

**URANIUM PRODUCTION IN EASTERN EUROPE AND
ITS ENVIRONMENTAL IMPACT: A LITERATURE SURVEY**

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ACRONYMS AND INITIALISMS

ECE	Economic Commission for Europe
GDR	German Democratic Republic
ISL	in situ leaching
MlbU	million pounds of uranium
MTU	metric tonnes of uranium

EXECUTIVE SUMMARY

A survey of the unclassified literature was made to determine the location, technology, throughput, and environmental status of the uranium mines and mills that have historically made up uranium production capability in Eastern Europe. Included in that survey were the following countries: the former German Democratic Republic (GDR), now part of a reunited Germany, Czechoslovakia, Romania, Bulgaria, Hungary, and Poland. Until recently, uranium was being produced in five of these six countries (Poland stopped production 20 years ago). The production began directly after World War II in support of weapons production in the Soviet Union. Eastern Europe has produced about two-thirds of the total Soviet uranium inventory historically, or about 330,000 metric tonnes of uranium (MTU) [730 million pounds of uranium (MlbU)] out of a total of about 490,000 MTU (1090 MlbU).

Currently, the customer for their uranium has become the Free World market. Because the cost of producing uranium in these countries has historically been significantly higher than required to compete on this market, each country has re-evaluated its position. Today, only Czechoslovakia, Romania, and Hungary remain as uranium producers, and their level of production is matched to their own needs within each country.

Uranium production areas were found in all countries. The former GDR has three production areas, each containing a mill, and a total of six mines; all are located in the southeastern portion of the country close to the Czechoslovakian border. Czechoslovakia has four production areas including three mills and a total of more than 17 mines; all are located in the western (Czech) portion of the country. Bulgaria has three production areas including two mills, but the number of mines was not specifically found; they are located in the west and southwest portions of the country. Romania has three production areas and one mill (although specific reference to this was not found). No specifics on the mines were found. Hungary has one production area containing one mill and five mines; this area is in the southwestern portion of the country in the Mecsek mountain area. Poland has one production area containing one mill and three mines; this area is in the southwestern portion of Poland in Jelenia Gora province near the Czechoslovakian border.

For a number of reasons, environmental control has been minimal at these uranium production sites; however, this is true not only for these sites but also for the whole of Eastern Europe and the Soviet Union. A major reason is the forced rapid industrialization that the Soviets dictated after World War II. This placed great stress on the environment in all the Eastern Bloc countries because of their lesser resources and consequently resulted in the environmental crisis that Eastern Europe is generally regarded to be in today.

Information was found concerning the environmental status of only a few of the uranium production sites; however, most of the problems that these sites have also apply generically to the others to a greater or lesser degree. The three major problems are:

1. Mine shafts. These tunnels and cavities stretch for thousands of miles under mostly mountainous landscape, some as deep as 1829 m (6,000 ft). These empty cavities must be remediated but only after the hazardous and toxic materials, steel supports, rail tracks, and air-conditioning equipment have been removed.
2. Mine waste tailings and mill waste ponds that represent the waste products of the mining and milling processes. These wastes contain uranium and its daughter products radium and radon gas. These radionuclides make uranium mining and milling the highest health risk area in the nuclear fuel cycle because their presence in the solid and liquid waste provides a source that continues to release over time, causing an increasing integrated exposure to the public.
3. Other pollutants. Separating the uranium from the ore involved dissolution with sulfuric acid and caustic solutions that were discarded and collected in mill waste ponds where the waters were gradually fed into local rivers and streams. Such waters contain significant quantities of toxic substances. For sites that utilize in situ leaching (ISL) technology rather than conventional mining technology, the potential for sulfuric acid leakage into the water table is of greater concern unless the site geology is such that this leakage is not a problem. ISL technology has been used at sites in the GDR, Czechoslovakia, and Bulgaria.

While very little information judged to be trustworthy was found concerning the control and release of radionuclides and hazardous chemicals to the environment at these sites, available data does indicate that attempts made were of lesser magnitude than in this country. In every country except Romania information was found indicating unrest among either the miners or the public toward the uranium production sites.

1. INTRODUCTION

Uranium production in Eastern Europe began directly after World War II in support of weapons production in the Soviet Union and has continued in some countries until the present time. The Eastern European countries discussed in this report include the German Democratic Republic (GDR), now part of a reunited Germany, Czechoslovakia, Romania, Hungary, Bulgaria, and Poland. Uranium has been produced in all of the Eastern European countries. The GDR and Czechoslovakia have historically been the two largest producers in Eastern Europe. Eastern Europe has produced about two-thirds of the total Soviet uranium inventory historically.¹ The cumulative total production of Bulgaria, Czechoslovakia, the GDR, Hungary, Poland, Romania, and the Soviet Union through 1989 is estimated at 490,000 metric tonnes of uranium (MTU) [1090 million pounds of uranium (MlbU)].¹ Cumulative production in the Soviet Union is estimated at 160,000 MTU (355 MlbU).¹ Subtraction places the East European total at about 330,000 MTU (730 MlbU).

