Strålevern Rapport 2006:19

Review of the current status and operations at Mayak Production Association

Statens strålevern

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Key words:
Mayak PA facilities, radioactive contamination, radioactive waste.

Abstract:
This report gives a brief but comprehensive overview of operations at Mayak PA. Information has been gathered from a variety of sources which have been cross-checked where possible to ensure accuracy. Mayak PA is currently the only facility in Russia involved in large scale reprocessing of spent nuclear fuel (SNF). Gaining increased knowledge about the current status at Mayak PA and future plans for this facility is therefore very important. Such information may also be useful to give an insight into the environmental consequences of day to day operations at Mayak PA.

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Emneord:
Majak PA anlegg, radioaktiv kontaminering, radioaktiv avfall.

Sammendrag:
Denne rapporten gir en kort, men omfattende oversikt av virksomheten ved anleggene i Majak. Flere informasjonskilder ble brukt og data sammenlignet fra forskjellige steder for kunne sjekke dem mot hverandre. Majak er pr. i dag det eneste anlegg i Russland som driver gjenvinning av brukt brensel (SNF) i stor målestokk. Derfor er det ønskelig å få vite mer om status og planene ved anlegget. Slik informasjon kan også gi oss et innblikk hvilke konsekvenser daglig drift i Majak har for miljøet.

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Norwegian Radiation
Protection Authority
Østerås, 2006

Contents

1 Introduction

The Mayak Production Association covers about 200 km^2 and incorporates the Mayak Chemical Combine, the Chelyabinsk-60 Research Facility and the unfinished South Urals Nuclear Power Plant (NPP). Mayak PA lies in South Ural, about 1400 km east of Moscow, close to the River Techa which forms part of the Techa-Iset-Tobol-Irtysh-Ob river system that eventually drains into the Kara Sea (Figure 1). Today, Mayak PA facilities include two reactors used for plutonium (^{238}Pu) and tritium production; fuel reprocessing facilities; a plutonium processing, finishing, and component manufacturing plant (Plant 20); mixed-oxide (MOX) fuel fabrication plants; fissile material storage and nuclear waste treatment facilities. Mayak PA had 14 000 employees in 2003. Two heavy water reactors (OK-190 and OK-190M) were shut down in 1965 and 1986, respectively. Weapons-grade plutonium production was stopped in 1987. All five of the plant's uranium-graphite plutonium production reactors (A, IR, AV-1, AV-2 and AV-3) were permanently shut down between 1987 and 1991. Mayak activities currently include reprocessing spent nuclear fuel (SNF), conversion of weapons-grade plutonium into MOX fuel, production of PuO_2 and UO_2, production of radioisotopes and manufacture of electrical devices as well as control and monitoring equipment for pipelines.

The Norwegian Radiation Protection Authority has had close cooperation with Mayak PA and Rosatom since 1993, including the completion of environmental contamination and risk assessments addressing activities at Mayak facilities. Joint fieldwork was carried out in the 1990s and two reports have been published by the Joint Norwegian-Russian Expert Group on Investigation of Radioactive Contamination in the Northern Areas (JNREG, 1997; 2004).

The objective of this report is to compile an as up-to-date summary as possible of the status at Mayak PA. Several different sources have been utilised and information about the sources is given in the appendix.

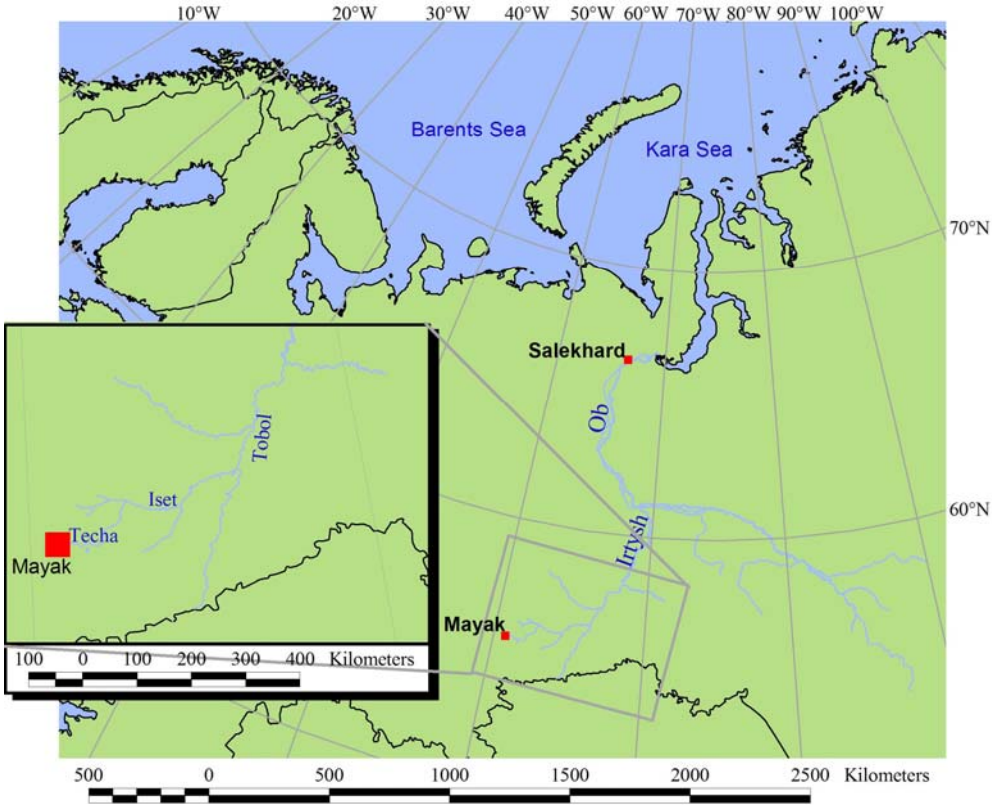

Figure 1: *Location of Mayak PA.*

2 History

Mayak PA included the first military ^{239}Pu production reactor in the former USSR. Geological surveys and construction work were started in 1945 including road, rail, electrical and sewage networks. A town was built close-by to house the workers and their families; formerly named after its postal codes; Chelyabinsk-40 and then Chelyabinsk-65, this "closed" (access for non-residents is still granted on a permit basis) town was named as Ozyorsk in 1994. The first production reactor (Facility A) was started up in June, 1948, and the first batch of irradiated uranium fuel rods was sent to the radiochemical production works (Facility B) in December, 1948. Here, the plutonium produced in the reactor was separated from uranium and fission products using an acetate precipitation technique and refined.

