-Union Radio, May 19, 1991). Based on information the Soviets provided in response to a previous request by Norway, Norwegian experts concluded that 17 kilograms of material in the core of the submarine's reactor had fissioned, and that the enrichment level of the fuel was 10 to 35% ^{235}U. The Soviets told Norway that, when the submarine went down, its core contained about 2 kg of plutonium. The Soviets also informed Norway that the HEU-fueled nuclear icebreakers have cores containing 151 kg of uranium enriched to 90% ^{235}U (Nucleonics Week, April 18, 1991). Recent radiation monitoring studies in the area of the sunken submarine have indicated that the radiation is within the range of natural background (Krasnaya zveda, December 17, 1991).

7.0 FUEL REPROCESSING

7.1 REPROCESSING METHODOLOGIES OVERVIEW

In 1949, a reprocessing plant was put into operation to extract plutonium for military purposes at Chelyabinsk-65 and was taken out of operation in 1961 (Bradley, November 11, 1991). The Soviets state that the variety of fuel compositions reprocessed, as well as changes in reprocessing technology, have caused the accumulation at the plant of a variety of radioactive wastes with considerably different chemical compositions.

The first reprocessing method used by the Soviets was based on precipitation of slightly soluble sodium uranyl acetate, $NaUO_2(CH_3COO)_3$, from nitric acid solutions containing dissolved uranium fuel. Plutonium in the VI valence state as sodium plutonyl acetate, coprecipitates isomorphically with sodium uranyl acetate, or remains in solution if it is reduced to plutonium (IV) or plutonium (III). In the first case, uranium and plutonium purification from fission products was achieved, and in the second case--their separation from each other. The process of uranium and plutonium purification from fission products and their separation was developed at the Khlopin Radium Institute in St. Petersburg.

During the first years of plant operation [1949 to mid-1950s], acetate-nitrate solutions made up the bulk of high-level radioactive wastes, which had sodium nitrate concentrations exceeding 100 g/L and sodium acetate concentrations of 60 to 80 g/L. These solutions occupied a large volume, were "difficult to store," and due to their high salinity, concentration by evaporation was impossible. To process the acetate-nitrate radioactive solutions, a precipitation-crystallization-sorption technology was developed by Spitzin of the Physical Chemistry Institute of the USSR Academy of Sciences. This process solved three problems:

- radionuclide concentration [by a factor of 100 based on volume] by precipitation of insoluble compounds having a large sorption capacity for fission products
- recovery of acetate-ion for recycling

- production of high purity crystalline sodium nitrate, which could be used as a fertilizer or for producing alkali.

Radionuclide concentration was achieved by coprecipitation with low-solubility compounds such as iron and chromium hydroxides, iron and nickel sulfides and nickel ferrocyanide. Ruthenium and strontium were "concentrated" on nickel and chromium hydroxides; zirconium, niobium and protactinium on iron and nickel sulfides; and cesium was coprecipitated with nickel ferrocyanide.

Concentrated fission products, in the form of a suspension, were placed in long-term storage facilities [in stainless steel tanks inside stainless steel-clad concrete vaults], and the clarified solution after acidification by nitric acid was concentrated by evaporation. Simultaneously, acetic acid was distilled and recovered in a plate column sprayed with alkali. Residues containing 1,100 to 1,150 g/L of sodium nitrate were purified by crystallization and recrystallization if higher purity was required.

As a result of the reprocessing plant's "reconstruction," the precipitation technology was replaced by that of liquid extraction using tributylphosphate in an inert diluent as an extractant [i.e., the PUREX process]. The salinity of high-level radioactive wastes decreased several times and there was no longer any need for the precipitation-crystallization-sorption technology. The waste processing technology was reduced to evaporation with nitric acid recovery for its recycling in the reprocessing operation, and preparation of radionuclide concentrates (Drozhko et al. 1989). A discussion of radioactive releases, and other waste management activities associated with reprocessing operations, is given in Chapter 12.

7.2 ELEMENTAL SEPARATIONS TECHNOLOGIES

Extraction technology for the separation [partitioning] of elements from radioactive waste streams, particularly high-level waste solutions, continues to have a high priority in Soviet reprocessing activities. A great deal of specific information was given on Soviet separation technology at conferences in the spring of 1991, and a brief synopsis of the studies being done is as follows:

1. There is a continued emphasis on separations based on metal carbolides and crown-ethers. It was stated that crown-ethers exhibit high selectivity, and flowsheets were developed for separation of ^{90}Sr and ^{137}Cs with organic solutions of dicyclohexyl-18-crown-6 and dibenzo-21-crown-7 from strongly acidic solutions (3 to 5 M HNO_3) of different salt compositions (Egorov et al., April 1991). More specific information was given by Kudryavtsev et al. (1991):

   - Successful tests of Sr and Cs recovery and purification technology have been done, which were followed by the development of a process for recovery of trans-plutonium elements (TPE) and rare earths (RE) from HLW. Methods of extraction of actinides and lanthanides using cobalt dicarbolide in nitric acid solutions were checked under experimental conditions in a counter-flow test facility. These tests showed that for the successful recovery of TPE and RE, a higher concentration of extractant was required and it was advisable to use a synergetic additive agent, for example, Slovofol-909 (n-nonylphenylpolyethylene glycol).

   - A search was then begun for other polyoxocompounds that could increase TPE and RE extraction and also achieve efficient separation of actinide and lanthanide fractions. The extraction of americium and europium was studied using the following polyoxocompounds in the presence of hydrophobic anion of chlorated cobalt dicarbolide:

     - dimethyl ether - tetraethylene glycol (DMT)
     - Slovafol-909
     - 3,6,9-trioxoundecane - 1,11-diol (TOUD)
     - trihexaoxyethylamine (THoEA)
     - six different crown-ethers:

       - 15-crown-5 (15-C-5)
       - 18-crown-6 (18-C-6)
       - dicyclohexyl-18-crown-6 (DC-18-C-6)
       - dibenzo-18-crown-6 (DB-18-C-6)
       - dibenzo-24-crown-8 (DB-24-C-6)
       - diazo-18-crown-6 (DA-18-C-6).

   - Separation factors for "europium (III)/americium (III)" were obtained in the presence of 18-C-6. It was noted that nitrobenzene solutions of 18-C-6 possess the most selectivity towards Am/Eu. The separation factors for europium/americium in the presence of 18-C-6 are, as a rule, 1.5 to 2 times higher than for 15-C-5 when used in conjunction with:

     - picrine acid - nitrobenzene
     - dipicril amine - nitrobenzene
     - higher isomer acids - nitrobenzene
     - di-(2-ethyl hexyl)phosphoric acid - nitrobenzene
     - di-(2-ethyl hexyl) phosphoric acid - octane.

- It was concluded that mixtures of "dicarbolide" with crown-ethers 15-C-5 and 18-C-6 had the most promise for use in HLW solution processing.

2. The separation of U and Pu, as noted by Gomonova et al. (1991), is as a rule accomplished by plutonium reductive stripping from the organic phase into the aqueous one, in many cases using tetravalent uranium as a reductant. U(IV) is usually produced outside the stripping apparatus and is fed to the latter as a nitric acid solution of U(IV) stabilized with hydrazine. Recently, investigations were carried out to develop a method of U(IV) generation directly inside the stripping apparatus by the electrochemical reduction of a small fraction of U(VI) in process solutions. It was felt this was a more promising method to use for higher-burnup fuels (Gomonova et al. 1991).

3. The use of hydrophilic homogeneous neutron absorbers in their extraction technology is being developed by the Soviets to help ensure criticality safety (Renard et al. 1991b).

4. The use of isoparaffin--mono- and dimethyl derivatives of C_{10}-C_{16}, used instead of n-paraffine diluents in extraction of thorium, plutonium and strontium, is being studied. The Soviets indicate that this considerably increases the extraction capacity for metal ions, and reduces organic phase separation (Goldfarb et al. 1991).

5. The acid salts of "phosphorus-organic" acids with polyvalent cations of zirconium and hafnium are reported to be a "new class" of effective extractants for alkaline-earth, rare-earth and transplutonium elements from nitric acid solutions, which the Soviets indicate was first published by Weaver in 1968 (Galaktionov et al. 1991).

6. Phosphine oxides, dioxides of diphosphines, carbamoylphosphine oxides, dialkylsulfides and trialkylamines have been used to test for extraction of rhodium and palladium (Arseenkov et al. 1991).

7. Triisoamyl phosphate (TIAP) and diisobutylisooctylphosphate (DIBIOP) have been recommended to be used to improve the first extraction cycle and plutonium separation. Use of these chemicals was stated to prevent the formation of a second organic phase at any plutonium concentration and reduce extractant losses caused by its solubility in the aqueous phase. The recommended extractants--TIAP and DIBIOP--were successfully tested with high burnup (100 GWd/t) short cooled (in some cases, 3 months) fast reactor fuel at a pilot plant. The solution activity was up to 10^3Ci/L, and the Pu concentration was up to 30 g/L. For a "deep" extraction of actinides from reprocessing waste streams, aryl substituted carbamoylphosphine oxides and diphosphine oxides were recommended (Rozen et al. 1991a).

The Soviets continued emphasis on separations technologies was noted by the series of papers on this subject at the recent waste management meeting in Tucson, Arizona. Further details of the dicarbolyde and crown ether processes are given in the papers by Romanovskii et al, Esimantovskii et al, Dzekun et al, and Filippov et al, March 1992. In addition to the work being done by the Soviets on extraction processes, significant work on the separation of elements, including the use of the dicarbolide process, is being done in Czechoslovakia (Rais and Selucky 1991a and 1991b).

7.3 REPROCESSING OPERATIONS AT CHELYABINSK-65

Spent fuel from VVER-440 and BN-350 and BN-600 reactors, naval reactors, and some research reactors in the former Soviet Union (NEI, January 1991) has been reprocessed since April 1976 at the "first national fuel reprocessing plant" (RT-1) at Chelyabinsk-65 (Kondratyev et al., April 1991; Dzekun et al. 1991a). Nuclear weapon material reprocessing was terminated in 1985 (NEI, January 1991). Spent fuel from VVER-440 reactors is arriving at Chelyabinsk-65 at the rate of about 150 tons/year from reactors in the former Soviet Union and about 90 tons/year from foreign reactors (Egorov et al., February 1991). The spent fuel storage pool at the reprocessing facility at Chelyabinsk-65 has a capacity of 400 MT. The Soviets have indicated that they had recently received fuel from Hungary and were still receiving it from Germany and Czechoslovakia (Bradley, November 11, 1991).

Reprocessing technology for Chelyabinsk-65 was developed by the All-Union Scientific Research Institute of Inorganic Materials, Moscow, and the Chemical Plant "Mayak" at Chelyabinsk-65. For the most part, the equipment was developed by the Sverdlovsk Research Institute of Chemical Machine Building, Yekuterinburg, and the plant designer was the All-Union Design and Research Institute of Complex Power Technology, St. Petersburg. The design basis was for spent fuel with a burnup of about 30 GWd/MTU, cooled for at least 3 years (Dzekun et al. 1991a). Current recovery is stated to be 99% of Pu and 85% of Np, or 8 kg of Pu (as a dioxide) and 460 to 480 grams of Np (as a concentrated acid) per ton of spent fuel reprocessed. By 1991, about 25,000 kg of Pu had been recovered. About 600 tons per year of 1.4% enriched uranium is recovered

from reprocessing operations (Bukharin 1991). Specific details of reprocessing operations at Chelyabinsk-65 were recently described as follows (Dzekun et al. 1991a, except where otherwise noted):

A. Removal of Spent Fuel from Cladding

- Fuel assemblies are removed from the storage pool, placed in a vertical cask, and transferred to a preparation and cutting bay. Held by a manipulator in a special "tilting" device, the end fittings are cut in a horizontal position by two underwater "electric-contact" circular saws. When the saw blade and the fuel assembly (which are electrodes) are brought together, an arc discharge occurs, and the metal is melted. The circulating saw blade "carries over" the cladding and oxide particles.

- Prior to separation of the spent fuel from the cladding material by grinding, the fuel elements are "flattened" using a hydraulic press.

- The fuel element "assembly" is ground using air cooling to maintain a temperature of -45 to 70°C, preventing the material from ignition. The cladding material is mainly within 7 to 15 mm dimensions. A machine grinds the fuel elements in a horizontal position using two triangular vertical knives, set at an angle to the delivery line.

B. Spent Fuel Dissolution

- A mixture of uranium dioxide powder with cladding material pieces is poured, using a "special sieve" and loading line, into a batch-operated ring-type [annular] dissolver. The dissolver (sealed from the cutting unit) is filled with 7 to 12 M/L nitric acid, which results in a uranium concentration of 300 to 500 g/L.

- The dissolution process is performed at boiling temperature, with heat supplied by steam jackets. The majority of the fuel is dissolved in 40 to 60 minutes; however, the batch dissolution process is continued for 2 hours. The dissolver "dephlegmator" [condenser?] provides (with reflux) nearly theoretical nitric acid consumption of 3.0 mole/mole.

- Insoluble residues and cladding material pieces are washed and discharged from the dissolver by pneumatic impulse, and sent for "burial" by pneumatic transport. Uranium and plutonium losses are up to 0.009% and 0.06%, respectively.

- The dissolver solutions obtained are suspensions with "graphite base high-dispersive components," "silica" acid and other components with particle dimensions of 0.2 to 5 μm and a total content of up to 1 g/L.

- The dissolver solution is clarified using high-molecular weight organic flocculants. Pearlite is used as an additional filtering agent. The main type of apparatus used is a batch-type filter composed of cermet cartridges which use pressed 40 to 60 μm steel powders, or titanium powders 7 to 20 μm in size. After each filtration cycle the filter is cleaned by "water hammer" with further "chemical recovery" if required. The clarified solution solid phase content does not exceed 5 mg/L.

C. Element Extraction and Separation

- The reprocessing plant at Chelyabinsk-65 uses the PUREX extraction process using mixer-settler extractors (Nikipelov 1991). Each actinide extraction line has two extraction cycles using 30% tributyl phosphate in an n-paraffin diluent having a molecular carbon range from C_{11}-C_{14} and a flashpoint of 96°C.

- Flow control in the extraction zone is maintained to give a uranium concentration of 100 to 105 g/L in the organic phase. Uranium, plutonium and neptunium extractant, after combined scrubbing, go to a regenerative reextraction operation. The reextraction is conducted with nitrate solution, containing tetravalent uranium, hydrazine and "complexator." Plutonium and neptunium reextract (plutonium 6 to 8 g/L, neptunium 150 to 200 mg/L) is an initial solution in the extraction solutions of these elements.

- Uranium is reextracted with nitric acid solution of about 0.03 M/L, at a temperature of 80°C. Uranium reextract (about 90 g/L) is directed to the second extraction cycle. An extractant regeneration cycle is performed at ~80°C using a 3% sodium carbonate solution. The second cycle operation conditions are identical to the first one.

- Purified uranium is transformed into uranyl nitrate hexahydrate which is enriched to 2 to 2.4% ^{235}U, to be used as fuel for RBMK reactors. The uranium purification factor (from fission products) during the first extraction cycle is 1.5-2 x 10^5, as compared to 10^5 for plutonium. As a result of the second extraction cycle the overall uranium purification factor increases to: from fission products, about 1-1.5 x 10^7, from cesium to 1.5 x 10^7, from ruthenium/rhodium - 6 x 10^6, from total rare earths - 7 x 10^7, and from plutonium - 3 x 10^6.

  The total amount of uranium, plutonium and neptunium losses in raffinates and rinsing solution from the first and second extraction cycles equal 0.01, 0.025, and 0.5%, respectively.

- Separation of plutonium and neptunium, and final removal of uranium, "macro admixtures" and fission products, is carried out by extraction using [a different] trialkyl phosphate with "cross-linked hydrocarbon chains in radicals." The second organic phase, with any

really existing plutonium concentrations, is excluded entirely using 30 to 35% solution of the trialkyl phosphates in hydrocarbon diluent of the type mentioned above. The main advantage of the extractant is that it is substantially less soluble in aqueous solutions, as compared to tributyl phosphate; so it is easier to get a purer plutonium product (low in phosphorus contamination). Np(IV)-Pu(III) are stabilized (at the stage of Pu and Np separation) and plutonium is oxidized subsequently to tetravalent state (at the stage of purifying and concentrating plutonium).

- Purified reextracts of plutonium (concentrated to 20 to 30 g/L) and neptunium (4 to 10 g/L) (free from admixture of the other) are turned into dioxides of these elements via an oxalate precipitation process.

- Raffinates from the extraction process are subjected to evaporation (nitric acid being regenerated and recycled), and their concentrates, which contain large quantities of fission-product nuclides and transplutonium elements, are stored prior to vitrification.

- The "production" reprocessing area is well ventilated, with the air being filtered and then released to the atmosphere through a 150-m-high stack.

- Purified uranium is obtained as uranyl nitrate hexahydrate; after it is mixed with higher enrichment uranium resulting from reprocessing "naval" spent nuclear fuel, and "in the form of uranyl nitrate melt" (^{235}U enrichment of 2.4%), it is manufactured into fuel for RBMK reactors (Nikipelov 1991). Plutonium and neptunium final forms are their dioxides. At present, plutonium dioxide is temporarily stored onsite until it can be used in fast reactors. The bulk of the neptunium dioxide is also stored, while a part of it is used to produce ^{238}Pu, currently being used for medical, biological and other studies.

The Chelyabinsk-65 reprocessing plant has several decontamination systems for reprocessing off-gases. Each system consists of multicyclones arranged in a series of "rough" and "fine" filters filled with fine and superfine glass fibers. The most complicated system is used for the spent fuel dissolver. Besides the multi-cyclones and filters there are also "dephlegmators," columns sprayed with water to remove nitrogen oxides, and sorption columns filled with silica gel impregnated with silver nitrate to remove ^{129}I (Dzekun et al. 1991a).

An evaporation process, used on reprocessing wastes from VVER-440 spent fuel, has apparently been in operation since 1979 to prepare wastes for

vitrification. The first generation of evaporators was made of stainless steel, type 18-8. However, the poor service life of the heating chambers led to the selection of another alloy (27% Cr, 22% Ni, 3% Mo, 3% Cu, 1.3% Ti) (Dzekun et al. 1991b).

Annular cartridge filters have been used to filter radioactive process solutions at the Chelyabinsk-65 reprocessing plant. These filters, however, proved to have serious problems when used in long-term operations, such as unpredictable failure due to inadequate corrosion resistance, which results in suspended matter and pearlite getting into the extraction system. To develop a better filter system, a laboratory unit was developed which has a glass column 40 mm in diameter and 400 mm high, filled to a height of 250 mm with stainless steel 06XH28MDT powder having a spherical particle size of 0.2 to 0.4 mm. The unit was tested with and without vibration and positive results were obtained (Rozen et al. 1991b).

The reprocessing operations at Chelyabinsk-65 are located in several buildings that have separate functions, such as (Dzekun et al. 1991a):

- a facility for spent fuel storage, fuel assembly end-fitting removal, and subsequent fuel pin-cutting and dissolution
- a facility for dissolver solution filtration, extraction processes, and uranyl nitrate hexahydrate and plutonium and neptunium oxide production
- a storage facility for spent fuel assembly end-fittings and cladding hulls
- a high-level liquid waste and residue storage facility
- a high-level waste vitrification and storage facility
- other production facilities.

The Soviets have recently discussed fast reactor (BN) spent fuel reprocessing. They have tested small-sized contactors having a capacity of up to 2 L/h (mixer-settlers and pulse columns), and up to 5 to 8 L/h for centrifugal contactors. This includes a 40-stage mixer-settler unit with a pulse mixing and transporting device (designed by the Institute of Physics and Power Engineering, Obninsk), 4- and 20-stage centrifugal contactor units (designed

by the R/D Design Institute for Installation Technology, Moscow) and small-size pulse column sieve-plate contactors 1300 mm in height and 16 mm in diameter (designed by the All-Union Scientific Research Institute of Inorganic Materials, Moscow). Due to "disadvantages" of the mixer-settler design, the Soviets are concentrating on using the PUREX-process as the "basic" reprocessing method, using either pulse columns or centrifugal contactors (Renard et al. 1991a).

The use of a centrifugal extractor (EC-33) in different operations of the first cycle of BN-irradiated fuel reprocessing has also been reported. The measurements of minimum-phase contact time were checked by reprocessing BOR-60 core and axial blanket fuel having a burnup up to 60 GWd/t, storage time about 2 years (Kuznetsov et al. 1991).

7.4 REPROCESSING OPERATIONS AT KRASNOYARSK

Another reprocessing plant is being designed for reprocessing VVER-1000 spent fuel. The Soviets state that the reprocessing plant [at Krasnoyarsk] is to be put into operation on the "turn" [unit] basis. The capacity of one unit is 1500 MTU/year (Dzekun et al. 1990a). The design of this reprocessing plant, called RT-2, was started in 1972, and construction began in 1978. There was a sharp reduction in funding for this project in 1985, and only the "first section is in operation." The Soviets are looking for financial assistance to complete RT-2 (Izvestia, January 11, 1992). Nikipelov has suggested that this plant be used for international commercial spent fuel reprocessing (Nuclear Fuel, July 8, 1991).

The spent fuel storage facility at Krasnoyarsk, which has a rated capacity of 3,000 MTU, has so far received 500 MT of spent fuel from VVER-1000 reactors and is expected to receive up to 650 MTU/year by the year 2000. At the Krasnoyarsk facility, the transport cask is extracted from the container under water in the reception area and fuel assemblies are placed in another pool where their burnup and uranium/plutonium contents are determined by measuring the ^{134}Cs to ^{137}Cs ratios and neutron emissions. The Soviets state that the burnup measurement error will be 10%. Following this, casks with fuel assemblies will be placed in a "special loading machine" and transferred

to a reprocessing preparation area. The end caps of the fuel assemblies will then be cut off using an underwater electric arc and, in the same area, the fuel assembly will be cut into fragments using a "press unit" [shear] without further disassembly. The fragments will then be transferred to a "periodic action" [batch operation] ring [annular] dissolver. The basic reprocessing technology is the PUREX process using tributyl phosphate in a "hydrocarbon diluent." Uranium in the form of a uranyl nitrate hexahydrate "melt" will be used to obtain uranium hexafluoride, then undergo "further enrichment" and be manufactured into fuel elements. Plutonium is expected to be used for manufacturing mixed-oxide fuel for VVER-1000 reactors (Egorov et al., February 1991).

The reprocessing plant at Krasnoyarsk will evidently be equipped with facilities to remove NO_x in water-sprayed columns, ^{129}I, and ^{14}C using sodium hydroxide-sprayed columns, and the majority of tritium will be removed with the condensates formed in the nitric acid recycling process. In addition, ^{85}Kr is expected to be removed at this plant, and the Soviets are studying krypton adsorption on activated carbon at "low temperatures," as well as freon absorption and cryogenic distillation. They plan to use cartridge cermet filters "of periodic action" [batch operation] using an inert layered material [pearlite] to remove solid suspensions from reprocessing solutions (Egorov et al., February 1991; Dzekun et al. 1991a).

An extra extraction cycle to separate the transplutonium element concentrate, as well as ^{137}Cs and ^{90}Sr in quantities required for radiation and independent power sources, is planned at the Krasnoyarsk reprocessing plant. As an extractant, a solution of "metal-carbolide" complex (cobalt dicarbolide) mixed with a polar diluent and polyethyleneglycol is expected to be used (Dubrovsky et al. 1991).

8.0 HIGH-LEVEL WASTE TREATMENT, STORAGE, AND DISPOSAL

The high-level waste vitrification program in the former Soviet Union started in 1967. The first large-scale single-stage (direct liquid-fed) melter at Chelyabinsk-65 started operation in 1986, and was decommissioned in February of 1987. The melter suffered an electrode failure after 12 months in operation due to a very high current load (2,000 amperes), which caused accelerated corrosion and eventual failure. VNIINM, the organization largely responsible for the design and pilot scale testing of melters, noted that this design had not received thorough enough testing at their institute, which was then charged with coming up with the modifications for the second large melter at Chelyabinsk-65 (Bradley, November 11, 1991). As previously reported, a total of 162 MT of HLW phosphate glass, produced from 998 m^3 of liquid HLW, was made by this first melter (Bradley and Schneider 1990). The liquid HLW composition, shown in Figure 8.1, contains high amounts of aluminum from "high-enriched fuel elements of type BM" (G. Medvedev 1991), which is probably from the reprocessing of submarine fuel, as learned during a visit to the vitrification facility in October 1991 (Bradley, November 11, 1991).

The second melter, also single stage, started testing operations in December 1990, and after 6 months went operational on June 25, 1991, using actual high-level waste solutions. The Soviets have again selected phosphate glass as their high-level waste form and are currently running a version with a higher aluminum content from the reprocessing of submarine fuel. The liquid HLW used as a feed for the second melter is based on reprocessing fuel of both the "BM" type as well as from VVER-440 reactor fuel. Figure 8.2 shows the composition of the liquid HLW (G. Medvedev 1991). The Soviets are processing up to 8 m^3/day of liquid HLW and have made 88 MT of HLW glass containing 13 M Ci of activity as of October 1991. They intended to process 1,200 m^3 of liquid HLW solution by the end of 1991 (Bradley, November 11, 1991). As of February 1992 they had made 220 MT of HLW phosphate glass containing 35 million curies (Nuclear Waste News, March 5, 1992). As of April 1992, 50 million curies of HLW had been incorporated into glass (Moscow Teleradiokompania Ostankino, April 24, 1992). Presentations on the Soviet's melter program, and a tour of their vitrification facility, were recently given to a DOE

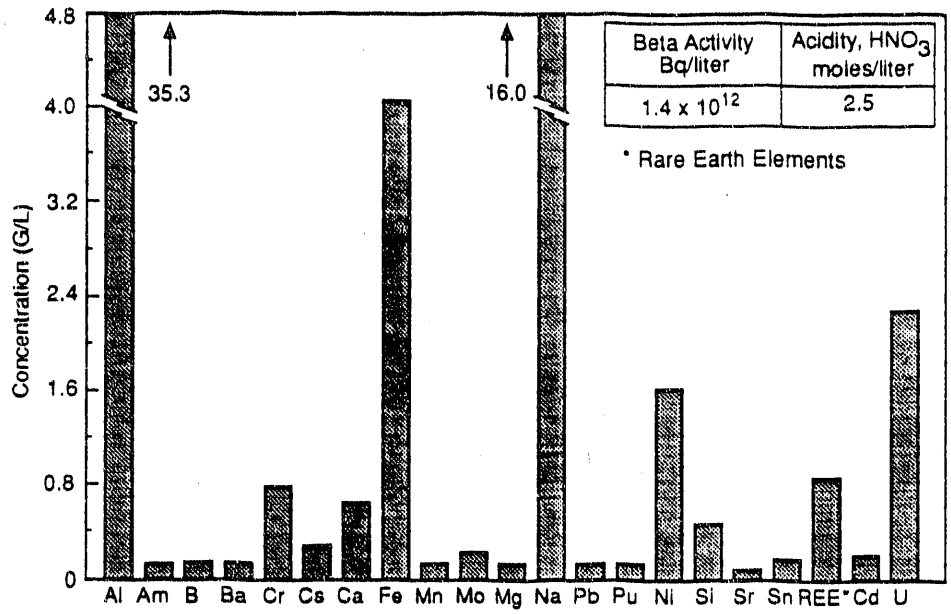


FIGURE 8.1. Liquid HLW Feed Composition for First Chelyabinsk-65 Melter Campaign

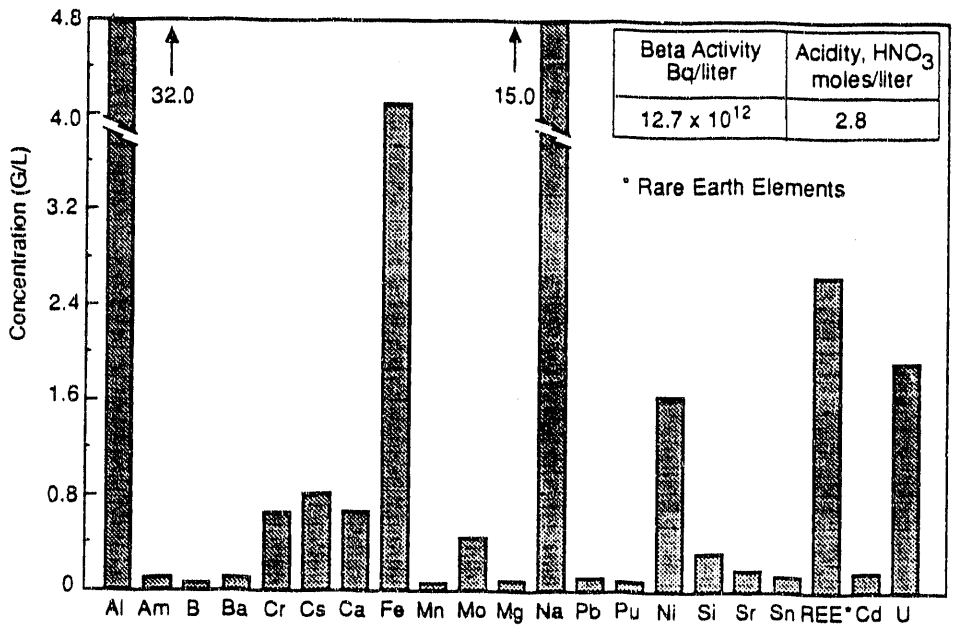


FIGURE 8.2. Liquid HLW Feed Composition for Second Chelyabinsk-65 Melter Campaign

delegation visiting the Chelyabinsk-65 site, and the following points were noted (G. Medvedev 1991; Bradley, November 11, 1991):

- Molasses is added to the melter to form a "cold-cap" to trap the volative radionuclides.
- There is no frit addition; HLW solutions are "spiked" with additives to get the proper phosphate glass composition.
- The Soviets have had no problems so far with the melter, including with noble metal precipitation. This was attributed to the fact that they alternate HLW solutions with solutions that contain no noble metals (such as intermediate-level waste streams), and the large melter volume, $12m^3$, for dilution/dispersion of noble metals.
- They are studying borosilicate waste glasses and may produce them when they have evaluated more data.
- Electrode and refractory corrosion is still a problem, but the Soviets only plan for a melter life of 3 years and expect that the electrodes will last that long as well as the refractories.
- The Soviets' glass leaching requirement is 10^{-5} to 10^{-6} grams/cm^2-day, with cesium release used as the basis for the requirement. They have no mechanical durability requirements for their glass.
- Melter refractories (called "Chamot") are alumina-zirconia based.
- The Soviets have considered using electrode materials other than molybdenum, such as tin oxide, but they have not looked at steels or super-alloys because they say they don't hold up to the phosphate glass.
- Each pour container is filled in a batch process with a pour time of 1-2 minutes. The Soviets use a "mechanical" valve to open and close the melter side-drain.
- The pour containers are made of mild steel and contain 200 liters of phosphate glass. After having lids welded on, three of these containers are placed in a stainless steel canister, and two are loaded into vertical holes in the storage hall located next to the melter. The pour canisters are not decontaminated prior to placement in the stainless steel canisters.
- In an adjacent hot-cell facility, the seal weld is made on the stainless steel canisters using a TIG weld fixture attached to the cell floor, and rotating the canister by the weld head to obtain the fusion seal. The weld design features tapered surfaces on the lid and the lop of the canister top surface which forms a "knife edge" where the fusion weld is achieved. No filler was noted. There are

no leak checks or other quality checks of the weld; the weld operator apparently uses visual inspection through the cell window to determine that the weld is adequate.