For a number of reasons (primarily weapons-oriented secrecy and forced and rapid industrialization imposed by the Soviet Union after World War II), environmental control has been minimal at the uranium production sites; however, this is true not only for these sites but also for the whole of Eastern Europe and the Soviet Union. While many reasons exist for this, forced rapid industrialization is a key reason because it placed stress on the environment in all the Eastern Bloc countries including the Soviet Union. Moreover, it placed even greater stress on the environment in Eastern Europe because the resources of the Eastern European countries are generally significantly less than those of the Soviet Union including mineral resources, open space, water, and others. As the Soviet Union developed after World War II, its tendency to be wasteful of these natural resources, its emphasis on quantity over quality, and its disregard for the long-term "external effects" of production decisions created a rippling effect in Eastern Europe, the effects of which have been felt there to a much greater degree.²

Therefore, Eastern Europe is generally regarded today to be in the middle of an environmental crisis.²⁻⁵ However, because of the tight government control that has existed until the last 2 years, the environmental movement in these countries is very recent but is rapidly developing. The purpose of this report is not to discuss in detail the overall environmental crisis and its causes but rather to reveal the impact of this crisis on the evaluation of the uranium production facilities and their environmental situations such that they are seen in proper context.

This report first presents information concerning uranium production in each East European country, including site locations for mines and mills, a discussion of the mining and milling technology used in each country, and then a discussion of the environmental practices at the uranium production sites. In this regard, information on the environmental practices used at specific sites was obtained only for some countries and sites; therefore, Sect. 3 begins with a discussion of the general physical status of sites in the GDR, which also represents the physical status of the uranium production sites in general. Section 4 presents the conclusions in which the potential for U.S. industry involvement in environmental cleanup in Eastern Europe is discussed. Section 5 depicts areas where

information gaps exist and where future efforts should be focused based on information found in this survey. Although classified information was not consulted for this report, it was independently reviewed with classified sources in mind.

2. URANIUM PRODUCTION IN EASTERN EUROPE

While uranium has been produced in all of the six Eastern European countries, the largest quantities have been produced in the GDR and Czechoslovakia. As communism has dropped away, Russia has severed its relationship as the customer for Eastern European uranium production. Therefore, these countries have begun to look to the Free World market as their customer. As this has occurred, it has become apparent that the low quality of ore available in most of the countries and the previously subsidized system under which they have operated, combined with the low cost of uranium on the world market, make it very difficult for them to compete price-wise. Therefore, the output by the Eastern Bloc countries is projected to decline steadily in the future.¹ This projection has been coming true as each Eastern European country has evaluated its position and announced a decrease or halt in its uranium production. The situation for the past 2 years has been in a state of flux as some countries have announced an intent to halt production and then changed their mind. A consideration in those countries that want to halt production is the loss of jobs to uranium miners.

The reunified German Republic ceased uranium mine operations in the former GDR in January 1991.⁶ Earlier (1972) Poland stopped producing uranium.¹ Recently, Bulgaria also stopped uranium production.⁷⁻¹⁰ Thus today, Eastern Europe uranium production comes from Czechoslovakia,¹¹⁻¹³ Romania,¹⁴ and Hungary,^{15, 16} and it appears that none of these intend to compete on the world market but rather to produce uranium only for their own nuclear energy programs.

Information concerning the future of the nuclear energy programs in Eastern Europe is not definitive but strongly leans toward substantial growth. One opinion (that may represent a fringe environmental opinion) is that nuclear power will decline; concerns about Chernobyl specifically and Russian technology in general are given as the reason.³ Other opinions are that nuclear power will expand using western technology.¹⁷⁻¹⁹ Some sources indicate that the people are voicing their support for nuclear power plants constructed using western technology;^{17, 18} others indicate that a majority of Hungarians favored nuclear power over coal in a 1991 poll.¹⁹

Planning documents for the Economic Commission for Europe (ECE), a United Nations planning group, indicate strong growth for nuclear power in Eastern Europe (i.e., Czechoslovakia, Poland, Hungary, Bulgaria, and Romania).^{20, 21} The former document (ref. 20) indicates that the ECE countries are expected to almost double in nuclear energy (i.e., from 5.5% in 1985 to about 10% in 2010); the later document indicates that in the longer term, nuclear power will remain the fastest growing supply source in central and Eastern Europe. Most opinions found concerning government attitude toward nuclear power in Eastern Europe were positive and recognized that this is a much needed energy source, just as almost all governments recognized that the burning of soft coal must go because of the air pollution problems inherent in this source.

2.1 THE GERMAN DEMOCRATIC REPUBLIC (GDR)

The German government stated in January 1991 that it is determined to initiate a national solidarity action of ecological reconstruction. This action would have the goal of incorporating environmental protection in its basic law. At that time uranium production was halted in the former GDR. Earlier, in August 1989, production was halted for safety reasons at the one site in the former Federal Republic of Germany (Ellweiler). This means that Germany must import uranium to support its reactors. Therefore, unless something changes, no further uranium production is expected in the reunited Germany.

The GDR has been by far the largest uranium producer in Eastern Europe in the past and has also been the most secretive about production. Uranium mining at one time employed some 40,000 people. GDR capacity had been estimated to be as high as 5780 MTU (13 MlbU/year).²² The total GDR output of uranium is estimated at 185,000 MTU (410 MlbU).⁶

The uranium-producing area in the GDR consisted of six mines grouped into three production areas across the southeastern portion of the country close to the Czechoslovak border. The mining sites are at Wismut, Koenigstein, Crossen, Sellingstaedt-Treunzig, Schmirchau, Schlema, and Aue (Fig. 1).

