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Past pollution and its remediation in Estonia

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Abstract In spite of its small area and relatively simple geological structure, Estonia is rather rich in mineral resources, the mining of which has caused severe environmental damage and left dangerous pollution. High pollution load was registered in most sites of the Soviet army units, which occupied about 1.9% of the whole Estonian territory. In National Environmental Strategy, adopted in 1997, nearly 40 significant environmental problems were identified. Among ten priority environmental problems past pollution caused by industrial, an agricultural and military activity of the former Soviet Union was mentioned. To date past pollution dangerous to human health is liquidated and thoroughly monitored in most areas and sites.

Keywords *Past pollution, mining activities, ex-military areas, radioactivity, ecological security.*

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INTRODUCTION

On the eve of World War II, Estonia was consigned to the Soviet sphere of influence by the secret protocols of the Molotov–Ribbentrop Pact signed on August 23, 1939. In 1940, the Republic of Estonia was forcibly annexed to the Soviet Union. On March 30, 1990, the Estonian Supreme Council declared Soviet power in Estonia to be illegal from the moment of establishment, and proclaimed the restoration of the independent Estonian Republic. However, the last occupying troops left Estonia finally not until August 31, 1994. During the years under Soviet regime the population of Estonia increased ca 1.4 times, the number of workers and employees ca 3.8 times, the production of mineral resources ca 15 times and the production of electric power ca 100 times. The military installations covered about 1.9 per cent of Estonian territory (Fig. 1). As part of a totalitarian state, Estonia was no longer able to undergo normal development; its economy was centralized under Moscow's control. Environmental pollution from industrial, agricultural and particularly military sources was high.

On March 12, 1997, the Estonian Parliament approved the National Environmental Strategy (Estonian … 1997). Nearly 40 significant environmental problems were identified while analysing the state of the environment and the use of natural resources. The most important aspect underlying prioritisation of environmental problems was the maintenance of human health. The environment affects human health primarily via polluted air, water and contaminated soil. Therefore, among ten priority environmental problems past pollution caused by industrial, agricultural and military activities of the former Soviet Union was mentioned.

ORIGIN OF PAST POLLUTION

The origin of chemical degradation and contamination of soils is complicated. In most cases, the chemicals used in agriculture do not behave as pollutants for soils. Some of them (nitrates) will not accumulate in the soil; others (phosphates, heavy metals) form relatively stable complexes. Contamination of soils with fuels and other oil products is usually a local phenomenon.

The principal factors causing soil pollution in Estonia include: pollutants leached out of oil-shale ash hills; pollutants leached out as a result of phosphorite