- Their phosphate waste glass storage is cooled by forced-air circulation and is designed to cool canister heat loads of up to 5,000 watts. The storage area, located adjacent to the melter hall, is sufficient to handle the output of their melters for 10-12 years. The Soviets have considered building a natural air-convection cooled storage facility, but have not finalized their plans, since they already have so much storage capacity.

- New melters can be added to the melter "hall," where old ones would be sealed in as they are shut down. They can extend the melter hall by adding on to the building, and are planning to build a total of 6-7 melters in this fashion.

- The Soviets plan to build an extension to the melter hall as soon as a decision is reached on the next melter "configuration." The "cold-wall" induction melter will be tested in this melter hall, apparently in 1992. The decision on the next type of melter to be built may be made early in 1992.

Two new "advanced" processes for dealing with solidification of HLW or specialized wastes derived from the partitioning of HLW were also presented by the Soviets. The first was a process using high-temperature absorption on silica-gel, which is then "calcined" and put into canisters for final disposal. Although they indicated that they would like to use this process on an "industrial scale," the annual throughput was said to be 400 kg. They further indicated that this process will be used to process wastes from VVER fuel reprocessing, and that they will try it out also on sludge wastes. The second process was a plasma technique for producing waste calcine at a temperature of from 7,000 to 8,000°C. The Soviets have not yet tried this method using radioactive solutions, nor have they looked at the obvious problem of volatility (Bradley, November 11, 1991).

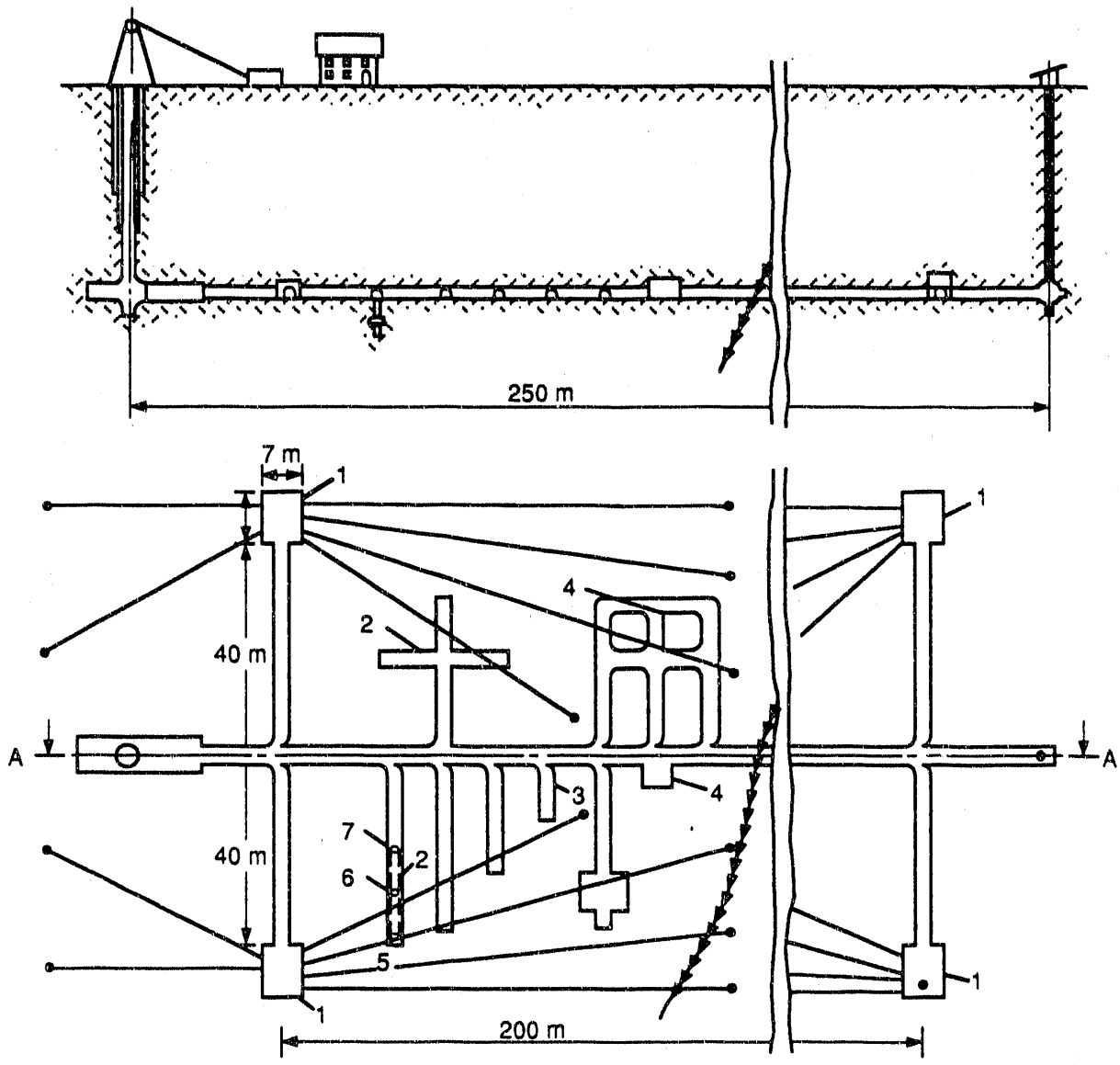
The Soviets are still studying other options for HLW solidification, including new vitrification processes such as induction melting and making synthetic minerals (Synroc-type) (Nuclear Fuel, July 8, 1991). For the transuranium element part of HLW, transmutation in fast reactors is believed to be promising, not only for neptunium, americium and curium, but for plutonium as well (Egorov et al., April 1991).

As reported previously (Bradley 1991), the Soviets are interested in an underground laboratory for high-level waste disposal research, and now state that their first priority is to establish such a facility in the Chelyabinsk region. Construction of such a laboratory in porphyritic rock would be used to study the behavior of this type of rock formation with respect to temperature and stress distribution, radiation effects and permeability. The shaft for the underground facility is planned to be 6 to 7 meters in diameter with a test shaft of 1.2 meters, and horizontal outlet and test shafts of unspecified size. Figure 8.3 is a diagram of an underground research laboratory (Kedrovskii et al. 1991a).

In parallel with the underground laboratory efforts, MAPI and other ministries continue to study disposal in salt formations, in the permafrost of northern Siberia, and also in abandoned uranium mine shafts (Nuclear Fuel, July 8, 1991). Dr. Kedrovskii [at the All-Union Design & Research Institute of Complex Power Technology in St. Petersburg] has recently further discussed Soviet geological repository activities. They have investigated radiation effects on silicate and aluminosilicate minerals that are expected to be found in their candidate geological formations. The thermal conductivity, strength, and thermal coefficient of expansion were studied for Porphyrites [such as those mentioned in the vicinity of Chelyabinsk-65]. Five types of experimental repositories were indicated to be under study. These concepts and related information are as follows (Kedrovskii et al. 1991a):

1. Vertical Storage Repository

   - Referred to as a "next generation" design for underground structures
   - Uses a 5 to 7 meter diameter shaft and a disposal "cylinder" at a depth of 600 to 900 meters
   - The entire cylinder is lined with a low thermal conductivity material
   - The cylinder is mounted to create a ventilation gap between it and the borehole shaft support. The lower end is open for air entry, and the upper end, having an air pumping system, is sealed
   - Waste containers or spent fuel are packed into "trays" that are placed into the cylinder



1 Zones for studying rock fracturing and effects due to the presence of water

2 Temperature and stress distribution tests from a single heat source

3 Temperature and stress distribution tests from a group of heat sources

4 Areas for studying rock permeability

5 Combined vertical outlet

6 Vertical hole for studying heat exchange from air-cooled sources

7 Hole for studying radionuclide migration

FIGURE 8.3. Diagram of Proposed HLW Underground Research Laboratory in Porphyritic Host Rock (Kedrovskii et al., May 1991a)

- A natural draft is created due to the decay heat; hot air is replaced by cold air from the surface entering through the ventilation gap
- The Soviets claim to have tested this technology, which keeps open the option for later retrieval of spent fuel

2. Large-Diameter Hole Repository

- Located at a depth of 1,000 meters with a working zone length of 600 meters
- The working zone shaft is reinforced with a perforated metal liner
- Canisterized vitrified wastes, having an activity of 200 to 400 Ci/L, are placed in the working zone shaft; the waste canisters have a diameter of 630 millimeters
- Concrete and bentonite would be used to fill open spaces after waste canisters are in place

3. Mine Shaft Repository

- Located to a depth of 1,000 meters with a 7 meter-diameter shaft reinforced with concrete
- The working zone is "below 300 meters"
- Intended for intermediate-level wastes only, with a useful volume of 27,000 m^3
- Concrete or bentonite will be used as a backfill material; the upper part of the shaft is equipped with a "sluice" chamber

4. "Leaching-chamber" Repository

- For storage of grouted or bituminized intermediate-level wastes, lowered into the repository using an ore elevator
- Useful storage volume of 20,000 m^3
- No details are given on how the underground chamber is made

5. "Shaft" Repository (shown in Figure 8.4)

- Proposed for use in salt formations
- The working level is joined to the surface using three shafts
- Intended for use with any type of radioactive waste

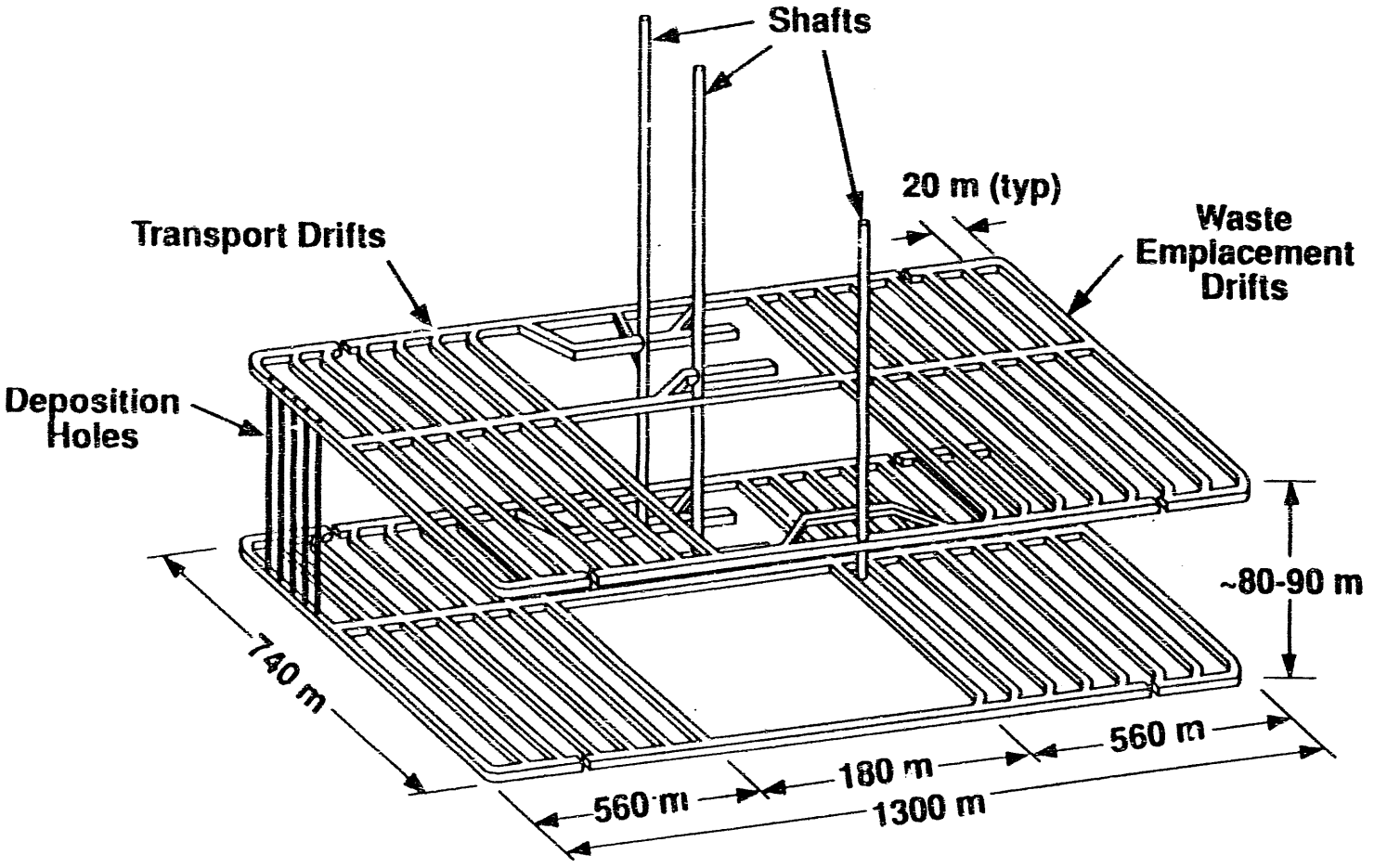


FIGURE 8.4. Drawing of "Shaft" Geologic Repository Concept for Salt Formations (Kedrovskii et al., May 1991a)

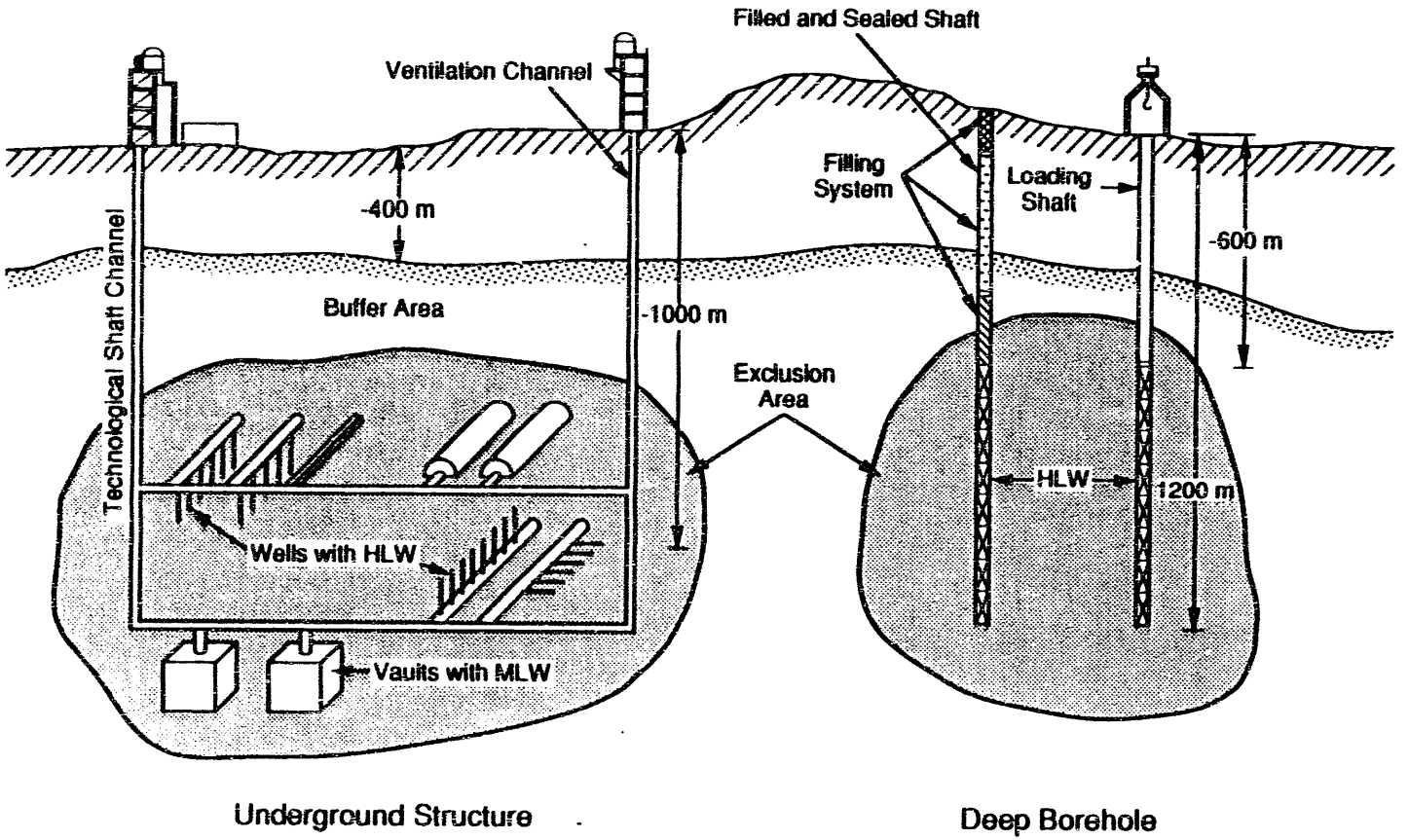


FIGURE 8.5. Geologic Disposal Concept for HLW and/or Spent Fuel (Strakhov et al., April 1991)

A drawing of a concept for geologic disposal of high-level waste and/or spent fuel [such as from RBMK reactors] is shown in Figure 8.5 (Strakhov et al. 1991). In addition to the above geologic disposal concepts and those reviewed previously (Bradley 1991), other creative ideas are being discussed by the Soviets. An example of this is to place a mixture of small packets of high-level waste and/or spent fuel together with a water insoluble, high-density, low-melting-point material in a very deep borehole. The radioactive decay heat would eventually produce a molten mass that would be expected to then turn into a monolith. An example of such a system has been described using galena (lead sulphide) as the matrix material. It was pointed out that it is also possible to use "raw products" of the lead industry, "the melted mixture of PbS, CuS, FeS and crude lead" (Byalko and Khavroshkin 1991).

An alternative to geologic disposal continues to be space disposal, especially for the "most dangerous" wastes such as long-lived transuranic wastes, which have relatively small volumes. The Soviets believe that in the long-term, the ultimate fate of the waste is more reliably predicted for space disposal as opposed to geologic disposal. Long-lived radionuclides being considered for space disposal include ^{99}Tc, ^{237}Np, ^{129}I, and ^{93}Zr (Nuclear Waste News March 5, 1992). Two space disposal options are being considered (Egorov et al. 1991):

- placement of waste containers into heliocentric orbits between Earth and Mars using the "Zenith" rocket
- placement of waste containers into interstellar space using the "Energia" rocket.

A method for high-temperature (100 to 150°C) adsorption of radionuclides by inorganic sorbents with subsequent annealing of saturated granules has been studied. Annealing the granules at 1000°C for 1.5 to 2 hours leads to decomposition of nitrate salts and formation of corresponding oxides. The Soviets state that this adsorption process incorporates more than 99% of the radionuclides into the solid phase. During annealing, some ruthenium and cesium are released into the gas phase, with 85 to 95% of the cesium and 7 to 15% of the ruthenium being fixed in the annealed sorbent. Other waste form matrices such as highly porous ceramics, metals, and alloys are stated to have "considerable promise" (Egorov et al. 1991).

The Soviets have conducted tests on radioactive borosilicate waste glasses that have been buried [for up to 12 years] in a site at the Radon Scientific Production Association (SPA) in Moscow, USSR. The specimens were representative of glasses that were experimental (BS-1) and those made by a more "promising" technology (BS-7). Table 8.1 provides more information on the vitrified waste specimens. The test specimens were held "under strict natural conditions." At the end of the test, the specimens apparently were examined extensively using scanning electron microscopy, and the leaching rate and total amount of radioactivity released were determined. [How this was determined was not stated, although it appears to have been deduced from surface analysis.] Individual radionuclide release rates were not stated. The "average" radionuclide leach rate for glass BS-1 was 2.1×10^{-5} g/cm^2 day, while that for BS-7 was 1.7×10^{-6} g/cm^2 day. The Soviets accounted for the order-of-magnitude-improved leaching resistance for the more advanced glass composition as due to its lower radionuclide content, noting that when the radioactive waste content in the glass exceeds 12 to 14%, the glass structure changes enough to increase its reactivity significantly (Doklady Akademii Nauk 1990).

TABLE 8.1. Data on Vitrified Radioactive Waste Used for "In situ" Leaching Tests

Glass Block	Testing Start Date	Glass Radwaste Content, % (weight)	Specific Activity of Radwaste in Glass, Bq/kg (weight)	Radwaste Isotope Makeup Isotope	Content, % (weight)	Glass Block Contact Surface Area, cm^2
BS-1	April 1977	22.2	$\Sigma_\beta = 2.2 \times 10^5$	^{137}Cs	44	282
			$\Sigma_\alpha = 2.3 \times 10^4$	^{90}Sr	16	
				^{134}Cs	7.2	
				^{144}Ce	15	
				^{60}Co	14.5	
				Other	3.3	
BS-7	October 1977	14.8	$\Sigma_\beta = 9.6 \times 10^5$	^{137}Cs	62	450
			$\Sigma_\alpha = 4.1 \times 10^4$	^{90}Sr	16	
				^{134}Cs	10	
				^{144}Ce	7.6	
				^{60}Co	4.4	
				Other	1	

Note: Other isotopes: ^{241}Am, ^{65}Zn, ^{57}Co, and ^{139}Ce.

9.0 LOW- AND INTERMEDIATE-LEVEL WASTE TREATMENT, STORAGE AND DISPOSAL

Although statements were made last year to the effect that well-injection of radioactive waste was not a reliable method and may be discontinued (Nikipelov et al., February 1990), it now appears that this practice is being continued in the former Soviet Union. Nikipelov has stated that "Soviet organizations" have successfully carried out deep-well injection of intermediate-level wastes for 20 years with "no signs for alarm." Noting that "there was no scientific consensus" on this disposal method, he indicated that MAPI plans to continue this practice and dispose of a large volume of waste in underground formations after the year 2005 (Nuclear Fuel, July 8, 1991).

Low- and intermediate-level radioactive wastes have been disposed of by well-injection into porous geologic formations for a long time in the former Soviet Union. This has been described as having occurred at the Scientific Research Institute of Atomic Reactors (NIIAR) in Dimitrovgrad (near Ulyanovsk) (Yudin et al. 1968; Bradley and Schneider 1990; Bradley 1991), and was given as the policy [in 1978] for disposing of liquid low- and intermediate-level wastes at nuclear power stations with appropriate geology and hydrology (GKAE 1978).

The extent of Soviet well-injection operations, however, may be significantly larger than previously thought, and include high-level wastes, as well as large volumes of hazardous chemical and other industrial wastes. Extensive geologic explorations for the injection of liquid radioactive wastes were begun in the late 1950s, at the suggestion of experts in the Ministry of Oil Production, Ministry of Geology, and the USSR Academy of Sciences. The Ministry of Medium Machine Building and the Ministry of Health of the Oil Industry also participated in these efforts. As a result, experimental and pilot-plant well-injection systems (referred to as "polygons") were put into use. It was noted that the "first selected region" in Chelyabinsk proved unsuitable for this type of disposal due to the type of geologic formations present, which eventually caused "great difficulties in localizing wastes" at the site (Kedrovski et al., May 1991b), which can be seen from the information presented in Chapter 12.

As a result of experimental and pilot-plant studies (carried out for more than 20 years), the Soviets evidently felt that well-injection was an acceptable means of waste disposal, stating that this method successfully solved the [waste disposal problems] at "a number of radiochemical installations and one research center" [the research center being NIIAR in Dimitrovgrad]. In light of this, it should be noted that it has been recently reported that radioactive wastes have been injected at the Siberian Chemical Combine [or Complex], also called "Tomsk-Seven" (see Chapter 13.0 for additional discussion).

It was noted that due to the Soviets positive experience with this type of disposal, it may be used for relatively short-lived materials, such as tritium, as well as wastes formed by transmutation of long-lived radionuclides (Kedrovskii et al., May 1991b).

At the Dimitrovgrad site, favorable "absorbent" formations were found at depths of 1410 to 1470 meters (Zone III, composed of sandstone, limestone and clay layers) and at 1130 to 1410 meters (Zone IV, composed of limestone and dolomite layers). These absorbent layers contain salt water (200 to 200 g/L) and have a migration rate of less than 1 meter/year. Wastes containing strontium, cesium, cerium, ruthenium and tritium, along with salts, oils, and "other compounds," were pumped into Zone III from 1966 to 1973 and then into Zone IV (1973 - present?) (Kedrovskii et al., May 1991b). The wastes evidently are pumped into the boreholes at a pressure of 40 to 60 atmospheres (USSR Technology Update, September 5, 1991). The amounts of wastes injected were 0.6 million m^3 into Zone III, and 1.5 million m^3 into Zone IV, and migration of wastes from the pumping wells is said to be 1 to 2.5 km after 26 years (Kedrovskii et al., May 1991b). Figure 9.1 shows a drawing of the migration of radioactive wastes from the Dimitrovgrad injection site (Kedrovskii et al. 1990).

In addition to the Dimitrovgrad site, waste-injection was performed at an experimental pilot-plant at an undisclosed location. This site is located in a synclinal structure layered with sedimentary Mesozoic sandy-clays on top of a crystalline pre-Cambrian basement rock that has a maximum depth of 500 meters in the central part of the structure. Details of the geologic structure of this site are shown in Figure 9.2 (Kedrovskii et al., May 1991b).