In February, 1949, the first batch of plutonium concentrate was sent on to Facility V (Plant 20), where it was further refined to produce weapons-grade plutonium and fashioned into the components necessary for making an atomic bomb. The USSR's first atomic bomb was subsequently detonated on the 29th August, 1949, at a test site near Semipalatinsk.

2.1 Environmental legacy

Mayak PA was the first production reactor complex built in Russia. Historically it has been a source of significant radioactive contamination to the surrounding region. Drainage of the area is mainly via the Techa River. In addition, a number of natural lakes and ponds on the Mayak site have been used as reservoirs to manage intermediate and low-level radioactive effluents. These include Lake Karachay (Reservoir 9) and Lake Kyzyltash (Reservoir 2), Reservoirs 3, 4 and 17 (originally local ponds) and artificial Reservoirs 10 and 11, created by damming the Techa River.

2.1.1 Contamination events

Three significant contamination events have occurred at Mayak PA:

- Direct releases of radionuclides to the Techa between 1949 and 1956
- An explosion in a high-level radioactive waste tank in 1957 (Kyshtym)
- Dispersal of radionuclides from the dried out bed of Lake Karachay in 1967

Direct releases of radionuclides were made to the Techa river system via sedimentation ponds (Reservoirs 3 and 4) between 1949 and 1956, with approximately 98% of the total activity released between December 1949 and November 1951. In 1951, high levels of radioactivity were discovered at some distance downstream from the facility. A natural pond on-site with no outlet, Lake Karachay, was used thereafter for radioactive discharges of the highest activity. Over 100 PBq (PBq = 10^{15} Bq) of radioactive material was discharged to the Techa between 1949 and 1956 (JNREG, 1997), causing severe contamination along the entire length of the Techa River. Ruthenium isotopes (^{103}Ru, ^{106}Ru) and rare earth nuclides accounted for over 50% of total activity releases and an estimated 12 PBq ^{90}Sr and 13 PBq ^{137}Cs were discharged. Alpha releases (including Pu and U isotopes) were lower, amounting to about 2 TBq according to discharge records (JNREG, 1997). Discharges of ^{90}Sr and ^{137}Cs during the period 1949-1957 contaminated 240 km^2 of the Techa River floodplain: an area of 80 km^2 had concentrations above 37 $kBqm^{-2}$ (Bradley 1997). About 7500 people were evacuated from Techa riverside villages and relocated due to contamination caused by the direct discharges of radioactive wastes into the Techa River (1953-1960). Dams were also constructed along the Techa in order to contain the activity and act as a storage basin for low level wastes, creating reservoirs (R-3, R-4, R-10 & R-11) containing high levels of radionuclides such as ^{137}Cs, ^{90}Sr, ^{60}Co and isotopes of plutonium (JNREG, 1997; 2004).

The thermal explosion in a tank containing high-level liquid waste (HLW) in September 1957 created what has become known as the East Urals Radioactive Trace (EURT). Some 740 PBq was released during the accident but an estimated 90% settled in the immediate vicinity of the explosion site. The remainder, about 74 PBq, was released in a plume that is assumed to have reached an altitude of 1 km and become dispersed by the wind in a NNE direction to form the EURT (JNREG, 1997). The trace was some 300 km long and 30-50 km wide, creating a contaminated area estimated as being between 15,000-20,000 km^2. Approximately 100 km^2 was defined as being a serious radiation hazard to man (>7.4 MBq m^{-2} ^{90}Sr). More than 10000 inhabitants from 23 settlements had to be relocated following this accident.

The third contamination event occurred between 10th April and 15th May, 1967, when dried-out, contaminated sediments from Lake Karachay were dispersed by wind up to 50-75 km from the Mayak PA site. An estimated 22 TBq was deposited over 1800 km^2, leading to contamination concentrations in the range 11-210 kBq m^{-2} ^{137}Cs (JNREG, 1997). Caesium-137 was the predominant long-lived radionuclide dispersed and may have accounted for 75% of the total radioactive inventory (Aarkrog *et al.*, 1997).

3 Mayak PA Facilities

3.1 Isotope production reactors

One important activity at Mayak PA is the production of radioisotopes for industrial and medical purposes. Two tritium-producing reactors (Ruslan and Lyudmila: Plant 37) are still in operation; the heavy-water moderated reactor Ruslan was put into operation at the end of 1940s to produce tritium and isotopes for nuclear weapons. It was redesigned towards the end of 80s to a light-water reactor with a capacity of ~1000 MW. Lyudmila (LF-2) is a ~1000 MW heavy-water reactor that also produces tritium and various isotopes. Both these reactors have cooling systems utilising water from Lake Kyzyltash (R-2). The Mayak PA radioisotope plant was originally known as Plant BB, the successor to Facility B. It now incorporates several additional laboratories and buildings, and is known as Plant 45. It is one of the world's major suppliers of radionuclides, radiation sources and radionuclide preparations. It has supplied companies in Europe and the USA with a large variety of products including α, β, γ and X-ray sources, fast neutron radiation sources, heat sources (^{90}Sr and ^{238}Pu based) and a wide range of radioactive isotopes such as ^{14}C, ^{137}Cs, ^{60}Co, ^{241}Am, ^{238}Pu, ^{237}Np, ^{193}Ir and ^{147}Pm (with specific activities up to ~11 TBq g^{-1} and ~30 TBq g^{-1} for ^{60}Co and ^{193}Ir, respectively).