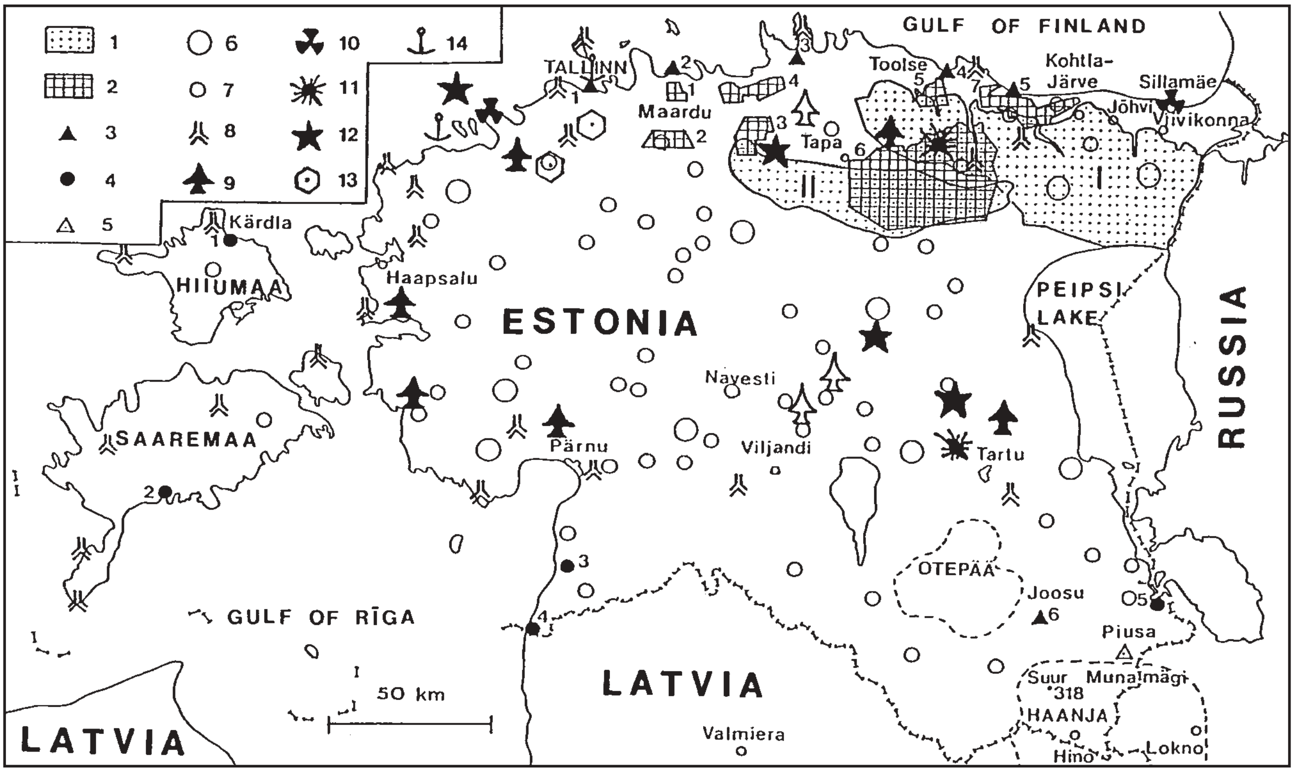

Fig. 1. Main sources of past pollution in Estonia. *A – Mining of mineral resources.* (1) Oil shale: I – Estonian Deposit; II – Tapa Deposit; (2) Phosphorite: 1 – Maardu; 2 – Raasiku; 3 – Kehra; 4 – Tsitre; 5 – Toolse; 6 – Rakvere; 7 – Aseri; (3) Clay: 1 – Kopli; 2 – Kallavere; 3 – Kolgaküla; 4 – Kunda; 5 – Aseri; 6 – Joosu; (4) Mineral Water: 1 – Kärdla; 2 – Kuressaare; 3 – Häädemeeste; 4 – Ikla; 5 – Värska; (5) Sand for glass (Piusa); (6) Peat bogs more than 10,000 ha; (7) Peat in bogs 2,000-10,000 ha. *B – Former military objects.* (8) Missile bases; (9) Airfields; (10) Radioactivity; (11) Explosives; (12) Training areas; (13) Tanks; (14) Military ports.

processing; pollutants washed out of thermal power plants and basins and oil-shale processing plant waste depositories, spillages of oil products and missile fuels at former Soviet military bases; fuel storage (oil products, shale oil) and landfills (hazardous waste) established without any consideration of environmental requirements; pollution from former primitive asphalt pavement plants; waste dumping (storage) by industrial enterprises, abandoned toxic chemicals in former storage areas for pesticides and poisonous substances; illegal dumping of waste, including municipal and hazardous waste; oil pollution on main railway junctions.

According to the Decree of the Minister of the Environment of October 25, 1993 the past pollution is thoroughly monitored through the environmental monitoring system, consisting of state, county and municipal levels. The results of state monitoring constitute a base for political decisions undertaken by the government.

All waste disposal sites (enrichment waste, ash and semi-coke dumps) and former municipal landfill sites have to be prevented. Areas disturbed by the mining industry ought to be reclaimed, aesthetic artificial landscapes created and preconditions for restoration of soil fertility of the disturbed areas established.