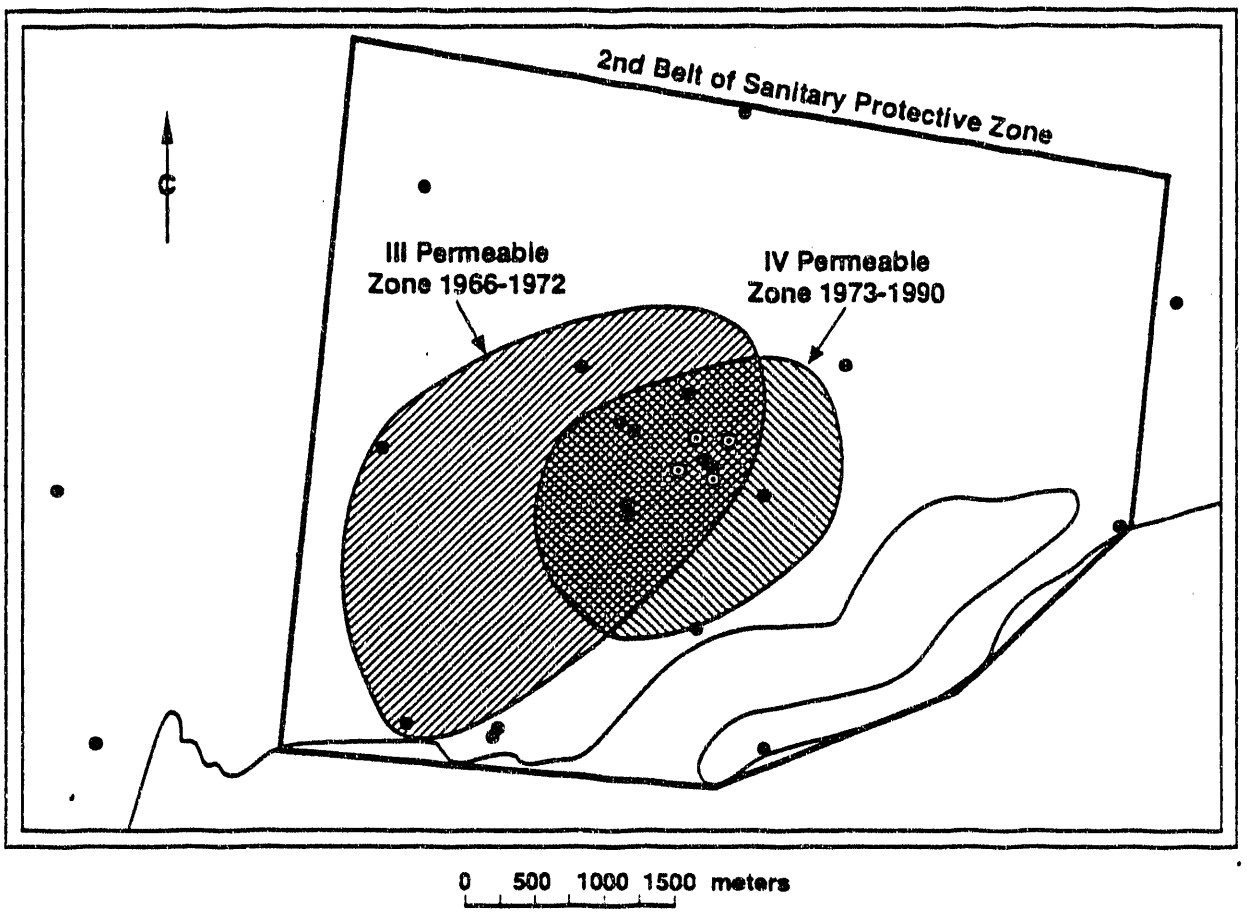


FIGURE 9.1. Migration of Radioactive Wastes from the Well Injection Site at the Scientific Research Institute of Nuclear Reactors at Dimitrovgrad (Kedrovskii et al. 1990)

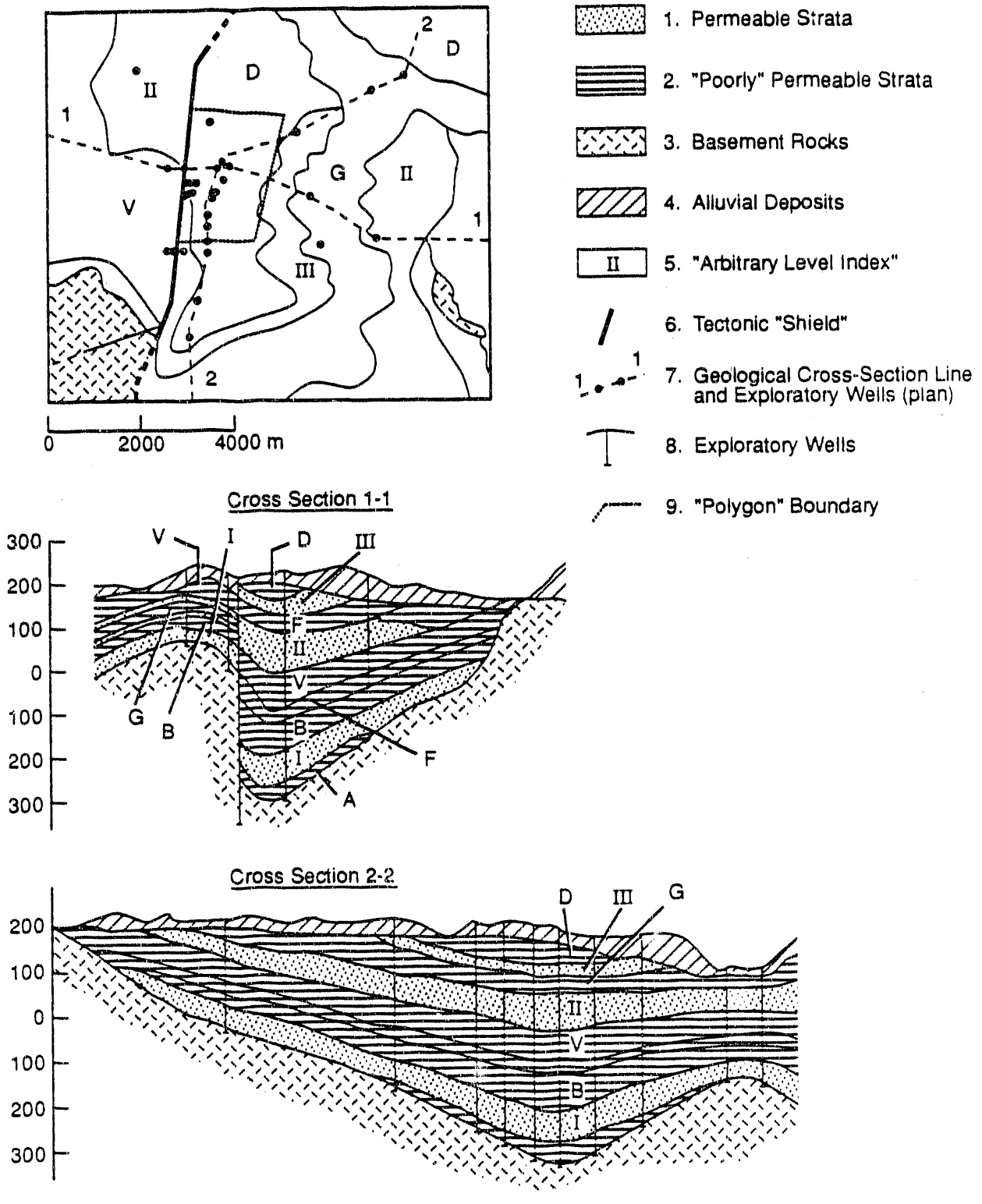


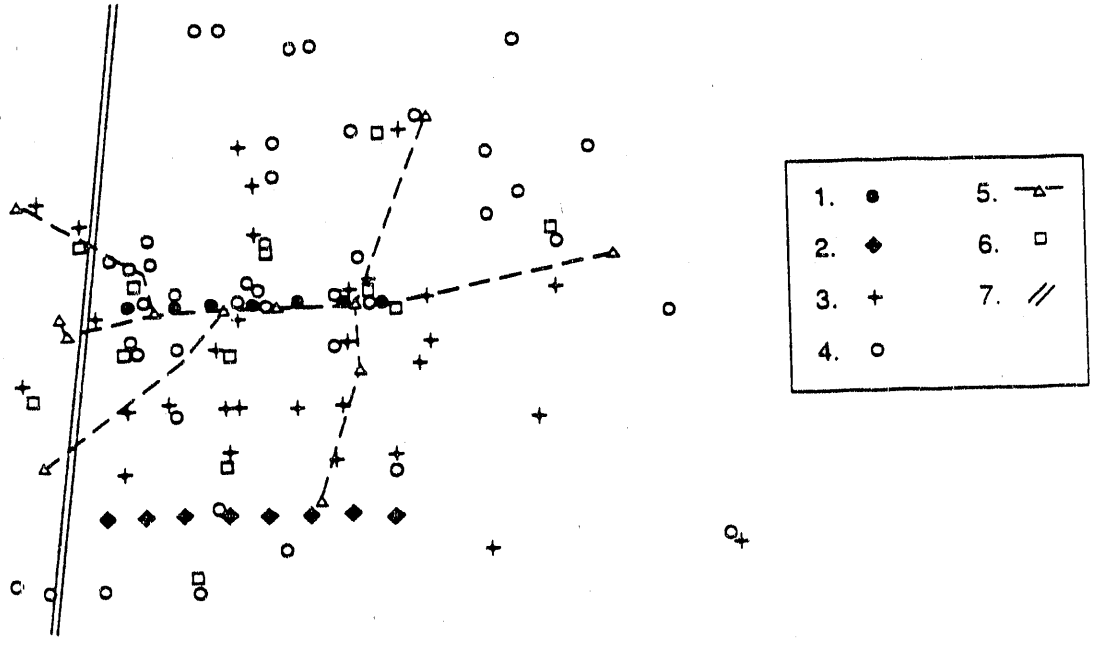
FIGURE 9.2. Geologic Structure of an Experimental Pilot-Plant Site for Injection of Liquid Radioactive Wastes (Kedrovskii et al., May 1991b)

The wastes disposed of at this site span all levels of radioactive wastes (including strontium, cesium, cerium, ruthenium, zirconium, and niobium) and industrial wastes (including nitrate solutions, acids and bases, heavy metal hydroxides and organic compounds). The wastes are pumped into the disposal formation simultaneously with the withdrawal of "pure water" from wells, illustrated in Figure 9.3, and placed in a linear array 1,000 to 1,200 meters away from, and in the opposite direction of, the natural groundwater flow (Kedrovskii et al., May 1991b).

In addition to ILW, experiments on the disposal of HLW were also conducted at this site. The HLW was diluted to the radionuclide concentrations of ILW, and was then periodically pumped over 1 to 2 years in "portions" of up to 2,000 to 3,000 m^3. The Soviets report that extensive measuring and monitoring studies were done that allow them to model the waste-groundwater boundaries, as shown in Figure 9.4, as well as the migration of waste components 800 years after their disposal, depicted in Figure 9.5. Based on their analysis, the Soviets feel that disposal of HLW in this fashion is just as safe as for LLW and ILW. Disposal of HLW in batches allows them to "treat" these wastes prior to disposal using reagents that, upon reaction with the host rock, will convert the radionuclides to solids, or ensure their solidification into the rock formation via a thermal reaction. Future research on this type of disposal method was stated to include technologies for ensuring or minimizing waste migration, and decontamination of wells and equipment (Kedrovskii et al., May 1991b).

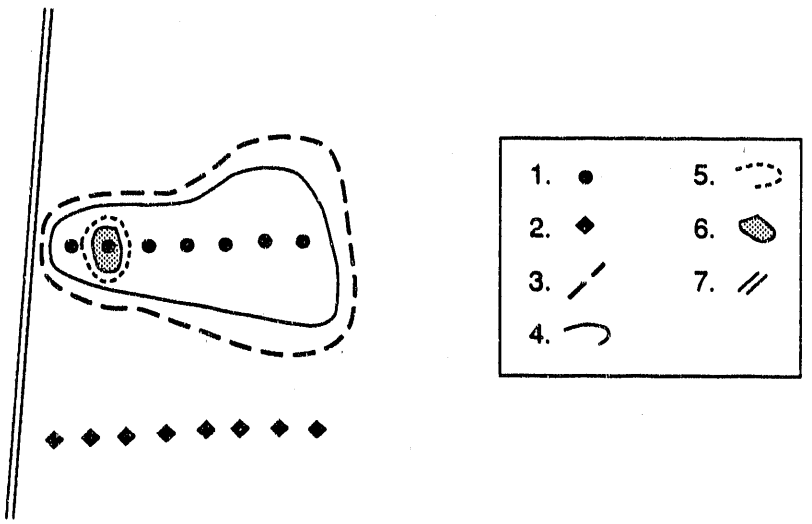
Disposal of hazardous chemical wastes by injection into geologic formations, possibly in conjunction with liquid radioactive wastes, may also have widespread use in the former Soviet Union. The following methods have been used, or are being developed for industrial waste disposal (USSR Technology Update, September 5, 1991):

- injection into absorbent formations at depths of 1,500 to 2,000 meters
- confinement in underground reservoirs, formed by dissolution in salt formations, or by mining in hard rock
- discharge into rock formations above the water table



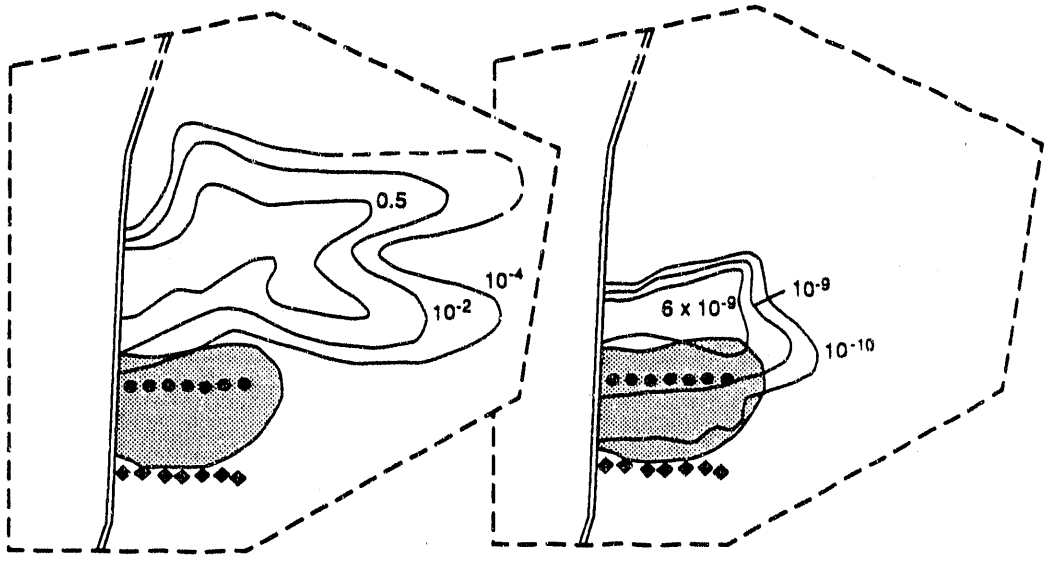
1. Waste Injection Well
2. "Pure Water" Exit Well
3. Observation Well
4. Monitoring Well
5. Leveling & Reference Profile
6. Seismic Monitoring Point
7. Tectonic "Shield"

FIGURE 9.3. Placement of Injection Wells and Monitoring Points for the Experimental Pilot-Plant Site (Kedrovskii et al., May 1991b)



1. Waste Injection Well
2. "Pure Water" Exit Well
3. Contour of Non-Radioactive Tracers
4. Contour of Radioactive Tracers
5. Outer Contour of High-Level Waste Components
6. Contour of Maximum Concentration of High-Level Waste Components
7. Tectonic "Shield"

FIGURE 9.4. Distribution of Wastes in the Geologic Structure at the Experimental Pilot-Plant Waste-Injection Site (Kedrovskii et al., May 1991b)



Migration of Liquid Wastes

Migration of Strontium-90

1. ● 4. 10^{-4}
2. ◆ 5. //
3. 6.

1. Waste Injection Well
2. "Exploratory" Well
3. Predicted area of waste migration following injection
4. Predicted isolines of relative concentration of liquid wastes and ^{90}Strontium (probably accounting for radioactive decay) after 800 years.
5. Tectonic "Shield"
6. Outcrop Boundary

FIGURE 9.5. Modeling Predictions of Radionuclide Migration from the Experimental Pilot-Plant Waste Injection Site 800 Years After Disposal (Kedrovskii et al., May 1991b)

- solidification and subsequent burial in geologic repositories
- injection of wastes along with cement or other solidifying materials into jointed rock formations causing hydraulic rupture of the formation.

The first two methods are reported as being widely used, with the remaining techniques being under development, undergoing field tests, or used in "pilot" facilities. The USSR Ministry of Geology has conducted studies on the disposal of industrial wastes in geologic formations, through studies at the All-Union Scientific Research Institute of Hydrogeology and Engineering Geology (VSEGINGEO) in the Moscow region, at the No. 2 Hydrogeological Administration in Moscow, and at the All-Union Oil Geological Prospecting Research Institute (VNIGRI) in St. Petersburg. The Ministry of the Gas Industry's All-Union Scientific Research Institute of Industrial Gas Use was also involved as the lead organization for the construction, design, and operation of all types of underground storage facilities.

Maps have been prepared by VSEGINGEO and VNIGRI that are still being used to locate potential waste-injection sites. A mine-type storage facility, for the use of the Defense Ministry, was built at a depth of around 100 meters in clay formations near Tallinn, Estonia. Salt formations indicated on the maps as suitable for storage of liquid hydrocarbons or disposal of liquid radioactive wastes are extensive and occur in the Ukraine, Byelorussia, Moscow region, Ural mountains area, around the Caspian Sea, and in Central Asia, Transcaucasia and Eastern Siberia. Multichamber storage reservoirs in salt formations, officially designated for liquid hydrocarbons, are located at the following (USSR Technology Update, September 5, 1991):

- Sterlitamak in Bashkir (Bishkadakskoye facility)
- Piryatin in Ukraine (Lubnenskoye facility)
- Yerevan in Armenia
- Astrakhan and Usolye in the Irkutsk region
- Guryev in Kazakhstan.

10.0 TRANSPORTATION

No additional information has been found on the transport of radioactive waste in the former Soviet Union. The reader is referred to PNL-7182 (Bradley and Schneider 1990) and PNL-7645 (Bradley 1991) for summaries of information in this area.

11.0 ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT AT CHERNOBYL

11.1 CHERNOBYL SITE REMEDIATION

The stability of the sarcophagus at the Chernobyl site is uncertain and is dependent on parts of the original reactor building whose structural integrity is "no longer assured." The sarcophagus roof is supported on beams which are, in turn, supported by the original ventilation shafts. Estimates have been made of the area of unsealed surfaces in the sarcophagus that range from 400 to 1500 m^2. Engineers confirmed that there are some 10 tons of radioactive dust in the sarcophagus of around the one to a few micron size (Nucleonics Week, June 6, 1991b). The 2,000-MT upper reactor head remains hanging above the shaft, and if it falls into the shaft it could "discharge" the dust that has accumulated inside the reactor (Tass, April 2, 1991). The sarcophagus contains about 180 MT of nuclear fuel and has a current temperature of 70°C, and a gamma radiation level of about 4,000 R/hr inside the reactor. Current radioactivity releases from the structure are about 15 microcuries of ^{137}Cs/day, according to Georgy Gotovshits, Ukraine's Minister of Chernobyl Affairs (Nucleonics Week, April 30, 1992).

The Soviet Council of Ministers has narrowed to three options the original list of seven or more for dealing with the Chernobyl sarcophagus. These are as follows:

- Construction of a new, entirely separate cover, as a secondary containment, over the top of the existing structure. This would be built of all new materials, with controlled entry, good ventilation, and environmental monitoring.
- Pumping the existing sarcophagus stiff with something like concrete--polymers are a possibility--with the dual result of supporting the internal structures and fixing the dust.
- Decommissioning the reactor buildings and sarcophagus to a "brownfield" site, a description ruefully agreed to by the Russians.

Most of the work currently being done on the sarcophagus is to secure the internal structures. The 2,000-MT "reactor lid," which was thrown into the air during the explosion, is supported by crushed and rusting steam pipes. Work inside the sarcophagus was stated to be extremely difficul., with

attendant high dose rates (Nucleonics Week, June 6, 1991b). To aid sarcophagus studies, the Soviets have bored 100 holes into the structure to obtain samples. Apparently 135 MT of nuclear fuel, primarily in lava-like masses, has accumulated on the facility's lower floors (IAEA Bulletin, January 1991b), elsewhere reported to be at least 150 MT of fuel (Rossiyskaya Gazeta, June 5, 1991).

It was noted that the 10-km radius zone surrounding the accident site contains nearly 800 nuclear waste disposal [makeshift] sites. They contain contaminated equipment and vehicles, clothing, topsoil scraped from nearly 100,000 acres, asphalt, trees from nearly 1,000 acres of pine forest, etc., which were buried in the "second half of 1986" (Medvedev 1991). In addition to the relocation of radioactive wastes from makeshift disposal areas to better designed burial sites, the Soviets state that work is under way to restore and reuse many materials after decontamination. Metals, including 20,000 MT of stainless steel, may be recycled (Tass, April 9, 1991). A joint venture between the Chernobyl PO-Kombinat of the former USSR and Recytec of Nyon, Switzerland, delivered a decontamination plant to Chernobyl in December 1990, manufactured by Anlagen Bau Contor of Stutensee, Germany. The decontamination process uses fluoroboric acid, at an operating temperature of 30 to 100°C, to dissolve the contaminated metal surface. The plant has a capacity of 5 MT/day of steel, with a dissolving vessel capable of accommodating 8-meter pipe lengths, standard in the former USSR (Nuclear Engineering International, April 1991). The Byelorussian government is also setting up a program to recover the nearly 1,000 cultural monuments contaminated by the Chernobyl accident (Tass, April 9, 1991).

With respect to the original reactor accident, the IAEA's International Nuclear Safety Advisory Group (INSAG) has voted to produce a supplement to its 1986 INSAG-1 report analyzing the causes of the accident. The report amendment was said to be justified because of the possibility the information it had in August 1986, on which INSAG-1 was based, was incomplete or even incorrect (Nucleonics Week, June 6, 1991b). The report was published in January 1992 (Nucleonics Week, January 9, 1992).

A new law on the freedom of the press in June 1990 has been stated to have helped in the release of previously classified information on Chernobyl. However, some reports containing quantitative information on contamination of agricultural products and health effects are still considered sensitive. This may account for the fact that detailed ^{137}Cs contamination maps were not published until 1990. Rough maps of the ^{90}Sr and $^{239+240}Pu$ contamination have been published by Ukrainian and Byelorussion newspapers that indicate that the boundaries of the 30-km exclusion zone were amended [based on ^{137}Cs levels greater than 40 Ci/km^2] by expanding the exclusion zone on the west and north sides of the accident and reducing it on the eastern side (Medvedev 1991). The Soviets obtained more precise data in 1990 on radiocontamination from Chernobyl in 22 oblasts. New spots where the density of radiocontamination is 1 curie per square kilometer were discovered in Vitebsk Oblast, and zones where the density is 1 to 3 curies per square kilometer were discovered in Ryazan and St. Petersburg Oblasts. The Soviets have also concluded that there has been relatively little migration of radioactivity from the effect of wind. Radionuclides have penetrated the soil to depths as great as 25 centimeters, but 80 to 90% of this radiocontamination occurs in a layer of soil that is only 5 centimeters deep. Currently, about 14,000 curies of ^{90}Sr are located in the banks of the Pripyat River (Nucleonics Week, May 7, 1992b). A book entitled Chernobyl: Radiocontamination of Natural Environments (Chernobyl: radioaktivnoye zagryazneniye prirodnykh sred) was published recently by the "Gidrometeoizdat" publishing house. This work is said to contain complete scientific data and much operational data for a period of 4 years (Pravda supplement, April 26, 1991). A map has also been published showing the extent of radiation damage of coniferous forests in the Chernobyl region (Templeton 1991). Another source for further spreading contamination from the Chernobyl accident is from fires in these contaminated forests. This occurred, apparently from the May Day celebrations, in 2,450 acres of forests and grassland in Southern Belarus in early May. Radioactivity in the ashes from the fires was stated to be 10-15% above normal levels (Paris AFP, May 5, 1992).

The Kholinsky deposit of zeolites, said to be located in Buryatia in eastern Sibera, is producing up to 20,000 MT/year for filters to be used in

decontamination of water and soils at Chernobyl (Tass, May 7, 1991), and Soviet scientists have advocated its increased usage as a decontamination material (TRUD, October 18, 1991).

The former USSR budget for 1991 includes 10.3 billion rubles for restoration activities resulting from the accident at Chernobyl (Pravda, January 16, 1991). The budget for the years 1986 to 1989 was 9.2 billion rubles (Tass, April 17, 1991), and for 1989 and 1990, 1.1 and 2.2 billion rubles, respectively (Pravitelstvennyy Vestnik, February 9, 1991).

11.2 HUMAN EXPOSURE DUE TO THE CHERNOBYL ACCIDENT

The IAEA Report on the International Chernobyl Project (ICP) was issued in May 1991, and indicates that "the radiological impact is much lower than was originally assessed and is not related to surface contamination." The radiation exposure of the population was not significant enough to warrant massive relocation, and the report indicated that "the Soviet Union has been overly cautious" (Nucleonics Week, May 16, 1991). However, the Byelorussian and Ukrainian republics contend that they have medical data, not included in the international study, that show clear health effects in the same population, following the accident (Nucleonics Week, May 30, 1991a). It has also been reported that about 150,000 residents of the Ukraine have received excessive doses to the thyroid, with 5,000 children and 7,000 adults receiving more than 200 rads (Trud. April 25, 1991).

The ICP was the response to an appeal by the former USSR to the IAEA in October 1989 for an expert assessment of Soviet policy to protect the population living in the areas contaminated by fallout from the Chernobyl accident. The IAEA coordinated the response, with participation by the Commission of the European Communities (CEC), the United Nations (U.N.) Food and Agriculture Organization, the International Labor Office, the U.S. Scientific Committee on the Effects of Atomic Radiation, the World Health Organization, and the World Meteorological Organization. The governments of the Byelorussian, Ukrainian and Russian republics also signed on to the effort. An International Advisory Committee was established to oversee the project, under the direction of Itsuzo Shigematsu, Director of the Radiation Effects Research Foundation in

Hiroshima. The project was formalized at a February 1990 meeting in Moscow, a fact-finding mission was carried out in March 1990, and field work was done that summer.

The goals of the project were to examine assessments of the radiological and health situation in areas of the former USSR affected by the accident and to evaluate measures to protect the population living in the affected area during 1990. This population numbers officially 825,000 people, of whom 45% live in Byelorussia, 24% in Russia, and 31% in the Ukraine. Thirteen districts in the former USSR have been officially identified as having ^{137}Cs ground contamination in excess of 1 curie per square kilometer (Ci/km^2). Some 25,000 km^2 have more than 5 Ci/km^2, more than half of which is in Byelorussia and less than a tenth is in Russia (Nucleonics Week, May 30, 1991a). The reader is referred to the complete ICP report by the International Advisory Committee for detailed information and maps showing the distribution of radionuclide contamination from the Chernobyl accident (International Chernobyl Project, May 21-24, 1991).

Compared with official Soviet 70-year dose estimates for the 28 contaminated areas ICP reviewed of 150 to 400 milliSievert (mSv), the ICP team estimated that the total dose from all sources would be closer to 80 to 160 mSv. The original Soviet request to the IAEA excluded two categories from the study: the "liquidators" and the 116,000 people evacuated within 2 days of the accident. Any person is recognized as a "liquidator" if he can prove he has worked at Chernobyl--either inside unit 4, in "isolating the radiation source," or within the 30-kilometer zone around the site--since 1986. The average dose to this group has been estimated at 12.5 rem (125 mSv) (Nucleonics Week, May 30, 1991b). The state register of the "victims" of Chernobyl contains 539,000 people (as reported in April 1991), which includes 192,000 "liquidators" (Tass, April 15, 1991).

Tables 11.1 through 11.6 give a synopsis of dose distribution data to various regions and populations of the former USSR (Ilyin 1991). According to the author's conclusions, children up to 6 years old exposed to radioiodine require the most thorough medical care. At the end of 1990 and beginning of 1991, the pronounced tendency towards the increase in child thyroid cancer

TABLE 11.1. Dose Distribution in the Population of Strict Surveillance Settlements for the Period from April 26, 1986, to January 1, 1990

Individual Dose Range, cSv	Population, $\times 10^3$	Persons with Specified Dose, %	Collective Dose to 1990, 10^3 Persons·Sv	Population, $\times 10^3$	Persons with Specified Dose, %	Collective Dose to 1990, 10^3 Persons·Sv
0.5-1.0				18.6	6.8	0.14
1.0-2.0	16.4	6.0	0.24	69.3	25.4	1.04
2.0-3.0	13.5	5.0	0.35	63.9	23.4	1.60
3.0-4.0	105.7	39.0	3.88	42.6	15.6	1.49
4.0-5.0	33.7	12.0	1.56	25.3	9.3	1.14
5.0-6.0	31.0	11.4	1.67	15.6	5.7	0.86
6.0-7.0	24.9	9.1	1.62	11.5	4.2	0.75
7.0-8.0	6.8	2.5	0.51	8.2	3.0	0.62
8.0-10.0	29.0	10.6	2.49	9.0	3.3	0.81
10.0-12.5	6.0	2.0	0.67	4.9	1.8	0.55
12.5-15.0	2.4	1.2	0.31	1.8	0.7	0.24
15.0-17.3	2.6	0.9	0.41	1.0	0.4	0.16
17.3	0.8	0.3	0.18	1.1	0.4	0.2
Total	272.8	100	13.9	272.8	100	9.6

TABLE 11.2. Revised Estimation of Collective Total Dose Commitments to the Population of Strict Surveillance Zones[a] in Five Regions of Russia, Ukraine and Byelorussia (10^3 persons·Sv)

Region	Lifetime Dose Limited by 350 mSv		Lifetime Dose Unlimited	
	Basic Prediction	1990 Revised Estimation	Basic Prediction	1990 Revised Estimation
Zitomir	7.7	1.9	9.3	2.6
Kiev	4.2	2.6	7.2	2.8
Gomel	17.6	8.0	21.1	9.4
Mogilyov	4.8	2.5	7.9	3.8
Bruansk	19.7	8.7	27.1	12.4
Total	54	23.7	72.6	31.0

(a) Strict surveillance zones make up different fractions by area and population of different administrative regions. The population of these zones in five regions is an average of 35% of the total.