3.2 Central Works Laboratory

The Central Works Laboratory (CWL) was founded in 1947 and comprises of a number of smaller laboratories which work on nuclear and radiation safety as well as environmental monitoring and remediation projects (e.g., in-filling Lake Karachay).

3.3 Reprocessing Facilities

3.3.1 Reprocessing SNF from nuclear power plants

The first facility at Mayak PA for reprocessing irradiated fuel, plant (RT-1), was completed in 1977 on the site of the original Facility B. Since then, Mayak has reprocessed SNF from VVER-440 PWR, BN-350 and BN-600 fast breeder reactors (FBR), research reactors and nuclear vessel power units. Most reprocessing has been of VVER-440 SNF. RT-1 is equipped with a storage pond for spent fuel, two lines for reprocessing, using a version of the PUREX (purification/extraction) solvent extraction process and one line used for cutting and dissolving fuel. After delivery in specially built railway wagons, SNF is stored in the cooling pond for three years or longer before being chemically processed to separate fuel-grade plutonium and uranium from other waste products, which are then vitrified (see section 3.6.2). The facility's capacity (based on VVER-440 SNF) is 400 MT yr^{-1} (MT = metric tonne

uranium in fuel assemblies). According to Rosatom website data, RT-1 had reprocessed about 3500 MT of SNF by 2001, of which 3100 MT was from VVER-440 reactors, corresponding to about 35 MT of reactor-grade plutonium (source: Nuclear Threat Initiative, NTI). The plutonium is stored at Mayak in the form of powdered PuO_2. Almost all the uranium extracted from the SNF is sent to the Ust-Kamengorsk fuel fabrication plant in Kazakhstan, though some remaining uranium solution is blended with HEU to produce uranium with an enrichment of about 2.0% that is suitable for RMBK reactor fuel.

In 2000 the output at RT-1 was about 25% of capacity i.e., between 120-150 MT yr^{-1} (corresponds with NTI data, 126.4 MT in 2000). This under-production may be related to technical problems, increased costs of transportation and reprocessing SNF, maintenance costs and licensing restrictions on the amounts of LRW that can be discharged into the Techa Reservoir Cascade (TRC, see section 3.6.5).

Until 1996, Mayak PA has had reprocessing contracts with Finland, Germany, Hungary, Ukraine, Bulgaria, the Czechoslovakian Republic, Armenia and Slovakia. However, billing practices whereby the exporter had to pay all costs of transportation, and Russian legislation requiring the vitrified HLW to be transported back to the country of origin after 25 years of interim storage (source: NTI) decreased the amounts of SNF being sent to Mayak PA e.g., both Finland and Bulgaria constructed their own interim dry storage facilities to give more flexibility to their nuclear waste management needs. Finland's last shipment of SNF was in December 1995; future shipments were banned in 1996 due in part to environmental concerns. In 2001, the Russian lower house of parliament (Duma) passed a bill that would authorize the Russian government and private businesses to import SNF for reprocessing, without any commitment to return radioactive waste products. The then Atomic Energy Ministry (now Rosatom) hoped to earn some US $20 billion with this scheme, though foreign contracts have still not materialized, apart from a 20 MT planned shipment from Bulgaria in 2003.

The Russian Federal Inspectorate for Nuclear and Radiation Safety (Gosatomnadzor, GAN) refused to renew Mayak's reprocessing operating license in January 2003, citing the continued dumping of low- and medium-level radioactive waste into Lake Karachay and the Techenskiy (Techa) water reservoir system. However, on 5th March 2003, GAN renewed Mayak's Plant 235 operating license contingent on the phase-out of disposal of liquid radioactive wastes into the Techa reservoir system by 2008-2010 and introduced monthly inspections regarding the disposal of waste (souce: NTI).

A view across reservoirs 4 and 10 at Mayak PA. *Photo: NRPA*

3.3.2 Reprocessing SNF from dismantled nuclear submarines

Mayak PA also reprocesses SNF from dismantled Russian nuclear submarines (NS). By 2005, 195 NS had been decommissioned. Another 30 NS are waiting dismantling and still have SNF onboard, though the reprocessing capacity at Mayak PA is not considered to be a limiting factor for NS decommissioning.

A total of 48 newly upgraded 40-tonne metal-concrete casks (TUK-108) that were developed, produced and tested under the AMEC programme (Arctic Military Environmental Cooperation between Russia, Norway and USA) have been produced. These casks, together with the older TUK-18 casks, provide transport of SNF to Mayak from dismantling sites in the North West and Far East of Russia. A further 25 TUK-108 casks are to be produced under the US-Russian Common Threat Reduction programme (CTR). Two special trains are used for transporting SNF. One of the trains was built and commissioned with Norwegian finance in 2002; a new train is also planned using CTR finances. In 2000, the line used for reprocessing NS SNF at Mayak was substantially upgraded, including installation of a new vitrification plant (CEG, 2003) giving Mayak the potential capacity to reprocess NS SNF from 20 NS yr^{-1}. However, the SNF buffer storage at Mayak is "nearly filled" and a temporary storage would improve safety in case of unplanned shutdowns at Mayak. Therefore, building an interim storage for 154 casks has been agreed using CTR finances. Some NS SNF is reportedly "not suitable" for reprocessing due to deformation and/ or chemical content – it is unclear from the available literature how much unsuitable SNF exists or what storage/ processing options are being considered.