Prospecting, exploration, and exploitation in the development of these sites were carried out by a Soviet-German joint-stock company (SDAG Wismut). Five different types of deposits have been opened up since uranium mining started. Two of these are of greatest economic importance: the "Ronneburg"-type (in Lower Paleozoic slate, limestone, and diabas) located in the Eastern Thuringia area and hydrothermal vein deposits (in the exocontact of granite) located in the Western Erzgebirge area.⁶

More than 90% of the uranium has been produced by underground mining.⁶ Conventional mining methods, in situ leaching (ISL), and surface leaching (i.e., heap or tip) have been used. Milling has been carried out hydrometallurgically by acidic or soda-alkaline processes.⁶ The ore from the GDR sites has been processed in three uranium mills: Crossen, a mine and mill complex where 50 million MT of mill tailings is deposited, Sellingstaedt-Truenzig, a mine and mill complex where more than 150 million MT of waste is deposited, and Koenigstein, an underground mine and mill complex that was converted to underground leaching.

2.2 CZECHOSLOVAKIA

Czechoslovakia, historically, has been the next largest uranium producer in Eastern Europe after the GDR by a wide margin. Since 1950 when uranium production started there, a cumulative total of about 110,000 MTU has been estimated to have been produced (about 240 MlbU).²³ After World War II, as many as 32,000 prisoners were working in the uranium mines. Uranium mining in 1991 employed a total of some 18,000 people. By mid 1992 this number was down to 12,000.²⁴ The reduction is a result of Czechoslovakia's 1991 decision to reduce uranium production to a level consistent with domestic needs. As a result of this reduction, only the Hamr (Straz) and Rozna (Dolni

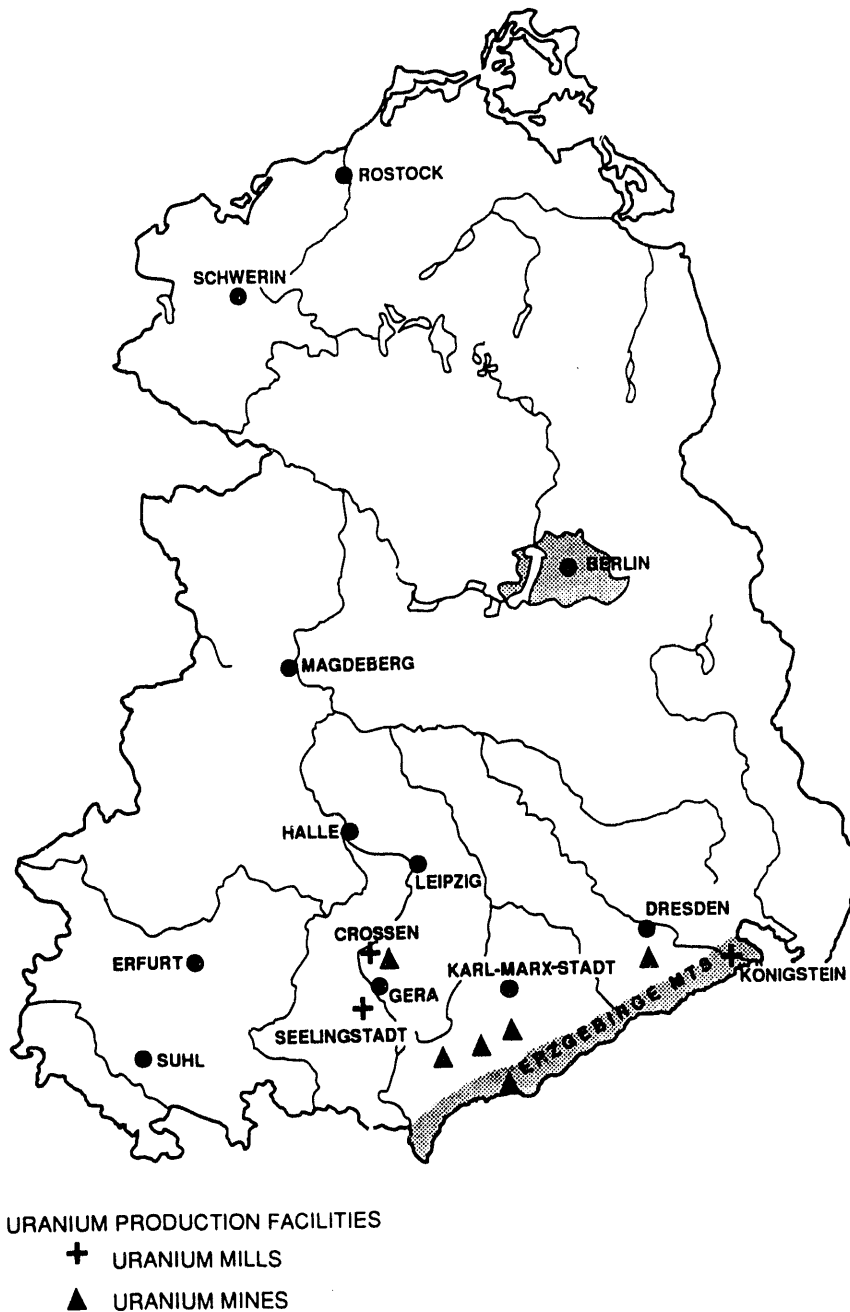


Fig. 1. Uranium production facility locations in the German Democratic Republic.