TABLE 11.3. Revised Collective Dose Commitments in Nine Regions of Russia, Ukraine and Byelorussia (10^3 persons·Sv)

Republic and Region	Population, x 10^3	Basic Prediction	Revised Estimation
Ukraine			
Zitomir[a]	1,547	26	18
Kiev[a]	4,446	47	41
Chernigov	1,428	9	
Subtotal	7,421	82	68
Byelorussia			
Gomel[a]	1,678	67	52
Mogilyov[a]	1,282	18	14
Subtotal	2,960	85	67
Russia			
Bryansk[a]	1,472	50	36
Tula	1,865	13	
Oryol	864	2	
Kaluga	1,035	6	
Subtotal	5,236	71	57
Total	15,617	238	192

(a) Regions with strict surveillance zones.

TABLE 11.4. Thyroid Doses to the Population of the Most Heavily Contaminated Areas of Byelorussia and Russia (1991 estimates)

Republic	Region	Number of Districts	Population, x 10^3	Mean Dose, cGy	Collective Dose, 10^3 persons·Gy
Byelorussia					
Rural population	Gomel	9	238.6	41.0	98.0
	Mogilyov	5	93.7	18.5	17.0
	Subtotal	14	332.3	34.6	115.0
Urban population	Gomel	9	85.6	17.8	15.0
	Mogilyov	5	48.7	7.8	4.0
	Subtotal	14	134.3	14.1	19.0
Entire population		14	466.6	28.7	134.0
Russia					
Entire population	Bryansk	6	286	13	37.0
	Tula	5	210	13.8	29.0
	Oryol	2	44	7.2	3.2
	Kaluga	7	171	13.5	23.0
	Subtotal	20	705	12.9	92.2
Total		34	1171.6	19.2	226.2

TABLE 11.5. Thyroid Doses to Children Under 7 Years Old in the Most Heavily Contaminated Areas of Byelorussia and Russia (1991 estimates)

Republic	Region	Number of Districts	Population, x 10^3	Mean Dose, cGy	Collective Dose, 10^3 persons·Gy
Byelorussia					
Rural children	Gomel	9	23.9	106.0	25.0
	Mogilyov	5	9.3	43.9	4.1
	Subtotal	14	33.2	87.7	29.1
Urban children	Gomel	9	8.6	44.2	3.8
	Mogilyov	5	4.9	21.5	1.1
	Subtotal	14	13.5	36.3	4.9
All children under 7 years old		14	46.7	73	34.0
Russia					
All children under 7 years old	Bryansk	6	29.8	37	11.0
	Tula	5	22.4	40	9.0
	Oryol	2	4.7	21	1.0
	Kaluga	7	17.5	43	7.5
	Subtotal	20	74.4	38	28.5
Total		34	121.1	51.6	62.5

TABLE 11.6. Thyroid Dose Distribution in Children Under 7 Years Old (1991 estimates)

Dose Range, cGy	9 Districts of the Gomel Region (32,420 Persons)		5 Districts of the Mogilyov Region (14,240 Persons)		14 Districts of the Gomel and Mogilyov Regions (46,660 Persons)	
	Persons	%	Persons	%	Persons	%
0-30	15,128	46.660	9,637	67.68	24,765	53.080
30-75	8,951	27.610	2,975	20.88	11,926	25.550
75-200	4,924	15.190	1,345	9.45	6,269	13.440
2000-500	2,428	7.490	251	1.76	2,679	5.740
500-1000	693	2.140	28	0.20	721	1.550
1000-2000	274	0.850	4	0.03	278	0.600
2000-3000	20	0.060			20	0.040
3000-4000	2	0.006			2	0.004

incidence in Byelorussia and Ukraine was reported. Despite the absence of the "documented scientific data" on these cases, the reported appearance of malignant thyroid tumors following 2 to 3 years after the accident is noteworthy and requires thorough research (Ilyin 1991). Table 11.7 summarizes the history of the development of radiation protection standards and population relocations since the Chernobyl accident. Some recent summary information on

TABLE 11.7. Evolution of Former USSR Radiation Protection Standards After the Chernobyl Accident

April 26, 1986	Chernobyl Unit #4 explodes at 1:23 a.m. A Government commission is formed
April 27, 1986	Pripyat, and the 30 km zone around Chernobyl, are evacuated, for a total of 116,000 people. The permissible total dose standard for those people remaining in the "affected area" was adopted by the Ministry of Public Health to be 0.1 Gy for the first year after the accident. This total dose limit for the first year was adopted in 1979 as the accidental dose limit. The following affected zones were subsequently determined: • "Constant relocation zone" - the area defined by a minimum γ-radiation dose rate of 20 mR/h (0.2 mGy/h). It was based on the radiation dose excess over an annual dose limit (0.1 Gy). • "Temporary relocation zone" - area defined by a γ-radiation dose rate of 5 - 20 mR/h. The population of this zone was not evacuated except for children and pregnant women. The sum of standards amounted to 173 mSv from April 1986 through December 1989.
May 6, 1986	End of 10 days of atmospheric release of radioactive materials from the reactor core and the introduction of temporary contamination limits for drinking water and foodstuffs. Evacuation completed for population within the prohibited zone
May 31, 1986	Temporary dose limits for population set at 100 mSv annual total dose (external and internal) for the first year after the accident.
July 1986	First full contamination map was prepared (published in 1989)
November 1986	Completion of "sarcophagus" over Chernobyl unit 4
1987	Temporary dose limits reduced to 30 mSv total
April 1987	Completion of work begun in May 1986 for protecting water system
1988	Temporary dose limits for population reduced to 25 mSv annual total dose
September 1988	Council of Ministers of USSR adopts 350 mSv as a total lifetime dose for relocation, to be implemented as of January 1, 1990. • According to local recommendations, this Resolution included additional intervention levels for public relocation in terms of Cs-137 deposition values greater than 40 Ci/km^2, and where more than 15 Ci/km - for relocation of children age 14 or less and pregnant women.

TABLE 11.7. (contd)

	• Using the concept of 350 mSv, and official Soviet dose estimates, some 218,000 people are eligible for voluntary relocation with compensation.
March 1989	Contamination maps officially published in the three affected republics.
April 1989	Byelorussian Academy of Sciences registers disagreement with the 350 mSv lifetime dose concept and makes new proposals.
October 1989	USSR requests the IAEA to organize an international assessment of the accident's consequences and protective measures taken.
1990	A total of 87,000 people were relocated from contaminated territories.
Mid-May 1991	A new "concept" is approved by the Supreme Soviet which sets two basic annual levels for excess doses (over background radiation) due to the Chernobyl fallout: a lower intervention level of 1 mSv (0.1 rem), and an upper boundary of 5 mSv.
	• The new "concept" apparently mandates relocating people living in areas with over 40 Ci/km^2--(considered equivalent to an annual individual dose of 0.5 rem or 350 m Sv over a 70 year lifetime)--with full compensation.
	• People living in areas with from 15 to 40 Ci/km^2 (1 to 5 mSv/year) will be offered the possibility to relocate, with priority given to those with young children or pregnant women. Controls, decontamination or other protective measures may be taken.
	• People living in areas with less than 15 Ci/km^2 contamination, considered equivalent to less than 1 mSv per year, will not fall under the new "protection regime."
	• The range of 1 to 5 mSv is projected to involve about 400,000 persons (relocation on voluntary basis) in addition to the previously recommended regular relocation of people exposed to the lifetime dose of 350 mSv (50,000 to 60,000 persons).
	• The purpose of the new law was essentially to authorize funds for compensating up to 218,000 people for loss of property, building new lodging elsewhere, and "providing social benefits." Over 700,000 people in areas with over 15 Ci/km^2 are receiving compensation, people living in the 15 to 40 Ci/km^2 areas were getting 30 rubles a month in 1990 and those in areas with 1 to 15 Ci/km^2, 15 rubles a month.
	• As of April 1991, 189,000 people have been relocated and an estimated 100,000 to 300,000 have moved voluntarily.
	• As of January 1, 1992, according to Ukraine's Minister of Chernobyl Affairs, Georgy Gotovshits, 163,000 people have been evacuated or left the area [presumably Ukraine only] voluntarily.

Sources: Ilyin 1991; Nucleonics Week, April 18, 1991; Nucleonics Week, April 25, 1991a; Nucleonics Week, May 30, 1991b; Nucleonics Week, May 7, 1992b.

population dose was given by Georgy Gotovshits, Ukraine's Minister of Chernobyl Affairs. Of the 444 people working in the vicinity of the plant, including 176 operating personnel, 32 died within the first few days, 2,145 got acute radiation sickness, and an additional 92 had symptoms of radiation

sickness. About 10% of the Chernobyl "liquidators" (up to 18,000 people) received doses of 70 to 100 R. Within the first five months of the accident, 1,874 people received doses greater than 25 R, and 75,000 received doses between 1 to 4 R. Thyroid doses of over 30 R were found in 150,000 men. The Russian Committee on Hydrometeorology meanwhile has reported measuring thyroid exposures exceeding 200 R in 2% of the children examined, and higher than normal cases of thyroid cancer in children continue to be reported (Nucleonics Week, May 7, 1992b).

11.3 CONTINUING CHERNOBYL POPULATION DOSE STUDIES

A National Commission of Byelorussia on Radiation Protection (NKRZ) was recently formed at the Byelorussian SSR Council of Ministers. The NKRZ's main tasks are development of recommendations in the area of the substantiation and standardization of permissible radiation levels and the contamination of food products with radionuclides, and of measures to protect the Republic's population in case of radiation accidents. Doctor of Medical Sciences V. I. Ternov, Vice-President of the Byelorussian State Institute of Advanced Medical Training, was confirmed as its chairman (Sovetskaya Byelorussia, March 14, 1991). On April 6, 1992 a pact providing the legal framework for this program was signed in Geneva by WHO and the health ministers from Belarus, Ukraine and Russia. Belarus researchers reported a steep rise in thyroid cancer among children in the most contaminated areas, over 100 cases in the last three years (Nuclear Waste News April 30, 1992).

The World Health Organization (WHO), working with other international organizations and the former Soviet Union, is initiating a program to determine the health effects of radiation from the 1986 Chernobyl nuclear accident. Epidemiological information on 240,000 people will be collected and analyzed, and the WHO also will study the psychological impact on the affected population. Thyroid disorders, especially in children, will be monitored to help develop guidelines for dealing with radiation emergencies in the future (Nuclear Waste News, May 2, 1991). On April 6, 1992, a pact providing the legal framework for this program was signed in Geneva by WHO and the health ministers from Belarus, Ukraine and Russia. Belarus researchers reported a

steep rise in thyroid cancer among children in the most contaminated areas, over 100 cases in the last three years (Nuclear Waste News, April 30, 1992).

A U.K. consortium of SAC Hitec, the Ove Arup Partnership, and AEA Environment and Energy is expected to sign a contract early this month (May 1991) with the Russian Federation to plan the redevelopment of areas contaminated by the Chernobyl accident. The project will set priorities for reducing dose levels in urban and agricultural areas and resettlement of an estimated 110,000 people from badly affected zones. AEA Environment and Energy is to conduct a full radiological assessment, analyzing existing contamination measurements made by Soviet authorities and calculating dose levels according to location, employment, and lifestyle. On this basis, it will establish a framework for overcoming harmful health and environmental effects (Nucleonics Week, May 2, 1991).

12.0 ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT AT CHELYABINSK-65

12.1 THE LEGACY OF CHELYABINSK-65

The Chelyabinsk-65 complex, located about 70 km north of the city of Chelyabinsk in Russia, covers an area on the order of 200 km^2. It is the site of the first production reactor complex built in Russia, and the site and surrounding area have been significantly contaminated via direct discharges of radioactive wastes to the environment for over 40 years. The site is located on generally flat terrain among numerous lakes, marshes, and floodplains of several rivers. The average annual rainfall is 525 mm (about 21 in.), with a maximum rainfall, being observed in the summer months, of 150 mm. Prevailing winds are from the west-southwest direction averaging 5 m/sec. Snow falls in the first half of November and melts away in April. Ground water is reported to be located at a depth of 0.9 to 4.0 m from the surface (Petukhov 1991). More detailed geological and hydrological information on this site has been reported by Foley et al. (1991).

In a recent visit to the site, Dr. Viktor I. Fetisov, Director of the Mayak Production Association which runs the Chelyabinsk-65 site, noted that it was the only facility for power and naval spent fuel reprocessing and had the largest factory for producing isotopes, as well as a large factory for producing measuring equipment. The former site name of Chelyabinsk-40 was dropped about 1 year ago, and the city housing the workers and the site are now both referred to by the Soviets as Chelyabinsk-65 (Bradley, November 11, 1991). Dr. Fetisov recently noted that between 1948 and 1960, "occupational radiation sickness" was diagnosed in 2,089 workers, and 6,000 received doses greater than 100 rems. More than 2,000 people (today) have plutonium levels exceeding the maximum permissible lifetime dose, i.e., greater than 40 nanocuries (Moscow Central Television, November 21, 1991). In addition, the numbers of prisoners (from Gulag #10), drafted military personnel, and policemen and residents of nearby villages who participated in emergency cleanup teams is not known but is estimated to be at least 20,000. Their dose history is

not known and they are not part of the registries of those contaminated by the accidents at Chelyabinsk-65 (Kossenko et al. 1992a).

During operation of the Chelyabinsk-65 site, the Soviets indicate that over 1 billion curies of wastes have been "accumulated" in a "technically controllable" form. The current inventory, evidently accounting for radioactive decay, has been given as follows (Chukanov et al. 1991; Nazarov et al. 1991):

- About 900 million curies [823 million curies, according to Petukhov (1991)] of liquid HLW is stored in more than 60 special tanks [the tanks are single-walled, and ^{90}Sr has been partially extracted from the waste (Bukharin 1991)]. The tanks are stainless steel placed in reinforced concrete "shells" with a metal liner.

  [Note: It was stated during a recent visit to the site that the "reprocessing" of HLW wastes in storage tanks is becoming a problem due to their high salt content (Bradley, November 11, 1991).

  Furthermore, a paper was given to the DOE delegation visiting Chelyabinsk-65 in October 1991 that briefly discusses the Soviets' experience with high-level waste storage tanks that had instabilities in the sludge and precipitate layers on the bottom of the tanks. They note that this led to a "sharp pressure increase (20-25 mm Hg) of the gas over the liquid surface," the so-called burping tank phenomenon. The paper notes that high-level waste tanks in one of their buildings experienced instabilities "for a long time," especially between 1968 and 1972, which allowed them an opportunity to investigate this phenomenon.

  The Soviet scientists studied the temperature and radiation variations within a high-level waste tank, and made thermophysical calculations based on a model of the tank. Each tank had a volume of 1,300 cubic meters and contained 10-15 million curies of activity, mainly due to cesium and strontium. It appears that the method used to solve the problem was to break up the high-activity sludges or remove them from the tank. The methods used to do this are not discussed. Several means are used to try to prevent explosion hazards within the tank such as blowing air over the surface of the tank, monitoring temperature levels, and limiting the organic content of solutions discharged to the tanks to less than 3% by weight (Chelyabinsk-65, October 1991)].

- About 150 million curies [153 million curies, according to Petukhov (1991) and Nazarov (1991)] of precipitates (medium-level wastes) with a volume of 20,000 m^3, which has been recovered from reprocessing and partitioning operations, has been placed in "special storage sites" [this means in tanks as well as in "reservoirs" such as Lake Karachai].

  [Note: according to Nazarov (1991), no less than 976 million curies of liquid radioactive wastes are stored in "reservoir-tanks," which equals the alternate data given above. The remainder of "medium-level wastes" (totaling 153 million curies) not disposed of in Lake Karachai or to Staroye Boloto are said to be located in stainless steel storage tanks.]

- On the order of 4 million curies [as of June 1991] is in the form of vitrified high-level wastes, stored in a special "bunker."

- About 2 million curies is in the form of buried solid radioactive wastes.

Summing up all the above sources essentially equals 1 billion curies of wastes being stored at the Chelyabinsk-65 site. Nikipelov has further stated that "at radiochemical plants in the ministry" about 1.2×10^9 curies of wastes are stored as liquids in special containers (Nuclear Waste News, March 5, 1992). The Soviets indicate that, in addition, they have about 20 tons of "high-background" plutonium onsite at Chelyabinsk-65, having a critical mass of ~10 kg (Chukanov et al. 1991).

The Soviets acknowledge that at least 130 million curies of radioactivity has been released directly to the environment at the Chelyabinsk-65 site, some 2.6 times the total amount released from the accident at the Chernobyl Unit #4 in April 1986. As a result of these releases, about 500,000 people have received an "elevated radiation dose," and about 18,000 have been relocated. The radioactivity discharged directly to the environment has been distributed as follows (Chukanov et al. 1991; Bol'shakov et al. 1991; Nazarov et al. 1991):

- About 120 million curies of medium-level wastes in Lake Karachai (Reservoir #9), having a volume of 400,000 m^3, and an area of 0.25 km^2, where intermediate-level liquid wastes continue to be discharged. In 1967, winds carried about 600 curies, primarily associated with dust from the dried exposed shoreline of Lake Karachai, up to 75 km from the site. The contamination in 1967 was due to a combination of meteorological events, primarily a low

snowpack in the winter followed by early melting and an unusually warm, dry spring, and high winds of up to 15 m/sec with numerous small cyclones. Although the dry exposed shoreline of Lake Karachai is normally given credit as the source of the contamination, other contaminated areas, similarly dried out, could have contributed to the overall contamination. The first radioactive fallout (dust) was detected on March 18, 1967, and the contamination continued through the summer and possibly as long as August 1968. Some secondary contamination may have continued up through 1972 to 1973. Due to the highly uneven nature of the winds, "hotspots" were formed having activities of up to 50 Ci/km^2. Based on calculations, individual doses of up to 0.5 R may be reached from this wind-borne contamination in 1992 in the most contaminated areas (Botov 1992). Figure 12.1 shows a map of the reservoirs associated with Chelyabinsk-65 with contamination plumes emanating from Lake Karachai. Wind-blown contamination plumes from Lake Karachai in 1967, as well as further details on the contamination plume from the 1957 HLW tank explosion, are shown in Figure 12.2 (Bol'shakov et al. 1991).

- About 2 million curies of medium-level wastes in Lake Staroe Boloto (Reservoir #17), having a volume of 300,000 m^3, and an area of 0.17 km^2, also where intermediate-level liquid wastes continue to be discharged. [Nazarov et al. (1991) notes that tritium wastes are also discharged to Reservoir #17.]

- About 2 million curies of low-level wastes contained in the five artificial reservoirs (#'s 2, 3, 4, 10 and 11) along the Techa River, having a volume of 380 million m^3 [407 million m^3, according to Nazarov et al. (199?)], and a total area of 81 km^2. Raising the dike by 1 meter adds another 48.5 x 10^6 m^3 of capacity to reservoir #11. Domestic "sewage" is also dumped into Reservoirs #2 (3 million m^3/yr) and #4 (2.5 million m^3/yr).

- About 2 million curies of spent equipment is located in 200 repositories, 25 of which are active. The repositories have an area of 30 hectares, and contain 500,000 tons of solid radioactive waste, 30% of which is metal. Owing to the lack of units to reprocess and compact them, all of the solid radioactive wastes are buried in different types and sizes of repositories (on average, with a density of 6.6 repositories per hectare).

  The types of solid radioactive wastes that have been placed in the 200 repositories at Chelyabinsk-65 are as follows (Nazarov et al. 1991; Bukharin 1991):

  - high-level wastes [according to 1981 inventory data, these amount to 25,000 tons], which are stored in reinforced concrete repositories

  - medium-activity wastes (300,000 tons), with an activity of 150,000 Ci

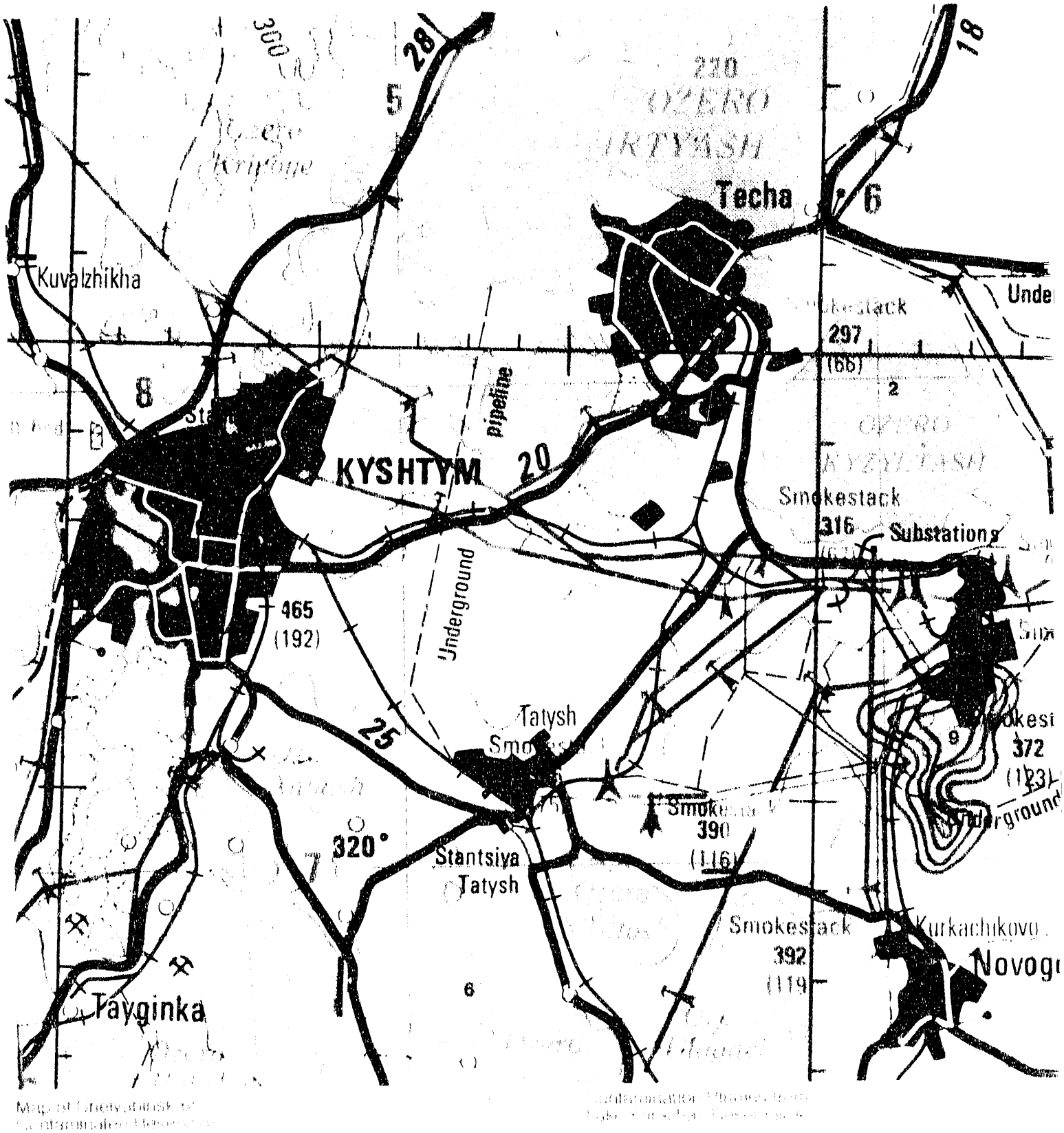
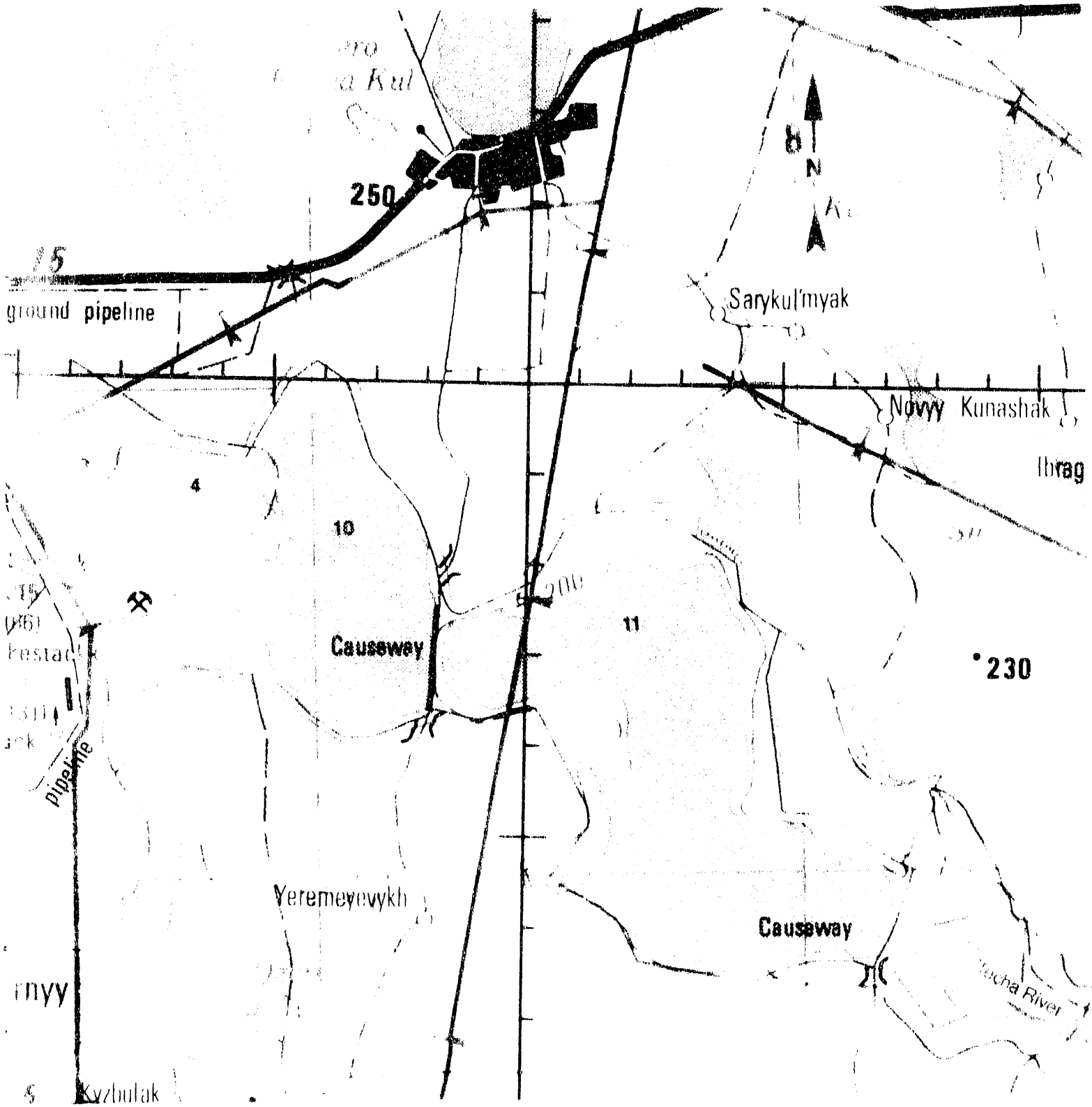
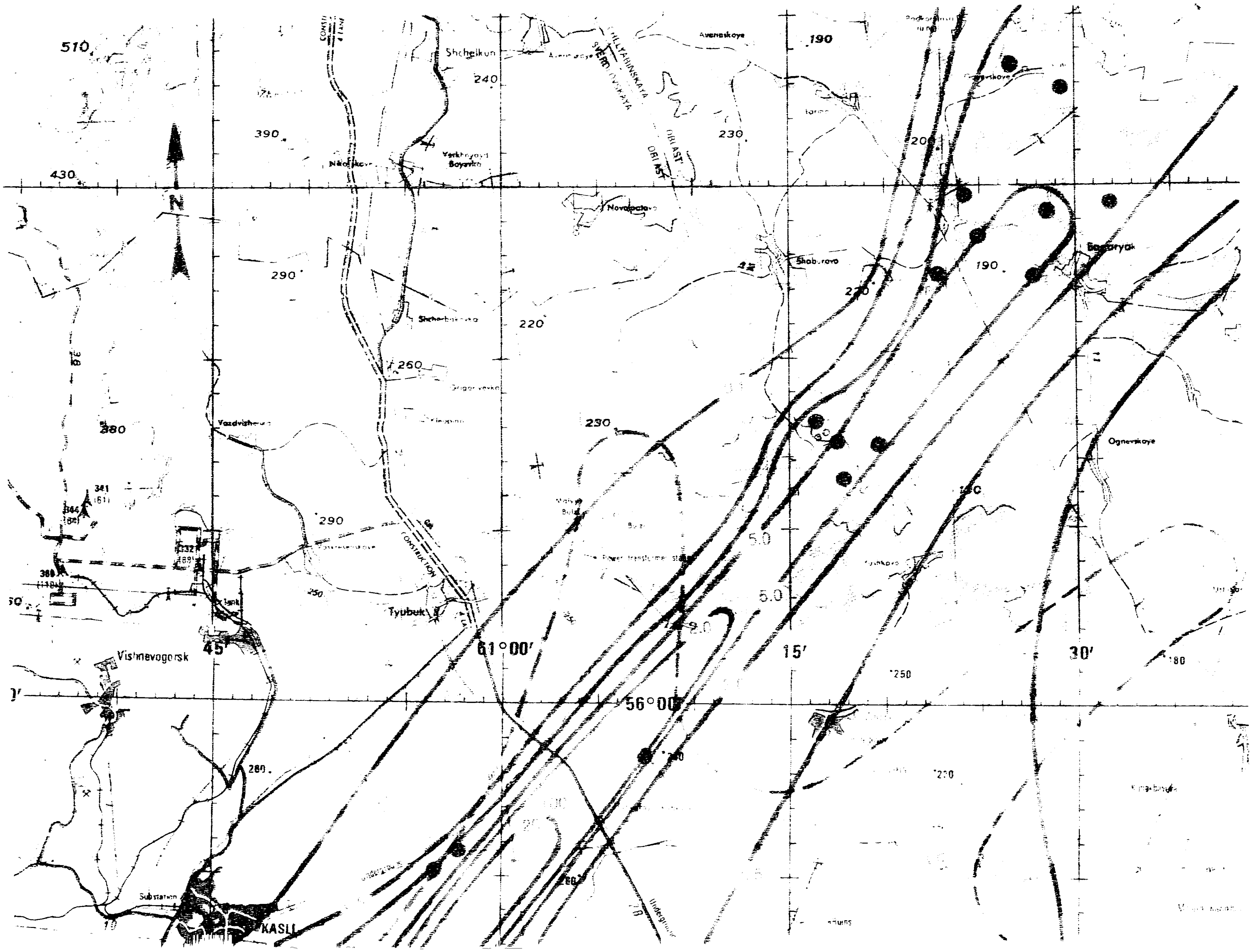