MINING ACTIVITIES AS A MAJOR FACTOR OF POLLUTION

Estonia is rather rich in mineral resources (Fig. 1), the mining of which has caused severe environmental damage. Estonian phosphorite deposits (ca 750 million tonnes of P_2O_5) are largest in Europe (Raudsep 1991). Reserves of limestone, dolomite and clay are practically unlimited. Bogs cover 22.3% of the territory with the max thickness of peat 16.7 m. Mineral waters with differing degrees of mineralization and balneological properties are used in many parts of the Republic.

Fig. 2. Blasting operations in Narva opencast. Photo by A. Raukas, 2003.

Curative sea muds have been used since the beginning of the 19th century. Serious ecological problems relate to the world's largest exploited oil shale deposits in NE Estonia (Fig. 2), supporting the generation of electric power (80% of the total mined) and the chemical (20%) industry. Proven oil shale reserves are estimated at 3800 million tonnes, possible reserves are considered much larger.

Alum shale (up to 60 billion tonnes) is rich in uranium and other (Mo, V, Th, Re a.o.) valuable microelements. During the opencast mining of phosphorite at Maardu in the neighbourhood of Tallinn *Dictyonema* argillite (alum shale) rich in uranium (average 80-120 g/t, maximum 300-450 g/t) was deposited in waste dumps. In 1989, opencast mining at Maardu was carried out in an area of 6.36 km^2. Waste hills at Maardu contain 73 million tonnes of alum shale. If there were only 30 g of U per tonne of alum shale, then 2.19 million kg of uranium would leach into surface and ground waters and reach the Gulf of Finland (Veski 1995). As a result of mining activities, both air and water are polluted, and natural landscapes spoilt in about 8% of the Republic's territory (Raukas 1994).

POLLUTION LOAD ON GROUNDWATER

As a result of extensive economic activities, high vulnerability of the uppermost aquifer and due to a thin aeration zone (mainly 1.5-3 m), the shallow groundwater is in places heavily polluted and unfit for drinking. In 1990 the groundwater did not meet the requirements established for drinking water in 40-70% of the total number of shallow wells (depth up to 15 m) in southern, 20-40% in northern, 30-60% in central Estonia and in 10% of wells on the islands of the West-Estonian Archipelago (Põllumajanduslik ... 1994). Extensive fuel leakages occurred on military airfields and in railway junctions. In the Ida-Viru County, essential point-pollution sources are the spoil heaps of oil shale mines and ash plateaus of Narva thermal power plants. Cracking processes accompanying fires in oil shale mines has caused extensive surface and groundwater pollution. In the regions of agricultural activity, mainly nitrogen compounds contaminate groundwater, but the concentration of chlorides and sulphates is also rather high. As a result of dewatering of oil-shale mines, the groundwater level of Quaternary and Ordovician aquifers has lowered by 15-65 metres and several local cones of depression, influencing each other, have formed over an area of 600 km^2 (Vallner 1997).

POLLUTION IN EX-MILITARY AREAS

After the withdrawal of Russian troops, Estonia regained the control of approximately 87,000 hectares of land under the former military sites suffering from a high pollution load. The largest area (more than 30,000 ha) in possession of occupational troops was the artillery range at Aegviidu followed by military airfields at Tapa (771 ha), Tartu (682 ha), Pärnu (731 ha), Ämari (930 ha) and Haapsalu (799 ha) and the missile bases at Karujärve (1218 ha), Sõrve (1647 ha), Sänna (543 ha), Kaidla (941 ha) and Keila-Joa (480 ha). All these sites were heavily contaminated by oil products, chemicals, demolished buildings and domestic waste (Raukas 1999). For instance, so much fuel has been dumped into the ground at the military airfield at Tapa that the soil and water in the town were almost completely polluted. Water was undrinkable in an area of about 16 sq km. In some drill holes the free petrol layer was more than 5 m thick. The amount of free oil under the surface was estimated at 400-1600 tonnes. Several big accidents, as a result of which thousands of tonnes of fuel went out of control, took place at the Sillaotsa fuel storage of the Tartu military airfield. As a result, the upper soil layer in an area of 20 hectares was saturated with oil products, in some places to a depth of 3.5 metres (Raukas 1999).