Rozinka) Uranium Districts continue in operation.²³ Although it is not clear in the referenced information, it has been assumed that both the mill at Straz in Hamr and the mill at Diamo in Rozna continue to operate.

The uranium-producing area in Czechoslovakia has consisted of four districts: Pribram, Rozna, Western Bohemia, and Hamr. All four are located in the western or Czech portion of the country (Fig. 2). Uranium production began in Pribram in 1950, in Western

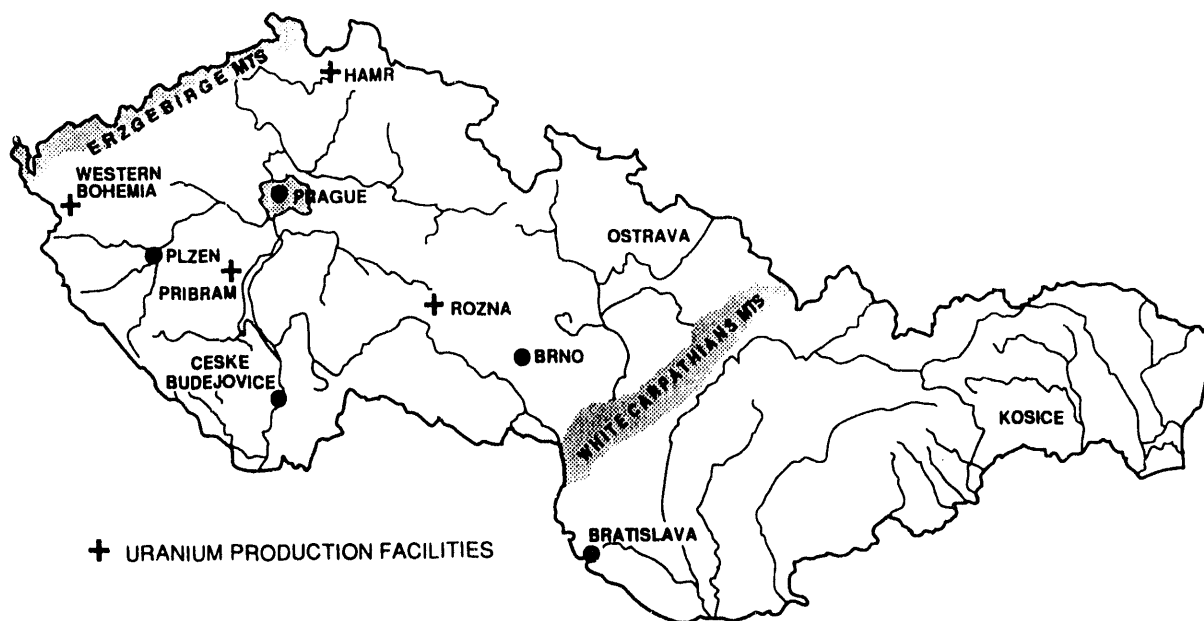


Fig. 2. Uranium production facility locations in Czechoslovakia.

Bohemia in the early 1950s, in Rozna in 1958, and in Hamr in the mid 1960s.²³ Many mines were developed in these four Czech districts, and three uranium mills (i.e., Diamo in Rozna, Mape in Western Bohemia, and Straz in Hamr) operated until 1991. These mills had a combined annual capacity of 2290 MTU/year (5 MlbU/year) prior to the cutback in 1991.¹ A summary of the historical uranium operations in each district is presented in the following subsections.

2.2.1 Pribram

This district is located in western Czechoslovakia about 48.3 km (30 miles) south of Prague. Over ten mines were developed during peak operations. This district consists of 2414 km (1500 miles) of horizontal openings and 26 vertical shafts reaching more than 1829 m (6000 ft). The uranium is present in steeply dipping hydrothermal veins, and only conventional mining methods have been used (i.e., no ISL). No milling has been done in Pribram. All ore through September 1990 was shipped to the Soviet Union for processing. Ore production from Pribram prior to the shutdown was 545,000 MT/year (600,000 tons). More than 58,000 MTU (125 MlbU) has been produced from this district. Peak production occurred in the 1960s. About 2500 employees are currently employed in the various operations.²³

2.2.2 Rozna (Dolni Rozinka)

This district is located in western Czechoslovakia about 129 km (80 miles) east of Prague. This district has consisted of two mines: Rozna and Olsi. The Olsi mine was closed in 1989

leaving Rozna as the only operating mine in the district. Initial reserves in the Rozna district have been estimated at 20,000 MTU (44 MlbU). Uranium mineralization at the Rozna mine occurs as disseminations (the bulk of operations) or in veins and stockworks. The main zone is 1.6 km long (1 mile) and extends to a depth of 1219 m (4000 ft). Conventional mining methods have been used here (i.e., no ISL). Ore quality from the Rozna mine has been around 0.2% U_3O_8 . Ore from the Rozna mine is processed on-site at the Diamo mill to produce yellowcake. Overall employment at the Rozna Diamo center is 3000.²³ The Diamo mill has a production rate of 510 MTU/year (1.1 MlbU/year).²⁵

2.2.3 Western Bohemia

This district is located near the border of West Germany and has consisted of three mines: Zadni Chodov, Vitkov II, and Dylen. Developed from the early 1950s through 1963 respectively, these mines consist of vertical shafts and horizontal levels to depths of 610 to 762 m (2000 to 2500 ft). Initial uranium reserves in this district exceeded 11,500 MTU (25 MlbU).²³