FIGURE 12.1. Map of Chelyabinsk-65 Contaminated Reservoirs


250
ground pipeline
N
Sarykul'myak
Novyy Kunashak
Ibrag
4
10
11
Causeway
230
Pipeline
Yeremeyevykh
Causeway
Kyzbulak



N
510
430
390
290
380
240
230
220
260
250
290
280
190
200
230
Shchelkun
Nikolskoye
Verkhnyaya Boyevka
Shcherbakovka
Vozdvizhenka
Novopestovo
Shaburovo
Tyubuk
Vishnevogorsk
Bagaryak
Ognevskoye
Avenaskoye
CHELYABINSKAYA
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Power transformer station
45'
61°00'
15'
30'
56°00'

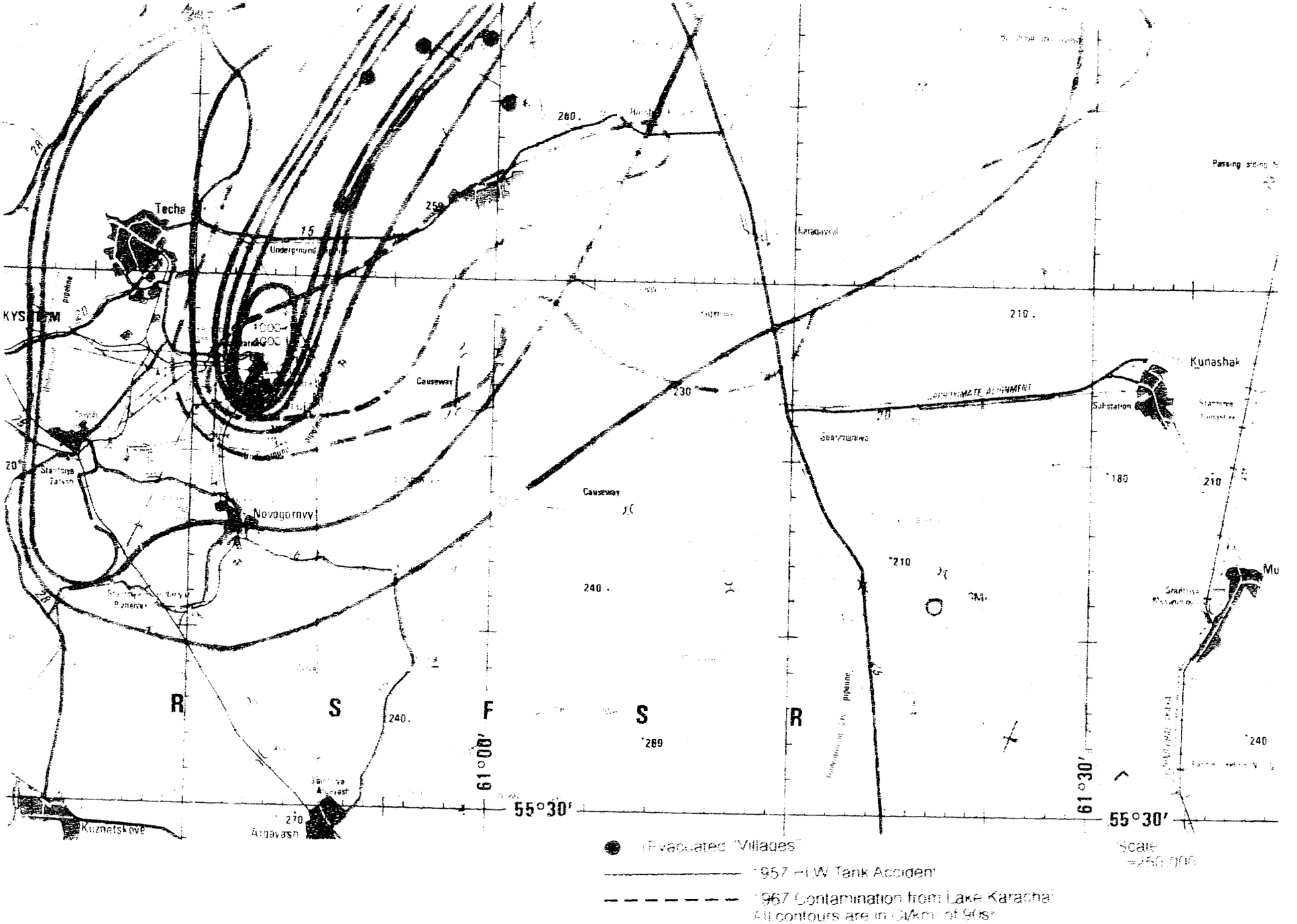

FIGURE 12.2. Map of Contamination Plumes from the 1957 HLW Tank Accident and the 1967 Wind-blown Contamination from Lake Karachai

- low-activity wastes (150,000 tons), which are stored in trench-type repositories with clay "cutoff" walls, with an activity of 30,000 Ci.

- About 6,000 curies of ^{90}Sr and about 6,000 curies of ^{137}Cs in the Asanovski Marsh in the flood plain of the Techa River. The Asanovski Marsh, covering an area of 30 km^2, is a primary source of contamination of the Techa River.

A solid radioactive waste storage accounting has been recorded in the "enterprise documentation" since 1981, and attempts are now being made to inventory all of the solid radioactive waste repositories and storage sites at Chelyabinsk-65. Only the repositories for high-level solid radioactive wastes are equipped with monitoring instrumentation and warning equipment; "measuring and test systems" are absent in the trench-type repositories. There are growing concerns about solid waste management at the site due to the fact that there is no processing facility for treating these wastes, which are increasing due to efforts to rebuild and update facilities at Chelyabinsk-65 (Nazarov et al. 1991).

Tables 12.1 and 12.2 show some of the physical and radiological characteristics of the Chelyabinsk-65 reservoirs (Environmental Workshop, October 1991). There are four dams associated with the reservoirs 3, 4, 10 and 11 shown in Figure 12.1. Dam #3 was built in 1951, dam #4 existed prior to 1917 but was raised in 1956, dam #10 was built in 1957, and dam #11 was built in 1964. In addition to the dams, canals were built to divert the Techa River

TABLE 12.1. Physical Characteristics of the Chelyabinsk-65 Contaminated Reservoirs

Reservoir Number	Normal Surface Elevation, m	Maximum Surface Elevation, m	Surface Elevation Relative to Lake Irtysh, m	Surface Area, km^2	Actual Volume x 10^6 m^3
2	225.5	225.6	-2.1	18.6	84.4
3	223.03	223.19	-4.6	0.5-0.8	0.78
4	219.8	220.1	-7.6	1.3	4.1-4.3
6	219.3	--	-8.3 (?)	3.6	17.5
9(a)	227.3 (?)	--	-0.3 (?)	0.25	0.40
10	209	209.5	-17.9	18.0-19.0	76.64
11	205	206.0	-21.4	44.0	215.74
17	226.9	--	-0.7	0.17	0.30

(a) Reservoir #9, most often referred to as Lake Karachai, is being filled in as part of a radioactive contamination "restoration" project. The data listed are believed to be applicable for 1990-1991.

TABLE 12.2. Contamination Characteristics of the Chelyabinsk-65 Reservoirs

Reservoir Number	Concentration of Radionuclides In Solution, Ci/liter				Concentration of Radionuclides In Sediments, Ci/kg		Total Curie Content		
	^{90}Sr	^{137}Cs	Tritium[a]	Sum of Alpha Emitters	^{90}Sr	^{137}Cs	In Solution	In Sediments	Total
2	1.1×10^{-8}	4.5×10^{-9}	2.5×10^{-7}	1.2×10^{-11}	1.3×10^{-6}	3.0×10^{-5}	2.0×10^{3}	1.8×10^{4}	2.0×10^{4}
3	1.6×10^{-6}	2.0×10^{-7}	1.4×10^{-6}	3.0×10^{-10}	1.4×10^{-4}	1.0×10^{-3}	2.6×10^{3}	1.53×10^{4}	1.8×10^{4}
4	1.7×10^{-7}	7.3×10^{-8}	5.2×10^{-7}	4.5×10^{-9}	4.0×10^{-6}	6.0×10^{-5}	1.7×10^{3}	4.2×10^{3}	$\sim 6.0 \times 10^{3}$
6	3.7×10^{-10}	2.0×10^{-11}	1.0×10^{-8}	1.0×10^{-10}	3.0×10^{-7}(?)	--	2.0	3.0×10^{2}	3.0×10^{2}
9[b]	1.7×10^{-3}	1.2×10^{-2}	5.3×10^{-5}	5.7×10^{-6}	0.3	1.4	8.4×10^{6}	1.1×10^{8}	1.2×10^{8}
10	3.5×10^{-7}	8.6×10^{-9}	3.2×10^{-7}	1.0×10^{-11}	3.5×10^{-6}	1.5×10^{-4}	5.0×10^{4}	6.0×10^{3}	1.1×10^{5}
11	5.1×10^{-8}	$<2.0 \times 10^{-11}$	4.5×10^{-8}	$<2.0 \times 10^{-12}$	1.3×10^{-6}	1.3×10^{-7}	2.4×10^{4}	1.5×10^{4}	3.9×10^{4}
17	7.0×10^{-4}	4.0×10^{-6}	1.0×10^{-4}	1.2×10^{-3}	1.2×10^{-1}	3.3×10^{-2}	4.5×10^{4}	2.0×10^{6}	2.0×10^{6}

(a) Reported as HTO (hydrogen-tritium-oxygen).
(b) Reservoir #9, Lake Karachai, has a sum of beta emitters in solution of 1.9×10^{-2} Ci/liter, and a sum of alpha emitters in sediments of 3.9×10^{-5} Ci/kg.

from flowing into the reservoirs. The canal on the north side of the reservoirs (left-bank canal) was built in 1963, and the canal on the south side (right-bank canal) was built in 1972. Both of the canals can be seen in Figure 12.1 (Environmental Workshop, October 1991).

12.2 TECHA RIVER BASIN CONTAMINATION

The contamination of the artificial reservoirs and the Asanovski Marsh is associated with the direct discharge of high-level and other waste streams to the Techa River at a point 6 km from its source, primarily from 1949 to 1952. During this period, 76 million m^3 of liquid wastes were discharged, with a total beta activity of 2.75 million curies. The Soviets state that 95% of this radioactivity was discharged between March 1950 and November 1951, with an average daily discharge of 4,300 curies. In 1952, 9,500 curies were discharged, and from 1953 to 1956 anywhere from 500 to 2,000 curies were discharged per year (Chukanov et al. 1991). Figure 12.3 depicts the daily

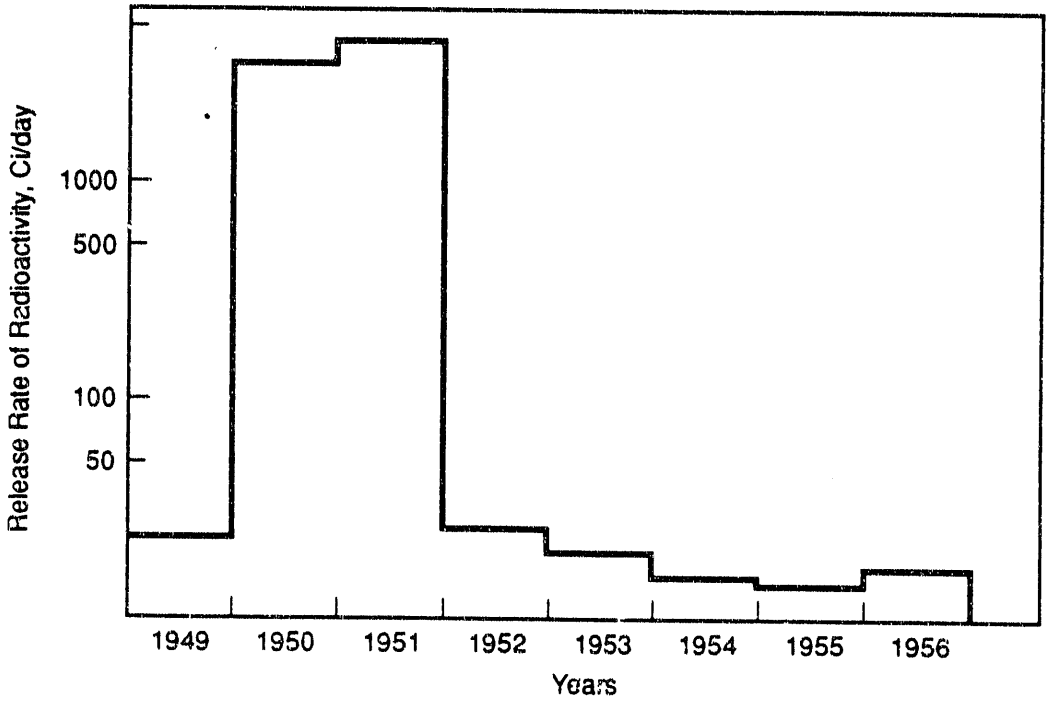

FIGURE 12.3. Discharge of Radioactivity to the Techa River, 1949-1956 (Kossenko et al. 1990)

discharge in curies to the Techa River, and Figure 12.4 shows the dose rate at the shoreline of the Techa River in the early 1950s. The composition of the discharged liquid waste is given in Table 12.3 (Kossenko et al. 1990). It was further noted that the radioactive release to the Techa River Valley was reduced to 0.5 curies/day starting in 1956, and the Soviets state that the contamination was "practically completely isolated" with the construction of

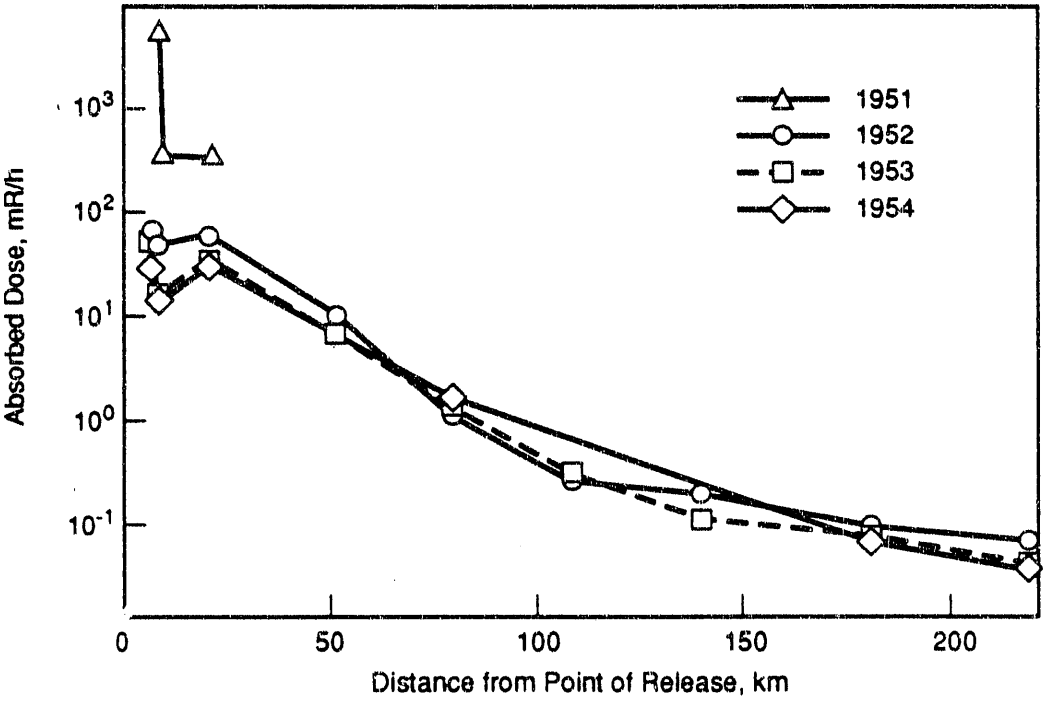

FIGURE 12.4. Dose Rate Measurements Near the Shoreline of the Techa River, 1951-1954 (Kossenko et al. 1990)

TABLE 12.3. Composition of Liquid Radioactive Wastes Discharged to the Techa River, 1949-1952

Rare earth elements	26.8%
^{103}Ru, ^{106}Ru	25.9%
^{95}Zr + ^{95}Nb	13.6%
^{137}Cs	12.2%
^{90}Sr	11.6%
^{89}Sr	8.8%

another dam [Reservoir #11] in 1964. Most of the radioactivity was absorbed by the silts on the banks of the Techa River; however, the Iset, Tobol, and Ob Rivers, which successively drain into each other, were also contaminated. The concentration of radionuclides in the Iset was about a factor of 10 lower than in the Techa, and about 100 to 1000 times lower in the Tobol (Kossenko et al. 1992a). It was stated that 124,000 people who lived near the Techa River were exposed to radiation, of which 28,100 [in 39 villages (Kossenko et al. 1990)] who lived along the bank received the highest doses. The range of average effective equivalent doses received by the 7,500 people who were relocated from 20 different villages was 3.5 to 170 rem, the highest doses being in the village of Metlino, having 1,200 people. The residents of the village of Muslyumovo, who were not relocated, apparently have received effective equivalent doses of about 28 rem, and children received effective equivalent doses of from 0.5 to 1.0 rem/year [from 1949]. For the remaining population centers in the region, the effective dose [apparently to date] is from 3.5 to 16 rem (Chukanov et al. 1991). There are reported to be 12 such population centers along the bank of the Techa River (Dubenyok et al. 1991).

A study of the leukemia risk estimate in the Chelyabinsk-65 area has been reported by Kossenko et al. (1990). They conclude that a statistically significant increase in leukemia has occurred between 5 and 20 years after the initiation of radioactive contamination of the surrounding population. This increase in leukemia is due to the discharge of radioactive wastes directly into the Techa River, primarily between 1949 and 1951. Kossenko et al. (1990) indicated that the work started in 1951 and is still continuing, although results were only presented through 1981. Kossenko et al. (1990) estimated the external doses by measuring gamma dose rates near the Techa River, in the areas of the villages and inside homes. Internal dose assessments were made via teeth and whole body counting for ^{90}Sr. Figures 12.5 and 12.6 show the external and internal absorbed dose, respectively, for the population living near the Techa River. In another study, the detailed medical effects of the Techa River contamination is discussed, and comparisons are made to other events, such as the bombing in Japan of Hiroshima (Kossenko et al. 1992b). Table 12.4 shows organ dose estimates for inhabitants of selected villages

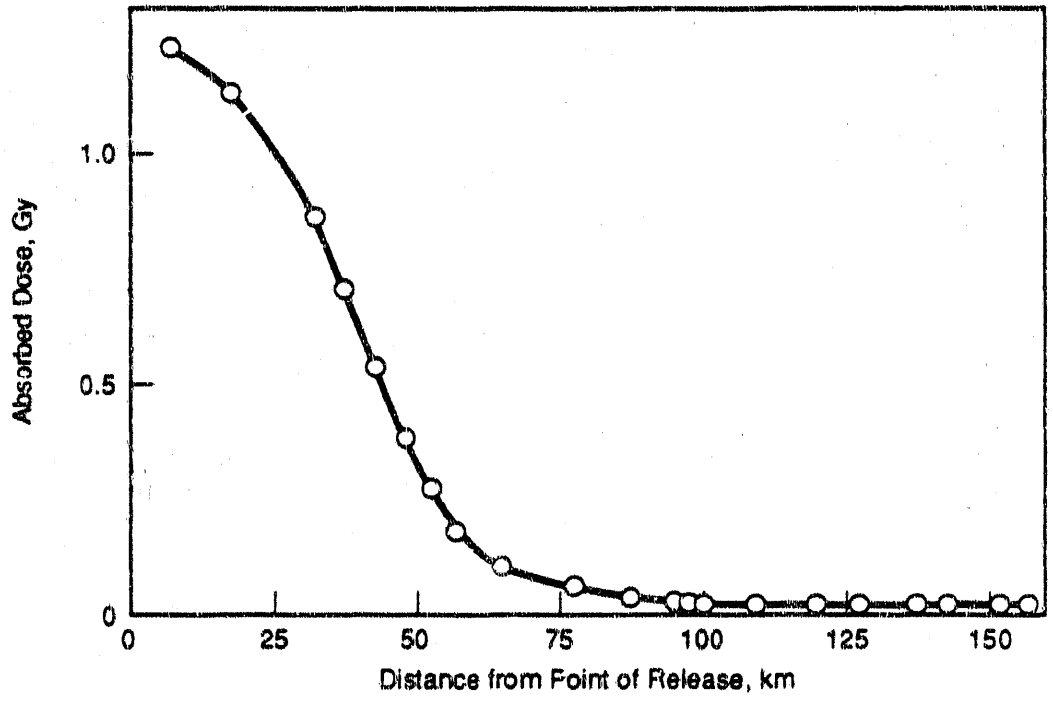

FIGURE 12.5. Average External Whole Body Absorbed Doses to Inhabitants of Villages Along the Techa River (Kossenko et al. 1990)

along the Techa River (Kossenko et al. 1990). Presently, the register of those contaminated by discharges to the Techa, including descendants, totals 66,000 people. Kossenko also notes that the control of radioactive releases to the atmosphere from Chelyabinsk-65 (mainly from ^{85}Kr) was only started in 1961 to 1963. The release of aerosols (containing ^{239}Pu) was started in the mid-1970s, and tritium releases were controlled since 1971 (Kossenko 1992a).

12.3 CONTAMINATION OF LAKE KARACHAI

The Soviets began radioactive waste discharges to Lake Karachai in 1951, corresponding to the stoppage of discharges of radioactive waste to the Techa River. The Soviets have been filling in the lake since 1967 to help minimize the release of contaminants to the environment, and President Yeltsin has allocated 1.5 billion rubles for the cleanup of Lake Karachai (Nuclear Waste News, January 16, 1992). About 5,000 hollow concrete blocks, 1 meter on a side with one side open, have been placed into the lake as of October 1991.

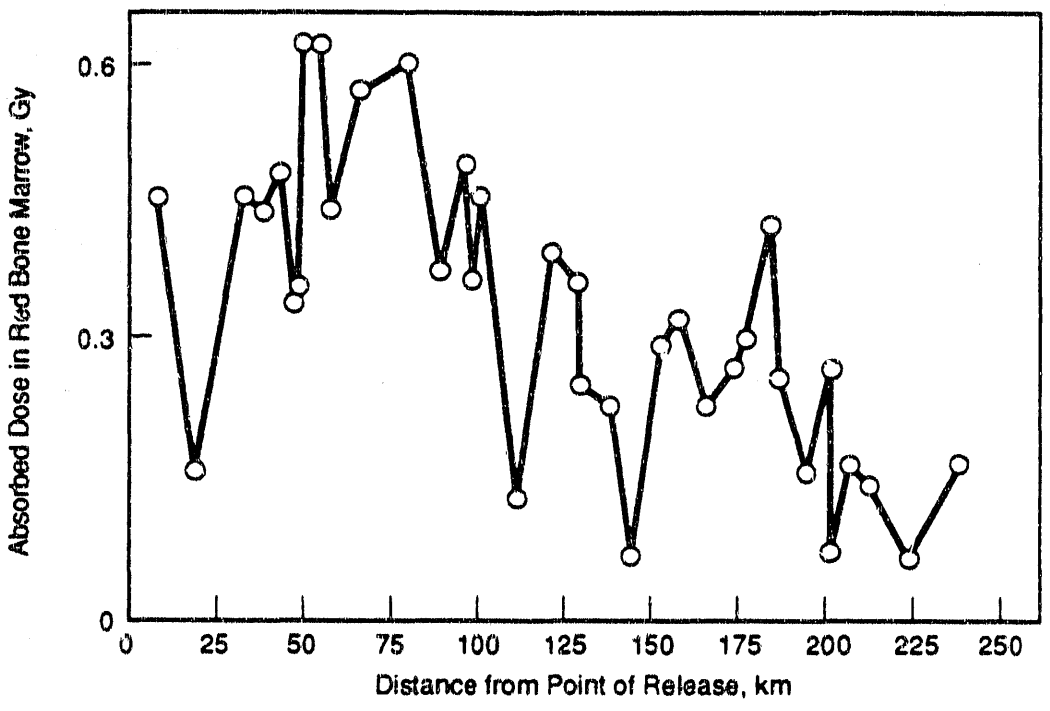

FIGURE 12.6. Mean Absorbed Doses to the Bone Marrow of Inhabitants of Villages Along the Techa River (Kossenko et al. 1990)

TABLE 12.4. Organ Dose Estimates for Inhabitants of Some Selected Villages on the Techa River

Villages	Distance from Point of Release, km	Mean Doses, Gy			
		Red Bone Marrow	Bone Surfaces	Large Intestine	Other Tissues
Metlino	7	1.64	2.26	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

They are intended to trap the muddy bottom deposits inside, preventing them from "squeezing" up the sides of the lake bank as the lake is gradually filled in. Following emplacement of the concrete blocks, rock and soil are then used to cover them up. Lake Karachai has been reduced to about 0.20 km^2 by October 1991, down from the original size of 0.45 km^2. The Soviets intend to put a layer of clay on top of the rock and soil to prevent rain and snowmelt

infiltration, and to finish covering the lake by 1993. Following this, pumping out contaminated water from nearby wells, and treating it to remove radionuclides, is scheduled to begin in 1994 to 1995 in an effort to minimize radionuclide migration. During a recent visit to Lake Karachai, a dose rate of 300-600 mr/hr at a point about 30 to 40 feet from the lake edge was observed. The Soviets noted that contamination from Lake Karachai is primarily flowing north and south, as noted in Figure 12.1, and was said to be in the top 100 meters since that was the zone of water "exchange." They have three monitoring wells 1,000 meters deep, and 300 wells for more active sampling, although the placement of the wells, frequency of sampling etc., was not given (Bradley, November 11, 1991). Further information on Lake Karachai was previously reported (Bradley and Schneider 1990; Bradley 1991).