3.4 MOX – Facts and Facilities

3.4.1 MOX and the Plutonium Disposition Agreement

Use of MOX fuel in NPPs (mixed oxide – blended Pu with U) is seen by the nuclear industry as a viable way of decreasing stockpiles of weapons-grade Pu. In addition, new reactor-grade Pu is generated as uranium oxide in the fuel is transformed to Pu during irradiation ($^{238}U \rightarrow {}^{239}Pu$). After irradiation, the MOX fuel rods can be reprocessed and the Pu re-used, forming a closed fuel cycle for Pu.

On 01/09/2000, the US and Russia signed the Plutonium Disposition Agreement in which both countries were committed to "dispose" of 34 MT of their weapons-grade Pu stockpiles in a form that is inaccessible for use in weapons: e.g., the "spent fuel standard", which can mean immobilised (mixed with HLW and vitrified in glass or ceramic) and /or converted to MOX fuel. The Agreement is scheduled to commence in 2007, with both parties disposing of 2 MT yr^{-1}. The US was to convert 25 MT Pu to MOX and immobilise 9 MT Pu. Russia agreed to convert all 34 MT to MOX fuel. Both parties agreed that no reprocessing of spent MOX fuel could begin before all 34 MT of Pu were disposed of. The costs of this Agreement (developing MOX fabrication facilities, building new and re-fitting existing reactors) were to be borne by G-8 nations though despite rhetorical statements of support, financing has been a continuing problem. As of today, Russia does not have industrial-scale MOX production facilities.

3.4.2 Complex 300 (aka A-300 & Shop 300)

Construction of this MOX fabrication plant at Mayak PA started in 1984 and stopped in 1991, with the facility about half-finished. This facility was destined to receive German (Siemens) reprocessing equipment from the now abandoned Hanau MOX plant in Germany. However, Germany pulled out of its trilateral cooperation (Germany, France and Russia) in 2002 and use of the Hanau components was a political hurdle for the German government. Complex 300 was planned to fabricate up to 900 MOX fuel assemblies per year for BN-800 reactors that are still "under construction" at South Urals and Beloyarsk NPPs.

3.4.3 Zhemchug, Granat and Paket plants at Mayak PA

Zhemchug plant operated through 1986-1987 and produced 35 kg Pu yr^{-1}, equivalent to about 5 Pu fuel assemblies per year, for fast neutron reactors. Granat plant started pilot production of MOX fuel in 1988 – producing about 10 fuel assemblies per year. It was shut down in 1997 due to safety reasons and was still closed as of April, 2001 (source: NTI). The Granat plant is still non-operational. Paket plant was constructed between 1980 and 1993, when it produced 100 kg of MOX fuel (equivalent to about 3 fuel assemblies for testing in BN-350 and BN-600 reactors). The plant has produced over 2000 MOX fuel elements to date. Paket was designed to have a capacity of producing 40 MOX assemblies per year though it is not clear whether it has achieved this to date.

3.5 Storage Facilities

Storage at Mayak PA can be divided into storage of fissile and/or reactor-grade radioactive materials and the storage of waste products, both "historical" from weapons production and "contemporary" from reprocessing activities. According to inventory estimates made in 1990, some 30,000 PBq of solid and liquid waste had been accumulated at Mayak (JNREG). Mayak is also one of the two principal storage sites for HEU and plutonium recovered from dismantled weapons. The second storage site is at Seversk, a third is situated at Zheleznogorsk (previously known as Tomsk-7 and Krasnoyarsk-26, respectively). In addition, Mayak has a reactor-grade plutonium stockpile of approximately 30-40 MT that has accumulated from its civil reprocessing program (source: NTI).

3.5.1 Fissile Material Storage Facility

This facility (FMSF) is part of a US-Russian collaboration funded by the US Department of Defence's Cooperative Threat Reduction (CTR) program. Originally, the two-building facility was designed to store 12,500 dismantled nuclear warheads in 50,000 purpose-built canisters. Re-evaluation of storage and budget requirements has meant that only building one has been constructed – the building, completed in December, 2003 (a concrete fortress with 7 m thick walls and an 8 m thick roof) has a capacity to store 200 MT HEU and 50 MT Pu (25,000 canisters). The Mayak press service reported that 25 MT of excess plutonium is to be stored there (01/07/2003, statement from the Russian Minister of Atomic Energy) and the projected lifespan for the facility was 100 years. However, transparency and "other issues" delayed utilization of the facility until 2006. Loading began in July 2006, thanks to the conclusion of a monitoring Protocol. This Protocol provides for a random sampling methodology – any container loaded into the facility is subject to being selected for measurement of the contents via assessment of nuclear radiation.

Each weapon contains about 4 kg Pu, enough to fill 3-4 canisters in storage, allowing the storage of weapons Pu from 6000 to 8000 dismantled nuclear weapons. The number of Pu containing canisters is limited primarily by the heat generated and the facilities cooling capacity. Contrary to design estimates, Russian and US experts concluded in November, 2002, that all canisters could safely store weapons Pu without exceeding the facilities safety limits, giving the FMSF a total capacity of 100 MT weapons Pu.

The US DoE has publicly estimated that about 600 MT of separated Pu and HEU exist in Russia outside of weapons (not all weapons-grade but weapons-usable). Weapons-grade material is defined as Pu with a 239Pu content that is at least 10 times the 240Pu content, or U that is enriched to at least 90% 235U. Some of this material could also be stored at the FMSF dependent on political negotiations between Russia and the US. HEU may or may not be stored at the FMSF depending on if there is excess HEU after weapons dismantling and blending of HEU for delivery to the US under the HEU Purchase Agreement.