A very serious problem relates to the pollution of soil and ground water by samine, a toxic alkaline component of liquid rocket fuel, which consists of about 50% of triethylamine and 48% of xylidine. The spill of some 10-15 tonnes of samine at the Keila-Joa missile base west of Tallinn (Fig. 3) has contaminated an area of 32 hectares.

Fig. 3. Keila-Joa missile base west of Tallinn. Rockets with nuclear heads were located in such vertical shafts. Photo by A. Raukas, 2003.

The withdrawing army left behind a large amount of different waste, including scrap metal, tyres, accumulators, plastic waste, debris, etc. The low-quality constructions far away from settlements cannot be used for civil purposes and must be pulled down. The total extent and load of different kinds of pollution was estimated as follows: oil pollution in an area of 4100 ha; waste of iron, steel and non-ferrous metals – 158,000 tonnes on 2600 ha; mineral construction waste – 365,000 tonnes on 700 ha. There were about 5080 tonnes of oil products in tanks and containers, more than 170 tonnes of lead accumulators, 2800 tonnes of hazardous chemicals, 2900 tonnes of rubber and plastics waste, 160 tonnes of paint and varnish waste, more than 12,000 tonnes of manure and privy waste (Raukas 1999). There were more than 50 sunken warships, including a whishey-type submarine, in the Estonian coastal waters. Nineteen Russian warships, missile launching ships, mine sweepers and submarine destroyers were detected in the area of Miinisadam harbour in Tallinn. Lifting these ships up from the sea bottom was a very difficult task, because many of those wrecks were heavily corroded and could broke during the upheaval. Besides, they contained oil that could have flown into the sea if they had been cut into pieces in the water.

Up to 1996, the assessment and liquidation of pollution were mainly carried out at the sites where the pollution load was high or very high. During 1992-1995, environmental damage was assessed at 175 former military sites; 50 sites were subject to detailed studies. To date, military pollution is liquidated in most areas.

For the purposes of past pollution elimination, special acts were approved to enact the liabilities of the site owner for environmental pollution and damage as well as the responsibility to eliminate past pollution in the case where ownership changes.

RADIOACTIVITY PROBLEMS

In the spring of 1945, after the discovery of uranium in Estonian alum shale, a high-level meeting attended by L. Berija, K. Voroshilov, G. Malenkov and some other high ranking members of the Soviet Government, as well as leading scientists (P. Kapica, M. Althausen) took place in the Kremlin, where the problems of uranium production from Estonian alum shale were discussed. Production of uranium concentrate was undertaken at Sillamäe, NE Estonia. The data about the production technology and wastes were kept top secret. It was only in April 1992, when the Russian Ministry of Atomic Energy notified for the first time the Chairman of the Presidium of the Estonian Supreme Soviet of what was going on in that region.

The Sillamäe Plant

The plant was built in 1948 originally for processing alum-shale from Estonia and afterwards uranium ore from eastern Europe (Nosov 1995). In the beginning of the 1970s, the plant switched to processing loparite – a mineral from the Kola Peninsula rich in niobium, tantalum and other rare earth metals. Besides, it also contains elevated concentrations of uranium (about 0.03%) and thorium (0.6%). A total of more than 4 million tonnes of uranium ore and about 140,000 tonnes of loparite were processed at the plant during 1948–1977.

The waste from the uranium processing was conveyed to the first marine terrace of the Päite Cape near the plant and stored on the surface until 1959, when a waste tailings pile was established. The pile has been reshaped a couple of times and in 1969/70 it was expanded to its present size with an overall area of some 350,000 m^2 and height of about 25 m above sea level (Fig. 4). It contains ca 12.4 million tonnes of various wastes, including 6.3 million tonnes of waste from processed uranium ore and 6.1 million tonnes of oil-shale ash mixed with waste from loparite processing (Ehdwall et al. 1994). The estimated amount or naturally occurring radionuclides in the depository includes some 1830 tonnes of uranium and 7.8 kg (3×10^{14}Bq) of radium, which are stored under the open sky at the waterfront of the Gulf of Finland. The dose rate in the depository varies between 0.5 and 35 μSv/h. The estimated annual amount of effluent from the tailings pond to the Gulf is some 300,000 to 500,000 m^3 (Putnik et al. 1996).