12.4 THE 1957 HLW TANK ACCIDENT

Although details of the 1957 accident at Chelyabinsk-65 have been summarized in other publications (Bradley and Schneider 1990; Bradley 1991), the Soviets note that the 1,054 residents of the three villages that were evacuated within 7 to 10 days of the accident received an average dose of about 57 rem, the 2,280 residents resettled in 250 days received an average dose of about 17 rem, while the 7,300 people who lived on the contaminated territory for 330 to 370 days received a dose of about 6 rem. Pine trees had observable damage at 10 Ci/km^2 of ^{90}Sr (440 Ci/km^2 total beta activity) and died at levels above 300 Ci/km^2 of ^{90}Sr. Birch trees behaved similarly at 10 times the levels observed for pine trees. Forests contaminated above 4 Ci/km^2 were designated "special areas" where hunting was not permitted. Timber could be cut only from areas with contamination up to 50 Ci/km^2 of ^{90}Sr. Currently, about 99.3% of the contamination results from ^{90}Sr (Chukanov et al. 1991).

In a tour of the Chelyabinsk-65 site in October 1991, the general location of the HLW tank which exploded September 29, 1957, was pointed out across the road from the reprocessing plant that was also visited. The Soviets indicated that radiation readings up to 3,000 R/hr were observed in some areas after the accident, and a large part of the soil and plant material was removed from the area and buried (Bradley, November 11, 1991). The

radioactivity discharged into the atmosphere, 2 μCi, was spread by 25-km/hr winds at the time of the accident (Botov 1992). Some 30,000 people took part in the "elimination" of the consequences of the 1957 accident (Moscow Central Television, November 21, 1991). Figure 12.7 shows a large-scape map of all of the contamination plumes from the 1957 HLW tank accident (Romanov et al. 1991b), and Figure 12.2 shows an enlarged map of the contamination plumes from the 1957 accident and the plumes from the 1967 wind-blown contamination from Lake Karachai (Bol'shakov et al. 1991).

The study by Kossenko et al. (1990) also included the 1957 HLW tank accident. The dose assessments by Romanov et al. (1991a) on the 1957 accident are based primarily on environmental food chain models and not from direct measurements as was apparently done by Kossenko et al. (1990). Their analysis of the 1957 HLW tank accident showed the absence of a statistically significant elevation in leukemia occurrences. In comparison, the mean dose distribution for those in the Techa River study was 0.4 Gy (40 rad) as opposed to 0.02 Gy for the 1957 accident, and the range of individual doses was up to 3 Gy for the Techa River study and up to 0.9 Gy for the 1957 accident (Kossenko et al. 1990).

In the "region" of Muslyumovo, it is estimated that not less than 400 curies of ^{90}Sr and ^{137}Cs are deposited, and ^{137}Cs in the nearby river sediments is estimated at 300 to 500 curies (Dubenyok et al. 1991). The concentration of ^{137}Cs in the river mud at Muslyumovo ranges from 300 to 500 nCi/kg (Bol'shakov et al. 1991). Estimates of the ^{90}Sr and ^{137}Cs stocks made in 1967 to 1979 are from 3220 to 6280 curies for ^{137}Cs and from 1800 to 4850 curies for ^{90}Sr for the contamination in the Asanovski Swamp located between Reservoir #1 and Muslyumovo (Petukhov 1991).

A special scientific research organization, called ONIS or the Experimental Research Station, was set up in 1958 on the south shore of Lake Kashakal near the Chelyabinsk-65 site to study the contamination of the site (due to ^{90}Sr-^{90}Y). ONIS determined "coefficients" between agricultural product uptake of radionuclides and soil contamination levels which it used to develop recommendations for their use as well as what lands could be farmed. As a result, lands having up to 25 Ci/km^2 of ^{90}Y were put in use starting in 1961, which

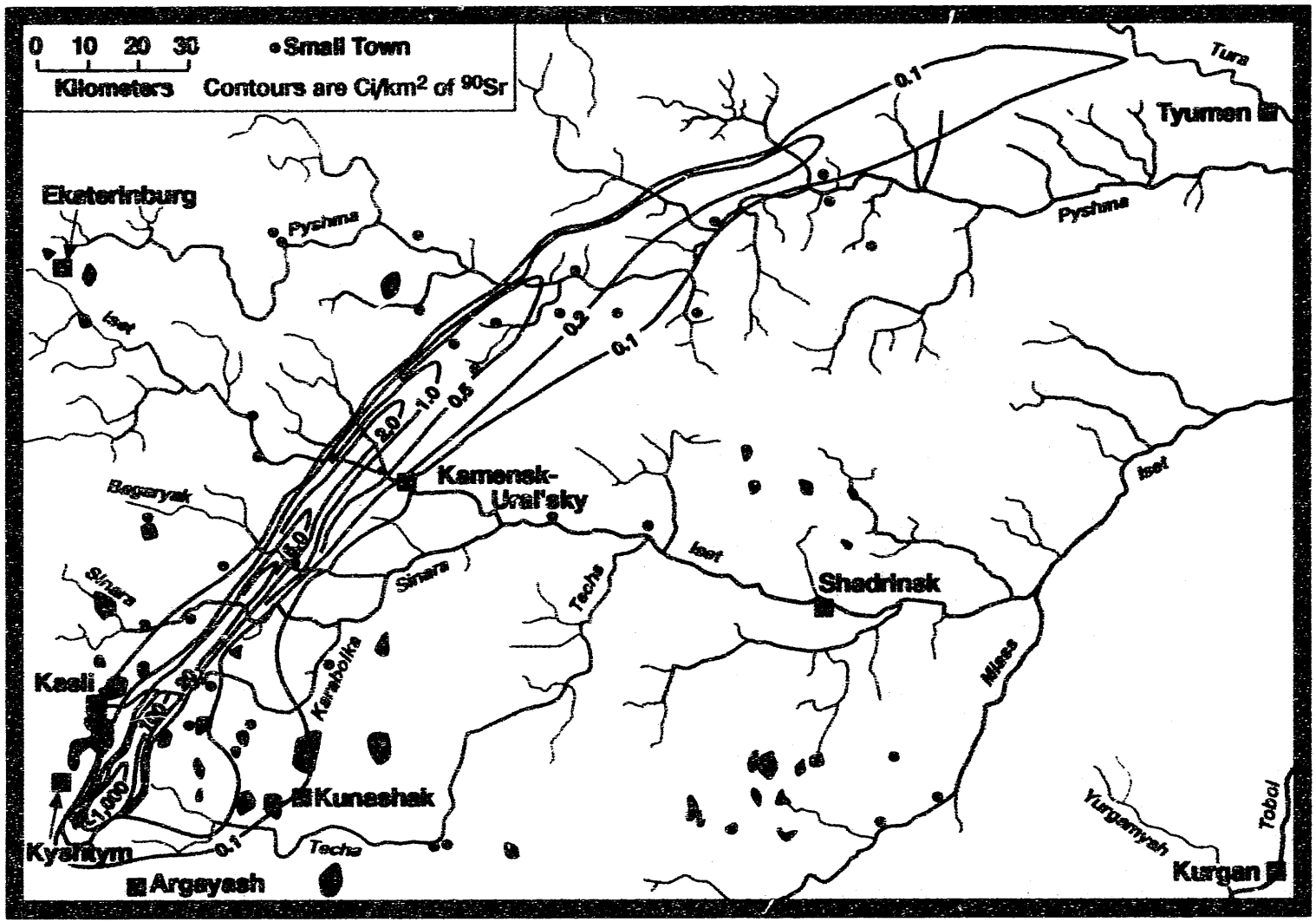

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FIGURE 12.7. Map of Contamination Plumes from the 1957 HLW Tank Accident

resulted in six "specialized" state farms in the Chelyabinsk region and three in the Sverdlovsk region. These produced meat and forage and seed grains. In 1982, 590 km^2 of land in the Chelyabinsk region was made available for agricultural use, of which 400 km^2 is used today--240 km^2 in agriculture areas of state farms and 160 km^2 in the state forest. Today about 3,000 cattle graze on the controlled zone; however, it was stated that due to "misdirected specialization of a number of farms towards milk production," the state milk supply has elevated levels of ^{90}Sr. In order to decrease the contamination level in agricultural products, potassium and phosphorus-based fertilizers were used to treat the soil, and lime was applied to acidic soils (Bol'shakov et al. 1991). Information on some of the details of ^{90}Sr contamination from the 1957 HLW tank explosion at Chelyabinsk to include uptake and accumulation in plants and animals, as well as civilian radiation protection measures and rehabilitation techniques used on the "East Urals radioactive track," has recently been reported (Romanov et al. 1991a and 1991b).

The key medical consequences to the surrounding population from the discharge of radioactive wastes from the Chelyabinsk-65 site can be summarized as follows (Bol'shakov et al. 1991; Kossenko et al. 1990):

- 935 residents were diagnosed with chronic radiation sickness. This was confirmed for 66 of these in a repeat examination. The remaining group had "general somatic illnesses" where radiation could not be ruled out as the cause. This latter group had received an annual dose to the bone marrow of 11 rem (cSv).

- 37 cases of leukemia were reported among 17,200 [28,100, according to Kossenko et al. 1990, 1992a] people followed since 1950, 15 cases greater than expected. These cases occurred between 5 and 20 years after the initiation of radioactive waste discharges to the Techa River.

- Greater mortality index for those living near the source of the Techa River, primarily due to a higher infant mortality from infectious diseases at first, and increased incidence of malignant tumors in the longer term.

- Irradiation from the 1957 and 1967 accidents did not cause radiation sickness. It was noted, however, that the population was not examined clinically following the 1967 accident and no registry of people who were contaminated exists. Analysis of the 1957 HLW tank accident showed the absence of a statistically significant elevation in leukemia.

- Current protective measures are insufficient since some of the surrounding population, such as the residents of Muslyumovo, are still receiving greater than 0.5 rem per year.

Table 12.5 summarizes the releases of radioactivity at Chelyabinsk-65, including available data on radiation doses to workers at the site. Table 12.6 provides a perspective on releases at Chelyabinsk-65, as compared with worldwide radioactivity releases.

12.5 RESTORATION ACTIVITIES

In April 1990, the Deputy Chairman of the USSR Council of Ministers authorized the Academy of Sciences to organize a commission for the study of the ecological situation around the Chelyabinsk-65 site [which is currently managed by Viktor Ilich Fetisov (Izvestia, March 4, 1991)] in the South Urals. At the same time a decision was made to release "practically all the data" related to the ecological aftermath of the "Mayak's activities open to the public." Academician, V. N. Bol'shakov, Director of the Plants and Animals Ecology Institute of the Academy of Sciences, Urals Branch, was elected chairman of the commission. V. N. Chukanov was appointed leader of the first group, Director of the Scientific-Research Ecological Safety Center of the Academy of Sciences Urals Branch, located in Ekaterinburg. The area surrounding Chelyabinsk-65 is stated to be "in a terrible condition" from the point of view of health care and social services. Even if compared with other regions of the Chelyabinsk district, medical service is much worse here and the lack of good roads and medical facilities aggravates the situation. People, resettled 20 years ago, still live in cottages made of "panel-wood," which collapse and cannot be rebuilt. The greater part of the younger generation has abandoned those settlements and only old people remain (Petukhov 1991).

The Commission is not sure that all the people subject to contamination from Chelyabinsk-65 have been registered. Currently, there is no available data on the people who participated in "liquidation" of the 1957 accident aftermath. The first medical inspections of the population contaminated by the discharges into the Techa River were conducted 2 years after the discharges had started and they dealt only with the population of the Metelino village in the upper part of the Techa River. In other settlements and

TABLE 12.5. Summary of Radioactive Releases from Chelyabinsk-65 and Subsequent Population Relocation and Estimated Dose (Nikipelov et al., February 1990; Chukanov et al. 1991; Bol'shakov et al. 1991; Nucleonics Week, April 25, 1991b; Nazarov et al. 1991; Kossenko et al. 1992, Nucleonics Week, May 7, 1992)

Event	Time	Radioactivity Released	Population Relocated	Estimated Population Dose
1. Workers at reactor commissioned in June 1948	1948 to 1952	-	-	35.4 rem average gamma dose/yr (127 rem maximum for a year)
2. Workers at reprocessing plant commissioned in December 1948	1949 to 1952	-	-	80.3 rem average gamma dose/yr (150 rem maximum for a year) [**Note:** A group of 1812 workers (not specified as reactor or reprocessing plant workers) received 245 rem from 1949-54. Another 1286 workers received 122 rem. From 1953-58, a "third and fourth group" received 49 and 71.6 rem, respectively. 10,000 workers (over 40 years) have contracted occupational diseases and 4,000 have died of acute radiation sickness and 1,500 contracted chronic radiation sickness.]
3. Discharge of high-level and other wastes to the Techa River	1949 to 1952	2.75×10^6 Ci (Total Beta) [**Note:** includes 2×10^6 Ci in the 5 artificial reservoirs and 12,000 Ci of Sr + Cs in Asanovski Marsh between reservoir #1 and the village of Muslyumovo.]	1,200 starting in 1953; 6,300 from 1956-1960 for a total of 7,500 from 20 villages [**Note:** 124,000 people were exposed to radiation; the 28,100 people living along the Techa River received the highest doses and a collective total dose of about 600,000 man-rem.]	3.5 to 170 rem for those relocated. 3.5 to 16 rem for those not relocated. [**Note:** children in Muslyumovo received 0.5 to 1.0 rem/yr. 935 cases of chronic radiation sickness were reported as well as 15 excess cases of leukemia. The general mortality index for the affected group was 17-24% above the control group.]
4. Discharge of radioactive wastes to Lake Karachai	1953 to present	~120 $\times 10^6$ Ci	-	?
5. Discharge of radioactive wastes to Lake Staroe Boloto	1953(?) to present	~3 $\times 10^6$ Ci	-	?
6. Disposal of solid wastes to 200 trenches	1950s to ?	? [**Note:** 500,000 tons of solid wastes were disposed of.]	-	-

TABLE 12.5. (contd)

Event	Time	Radioactivity Released	Population Relocated	Estimated Population Dose
7. Explosion of high-level waste storage tank	1957	2×10^6 Ci [**Note:** the radioactive "track" measured 300 km by 10 to 15 km. An area of 23,000 km^2 with a population of 270,000 was contaminated to $\geq$0.1 Ci/km^2 of ^{90}Sr. An area of 1,000 km^2 (10,000 people) had over 2 Ci/km^2, 117 km^2 (2,100 people) had over 100 Ci/km^2.]	1,054 in 7-10 days 2,280 in 250 days 7,300 in 350-370 days 10,634 total population relocated	57 rem **(for 1,054 people)** 17 rem **(for 2,280 people)** 6 rem **(for 7,300 people)** [**Note:** A level of 2 Ci/km^2 was deemed safe for the public. Those who were not relocated from areas having 1 to 4 Ci/km^2 received 3.8 rem to the bone marrow. The total effective dose for those relocated was 1,300 man-Sv; for those who remained, 4,500 man-Sv.]
8. Wind-blown radioactive dusts from the shores of Lake Karachai	1967	500-600 Ci [**Note:** An area of 2,700 km^2 was covered with $\geq$0.1 Ci Sr-90/km^2 or 0.3 Ci Cs-137/km^2. Radioactivity was carried up to 75 km from Lake Karachai.]	-	0.7 to 1.3 rem to 41,500 people living in 63 villages
9. Continuous releases as seepage from artificial reservoirs	~1980 to present	0.05 to 0.1 Ci/yr [**Note:** up to 500 Ci of Sr-90 is expected to be released to the Techa River if the reservoirs overflow due to the annual increase in water level.]	-	-
Summary				
Releases from Chelyabinsk-65	1944 to present	$\geq 130 \times 10^6$ Ci [**Note:** Bol'shakov et al. (1991) states that "the structure of the EED over the last 20 years is caused 70% by Pu-239.)	~18,000	500,000 people "affected" with a total EED of 1.2 million man-rem. Some Effective Equivalent Doses (EED): A. 11-15 rem for Novogornyi, Chelyabinsk-65, Metlino -ONIS. B. .3-.4 rem for Chelyabinsk, Karabash, E. Ufalei C. 0.05 rem/yr at present to Chelyabinsk and Kurgansk regions

TABLE 12.6. Major Worldwide Releases of Radioactivity to the Environment

Source/Location	Quantity/Type
U.S./USSR atmospheric weapons tests	5-billion Ci
Chelyabinsk-65, 1949 to ~1956	≥130-million Ci, HLW, ILW, and LLW
Chernobyl, 1986	50-million Ci, including 2.5 million Ci of cesium
Chelyabinsk-65, 1957	2-million Ci, mainly ^{90}Sr
Windscale, 1957	25,000 Ci, mainly iodine-131
Goiana, 1987	1,200 Ci, mainly ^{137}Cs
Chelyabinsk-65, 1967	600 Ci, mainly ^{137}Cs and ^{90}Sr
Three Mile Island-2, 1979	5 to 50 Ci, iodine-131

Source: Nucleonics Week, March 21, 1991; Chukanov et al. 1991.

villages, examinations were started only 3 to 6 years after the discharges; hence, earlier stages of irradiation effects could not be determined. It was not until 1968 that efforts were made to "register" those irradiated who were living in the Techa River Basin area. Inspections of the population in the area of the "radioactive track" from the 1957 HLW tank accident were as a rule carried out in the first year after the accident. However, not one of those irradiated in 1957 was registered. Migration of the irradiated population was quite active; hence evaluation of the long-term aftermath is very uncertain (Petukhov 1991).

Far from being a problem of the past, severe problems exist today from the contamination of the Chelyabinsk-65 site and surrounding region. The Soviets have listed several key problems that they feel require immediate attention (Chukanov et al. 1991; Bol'shakov et al. 1991; Nazarov et al. 1991):

- Water level regulation of the Techa River Reservoirs - During the last 15 years, the Soviets report that the water level in the last reservoir, #11, has risen by 2.87 m, and is now at its maximum level, and they have calculated that overflow of the annual increase in water could lead to the release of 500 curies of ^{90}Sr

into the Techa River (Chukanov et al. 1991). The water level in the pool at present is 26 cm lower than the emergency discharge level (Petukhov 1991). They are now raising the height of the dam by 1 meter, although they note that since the average water level rise has been 26 cm per year over the last 10 years, this is a short-term measure. The seepage of contaminated water increases "sharply" with an increase in dam height, and the sorption capacity of the dam and the banks of the reservoir is "practically exhausted." Further, they note that the concentration of radionuclides in the seepage water has increased 5 times from 1978 to 1988, and the release of radioactivity through the right "side" of the reservoir has increased 10 times and now is 0.5 curies per year (Chukanov et al. 1991).

Figure 12.8 depicts the characteristics and radioactive discharge as a function of time for Reservoir #11 (Environmental Workshop, October 1991).

- Migration of contaminated groundwater - A "lens" of contaminated groundwater emanating from Lakes Karachai and Staroe Boloto with an area of 30 km^2 [10 km^2 of which is said to be due to contamination from Lake Karachai] and a volume of 4 million m^3 has formed in the upper zone of fractured porphyritic rock to a depth of 100 m, and is spreading at the rate of about 80 m/year. Evidently this contaminated water is connecting to reservoirs 3, 4 and 10 and the Mishelyak River. The Soviets are

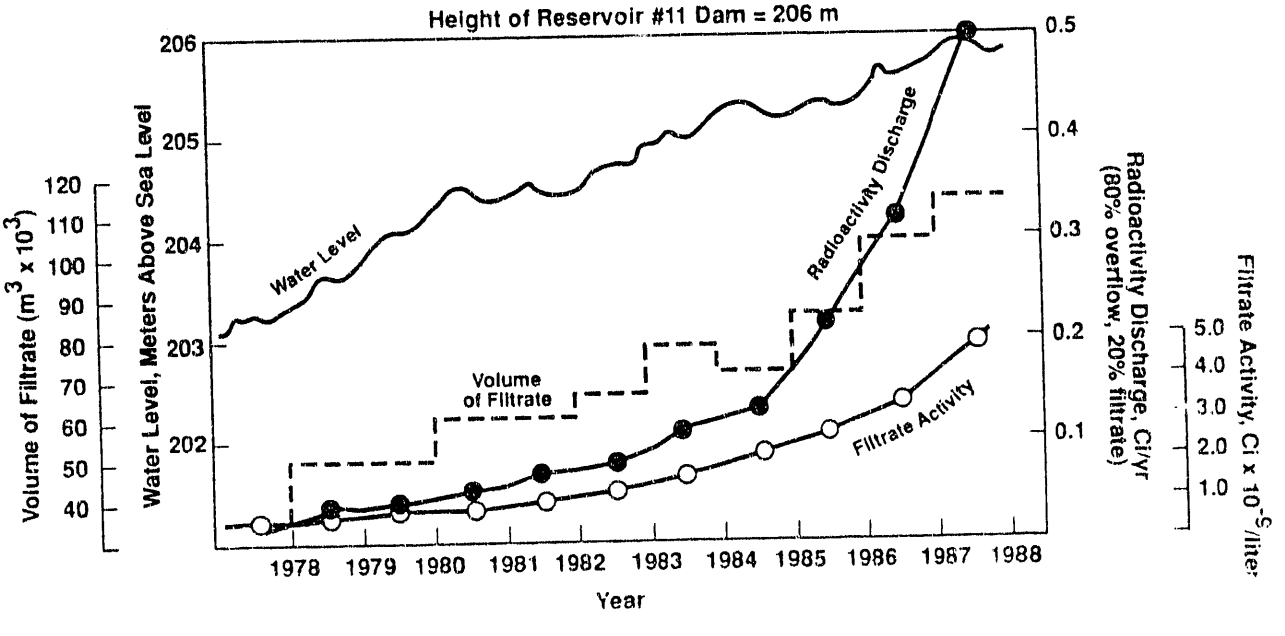

FIGURE 12.8. Characteristics and Radioactivity Discharges from Reservoir #11 near Chelyabinsk-65 (Environmental Workshop, October 1991)

concerned that the contaminated water will break into the open hydrologic system, contaminating the Ob basin out to the Arctic ocean. A rough drawing of the contamination plumes from Lake Karachai is shown in Figure 12.1.

- The further prevention of radioactive release from Lakes Karachai and Staroe Boloto - In addition to the problem noted above, draining the lakes, which allows for the shores to dry out, also poses a severe problem from wind-borne contamination. The Soviets note that in 1967, when the banks of Lake Karachai were exposed due to an especially arid season, winds blew 500-600 curies of radioactivity up to a distance of 75 km, causing further contamination of the area contaminated from the 1957 HLW tank explosion. The fallout, primarily ^{90}Sr and ^{137}Cs, covered an area of 2,700 km^2 [defined by a 0.1 Ci/km^2 for ^{90}Sr] on which were located 63 villages with a total population of 41,500 people. The external radiation dose ranged from 0.7 to 1.3 rem with the highest doses received by the 4,800 nearby residents.

The Commission also drew up a detailed listing of measures that it proposed be acted upon to resolve the problems caused by radioactive releases from the Chelyabinsk-65 site. These included organizational, general scientific (such as mapping contaminated zones), planning and engineering, and medical measures to be taken (Bol'shakov et al. 1991).

Another panel of experts has also reviewed the problems with radioactive contamination at Chelyabinsk-65, primarily with respect to the proposed siting of the nearby South Urals fast-reactor station, and has concluded that grave consequences will result from delays in addressing its waste management and contamination issues. They state that the real threat lies in the fact that all the reservoirs are hydraulically connected--and virtually all discharge into the Techa River. It was further noted that contamination from Lake Karachai has reached the Mishelyak River floodplain and that in the next 10 years significant amounts of contaminated groundwater will be discharged into the Mishelyak. The lack of regulation of the cascade of reservoirs in the Techa's perched groundwater will also result in increased amounts of ^{90}Sr into the hydrologic system.

The concentration of ^{90}Sr in Reservoir #10 increased by a factor of more than 20, to 7.9×10^{-7} Ci/L, from 1983 to 1986. The raising of the water level in Reservoir #11 is increasing the "filtration" of water through the body of the reservoir #11 dam and the reservoir bed into the Techa River. The

water in the reservoirs is not characteristic of natural waters in the Chelyabinsk Oblast, which have a "mineralization" of about 0.5 g/L. Rather, the reservoirs contain highly mineralized water (4 to 4.5 g/L) with a calcium content of up to 500 mg/L, sulfates (2,700 mg/L), chlorine (335 mg/L), and other components. Free sulfuric acid (4,200 t/y) is released into Reservoir #10, and as a result, the pH level has been reduced to 4.5 to 5.5. The presence of these chemicals further complicates, and according to the panel of experts, increases radionuclide migration (Nazarov et al. 1991).

The Mayak Production Association at the Chelyabinsk-65 site has developed a comprehensive scheme for processing wastes, according to Nazarov et al. (1991), that would eliminate radioactive "discharge" but require "enormous" facilities and huge capital investments, about 30 billion rubles for the entire set of operations. Implementing the plan would require an estimated 15 to 25 years, or more if allowance is made for cleanup of the nine reservoirs and the waste storage tanks.

According to data from Mayak, each "plant" buries its own waste in its own system of repositories in accordance with its own activity. These systems are based on the principle that the closer to the plant the better, since it minimizes transportation. As a result, there are no longer enough places to bury wastes. The plan calls for a solid radwaste storage site called the "300" complex. Neither the storage site nor the complex itself currently exist, and the jobshop for "deactivation" of stainless steel scrap (200 tons/year) that has existed since 1983 should be closed soon.

It has been stated that part of the reason for siting the fast reactors 3 km from the Chelyabinsk-65 site is to help regulate the reservoirs by maintaining the water level from overflowing into the Techa River and subsequently releasing radioactivity into the river system. Nazarov, however, notes that many assumptions used to justify these plants are being called into question by experts, and he points out the following concerns related to radioactive waste management (Nazarov et al. 1991):

- Construction of the South Urals station will necessitate building solid waste storage sites at the Chelyabinsk-65 site; these are being planned to start up 5 years after the South Urals plant becomes operational.

- The yearly volume of solid wastes from the South Urals plant will be about 2,000 m^3.
- Storage of solid radioactive wastes contaminated with sodium is being established "temporarily" (in Building 012) until a facility to remove the sodium is constructed.

The Soviets have indicated that element extraction by ironmonoisooctyl-methylphosphonat (IMIOMP) is a standard procedure and widely used. A new application, however, is the use of this method for extraction of metals from the "environmental system" at the Chelyabinsk-65 radiochemical plant. The Soviets report that IMIOMP extracts tri-, tetra- and hexa-valent actinides, lanthanides and other rare metals (Drozhko et al. 1991a).

In order to forecast airborne radionuclide concentrations at Chelyabinsk-65, beta particle activities are being monitored within a 6- to 25-km radius of the reprocessing plant (Drozhko et al. 1991b).

It was noted, in a recent conference on Environmental Consequences of Nuclear Development, that V. Chukanov proposed an international research effort to study waste management problems at Chelyabinsk-65 and propose solutions. This was strengthened by former MAPI First Deputy Minister Nikipelov, who also suggested that an international research center be set up at Chelyabinsk-65 (Nuclear Fuel, July 8, 1991). The German government has indicated that it will donate $1.3 million to help clean up radioactive contamination from nuclear facilities in the "Urals region." Meanwhile, the Soviet government wants to evacuate 43,000 people from the Urals region by the middle of 1992 and spend 30 billion rubles for long-term mitigation of the consequences of the pollution as well as site cleanup (Nucleonics Week, March 19, 1992).

The Chelyabinsk-65 site has also been proposed as a host site for the storage of plutonium from warhead dismantlement. Due to local public opposition, President Yeltsin is considering Tomsk as another potential site (Nuclear Fuel, April 27, 1992). Some further information on the history of the Chelyabinsk-65 site, with respect to the Soviet nuclear weapons program, has been recently published (Zaloga 1991; NEI, January 1, 1991).

13.0 OTHER CONTAMINATED SITES AND ENVIRONMENTAL-RESTORATION RELATED ACTIVITIES

13.1 SIBERIAN CHEMICAL COMBINE AT TOMSK

Radioactive waste management practices at the Siberian Chemical Combine, referred to as the nuclear city "Tomsk Seven," are beginning to be made public. A defense reactor at the site was shut down in August of 1990 (Tass, August 21, 1990) and a second in January 1991 (Moscow Central Television, January 2, 1991). In the summer of 1991, a group of "environmental researchers" visited the site, which occupies an area of more than 20,000 hectares along the Tom River and has more than 100,000 people in the city. It was stated that some of the facility's employees accused the complex of disposing of liquid radioactive wastes by dumping them directly into the Tom River. Information compiled by the Tomsk Oil and Gas Geology Association stated that "wastes" were pumped into sandy layers at a depth of 220 to 360 meters, at "burial grounds of the complex," located 10 to 13 km from the Tom River. The sandy layers are reported to be covered by "water-confining" strata of clay "which may peter out beyond the territory of the burying grounds" (Izvestia, August 1, 1991). The radioactive wastes have been pumped into these strata at even higher pressures than at Dimitrovgrad [40 to 60 atmospheres] (USSR Technology Update, September 5, 1991). G. Khandorin, Director of the Siberian Chemical Complex, has indicated that the extent of contamination "has not been determined." Specialists at the site indicated that although about 127,000 tons of solid radioactive wastes and 33 million m^3 of liquid radioactive wastes have been "stored" underground, "practically no contamination" has occurred that would endanger local residents (Izvestia, August 1, 1991).