Under the U.S.-Russian HEU Purchase Agreement, 500 tons of HEU from dismantled Russian nuclear weapons is to be blended to low-enriched uranium (LEU) by 2013. The

LEU is then sold to the US for use as fuel in commercial nuclear power plants. As of 1 October 2006, 285 metric tons of HEU had been blended and delivered to the US, and roughly 30 tons HEU were being blended per year.

3.6 Waste Storage

Table 1 presents the classification system for radioactive wastes in Russia.

3.6.1 High-level liquid waste

About 2000 – 3000 m^3 of liquid HLW, up to 2200 PBq, is produced each year from reprocessing SNF at Mayak (JNREG, 1997). The amounts and composition of HLW will vary according to what SNF is reprocessed. By March, 1995 about 30,800 m^3 of liquid HLW (15,000 PBq) had been accumulated as suspensions and nitric acid solutions.

The average volumes of liquid waste produced per MT of VVER-440 reprocessed fuel (1997-2000) are 1875, 78 and 13 m^3 MT^{-1} for LLW, MLW and HLW, respectively. Corresponding values for BN-600 SNF are 1552, 59 and 31 m^3 MT^{-1} (EC, 2000). After solvent extraction of Pu and U during civil reprocessing, residual solutions are concentrated by evaporation and can have activity concentrations of up to 2 TBq/l and up to 4 M HNO_3.

HLW solutions are stored in one of 41 specially designed tanks. HLW nitric acid solutions (military waste) are stored in 18 cylindrical stainless steel tanks inside separate cells lined with stainless steel. These reinforced tanks have a diameter of 9 m, height of 5 m and an effective volume of 285 m^3. According to JNREG (2004) storage of HLW in these tanks represents no risk of a criticality accident.

Table 1: The classification system for radioactive waste concentrations in Russia.

Classification	low	intermediate	high
Solid α (per kilogram)	370 Bq – 37 kBq	37 kBq – 370 MBq	>370 MBq
Solid β (per kilogram)	7400 Bq – 3700 MBq	3700 MBq – 3.7 GBq	>3.7 GBq
Liquid (per litre)	<370kBq	370 kBq – 37 GBq	>37 GBq

Waste materials are classified as solid or liquid in Russia (EC, 2000)

Evacuated village Metlino, Reservoir 10 *Photo: NRPA*

The tanks are assumed to contain about 370 PBq each (JNREG estimated value), mostly ^{137}Cs and ^{90}Sr. Military and more recent civil reprocessing HLW waste is stored in 3 cylindrical stainless steel tanks with an effective volume of 1500 m^3 that began operation in 1960 (22 m diameter and 4.25 m in height). All the above tanks are equipped with level, temperature, pressure and gas emission monitoring systems as well as leakage collection pipes. One such storage tank was inspected for corrosion in 1976, by being emptied and flushed out with a variety of chemical solutions under high pressure. The internal surfaces and cooling coils were coated with a dense grey coloured deposit that was later washed off by "chemical blasting" (strong exothermic reaction caused by steaming with NaOH followed by strong HNO_3), leading to the routine washing and certification of the tanks in 1978, 1988, 1990, 1995 and 1996. Washing procedures were as follows: 18 HNO_3 washes; 45 steam washes with NaOH; 45 steam washes with HNO_3 and oxalic acid [$(CO_2H)_2$]; 20 cycles of "chemical blasting" (Bradley, 1997).

HLW liquid suspensions are also stored in 20 stainless steel-lined, concrete tanks (19.5 × 9.5 × 7 m) situated on the surface to avoid contaminating groundwater, with an effective volume of 1170 m^3 each. Twelve of these tanks have internal cooling systems; the other 8 do not require cooling (JNREG, 1997). Rising temperature in these tanks was a cause for concern since the early seventies. Lowering the temperature of the stored HLW has been achieved via reducing its volume by alkali treatment that dissolves accumulated Al hydroxides. Details of what specifically is stored in the sludge tanks are difficult to find, other than they contain Al and aluminate ferrocyanide sludges, hydrogen sulphide, hydroxides, perlite, nickel ferrocyanide and manganese with total activities of between 74 to 407 TBq (1986 values). By the summer of 1993 total sludge volumes had been greatly reduced from 108 000 m^3 to 15 000 m^3. Currently produced liquid HLW is evaporated, partially mixed with previously accumulated HLW and experimentally with dissolved sludges (Bradley 1997) and sent for vitrification. Other safety measures employed against possible explosions in tanks at Mayak are limiting the mass concentration of tributylphosphate (TBP) to 0.01% (in sludges 0.5%), limiting the concentration of nitrate ions to max. 8 moles/l and the dilution of gases arising from radiolysis to less than 0.4% by volume.

3.6.2 Vitrification facilities

Research into vitrification at Mayak PA as a way to store liquid HLW began in 1967. The first industrial vitrification facility, built in 1987, was shut down due to a seal failure on the electric current supply leads after about eighteen month's operation. Sludge materials were part of the waste stream at this time, containing crystalline structures with very high melting points that meant the furnace had to be run at higher temperatures than the equipment could tolerate. A second redesigned EP-500/l-r furnace operated from June 1991 until January 1997, exceeding its planned service life by 2.5 years. In total, the facility vitrified the equivalent of 10,500 PBq (285 MCi) of radioactive waste (EC; NTI; JNREG report the same up to 1996) into some 2200 MT of phosphate glass. Historic high-level liquid waste could not be vitrified alone due to the presence of harmful chemicals that would damage the furnace; though blending with current HLW (10-15% historic HLW) made vitrification possible. The highly radioactive sodium-aluminum-phosphate glass produced during vitrification (specific activities of between 7.4 and 22 TBq l^{-1}) was poured into 200 litre casks and stored in steel containers (3 casks per container) held at a specially designed facility. Vitrification was stopped in January 1997, due to an uncontrolled drainage of molten glass causing the breakdown of a conveyor system. This was due to corrosion in the furnace. Construction of a replacement facility was delayed by lack of funding. However, the new furnace, called EP-500 R-3 (designed to process 500 litres radioactive waste/hour throughout its planned six year lifespan), was eventually put into operation in late October 2001. The new furnace was reportedly shut-down from April

2002 until July 2002 for repairs due to malfunction (source: NTI).