At the Vitkov II mine the ore is uranophane and uranium phosphates, and the ore quality ranges from 0.12 to 0.35% equivalent U_3O_8 . Conventional mining methods have been used here (i.e., no ISL).²³ Total ore output for the district is estimated at 136,000 MT/year (150,000 tons), perhaps 190 MTU/year (0.4 MlbU/year). All ore in this district was removed and shipped by rail to the mill at Mydlovary,²³ which had an annual capacity of 425 MTU (0.9 MlbU).²⁵ The Mydlovary mill was shut down in late 1991 as part of the decision to reduce uranium production to domestic requirements.²⁶

2.2.4 Hamr (Straz)

This is the newest and currently most productive uranium district in Czechoslovakia. Located in the west, 72 km (45 miles) north of Prague, it covers an area of almost 259 km² (100 miles²). This district is seen as the key to the future of the Czech uranium industry. It includes at least eight uranium deposits of various sizes; mineralization occurs as cretaceous sandstones at depths of up to 488 m (1600 ft). This district consists of two underground mines, Hamr and Osecna, and one ISL project (Straz). Osecna is to be closed in the near term leaving the other two to provide production. Hamr mine and Straz ISL are adjacent to each other. Ore quality averages about 0.12% U_3O_8 equivalent for ISL production and 0.18% U_3O_8 equivalent for the Hamr underground mine. The ore production rate for the underground Hamr mine is 2000 MT/d (2200 tons). The total resources of this district are 200,000 MTU (440 MlbU). This includes a significant quantity of lower grade ore (<0.1% U_3O_8 equivalent). This makes Hamr a major uranium district capable of making a measurable contribution to world production.^{23, 27}

The Straz ISL project has been in operation about 17 years. The ISL process consists of leaching uranium directly from the ore, in situ, by pumping sulfuric acid solution directly to the ore. This is done by drilling sets of injection wells and companion sets of recovery wells. This ISL project consists of many injection and recovery wells involving ion exchange recovery of uranium solution. The first wellfield at Straz is now ready to be reclaimed, having recovered over 50% of the original uranium reserve there. Overall, it is estimated that the Straz project handles a fluid flow of about 37,854 L/min (10,000 gal) to

produce about 575 MTU/year (1.3 MlbU). This rate makes Straz more productive than any U.S. ISL project.²³ Both the ore from Hamr mine and the ion exchange beads from the Straz ISL project are processed in the uranium mill at Straz, which has a capacity of 930 MTU/year (2.1 MlbU/year).²⁵

2.3 BULGARIA

The uranium industry in Bulgaria began in 1945 with the evaluation of several mineral occurrences in the Balkan Mountains. Mining began in 1946, and all production was exported under contract to the Soviet Union. More recently the uranium has been exchanged for fuel fabrication services. The uranium exploration and development program was at a peak in late 1960s and early 1970s. Uranium mining has employed about 10,000 people. Bulgarian capacity has been estimated to be as high as 770 MTU/year (1.7 MlbU/year). The total Bulgarian output of uranium is estimated at 27,000 MTU (60 MlbU) (this was estimated from ref. 28 and therefore may contain considerable error).

In the past 2 years, since the fall of communism, uranium production in Bulgaria has been in the process of being re-evaluated as it has in all of Eastern Europe. In March 1992, after more than a year of evaluation, the government announced an intention to halt uranium production.⁷⁻¹⁰ The argument against continuing production was high cost and potential environmental hazards. As of July 1991 and March 1992, the Bulgarian miners were either striking or threatening to sue the government for closing the mines and putting a large portion of the miners out of work.⁷⁻¹⁰ As a result of this, the Bulgarian uranium industry is under pressure to resume uranium production as a base of support for 10,000 employees, to develop mineral deposits other than uranium as a replacement for high-cost uranium production, and to clean up past and present production sites (most of which have significant environmental problems).²⁸

Bulgarian uranium production has been accomplished through both conventional mining operations (Bukhovo and Elesnica) and an ISL facility (Plovdiv). Bukhovo and Elesnica are made up of uranium mines and a uranium mill. Plovdiv provides resin loaded with uranium solution to the mill at Elesnica for final processing. These facilities are discussed in the following subsections.

2.3.1 Bukhovo Uranium Production Center

This facility is located about 20 km (12 miles) northeast of Sofia (Fig. 3). It includes a conventional uranium mill and acted as milling center for a series of mines up to 100 km (62 miles) away, many of which are located in the Balkan Mountains. Mining supporting this facility has been largely by underground methods. Most deposits have occurred as irregular veins or stockworks where pitchblend has been deposited in breccia zones.²⁸

The plant began operation in 1949 and operated until 1956 utilizing solvent extraction technology. From 1956 until 1989 it operated utilizing sorption-type technology (based on ion exchange). During operation acid-amenable ores are ground and fed to a hydrometallurgical uranium recovery process that includes sorption (where uranium is dissolved from the ore), extraction (where uranium is purified), concentration, uranium