13.2 ELECTROCHEMISTRY (OR MINING - CHEMICAL) COMBINE AT KRASNOYARSK

This site, according to a recent article in Izvestia, is located near the Stolba preserve, 64 kilometers from Krasnoyarsk, and has had several names such as "Devyatka," Krasnoyarsk-26, Zheleznogorsk, and Atomgrad. It consists of two "secret" enterprises, one devoted to nuclear activities (the "Mining and Chemical Combine," directed by V. Lebedev), and the other on missile

technology, called the Scientific Production Association for Applied Mechanics. The volume of the excavation at this underground site is apparently enormous, with comparisons made to that of the Moscow metro system. More than 65,000 prisoners and 100,000 soldiers were required to dig the underground areas (Izvestia, January 11, 1992). The first reactor at Krasnoyarsk-26 was built in 1957, the second in 1961, and the last in 1964. The reactors are located 200 to 250 meters underground (Pravda, December 21, 1991).

According to Pavel Morozov, the combine's Deputy Chief Engineer, the three reactors at the Krasnoyarsk site will be shut down, the first one in July 1992, and the second within a year or two. They are concerned about the third however, since it also serves as a power source to a "city" of 100,000 people. Russian government officials recently stated that the first reactor is scheduled for shutdown by June 1, 1992, and the second no later than September 1, 1992. The cooling water for these reactors is taken from and discharged to the Yenisey River (Tass World Service, April 20, 1992). Contamination along the lower reaches of the Yenisey River has been reported to be up to 3-5 Ci/km^2, while narrow strips of land along the river below the site have contamination levels up to 40 Ci/km^2 (Moscow New Times, April 1992).

The site was built in the 1950s next to the Yenisey River (Izvestia, November 14, 1991). A road leads to a tunnel at the base of a mountain, where the nuclear station is located underground at a "depth of 250 meters." The site Director, Vladimir Kibo, has noted that the new underground site in Atomgrad for storing radioactive wastes, known as "Site 27," was "dropped" as a result of public protests following the Chernobyl accident. The more than 2-km-long tunnel under the Yenisey River, associated with this waste disposal site, is reported to be damaged and leaking water (Izvestia, January 11, 1992). Specialists in the Far East Soviet Fleet are preparing to dismantle 40 nuclear submarines, and the reactor cores may be shipped for burial near Krasnoyarsk (Moscow Teleradiokompania Ostankino Television, March 29, 1992). The Krasnoyarsk-26 site is exploring production of "especially pure" gallium arsenide, that may force the opening of this "closed" site (Izvestia, November 14, 1991) as well as producing "crystalline silicon," and installing an assembly line for Samsung television sets (Izvestia, January 11, 1992).

13.3 PEACEFUL NUCLEAR EXPLOSIONS AND WEAPONS TEST SITES

Peaceful nuclear explosions were apparently quite widespread in use in the former Soviet Union. They were used on the Kola peninsula, in the northern areas of the Pechora coal fields, in Perm Oblast, Yakutia, Kazakhstan and the Caspian Sea region (Krasnaya zvezda, November 25, 1990). The Soviets have conducted 108 [also reported to be 126 (Moscow Interfax, January 22, 1992) or 115 (Dagens Nyheter, February 13, 1992)] peaceful nuclear explosions since the first one in 1965. This includes the largest above-ground test of 58 megatons, and the largest underground test of 3 megatons, both at Novaya Zemlya (Nucleonics Week, October 24, 1991). It has been noted that nuclear explosions for military purposes needed the approval of a "special government resolution," while "peaceful" nuclear explosions, carried out for the gas, oil, or geological exploration industries, needed only ministerial level approval (Moscow Central Television, September 17, 1991). Available information is summarized as follows:

- The first Soviet peaceful nuclear explosion was exploded on January 15, 1965, in Kazakhstan in order to create a lake, now called Lake Chegan, to catch waters from melting snow (Nucleonics Week, May 9, 1991). This explosion [noted by Izvestia to be in December 1964], conducted in the shallow channel of the Chagan river, ejected some 3.5 million m^3 of dirt. The radioactive fallout covered a large area encompassing villages and farms, with "black ash" extending in an 8-km radius from the epicenter (Izvestia, July 22, 1991).

- From 1972 to 1984, three small (up to two kilotons) nuclear devices were exploded in an apatite mine about 20 km east of Kirovsk on the Kola Peninsula. The purpose of the tests was to see if such explosions would aid mineral extraction (Oslo Aftenposten, November 26, 1991).

- Peaceful nuclear explosions, detonated in the northern Urals in 1976, are reported to have left an artificial lake 400 meters wide by 600 meters long which "supports no life" and has dose readings of 1.5 rem/hr on the surface and 5 rem/hr at a depth of 12 meters (Nucleonics Week, May 9, 1991).

- Three small (5-kiloton) nuclear explosives placed 200 meters underground were set off 20 km from the city of Krasnovichersk (300 km northeast of Perm), which lies between the Kama River, a tributary of the Volga which flows into the Caspian Sea, and the Pechora River, which flows into the Kara Sea (Nucleonics Week, May 9, 1991).

- Twelve peaceful nuclear explosions were conducted near the town of Udachnyy in Yakutia ASSR (near the Arctic Circle), including one which caused a release of radioactive materials to the atmosphere as well as to the surrounding area (Rossiyskaya Gazeta, July 30, 1991).

- The last peaceful nuclear explosion was conducted in 1987 in the Bashkir region west of Perm, where two bombs were used to try to stimulate deposits of oil and gas. A nuclear explosive was also reported to be used to stop an uncontrolled fire in a gas well near Bukhara (Nucleonics Week, May 9, 1991).

The Soviets have proposed using nuclear devices to create underground cavities for the disposal of toxic industrial wastes. They note that the 200 to 600 grams of fission products produced are incorporated in the 500 to 700 tons of rock melted per kiloton yield of the nuclear device, thus the blast creates "negligible" radioactivity. Assuming a yield "of a few kilotons" [probably 10 to 20 kilotons], a network of "extended cracks" of up to 200 meters from the blast chimney, plus the cavity itself, would allow up to 5,000 to 6,000 m^3 of toxic industrial wastes to be injected per day for a period of up to 30 years. The Soviets project that this would save up to 100 million rubles over the cost of cleanup from the disposal of effluents in other ways, such as direct discharge into rivers and lakes. This concept has already been performed via two test explosions conducted "over 15 years ago" [one of them evidently in strata filled with "highly mineralized water]. More than 20 million m^3 of liquid wastes were pumped into one cavity over a period of 13 years that included 1,000 tons of solid "residues." More than 150,000 m^3 of "toxic effluents," which included a large quantity of suspended particles and "resinous substances," was pumped into the other test cavity over 5 years. It was pointed out that underground nuclear explosions had also been used to study the earth's "deep structures," extinguish gas fires, stimulate gas wells, and create storage cavities in salt formations. Uranium and plutonium warheads being removed from missiles were suggested as being used to create these underground cavities for liquid wastes, as it would be "politically and economically advantageous" (Priroda, February 1991).

Meanwhile, a Soviet firm, apparently created in December 1990, is trying to market underground thermonuclear devices for destruction of toxic chemical and industrial wastes. Called the International Chetek Corporation, it

consists of "partnerships" with Soviet weapons complex experts, notable from the All-Union Research Institute of Experimental Physics, which is located near Gorky and often referred to as Arzamas-16, where the Soviet thermonuclear bomb was developed. Another "partner" is stated to be Viktor Mikhailov, former MAPI Deputy Minister of nuclear defense research and now Minister of Minatom. The Director of Chetek is Vladimir Dmitriev, a former trade official, and its Vice-President is Valery Siderov, formerly with the Ministry of Foreign Affairs. Chetek, started with an equity of 250 million rubles, claims to be the "sole proprietor" of this technology, and is seeking foreign capital for further research (Nucleonics Week, October 24, 1991.)

Chetek, in spite of the previous closure of the testing of nuclear devices at Semipalatinsk by Mikhail Gorbachev, and a test ban at Novaya Zemlya imposed by Boris Yeltsin (Nucleonics Week, October 31, 1991) which is effective until October 1992 when it is to be reevaluated (Tass, March 20, 1992), still plans to perform a test at Novaya Zemlya in 1992. [Note: On February 27, 1992, President Yeltsin signed a decree to prepare for testing at Novaya Zemlya by making new tunnels and galleries for underground testing (Moscow New Times, April 1992.)] This test is supposed to destroy up to 1,000 metric tons of toxic chemical wastes supplied by "foreign clients," and is being "designed" by about 10 experts at Arzamas-16 (Nucleonics Week, October 24, 1991). Chetek also has established an office in Krasnoyarsk, involving "shareholders" who had participated in building the large commercial-scale spent fuel reprocessing facility there, apparently so they can market chemical extraction technologies. They may also survey commercial prospects for conversion of highly enriched uranium, of which it has been stated there is greater than 500 metric tons in existence (Nucleonics Week, October 31, 1991).

The Semipalatinsk nuclear test range occupies 18,000 km^2, and stretches more than 150 km south and southwest of Kurchatov City, known as Semipalatinsk-21, where the test site staff live. The city, on the left bank of the Irtych River, is located 120 km from Semipalatinsk, and has three underground research reactors, numerous laboratories and 15,000 residents. A total of 467 nuclear explosions were carried out there, including atmospheric tests from 1949 to 1963. The test site was ordered closed by Kazakhstan

President Nursultan Nazerbaev on August 29, 1991, 42 years to the day since the first Soviet nuclear explosion (Nucleonics Week, November 7, 1991).

Radioactive contamination at the Semipalatinsk nuclear test site has been reported on and compared to the contamination in the Ukraine from Chernobyl. An area of 200,000 km^2 was surveyed, including the 11,000 km^2 of the test range. Concentrations of ^{137}Cs in the loose soils on the sides of test shot craters measured from 1 to 1,000 nCi/kg. Figure 13.1 shows a ^{137}Cs distribution map of soils in the Semipalatinsk region. Measurements of the ^{137}Cs content in the top 5 cm of Ukrainian soils as a result of atmospheric nuclear testing fallout were reported to be in the "hundredths" of a nCi/kg in 1985. In comparison, in Pripyat after the Chernobyl accident, the top 5 cm of soil contained over 1,300 nCi/kg of ^{137}Cs [over 100 Ci/km^2]. It was pointed out that the low uptake coefficient of ^{137}Cs by plants at Semipalatinsk was used to defend the use of agricultural products from Ukrainian lands contaminated with $\geq$ 40 Ci/km^2 of ^{137}Cs. However, this may have been a mistake, since the particles containing ^{137}Cs from nuclear test shots are stated to be larger and much more insoluble than the particles containing ^{137}Cs from the Chernobyl accident (Komsomolskoye Znamya, May 8, 1991). Further information on the nuclear tests at the Semipalatinsk test site and contamination levels is being released. Contamination levels at "Lake Chegan" ranging up to 9 mR/hr, and zones at the test site of up to 10 mR/hr have been identified (Ogonek, January 1992).

Some information about the personnel radiation history at the Semipalantinsk nuclear test site has also been released. A special commission, headed by Anatoly Tsyb, Director of the Institute for Radiological Medicine Research of the former USSR Academy of Sciences, found 10,000 of the 70,000 local residents to have received radiation during the test period, primarily from 1949 to 1963. It was estimated that some 3,500 people received doses between 20 and 37 rem, 1,900 between 2 and 20 rem, with the balance less than 2 rem. At the upper end of the dose range, 900 residents of the village of Dolon received doses of up to 160 rem (Nucleonics Week, November 7, 1991).

The effects of nuclear tests at Novaya Zemlya are also expected to gather increasing attention with respect to waste management issues. Izvestia

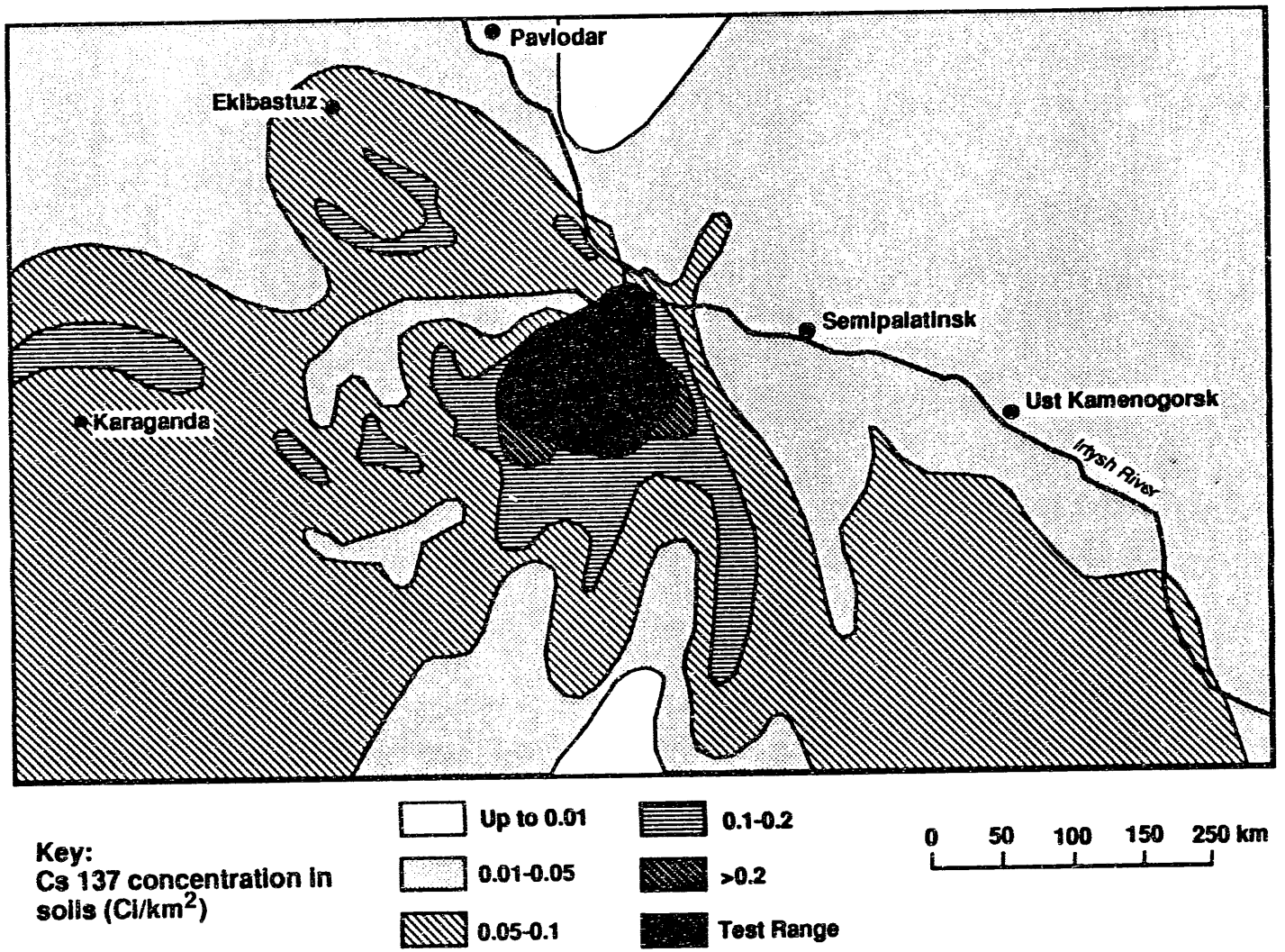

FIGURE 13.1. Cesium-137 Distribution in Soils Near the Semipalatinsk Test Range as of January 1991

reports that 132 nuclear tests have occurred there; 87 in the atmosphere, 42 underground, and 3 underwater, for an aggregate total of more than 90 megatons (Izvestia, October 29, 1991). The results of a radioactive contamination survey at Novaya Zemlya have concluded that the levels are "very slightly" above the global background. However, there were three areas having higher radiation levels, two of which were associated with atmospheric tests conducted prior to 1963. The third area was linked to an underground explosion in August 1987 that vented radioactive gases (Moscow Radio World Service, January 20, 1992).

More details on radioactive waste disposal sites on and around Novaya Zemlya were released in January 1992. Figure 13.2 depicts the locations of these radioactive "hotspots," which are described as follows (Sobesednik, January 5, 1992):

1. The Novaya Zemlya deep-sea trench - a cargo vessel with a damaged reactor (1700 curies), 1,450 submerged containers with radioactive waste, and a tanker with liquid radioactive waste.

2. Neupokoyeva Bay - solid radioactive waste with an overall radioactivity of 3,400 curies.

3. Tsivolki Bay - 4,750 containers of radioactive wastes, the lighter N. Bauman, the mid section of the ice-breaker Lenin with three damaged reactors and crane assembly.

4. Oga Bay - 850 containers of radioactive wastes.

5. Stepovogo Bay - 1,850 containers of radioactive wastes and a damaged nuclear submarine containing two reactors with nuclear fuel still inside.

6. Abrosimov Bay - 550 containers of radioactive wastes and sections of four damaged nuclear submarines (a total of eight reactors, three of which contain nuclear fuel).

7. Blagopoluchiya Bay - 650 containers of radioactive wastes.

8. Techeniy Bay - a damaged reactor (without nuclear fuel) with an aggregate activity level of 1,856 curies.

9. Open sea - 400 containers of radioactive wastes.

10. Open sea - 250 containers of radioactive wastes.

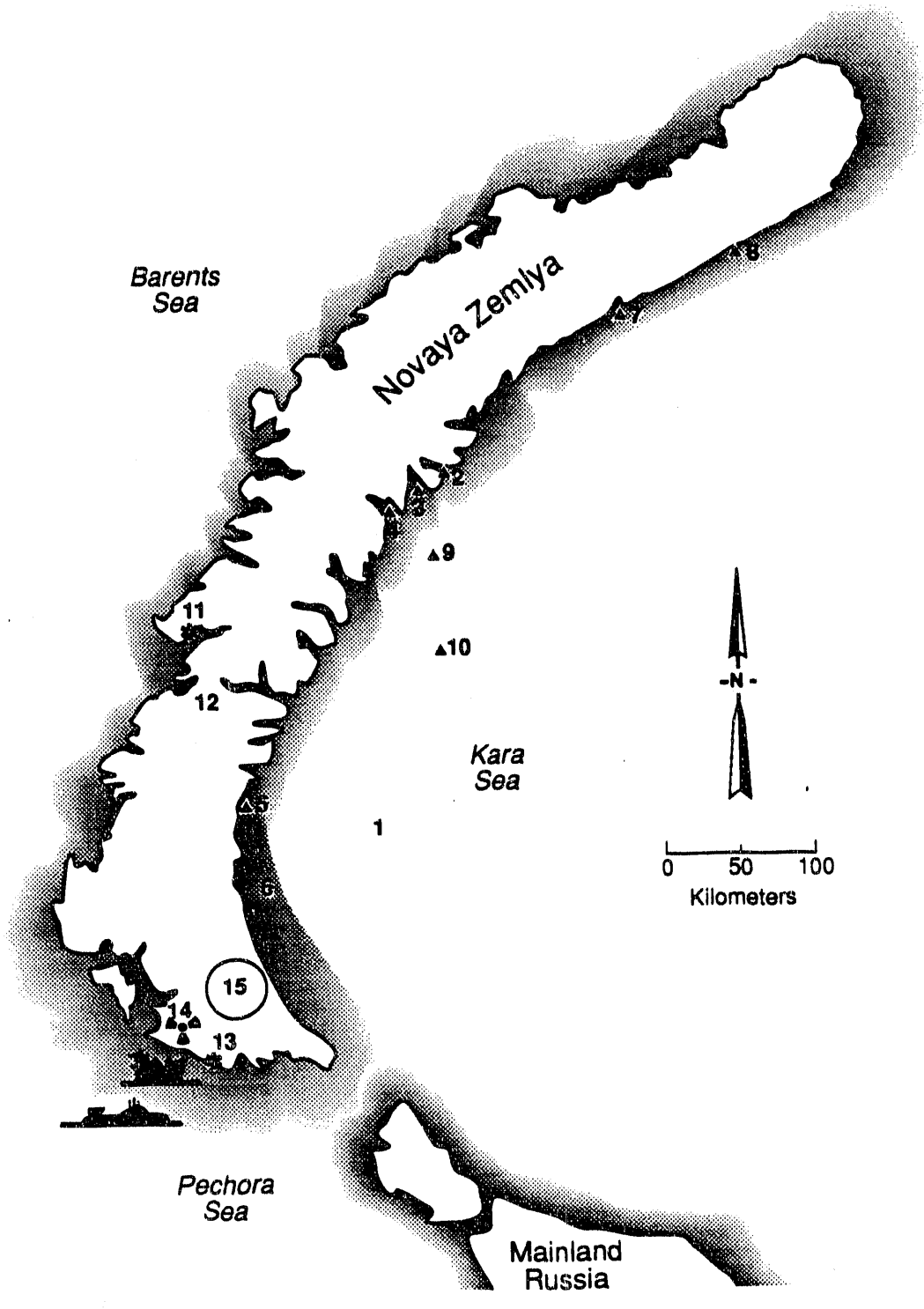

FIGURE 13.2. Radioactive Waste Sites Associated with Novaya Zemlya

11. The Cape Sukhoy Nos area where the highest yield atmospheric nuclear weapons tests were conducted. An off-limits area.

12. The Matochkin Shar Channel area - location of the latest underground nuclear tests in tunnels. An off-limits area.

13. The Chernaya Guba area - location of the first underwater, above-ground and initial underground (in emplacement hole) nuclear tests. The grave of the experimental ship Kit and the proposed burial site for the nuclear submarine Komsomolets (in the event it is raised). An off-limits area.

14. Proposed site for a regional nuclear waste repository.

15. The southwestern sector of the archipelago's south island. This is an area proposed for the long-term program of nuclear tests on Novaya Zemlya.

A nuclear test site has also been reported to be located west of Yakutsk in Siberia, near the city or Mirnyi, between the Lena and Illioui rivers (Nucleonics Week, November 7, 1991), and at the "Yunkom" mine at the city of Yenakiyevo in the Donetsk region of Ukraine, where a test occurred in 1979 (Tass, January 12, 1992).

13.4 WASTE DISPOSAL IN THE BARENTS AND KARA SEAS

Five sites have been noted as official storage areas for nuclear waste in the Kola Peninsula region. They are at Murmansk [home port for naval vessels having a total of 220 reactors (see Chapter 6.0 for information on spent fuel storage)], Polyarniye Zori (where the four VVER-440 "Kola" reactors are located), Severomorsk (home of the Soviet Northern Fleet), Litsa (a submarine base), and Kildin (Oslo Aftenposten, November 26, 1991). The Litsa Fjord is located about 45 km from Norway, and Kildin is an island in the Barents Sea about 120 km from the Norwegian border (Nucleonics Week, April 18, 1991). Also at Murmansk, a ship named the Lepse is being filled with radioactive wastes incorporated into concrete or grout. The wastes were derived from naval reactor operations (Tass, October 2, 1991). Radioactive waste is also said to be stored in ships in the port of Archangelsk (Daily Telegraph, November 26, 1991), and liquid radioactive wastes from facilities in nearby

Severodvinsk are placed on ships for discharge at sea. Three radioactive waste burial grounds are also located close to this city (Moscow Interfax, February 22, 1992).

Another waste management problem related to naval reactors, this time in the form of disposal of wastes at sea, has been reported. Andrey Zolotkov, a deputy to the Supreme Soviet from Murmansk, has acknowledged that Soviet civilian and naval vessels have dumped "highly radioactive" waste into the Barents and Kara seas between 1964 and 1986. According to the ships' log records, Zolotkov notes that 12 ships have disposed of 10,250 containers (of one cubic meter) of radioactive wastes in waters not greater than 1,100 feet deep (Daily Telegraph, November 26, 1991), or as shallow as 60 feet (Nuclear Waste News, November 28, 1991), and holes were put into some containers that did not readily sink (Komsomolskaya Pravda, September 28, 1991).

Izvestia noted that 11,000 containers have been dumped, containing reactor equipment and structures, and "other dangerous" wastes (Izvestia, October 29, 1991). These wastes include a container holding the damaged core of the ice breaker Lenin, which was dumped off of the Novaya Zemlya archipelago between the Barents and Kara seas, after suffering a "serious reactor accident" in the mid-1960s (Paris AFP, September 24, 1991). The number of containers disposed of has alternately been reported as 17,000 (Rossiyskaya Gazeta, February 27, 1992). In addition to the reactor core from the Lenin, other containers, metal components, and equipment from nuclear power installations have been sunk in the Novaya Zemlya archipelago. The wastes were dumped, in violation of the London Convention, in bays close to the shore where the water depth did not meet IAEA recommendations. This was due to the fact that the seaways were closed further offshore because of the close proximity of the nuclear testing ground on Novaya Zemlya. The wastes were supposed to have been placed in containers that were filled with bitumen or "liquid glass" and then hermetically sealed. However, Zolotkov indicated that this was not done (Tass International Service, September 27, 1991). With respect to naval reactors, at least 15 have been disposed of in the Kara Sea not far from Novaya Zemlya (Moscow Radio Rossii, March 25, 1992). Figure 13.2 shows sites around Novaya Zemlya where radioactive wastes have been disposed.

13.5 CONTAMINATION FROM MILITARY ACTIVITIES IN LAKE LADOGA

More information has been reported on the contaminated ship, once half-sunken in Lake Ladoga near St. Petersburg. Lake Ladoga is located 50 km from the Finnish border and is a major supplier of St. Petersburg's drinking water (USSR Technology Update, January 24, 1991). Evidently the ship, a destroyer named the Kit (formerly named the Podvizhnyy), and others were the subject of tests simulating nuclear explosions by using radioactive materials and explosives (Izvestia, April 17, 1991). The Kit was built in Germany in 1940 (Moscow Interfax, August 7, 1991). The "test division" was formed in 1953 and was based on the western shores of Lake Ladoga. The center of the test site was on the island of Kheynyasenma (formerly Suri), where test explosions were conducted on the Ki as well as on another ship called the Morskoy Okhotnik (Izvestia, April 17, 1991). The Kit was located almost at equal distances from the town of Priozersk, Sortavala and the island of Valaam (USSR Technology Update, January 24, 1991). Radioisotopes were transported to the Kit in lead-lined containers and placed next to explosives. "Experimental" animals such as dogs, rabbits and white mice were placed in the ship's quarters. It was noted that a good many of the "sailors and testers" who worked at the sites after the explosions did not wear any protective gear. Radiation levels exceed 1,000 microroentgens at several locations on the Kit, and the island of Makarinsari, where "scientific forces" were based and radionuclides were stored, is "particularly" contaminated. The experiments were stopped in 1955 (Izvestia, April 17, 1991). Following the tests the ship was sunk on the shore of Lake Ladoga (Moscow Interfax, August 7, 1991). Alternately, it has been reported that the Kit was used for testing by the Soviet Navy until 1961 (The European, November 1-3, 1991).

Apparently in 1990, a "filtration system" using two synthetic resins was used to prevent the leakage of radionuclides and "seal" the ship (USSR Technology Update, January 24, 1991). Prior to its removal, the contaminated water was pumped from the Kit to a tanker where the water was purified and then discharged into Lake Ladoga. Then the entire boat was encased in a "plastic shell" and towed through the canal system of the White Sea for the

3,200 km trip to Zovaya Zemlya (The European, November 1-3, 1991) in the summer of 1991 by the St. Petersburg Naval Base (Moscow Interfax, August 7, 1991.

The Soviet Army also carried out tests for over 30 years on the effects of nuclear weapons in the Heinamaa islands in the northwestern corner of Lake Ladoga. They evidently traced the spread of weapons fallout by exploding chemical explosives placed on timber pontoons. For test purposes, shelters for test animals and laboratories were built on these uninhabited islands (Suomen Yleisradio, October 10, 1991).

13.6 OTHER CONTAMINATED AREAS

Available information on other contaminated areas in the former Soviet Union is summarized as follows:

- A map of the general locations of radioactive "hot spots" in the former Soviet Union, assembled by A. N. Penyagin, is shown in Figure 13.3 (Meditsinskaya Gazeta, December 13, 1991).