Fig. 4. Protection works in Sillamäe tailings pile in May 2003. Photo by A. Raukas.

The waste tailings exhale great amounts of radon into the atmosphere. The mean concentration of radon in outdoor air measured near the tailings pile between September 1992 and May 1993 was 310 Bq/m^3 (Putnik et al. 1996). Between August 2002 and June 2003 after the remediation works, even on the surface of the tailings pond the radon exhalation rate varied in very low limits (0.05...12 Bq/m^{2}s), occasionally exceeding the target value.

Radon studies

In 1994, the national radon monitoring programme was initiated by the Ministry of the Environment. It addressed a nationwide study of radon levels in dwellings in order to identify the radon risk and construction types of buildings. The alphatrack radon detectors were exposed for three months during heating seasons in dwellings of Tallinn, Kunda and Toila on the northern coast of Estonia. The area is recognized as a potentially high radon risk region because of its geological structure; in several places the bedrock consists of alum shale rich in uranium and is covered only by a thin Quaternary cover. In total, 160 dwellings were studied in Tallinn, 80 in Kunda and 46 in Toila during the heating seasons of 1993/94 and 1994/95. The average and maximum radon concentrations were 60 and 630 Bq/m^3 for Tallinn, 160 and 1400 Bq/m^3 for Kunda, 304 and 880 Bq/m^3 for Toila (Pahapill et al. 1993, Pahapill & Rohumäe 1996). In 1997, the National Survey of Radon in Estonia started: indoor radon was measured in 550 randomly selected dwellings. The highest measured radon level was 6700 Bq/m^3 (Pahapill 2003). With regard to the types of construction, the highest radon risk relates to the buildings, which have no basement.

Radiation level

The radiation level in the environment in Estonia has been monitored from the beginning of the 1960s by local branches of central authorities of the former Soviet Union. In addition, some studies were performed in scientific institutions. However, the results were secret or meant for limited official use only (Johannes et al. 1979, a.o.).

Currently, the environmental radioactivity monitoring is carried out in co-operation with the Estonian Meteorological and Hydrological Institute and Estonian Radiation Protection Centre. Depending on different rocks and geological structures there are clear variations in radioactivity (Putnik et al. 1996).

The content of radioactive minerals in Estonian basement and bedrock is variable. In the granites of North Estonia the maximum concentrations of uranium are up to 928 g/t and thorium up to 3215 g/t (Raudsep et al. 1993). In the Palaeozoic bedrock the highest concentrations of uranium are connected to Lower Ordovician alum shales (*Dictyonema* argillites).

Serious measures were taken at the Sillamäe Plant to protect the environment. It was necessary to: (1) evaluate and recultivate of 100 hectares of land suffering from radioactive pollution; (2) built a new waste disposal storage; (3) liquidate of radioactive and toxic wastes with ash stockpiled in an area of 40 hectares; (4) deactivate former, radioactively polluted metal storages in an area of 20 hectares (Althausen 1992).

Protection works of the tailings pile will be finished in 2006 (Fig. 4).

Paldiski training centre

Serious radioactivity problems were related to the Paldiski nuclear submarine training facility for the USSR Navy (Kink et al. 1995). The facility included two scaled submarine mock-ups, one Delta and one Echo class, each containing an operational nuclear reactor (Sinisoo 1995). Construction of the facility began in the early 1960s with the first training submarine going critical in 1968 with 70 MW$_t$ reactor. A second training submarine was added in the early 1980s and went critical in 1983 with a 90 MW$_t$ reactor. The reactors were operated into 1989. Beside the two reactor compartments, the main Technological Building contained a spent fuel storage pool and some associated rooms, all were radiologically contaminated.