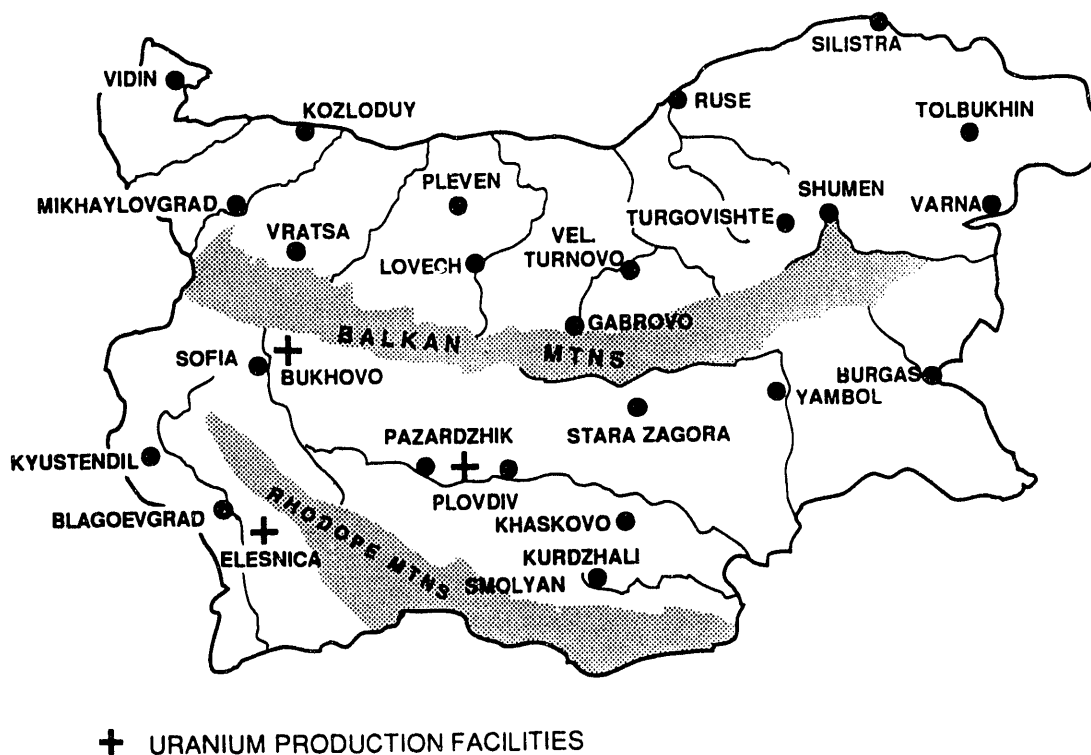


Fig. 3. Uranium production facility locations in Bulgaria.

precipitation, and calcining to U_3O_8 . The plant had a design capacity for ore of 600,000 MT/year, about 390 MTU/year (0.8 MlbU/year) with both an acid circuit (capacity 400,000 MT/year) and an alkaline circuit (capacity 200,000 MT/year) for processing differing types of uranium ore. Uranium recoveries were about 10% higher when utilizing the acid circuit.²⁸ In 1990 the plant was closed and placed on standby. Current efforts seem to focus on its use for processing minerals other than uranium. When active, the plant had an operating staff of 300 to 350 employees.²⁸

2.3.2 Elesnica Uranium Production Center

This facility is located about 120 km (75 miles) south of Sofia near the town of Banco (Fig. 3). Mining in this area began in 1955 with an open pit deposit; this was exhausted in 1960. Deeper drilling identified a richer underground ore body containing about 1200 MTU (2.6 MlbU). The production rate for this facility has been as high as 385 MTU/year (0.8 MlbU/year). Ore grades have generally been less than 0.10 wt % uranium, and the original resources of uranium totaled almost 10,000 MTU (220 MlbU). The mines in this area have included a number of related open-pit and underground deposits; mining is now focused on one underground mine. Mining in this area has utilized conventional mining technology. This mine is interconnected to several others.²⁸

The plant began operation in 1955 and until this time has continued utilizing ion exchange technology. Elesnica operates in a manner similar to the Bukhovo plant but has only an acid leach circuit. It has primary and secondary crushing, and the uranium is precipitated as ammonium uranyl tricarbonate and calcined to produce a U_3O_8 product. Acid consumption is relatively low owing to the high silica content of the ore. The design throughput for the plant is about 385 MTU/year (0.8 MlbU/year) as U_3O_8 per year. Employment totals 1400 workers at the mine and 300 more at the mill. Elesnica also treats loaded resin from the ISL operations at Plovdiv.

2.3.3 Plovdiv In Situ Leaching Facility

Located southeast of Sofia (Fig. 3), these facilities include 14,000 wells in 15 wellfields and four satellite recovery units. Current production is approximately 345 MTU/year (0.8 MlbU/year). The dissolved uranium is pumped out of the ground through the recovery wells, loaded onto resin beads, and shipped to the uranium mill where it is processed to U_3O_8 .²⁸

2.4 ROMANIA

Only a few publications concerning uranium production in Romania were found in this survey. Little information on specific sites was found. However, Romania has been a modest uranium producer in the past, and uranium production capacity could be as much as 770 to 965 MTU/year (1.7 to 2.1 MlbU/year).^{29, 22} Romania has aspirations as a nuclear power generator, but its first reactor project has not yet been completed. The Cernavoda nuclear power station project utilizes Western technology (i.e., Canadian, CANDU, heavy-water reactor). Because of this desire to have its own nuclear power reactors, Romania processes some of its own uranium to fabricate cores.^{1, 14} While limited information was found concerning Romania in this survey, it appears that Romania intends to continue uranium production in support of its nuclear power program but not beyond that level. Romania has three uranium production areas: the Brasov area in central Romania, the Bistritei Mountain area in the north, and the Almas Mountain area in the southwest.²⁹