The phosphate glass storage facility (Building 120/12) is divided into 7 sections, each with 338 "pits" and a ventilation system. Each pit can hold two of the steel containers and has air-cooling. There are 13 monitoring pits in the first compartment where containers are placed to control for leakage. As of 01/10/1993, 429 pits were occupied, storing 858 containers (JNREG, 2004) with only about 5% of vitrified waste having been transferred to underground engineered vaults (see section 3.6.6).

3.6.3 HLW partitioning

Scientists at Mayak have been developing partitioning techniques for HLW since 1980. The two aims of partitioning are to separate out long-lived radionuclides for eventual underground disposal and separation and purification of radionuclides needed to produce radioisotopes. The favoured method achieved up to 99% removal of ^{90}Sr and ^{137}Cs. The pilot plant UE-35 was put into operation in August, 1996. It functioned for 3 months but then was stopped due to financial difficulties. It re-opened in September 1998. By 2001, UE-35 had treated about 1200 m^3 of liquid HLW (Zilberman and Romanovskii, 2003), creating concentrates of containing a Cs and Sr total activity of approximately 45 million Ci (1665 PBq). The partitioning process has increased the specific activities attainable in vitrified glass, aiming at reducing costs. Further research into partitioning of actinides, refractory elements and technetium has been in progress at several Russian institutes. Such techniques are planned to be utilised on the ~4300 m^3 of historic, military liquid HLW that has a high salt content. Information about UE-35 current operations and status is scarce.

3.6.4 Intermediate-level liquid waste

As of 1997 Mayak produced 16,000 – 20,000 m^3 of liquid ILW per year (JNREG): specific activities are around 370 – 750 MBq l^{-1} with average salt concentrations of up to 15 g l^{-1} (total activity <30 PBq). Liquid ILW originates mainly from drainage, decontamination and extraction solutions. Since 1951, liquid ILW has mainly been discharged into one of two "industrial reservoirs" on the Mayak site: Lake Karachay (R-9) and Staroye Boloto (R-17): e.g., up to 1993 some 4400 PBq and 74 PBq had accumulated in R-9 and R-17, respectively, mostly from historic discharges (JNREG, 2004). Figure 2 is a satellite image showing the location of different Mayak reservoirs.

Swamp area near Mayak. *Photo: NRPA*

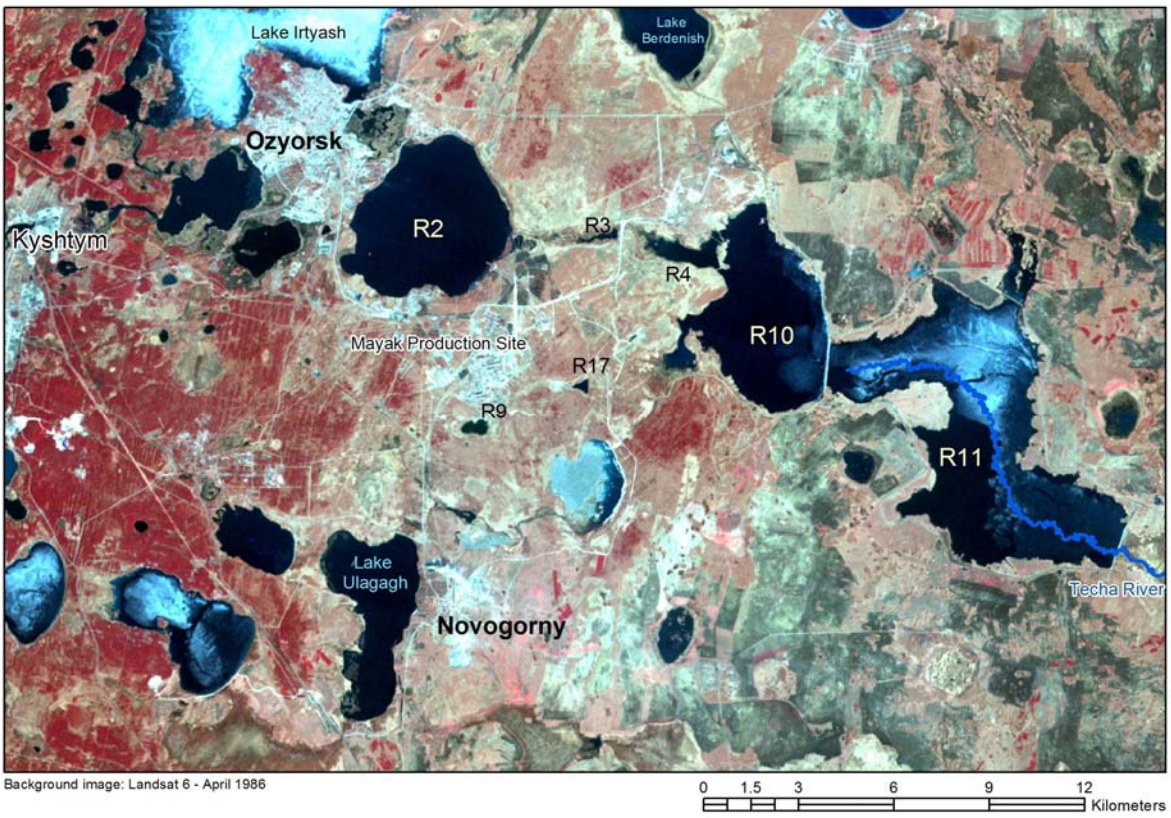

Figure 2: *LANDSAT image from 1986 showing the location of different Mayak reservoirs*