The area under the training centre was approximately 22 hectares. Both training submarines were housed within a single building in a common high bay area (Fig. 5). The auxiliary site facilities included a liquid waste processing facility, storage buildings for solid and liquid radioactive waste, a central facility ventilation centre, cooling towers, a cooling water pump facility, a central heating plant, a radioactive laundry facility, and a radiochemical laboratory. In 1994, when part of the negotiated Russian troops withdraw from Estonia, Russia agreed to defuel and safe store the reactors prior to September 30, 1995, when the control of the site was to be transferred to Estonia. Under Russian control, the spent fuel from the reactors was transferred to Russia in October 1994. Russian preparation for safe storage of the two reactors included dismantling of non-active components and systems related to reactor operation and some of the associated auxiliary facilities. Russia also undertook the construction of two concrete sarcophagi around the remaining submarine hull sections containing the reactor vessels, but did not take care of the clean up of the contaminated areas and conditioning of the radioactive wastes (Putnik et al. 1996).

Fig. 5. This building on Pakri Peninsula accommodated two submarines, both with operational nuclear reactors. Photo by A. Raukas, 2004.

The Chernobyl fall-out

Fall-out was very inhomogeneously distributed over the territory of Estonia, the maximum ^{137}Cs deposition level reached 40 kBq/m^2 in 1986, while the country-wide mean was 2.0 kBq/m^2 (Realo et al. 1995). It was estimated that about 60% of the total radiocaesium fall-out for Estonia deposited in its north-eastern part. The Chernobyl fall-out approximately doubles the mean deposition of ^{137}Cs from nuclear weapons tests (2.2 kBq/m^2) in the county. Fortunately, no serious damage in the soil, water and plant cover was discovered as a result of the catastrophe. In many places, the concentration of ^{137}Cs in fungi was higher than the maximum permissible concentration. The highest ^{137}Cs content (41.89 kBq/kg) was found in NE Estonia in the fungus *Leccinum scabrum*. Somewhat lower concentrations were registered at Häädemeeste (16.57 kB/kg in the fungus *Tricholoma flavovirens*) and Põltsamaa (12.06 kB/kg in the fungus *Clitocype* sp.). As a rule, the concentration of radiostrontium in fungi was low (13-50 Bq/kg; Martin 1991).

Radioactive waste depositories

Since Estonia has neither a nuclear power programme nor nuclear research reactors, a radioactive waste depository was needed for waste arising mainly from the use of radionuclides in medicine, research and industry. In 1963, the waste management facility for low and intermediate level waste was founded at Tammiku, 12 km from Tallinn. The facilities were established in accordance with the criteria developed in Moscow at the end of the 1950s. At Tammiku a 15×5×3 m concrete vault providing 200 m^3 disposal capacity for solid radioactive waste was constructed. The vault is divided into nine compartments 1.6×5×3 m by walls made of concrete. For storage of liquid waste, there is a 200 m^3 underground cylindrical concrete tank with stainless steel lining, the internal diameter of the tanks is 9 m and the height 3.2 m. Both storages are located below surface (Putnik et al. 1996).

In Estonia, radioactive waste is not treated at the place of its generation, except for the storage for decay. All the waste generated by the use of radionuclides, which cannot be treated as non-radioactive material, was transported to Tammiku where the solid waste was disposed of the concrete vaults without any conditioning. During 30 years, 1028 burials of radioactive waste took place. As of January 1993, some 97 tonnes of waste with total activity of about 200 TBq (5400 Ci) and with remaining activity of about 76 TBq (2050 Ci) had been buried in the depository (Putnik et al. 1996).

As the radioactive waste depository at Tammiku did not meet the current radiation safe and environmental protection requirements, it was closed in 1996. Wastes will be transformed up to 2006 to Paldiski depository and by the year 2010 a new depository, meeting the requirements of the European Union, will be built.

Radiation accidents

In the beginning of the 1990s, Estonia served as a bridge for reselling scarp metal from the republics of the former Soviet Union to the West. Quite often, radiation sources or radioactive pieces of metal, particularly in the scarp metal, were discovered in the country.

A total of sixteen ^{137}Cs sources were stolen from different Estonian plants during 1992–1994. Besides, eleven unknown radiation sources were found in 1993 and 1994. The most dramatic occurrence involved the accident in the settlement of Kiisa near Tallinn in 1994, where a high-level ^{137}Cs source was discovered in the kitchen of a family house. The man, who had stolen the source from the Tammiku depository, died after a week from acute radiation sickness. The other members of the family received different doses of radiation.