2.5 HUNGARY

Uranium production began in Hungary in 1956, following the 1952 discovery of the one exploitable uranium deposit found in that country. This deposit is located near the city of Pecs in the southern part of Hungary in the western flank of the Mecsek Mountains (Fig. 4). The deposit was discovered by a Hungarian-Soviet joint venture. The mining project has been operated by the state-owned Mecsek Ore Mining Company. Between 1956 and 1990, 18,900 MTU (42 MlbU) was produced from the Pecs project at an average ore grade of 0.08 wt % U_3O_8 .³⁰

In late 1989 the Hungarian government decided to shut down the Mecsek mine by December 1990 because the operating costs were not competitive on the world market. However, in 1990 the government reversed its decision and agreed to continue to subsidize uranium production because on August 31 of that year a preliminary agreement

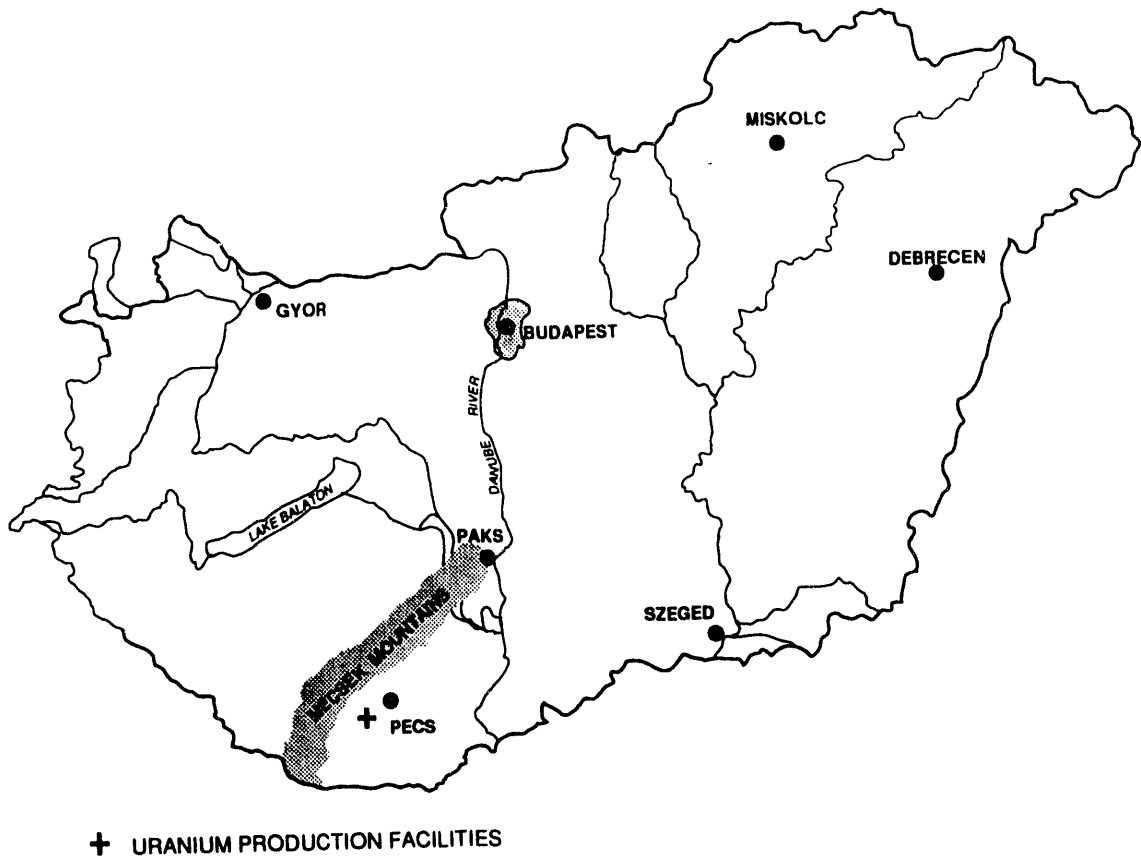


Fig. 4. Uranium production facility locations in Hungary.

was reached with the Glencar Company of Ireland to set up a uranium mining joint venture—a development that contributed considerably to the government's change of heart. The Irish company investigated the Hungarian mining company and indicated that it could be made profitable. The current production cost for uranium is \$60/kg (down from \$100/kg from 2 years ago). The new company is called Mecsek Uran Ltd.; Glencar will have a 60% share of the new company. Mecsek will remain as a shell company responsible for past debts so that the new company will be free of past debts. Uranium mining is stated to be economically attractive in Hungary if freed of earlier incurred costs. The Mecsek Uranium Mine Company had already cut its work force from 7100 to 2500.^{15, 31}

Ore at Pecs is lenticular and occurs in Permian sandstone. The thickness of the formation containing the productive lenses ranges from 10 to 50 m (33 to 164 ft). Uranium ore is mined by conventional underground methods using a series of shafts at intervals along the strike of the ore body. Each of these shafts is operated individually as a mine unit. Since the beginning of uranium mining in Hungary, five shafts have been opened. The first two have already been closed, shaft 3 was supposed to be exhausted early in 1992, shaft 4 is a little over half mined, and shaft 5 was commissioned in 1989. The average operational depth is about 600 m (1969 ft); the maximum depth is 1100 m (3609 ft). Ore is hauled to the surface to a central dumping system by an underground railway system. Trucks deliver the ore to the uranium mill.^{30, 32}