- A Soviet newspaper, Trud, has reported that an "explosion" in a nuclear-powered submarine occurred on August 10, 1985, at a nuclear ship repair plant on Chazhma Bay in Primorskiy Kray, about 1.5 kilometers from the village named Shkotovo-22. Evidently, a steam explosion occurred in the reactor due to a mishap in a repair procedure, and the reactor core was reported to have been compromised with fuel spilling into the water where the submarine was docked. Firefighters were said to have received doses of 30 to 40 rem. Ten men were killed and a radioactive trail 6 km by 500 meters was left on an adjacent hillside, and radioactivity is reported to have spread to nearby Konyushkovo, Abrek, and Razboynik Bays. The Taiga Geological Association in Khabarovsk has conducted an independent radiological survey, and the results are presently being analyzed (Trud, October 25, 1991). The reactor core debris and contaminated soil from the accident that was placed in a "hastily" dug trench near the site is being placed in a new burial site (Moscow Television, March 29, 1992).

- The radiation map of Moscow published in January 1991 in Rabochaya Tribuna has been revised. The earlier map shows where contamination has been discovered over the last 10 or more years. Many of these areas are now stated to be cleaned up, and final decontamination is to be completed in 1991. Figure 13.4 shows the revised map of contaminated areas in Moscow (Vechernyaya Moskva, February 18, 1991). Another map of radioactive "hotspots" has been published for the Moscow Oblast, which is shown in Figure 13.5 (Rabochaya Tribuna,

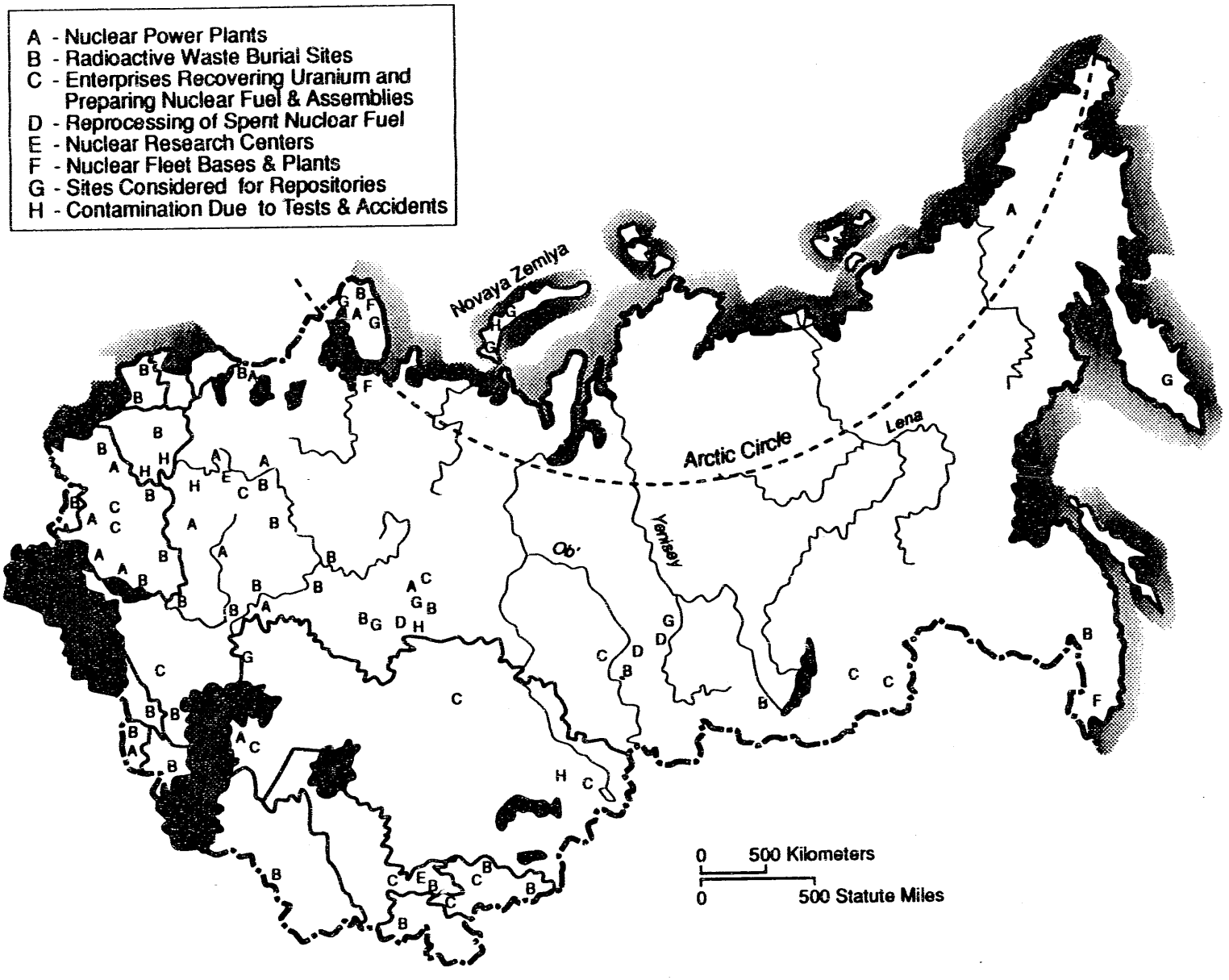

FIGURE 13.3. Map of Radioactive Hot Spots on the Former Soviet Union

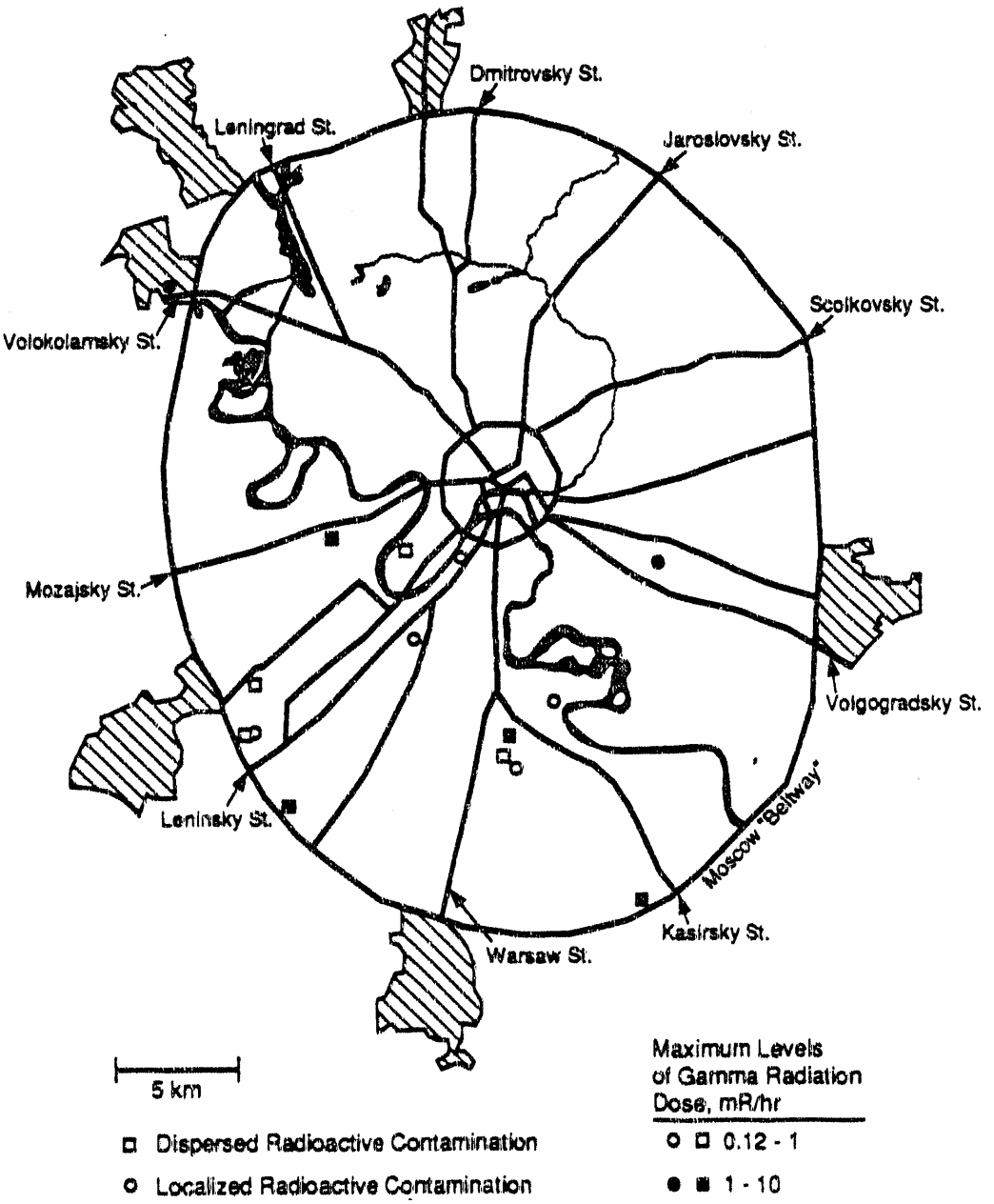

FIGURE 13.4. Revised Map of Radioactive Contamination in the City of Moscow, Russia (Vechernyaya Moskva, February 18, 1991)

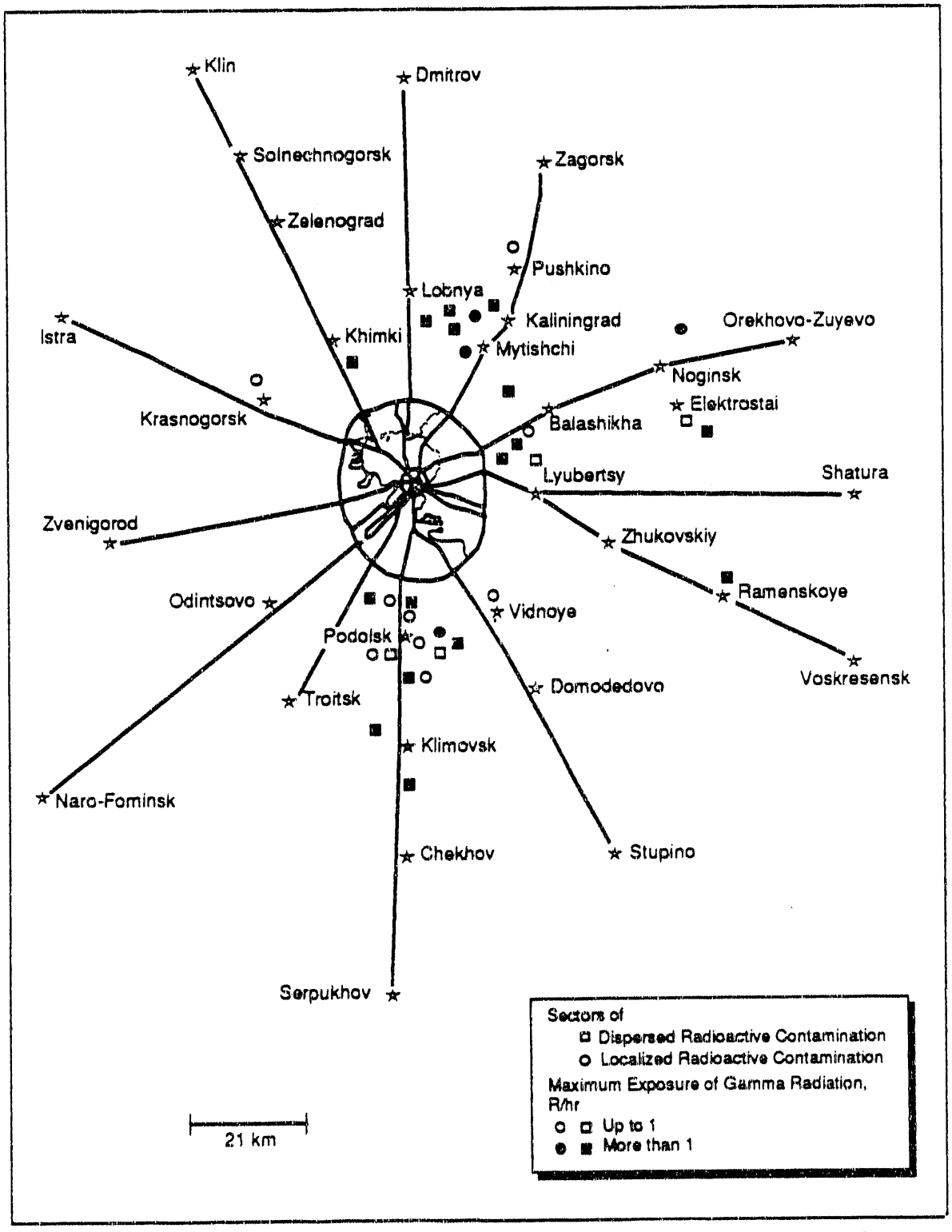

FIGURE 13.5. Radioactive Contamination Sites in the Moscow Oblast, Russia (Rabochaya Tribuna, February 6, 1991)

February 6, 1991). There have been reports of "excessive" radioactivity in other cities, such as Kazan, where it exceeded the norms in 13 locations, with readings up to 5 mr/hr (Moscow Interfax, July 31, 1991).

- A leak at a nuclear waste site on the Kamchatka peninsula has been reported. Apparently the leak was noted in 1990, when a crack in the frame of one of two storage sites for "untreated high-level waste" was discovered (Nuclear Waste News, January 2, 1992a).

- It appears that problems are surfacing with some of the regional centers for disposal of industrial and medical radioactive wastes. Khabarovsk, for example, now has to pay 4,000 rubles for disposal of one cubic meter of such wastes at a "radon centre" which used to be free, and the price may soon double (Moscow News, January 19-26, 1992).

- Radioactive wastes are reported to have become a "major problem" at the site of two submarine training reactors for submarine crews located in Paldiski, Estonia. Paldiski is also a submarine repair base (Dagens Nyheter, February 23, 1991).

- Radioactive waste management problems near Sillamae, Estonia, associated with uranium processing have surfaced again (Bradley and Schneider 1990). The processing facility was built in 1948 to extract uranium from oil shale located nearby. Processing wastes were placed in an open-air pool 20 meters deep and 2 miles wide, which contains 9×10^6 MT of radioactive materials and is still being used. Wastes are seeping into the Gulf of Finland through the seawall that separates the waste pool and the sea. Additionally, wind-born contamination of nearby areas has occurred, and radiation levels near the site are five times normal background (Nuclear Waste News, May 7, 1992). The former Soviet Union has not yet provided the promised aid to reinforce a gravel embankment between the reservoir and the Bay of Narva, drain the reservoir, and then cover the site (Svenska Dagbladet, March 7, 1992).

- In addition to the dumping of radioactive wastes at sea, 34,000 tons of "combat toxic agents" are reported to have been disposed of at sea as well. They were buried in the Baltic Sea at a depth of 80-90 meters close to Denmark's Bornholm Island and Sweden's Gotland island after World War II (Moscow RIA, March 13, 1992).

- It is reported that a new ecological magazine (EKOS) is being published by the Social and Ecological Union of the country and other sponsors (Moscow Central Television, March 12, 1991).

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APPENDIX A

SUMMARY TABLES ON NUCLEAR POWER REACTORS IN THE FORMER USSR

TABLE A.1. Operational Power Reactors in the Former USSR

Location	Republic	Name	Type	Capacity, MWe	Year in Operation	Reference
Obninsk	Russia	AM-1	Pressurized water (PWR), graphite moderated	5	1954	A
"			Mobile; PWR	1.5	1961	A
Siberian	Russia	Unit 3	LWGR	100	1960	B
"		Unit 4	LWGR	100	1961	B
"		Unit 5	LWGR	100	1962	B
"		Unit 6	LWGR	100	1963	B
Dimitrovgrad	Russia	ARBUS	Organic-cooled and -moderated	(0.75)[a]	(1963)[a]	A
(New Melekess)		BOR-60	Boiling water	12	1968	C
Novovoronezh	Russia	Unit 3	VVER	440	1972	D
"		Unit 4	VVER	440	1973	D
"		Unit 5	VVER	1000	1981	D
Bilibino	Russia	Unit 1	LWGR	12	1973	E
"		Unit 2	LWGR	12	1974	E
"		Unit 3	LWGR	12	1975	E
"		Unit 4	LWGR	12	1976	E
Kola or Kolsk	Russia	Unit 1	VVER	440	1973	D
(Polyarnyye		Unit 2	VVER	440	1975	D
Zori, Murmansk)		Unit 3	VVER	440	1982	D
"		Unit 4	VVER	440	1984	D
Sosnoviy Bor, St. Petersburg	Russia	Unit 1	RBMK	1000	1974	D
		Unit 2	RBMK	1000	1976	D
"		Unit 3	RBMK	1000	1980	D
"		Unit 4	RBMK	1000	1981	D
Kursk	Russia	Unit 1	RBMK	1000	1977	D
(Kurchatov, Kursk)		Unit 2	RBMK	1000	1979	D
		Unit 3	RBMK	1000	1984	D
"		Unit 4	RBMK	1000	1986	D
Beloyarsk	Russia					
(Zarechnyy, Ekaterinburg)		BN-600	LMFBR	600	1981	D
Smolensk	Russia	Unit 1	RBMK	1000	1983	D
(Desnogorsk, Smolensk)		Unit 2	RBMK	1000	1985	D
"		Unit 3	RBMK	1000	1990	D

TABLE A.1. (contd)

Location	Republic	Name	Type	Capacity, MWe	Year in Operation	Reference
Kalinin (Udomlya, Tver)	Russia	Unit 1	VVER	1000	1985	D
		Unit 2	VVER	1000	1987	D
Balakovo (Balakovo, Saratov)	Russia	Unit 1	VVER	1000	1986	D
		Unit 2	VVER	1000	1988	D
		Unit 3	VVER	1000	1989	D
Chernobyl (Pripyat) "	Ukraine	Unit 1	RBMK	1000	1978	D
		Unit 2	RBMK	1000	1979	D
		Unit 3	RBMK	1000	1982	D
Rovno (Kuznetsovsk, West Ukraine)	Ukraine	Unit 1	VVER	402	1981	D
		Unit 2	VVER	416	1982	D
		Unit 3	VVER	1000	1987	D
South Ukraine or Konstantinovka or Nikolaivev	Ukraine	Unit 1	VVER	1000	1983	D
		Unit 2	VVER	1000	1985	D
		Unit 3	VVER	1000	1989	D
Zaporozhye (Energodar)	Ukraine	Unit 1	VVER	1000	1985	D
		Unit 2	VVER	1000	1985	D
		Unit 3	VVER	1000	1987	D
		Unit 4	VVER	1000	1988	D
		Unit 5	VVER	1000	1989	D
Khmel'nitskiy (Neteshin, West Ukraine)	Ukraine	Unit 1	VVER	1000	1988	D
Ignalina (Snieckus)	Lithuania	Unit 1	RBMK	1500	1985	D
		Unit 2	RBMK	1500	1987	D
Shevchenko (Caspian Sea)	Kazakhstan		BN-350	LMFBR	350[b]	1973B

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E = Atomnaya Energiya, November 1977.

Notes:

(a) Data in parentheses represent estimates.
(b) Plant also desalinates 120,000 cubic meters of seawater per day, or about 200 MWe equivalent.

TABLE A.2. Decommissioned Power Reactors in the Former USSR

Location	Republic	Name	Type	Capacity, MWe	Year in Operation	Date Decommissioned	Reference
Beloyarsk (Zarechnyy, Ekaterinburg)	Russia	AMB-1	Boiling water; superheat; graphite moderated[b]	100	1963	1987	B, C, D
		AMB-2	Boiling water; superheat; graphite moderated[c]	200	1967	1989	B, C, E
Novovoronezh	Russia	Unit 1	VVER[d]	210	1964	1988	A, B
		Unit 2	VVER[e]	365	1969	1990	C, F
Siberian	Russia	Unit 1	LWGR	100	1958	1989	H
		Unit 2	LWGR	100	1959	1989	H
Dimitrovgrad (New Melekess)	Russia	VK-50	Boiling Water; superheat	50	1965	1989	I
Chernobyl	Ukraine	Unit 4	RBMK[a]	1000	1983	1986	A
Oktemberyan	Armenia	Unit 1	VVER[f]	408	1976	1989	C, G
"		Unit 2	VVER[f]	408	1979	1989	C, G

References:

A = Nuclear News, February 1989.
B = Seaborg, G. S., et al. 1963. Atomic Energy in the Soviet Union, Trip Report of the U.S. Atomic Energy Delegation, U.S. Atomic Energy Commission, Washington, D.C., May 1963.
C = Atomnaya Energiya, November 1977.
D = Nuclear News, August 1987.
E = Nucleonics Week, March 22, 1990, pp. 6-7.
F = Nucleonics Week, March 14, 1991, pp. 5-6.
G = Nucleonics Week, March 9, 1989, p. 3.
H = Nuclear News, August 1990, p. 81.
I = Nuclear News, February 1992, p. 67

Notes:

(a) Unit 4 was destroyed in an accident on April 26, 1986.
(b) Plant was taken off line for decommissioning in 1987, Reference D.
(c) Plant was taken off line for decommissioning in October 1989, Reference E.
(d) Plant was taken off line for decommissioning in 1988, Reference A. (It was noted that the plant was shut down in 1984, according to information given during a U.S. National Academy of Sciences tour February 12-23, 1990 to the USSR).
(e) Plant was taken off line in 1990 for decommissioning, Reference F.
(f) Units 1 and 2 were shut down in February and March of 1989, respectively, for conversion to a fossil-fuel plant (Reference G).

TABLE A.3. Countries with VVER Reactors Operating or Under Construction

Location	Name		Capacity, MWe	Year in Operation
Bulgaria	Kozloduy	-1	440	1974
"	"	-2	"	1975
"	"	-3	"	1981
"	"	-4	"	1982
"	"	-5	1000	1988
"	"	-6	"	(1992)
Cuba	Juragua	-1	"	(1995)
"	"	-2	"	(1997)
Czechoslovakia	Bohunice	-1	440	1979
"	"	-2	"	1981
"	"	-3	"	1985
"	"	-4	"	1986
"	Dukovany	-1	"	1985
"	"	-2	"	1986
"	"	-3	"	1987
"	"	-4	"	1987
"	Mochovce	-1	"	(1993)
"	"	-2	"	(1994)
"	"	-3	"	(1995)
"	"	-4	"	(1996)
"	Temelin	-1	1000	(1994)
"	"	-2	"	(1995)
Finland	Loviisa	-1	"	1977
"	"	-2	"	1981
Hungary	Paks	-1	440	1983
"	"	-2	"	1984
"	"	-3	"	1986
"	"	-4	"	1987

Reference:
Nuclear News, February 1992. "World List of Nuclear Power Plants." pp. 49-68.
NOTE: Years in parentheses are estimated commercial startup dates.

APPENDIX B

RADIOACTIVE WASTE CLASSIFICATIONS IN THE FORMER USSR

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RADIOACTIVE WASTE CLASSIFICATIONS IN THE FORMER USSR

Categories of radioactive waste in the former USSR are given as follows:

Type	Activity Level
Liquid[a]	
Low-Level	$<1 \times 10^{-5}$ Ci/L
Intermediate-level	$\geq 1 \times 10^{-5} \leq 1$ Ci/L
High-Level	≥ 1 Ci/L
Solid Wastes Based on Dose Rate, 10 cm from Surface[a]	
Low-Level	≤30 mr/h
Medium-level	30 ≤300 mr/h
Intermediate-level	0.3 ≤1 r/h
High-Level	≥1 r/h

Solid Waste Classes Based on Activity[b]

	Group 1	Group 2	Group 3
Beta Activity, Ci/kg	2×10^{-6} - 1×10^{-4}	1×10^{-4} - 1×10^{-1}	$>1 \times 10^{-1}$
Alpha Activity, Ci/kg	2×10^{-7} - 1×10^{-5}	1×10^{-5} - 1×10^{-2}	$>1 \times 10^{-2}$

Gaseous[c]		
Low-Level	$\leq 3.7 \times 10^{-3}$ Bq/liter	(1×10^{-13} Ci/liter)
Intermediate-level	$>3.7 \times 10^{-3} \leq 370$ Bq/liter	($1 \times 10^{-13} \leq 1 \times 10^{-8}$ Ci/liter)
High-Level	>370 Bq/liter	($\geq 1 \times 10^{-8}$ Ci/liter)

(a) National Academy of Sciences (1990), Bukharin 1991.
(b) Bukharin 1991.
(c) Mosinets (1991) (based on "Sanitary Rules for Radioactive Waste Management, SPORO-85).

NOTES: Solid wastes below μr/h are not considered radioactive and do not require any special treatment or handling.

In the United States, LLW is that remaining waste that is not classified as HLW or TRU (i.e., alpha activity >100 nCi/g and $T_{1/2}$ >20 years); HLW is defined as spent fuel and wastes from fuel processing.

Solid wastes in the Soviet Union are judged to be radioactive if they meet the following criteria (Drozhko 1990):

Specific activity for beta-active wastes	>2 x 10^{-6} Ci/kg
Specific activity for alpha-active wastes	>2 x 10^{-7} Ci/kg
Specific activity for transuranic wastes	>1 x 10^{-8} Ci/kg
Exposure dose rate for gamma-active wastes or the solid waste has a surface activity of:	>1 x 10^{-7} g-equi Ra/kg
For beta-activity	>50 particles/cm^2-min over a surface of 100 cm^2
For alpha-activity	>5 particles/cm^2-min over surface of 100 cm^2

Gamma-active wastes are categorized by disposal method as follows (Drozhko June 1990).

Group 1	less than 0.3 μR/h, in trenches
Group 2	from 0.3 μR/h to 10 μRh, in trenches
Group 3	more than 10 μR/h at the depth of 0.1 m from the surface waste storage

APPENDIX C

DECREE OF THE PRESIDENT OF THE RUSSIAN FEDERATION ON THE MINISTRY OF ATOMIC ENERGY OF THE RUSSIAN FEDERATION

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DECREE OF THE PRESIDENT OF THE RUSSIAN FEDERATION ON THE MINISTRY OF ATOMIC ENERGY OF THE RUSSIAN FEDERATION

Bearing in mind the role of nuclear armaments and the atomic power industry in securing the defense and energy potential of the Russian Federation and the need of succession in the fulfillment of international obligations and guarantees in the field of nuclear weapons, the atomic power industry and nuclear technologies, and also mindful of the nuclear, radiation and potential general technical hazard of enterprises and organizations of the nuclear complex of the Russian Federation, and meaning to ensure their stable functioning, I hereby decree:

1. To form a Ministry of Atomic Energy (Minatom) of the Russian Federation.

   To establish that the Ministry of Atomic Energy of the Russian Federation shall be the successor to the defunct Ministry of Atomic Power Engineering and Industry of the USSR in what concerns the interests of the Russian Federation.

   The Ministry of Atomic Industry of the Russian Federation shall:

   - ensure nuclear and radiation safety of the nuclear complex
   - organize and implement state regulation of the operation of enterprises and organization of the nuclear complex of the Russian Federation
   - implement the state scientific and technical investment and structural policy in the sphere of nuclear power engineering
   - ensure the development and implement the programs to develop, modernize, manufacture, and reduce nuclear weapons, to dispose of radioactive wastes and to implement systematic conversion of the nuclear complex.

2. Given the need to ensure the state monopoly on the production of nuclear weapons, to empower the Ministry of Atomic Industry of the Russian Federation to control the production and destruction of nuclear weapons at enterprises and objects in accordance with the list to be drawn up by the Government of the Russian Federation.

3. The Ministry of Atomic Industry of the Russian Federation shall:

- Accept from the abolished Ministry of Atomic Power Engineering and Industry of the USSR the buildings, structures, and other property (including that used on leasehold conditions) and assets and educational institutions, organizations and economic objects located on the territory of the Russian Federation

- For ensuring non-proliferation of nuclear materials and corresponding technologies and stable and safe operation of organizations and enterprises of the nuclear complex, carry out within three months negotiations together with the ministries and departments concerned with the corresponding bodies of other member-states of the Commonwealth of Independent States and other Sovereign States which were once Union Republics of the USSR on the establishment of common coordination and consultancy mechanisms in order to guarantee safe use of atomic energy.

- Draft and present for approval by the government of the Russian Federation within a month's time a list of legislative and other normative acts on guaranteeing safe use of atomic energy.

- Present within two month's time proposals on preserving the existing production and technological links of the complex, including the supply of its social units, with due regard for the development of market relations and the anti-monopoly policy.

- Submit proposals within a month's time together with the Ministry of Economics and Finance of the Russian Federation on the provision of a quota to enterprises of the nuclear complex on the export of general-purpose products with a view to partially meeting the demand for imported materials and equipment to ensure safe operation of the existing production works and systematic conversion of production for civilian purposes.

Signed: Boris Yeltsin
President of the Russian Federation
Moscow, Kremlin
January 29, 1992: No. 61

Reference

Moscow RIA, February 6, 1992

INDEX

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