Measurements taken in 1993 (EC, 2000) gave concentrations in water of 70 and 100 MBq l^{-1} for ^{90}Sr and ^{137}Cs, respectively, in R-9. Corresponding values for R-17 were 300 and 150 kBq l^{-1}, respectively. More recent discharges in R-9 are documented to be about 50, 27 and 24 PBq in 1994, 1995 and 1996, respectively (EC, 2000). Corresponding discharge values into R-17 are 21, 4 and 5 PBq of β-emitters. Pollution of groundwater from R-9 is a recognised problem. The plume containing R-9 contaminants was reported to cover some 10 km^2 and be spreading at 80-100 m yr^{-1} (JNREG, 1997; EC, 2000). Plans exist to fill in and cap R-9 with hollow concrete blocks, gravel, and soil and clay layers in an effort to stabilise the site and stop the groundwater contamination plume. Only partial in-filling is believed to have occurred to date. Russian authorities have developed plans to reduce discharges from Mayak PA; according to these plans, discharges to Lake Karachay will stop in 2009 (JNREG meeting in Oslo, November 2005)

ILW in the form of spent reagents and slurries has also accumulated at Mayak. JNREG reported about 400 m^3 of spent reagents (0.37-37 MBq l^{-1}) were stored in stainless-steel-lined tanks. In addition, about 14,000 m^3 of slurries were stored in stainless steel tanks (volumes of 285-1500 m^3): each located in a separate canyon with air-cooling, overflow and temperature monitoring.

3.6.5 Low-level liquid waste

Liquid LLW originates from process effluents such as trap water from the systems sewage network and cooling waters. The raw sewage water (up to 1 million m^3 yr^{-1}) has a maximum activity concentration of 0.56 MBq l^{-1} (i.e. can be classed as ILW, but is usually referred to as LLW) and an average salt content of up to 1 g l^{-1}. It is sent for purification where quartz filters and cation/anion exchangers are used. Purified water should have a maximum concentration of 7 kBq l^{-1} and is discharged into Lake Kyzyltash (R-2), the water supply circulation reservoir.

Cleaning of filters/exchangers generates up to 100,000 m^3 of solutions with maximum activities of 4 MBq l^{-1} (5% HNO_3 and 3-4% NaOH) per year. This is discharged into R-3 which then flows into the Techa Reservoir Cascade, TRC. Discharges into R-3 were about 47, 26 and 28 TBq yr^{-1} in 1994, 1995 and 1996, respectively. Corresponding values for discharges into R-4 were 10, 3 and 15 TBq yr^{-1}.

The Techa River Cascade (TRC, Figure 2) is still used for disposal of liquid LLW. The TRC comprises of four reservoirs (R-3, R-4, R-10 and R-11). The dam for R-3 was built in 1951; the dam for R-4 already existed but was heightened in 1956; the dam for R-10 was built in 1957 and the final R-11 dam was constructed in 1964. Table 2 presents details of the TRC reservoirs.

Seepage of radioactively contaminated water from R-10 and R-11 through dam 11 into the Techa is known to occur: ^{90}Sr concentrations in water samples collected downstream of dam 11 have increased from around 30 Bq/l in 1982 to 90 Bq/l in 2002 (Romanov, 2006). In addition, Asanov Swamp soils and sediments that were contaminated by the early discharges are another source of radioactivity to Techa waters.

The water level in the TRC has fluctuated and generally increased in recent years. This is thought to increase the amount of ^{90}Sr seepage through dam 11 and into the Techa. The average ^{90}Sr concentration in Techa river water sampled at Muslyumovo village (40 km downstream of dam 11) was 6 times the Russian intervention levels in July – August 2004, such that living in this settlement is seen as potentially hazardous to health by the Russian Federal Medical-Biological Agency (FMBA) (Romanov, 2006).

3.6.6 Solid waste

Some 400,000 MT of solid radioactive wastes (SRW) have been produced at Mayak PA up to the 1990s (JNREG, 1997). After the decline in production at Mayak PA, the annual accumulation is estimated as being 2000-2500 MT yr^{-1}. In total some 480 PBq of radionuclides have been buried at Mayak in underground repositories of which about 1.5 PBq were ILW and LLW (buried in containers) and 477 PBq was HLW (buried in concrete containers with multi-layer isolation). Three main areas for solid waste disposal are documented at Mayak:

- Most trenches are located at the oldest repository, 800 m east of R-9
- More recent trenches exist in the western part of the newly covered area of Lake Karachay
- An engineered vault repository (NE of Lake Karachay) for HLW, that is constructed of concrete with bitumen and steel isolation barriers.

Burial sites are situated in areas with clayey soil. Mayak PA has a comprehensive monitoring system were regularly sampling and monitoring takes place around the burial sites to control for groundwater contamination. Most trenches are no deeper than 4 m, though some of the older trenches do become seasonally saturated. SRW containing transuranium elements at any concentration is not buried in trenches or repositories, but is stored in specially engineered vault facilities.