Being not safeguarded against incidents like that at Kiisa, and considering the circumstance that Sosnovy Bor, close to the Estonian border in the Leningrad District, holds a nuclear power plant, analogous in construction to that at Chernobyl, we are convinced that the early warning radiation system is urgently needed. In order to prevent illegal transportation of radioactive material across Estonia's borders, the main frontier posts were equipped with hand-held radiation devices and the frontier post at Narva also with a vehicle monitor (Putnik et al. 1996). The system needs to be expanded in future.

Foreign aid

Five countries in CEE (Poland, the Czech Republic, Russia, Hungary, and Romania) received 45 percent of foreign government–sponsored technical assistance and 56 percent of bilateral and multilateral investment during the mid-1990s (Auer 2004). But on a per capita basis, Estonia, Latvia and Lithuania received the largest outlays on government-to-government financing, multilateral credit, and technical assistance among CEE nations (Organization ….. 1999). Virtually, EU environmental-related funds to Estonia in the 1990s and early 21st century were grants. Between 1990 and 2003, the EU's PHARE and ISPA programs spent nearly 52 million US$ on environmental projects in Estonia with the peak in 2001 at around 15.2 million US$. Nordic countries, and in particular Finland, provided millions more for a variety of projects (Auer 2004). It means that EU and our neighbouring countries made an important, positive contribution to Estonian environmental efforts in the post-communist transition period.

PRESENT SITUATION

Environmental policy reforms in Estonia were successful. In June 2001 Estonia's environmental law chapter was provisionally closed – part of the lengthy process of transposing the European Union's legislation into Estonia's own. At that point, according to European Report 2001, Hungary and the Czech Republic were the only other CEE accession countries to have successfully incorporated EU environmental directives into national legislation. Coupled with the toxic mess left by Russian army air force units Estonia confronted the most expensive environmental cleanup task of the newly independent Baltic Republics (Auer 2004). On a day-to-day basis, Estonia's greatest environmental insults are generated by the oil-shale industry. After operating for more than forty years, the oil shale-fired power plants left indelible marks not only on Estonia's environment but also on that of countries downwind of the Narva energy complex. By the end of the Soviet era, Estonia's power plants ranked among the ten largest stationary source emitters of sulphur dioxide, nitrogen oxide, and dust in Europe. The situation here has improved fast, but sometimes far from the necessary quality.

The most important and consequential examples of policy-driven environmental reform in Estonia included: vigorous cleanup of ex-military sites, which began in the early nineties; the overhauling of Tallinn's obsolete sewerage system; and investments in pollution abatement in primary industries that survived the economical recession (Auer 2004). Biochemical oxygen demand (BOD) from Tallinn treatment works declined from 100 milligrams per litre in 1991 to 4 milligrams per litre in 1998. Dust emissions from Kunda Cement Plant dropped more than 99 percent during the 1990s and by decade's end, sulphur dioxide emissions from Kehra Pulp and Paper Mill were reduced by more than 90 percent over 1991 levels (Auer and Raukas 2002).

However, unemployment, and in some districts, persistent economic recession, have had negative indirect effects on the environment, including on the country's smallholder forestlands and the decline of a unique natural treasure in Estonia – meadows. These ecosystems are highly complex and rich in plant species diversity, habitats for many animals. Due to the decline of agriculture, absence of grazing or other interventions, meadows tend to revert to scrubland forest or marsh.

Estonia has already demonstrated it can improve both economic and environmental conditions for citizens but much must be done in the coming future.

CONCLUSIONS

During the Soviet occupation not much attention was paid to the nature protection problems and industry; military troops and agriculture left behind heavy contamination. The former high pollution load is, for the most part, liquidated and thoroughly monitored. Great help in guiding Estonia's environmental restoration played foreign investments and technical assistance. At the present, growing disparities between urbanites and agrarians exist and much must be done in providing environmental services to small rural towns and hamlets.

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