A 1995 inventory revealed there were 230 operating and closed burial trenches and engineered disposal facilities (vaults) at Mayak (EC, 2000). Some 400,000 MT has been buried (data from Mayak PA). About 80% is classed as intermediate/low-level and is buried close to the surface. The remaining 20% is classed as HLW and stored in vaults. Inadequate record-keeping can mean that the official estimates of amounts of SRW buried are somewhat inaccurate. Of the 24 vaults on Mayak PA land, 13 are closed (EC, 2000). Of the total vault area (11,000 m^2), 10,000 m^2 are in use.

About 3200 MT of SRW is concentrated in the closed vaults, with a total activity of some 93 PBq (EC, 2000). Of the 206 near surface trenches, 51 are still operational and used for LLW and some ILW. The total area of all trenches is 115,000 m^2; 13,000 m^2 is still operational. RT-1 produced most of the SRW that was deposited in 1996: 70%, 93% and 85% of the solid LLW, ILW and HLW, respectively (Table 3; EC, 2000). Table 4 presents the EC report estimates of the amounts of radioactive waste that will be at Mayak in 2010AD.

Table 2: TRC areas, volumes and estimated inventories. (Bradley, 1997 [~1991 estimates presented at Environmental Workshop by Soviet Scientists in Washington D.C.]; JNREG, 1997)

Reservoir	Area (km^2)	Volume ($m^3 \times 10^6$)	Estimated inventory (TBq)	Percentage total activity in sediments (%)
3	0.5-0.8	0.78	666	85
4	1.3	4.1-4.3	222	70
10	18-19	76.64	4070 (1200)[a]	5 (25)[a]
11	44	215.74	1443 (1300)[a]	40 (60)[a]

( )[a] – JNREG estimates, 1997: data from 1994 fieldwork

Table 3: SRW disposal at Mayak PA (1994-1996). (Source: EC, 2000)

SRW	SRW buried					
	1994		1995		1996	
	tonnes	PBq	tonnes	PBq	tonnes	PBq
LLW	1680	0.22	1940	0.0011	930	0.0011
ILW	720	1.1	210	0.017	220	0.078
HLW	1790	5.5	340	24	200	9.0
Total	4190	6.9	2490	24	1350	9.1

Table 4: Estimates of radioactive waste at Mayak PA in 2010AD (Source: EC, 2000)

Radioactive waste/location	Activity (PBq)	Volume (m^3)
Liquid MLW		
Slurry in tanks	2.81×10^{-1}	330
Spent extractant in tanks	2.44×10^{-2}	660
Lake Karachay	4.75×10^{3}	930 000
Staroye Boloto	7.41×10^{1}	1 291 000
Liquid LLW		
R2, R3, R4, R6, R10 & R11	1.87×10^{1}	428 658 000
Solid HLW		
Vitrified waste, engineered storage*	5.33×10^{4}	4 917
Engineered repositories (vaults)	5.52×10^{2}	51 184
Waste from decommissioning 5 military reactors	5.03×10^{1}	1 260
Waste from decommissioning 5 isotope production reactors	2.41×10^{-1}	26
Solid MLW		
Engineered repositories (vaults) and trenches	9.15×10^{0}	85 350
Waste from decommissioning 5 military reactors	3.64×10^{-1}	4 260
Waste from decommissioning 5 isotope production reactors	1.71×10^{-2}	200
Solid LLW		
Trenches	5.63×10^{-2}	282 990
Waste from decommissioning 5 military reactors	7.08×10^{-4}	5 128
Waste from decommissioning 5 isotope production reactors	1.25×10^{-4}	922

** assuming all liquid HLW is vitrified and RT-1 decommissioned in 2010AD*

4 Summary and further work

This report gives a brief but comprehensive overview of operations at Mayak PA. Information has been gathered from a variety of sources which have been cross-checked where possible to ensure accuracy. Many data are not complete and up to date, this reflects the military nature of Mayak PA operations in the past and the difficulty in obtaining detailed information about nuclear related industries from the former Soviet Union. Mayak PA is currently the only facility in Russia involved in large scale SNF reprocessing. It is the endpoint for SNF from nuclear submarines, many of which have been decommissioned through funding from western donor countries.

Gaining increased knowledge about the current status at Mayak PA and future plans for this facility is therefore very important. Such information may also be useful to give an insight into the environmental consequences of day to day operations at Mayak PA. Further work should therefore include quantification of the amounts of different SNF being reprocessed at Mayak PA and finding out what management practices are in use. It would also be of great interest to find out more about discharges of ILW in to Lake Karachay and whether plans to stop such discharges in 2009 are on schedule, as well as getting information about current and planned discharges of ILW/LLW in to the Techa River Cascade.

The River Techa downstream of Mayak PA *Photo: NRPA*

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6 APPENDIX

The Joint Norwegian-Russian Expert Group for investigation of radioactive contamination in northern areas (JNREG) was formed in 1993. Since then, this collaboration has resulted in several publications about radioactive contamination in the Kara Sea (1996) and the Mayak PA (1997, 2004) and Krasnoyarsk nuclear facilities (2004) in the FSU.

NTI was established in January 2001 and is co-chaired by Ted Turner and former Senator Sam Nunn. Mr. Turner is the founder of CNN. Senator Nunn served as a U.S. Senator for 24 years (1972-1996). NTI is supported by a pledge from Mr. Turner and other private contributions. NTI is a global initiative, concentrating in the United States, Russia, other nations of the former Soviet Union, and on those regions of greatest proliferation concern in Asia and the Middle East. The main office is in Washington, DC and in January 2002, an office was opened in Moscow. They take info from other sources e.g., CNS (centre for non-proliferation studies).

IBR was established in 1991 as a consulting and engineering organization in the field of high technologies. Sponsors: International Science and Technology Centre, RWE NUKEM Corporation, Marubeni Utility Services Ltd, Knowlegy Experts LLC.

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Virksomhetsplan 2006

StrålevernRapport 2006:2
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