All ore from the mine is fully processed in the mill built on the site. The mill, which began operation 25 years ago, uses radiometric sorting followed by hydrometallurgy and produces calcium uranate $\text{Ca}(\text{U}_2\text{O}_7)$. Production has ranged from 345 to 620 MTU/year (0.8 to 1.4 MlbU/year) and recently averaged 450 MTU/year (1 MlbU/year). Approximately 2% of total production comes from leaching of surface heaps made of low-grade ore using sodium carbonate solution as opposed to sulfuric acid hydrometallurgy.³⁰

The Hungarian yellowcake product of the mill will be processed by the former Soviet Union, which has agreed to take delivery of 400 metric tonnes of yellowcake annually, the amount required to supply fuel to Hungary's four Paks nuclear power units plus Hungary's research reactors. Mecsek's production has been adjusted to that requirement.¹⁵

2.6 POLAND

Minimal information was found concerning Poland, probably because it has not been an active uranium producer for 20 years. Uranium production began in Poland in 1948, and the mines operated until 1963, employing 26,000 miners. Because no mention of a mill operation is made until after the mines were closed, it is assumed that all ore was shipped to the Soviet Union for further processing. After 1963 a mill was built in Kowary to recycle uranium from heaps (i.e., waste piles from the mines). The plant was closed in 1972 when uranium waste ran out. Since that time Poland has not been a uranium producer. Located in Jelenia Gora province, the three former mines are Kowary, Okrzeszyn, and Radoniow.³³ No information concerning the yearly throughput of uranium ore or the mining methods used in Poland was found.

3. ENVIRONMENTAL CONTROL PRACTICES AT URANIUM PRODUCTION SITES

3.1 ENVIRONMENTAL PRACTICES IN EASTERN EUROPE

The Soviets' decisions following World War II (primarily of weapons-oriented secrecy and forced and rapid industrialization) have resulted in an Eastern Europe that is in environmental crisis. Every reference found in this survey that refers to environmental subjects indicates that this is the case. Air pollution, water pollution, and soil pollution are reported to abound. The results of these decisions include an area that:

1. has almost no environmental pollution control on industrial equipment,
2. has minimal water treatment plant capability even for large cities, and
3. is terribly energy inefficient compared with the West.

These three items have been among the largest contributors to the ecological crisis that currently exists in Eastern Europe. The lack of pollution control equipment and the heavy reliance on coal plants (burning brown coal) for power generation, combined with energy inefficiency, has been the major contributor to the air pollution and acid rain problems.^{3, 34, 5}

The lack of water treatment plants even for large cities has resulted in severe water pollution problems to the extent that bottled drinking water must be transported into some areas.^{3, 34, 4, 5} In addition, the dumping of sewer water and industrial wastes directly into rivers is impacting both the quality of the Black Sea and the Baltic Sea.³ In short, all of these factors indicate that the cost of remediation in Eastern Europe will be quite high and that many sites will vie with the uranium production sites for priority.

3.2 ENVIRONMENTAL STATUS OF URANIUM PRODUCTION SITES

Detailed information was not found for each uranium mining and milling site in Eastern Europe. However, the information found for the sites in the former GDR (the subject of much attention since the reunification of Germany) is felt to be representative of the other uranium production sites in Eastern Europe. Subsection 3.2.1, therefore, discusses the general physical status of these GDR sites, while Subsect. 3.2.2 presents specific information on sites in each country covered by this survey.

3.2.1 General Physical Status of the Sites

Several types of problems exist at each site. One problem is the mine shafts: these tunnels and cavities stretch for thousands of miles under mostly mountainous landscape, some as deep as 1829 m (6000 ft). These empty cavities must be remediated, possibly by being pumped full of cement. However, prior to this, hazardous and toxic materials, steel supports, rail tracks, and air-conditioning equipment must be removed.³⁵

The second and greatest problem is the mine waste tailings and mill waste ponds that represent the waste products of the mining and milling processes. These wastes contain uranium and its daughter products radium and radon gas. These radionuclides make uranium mining and milling the highest health risk area in the nuclear fuel cycle³⁶ because their presence in the solid and liquid waste provides a source that continues to release over time, causing an increasing integrated exposure to the public.³⁵ This is discussed further in Subsect. 3.2.2.4.

A third problem is that the sites contain other pollutants, both hazardous and radioactive. Separating the uranium from the ore involved dissolution with sulfuric acid and caustic solutions that were discarded and collected in mill waste ponds, where the waters have been gradually fed into local rivers and streams in some cases. Mine officials in the GDR have acknowledged that such waters contain significant quantities of toxic substances like arsenic, uranium, and radium, all of which are waste products from the silver mining that was done in the region at an earlier time in addition to being waste products of uranium mining. Reclamation efforts have focused on protecting the water table and gradually ridding the landscape of these ponds.³⁵

For sites that utilize ISL technology rather than conventional mining technology, the potential for sulfuric acid leakage into the water table is of greater concern unless the site geology is such that this type of leakage is not a problem. ISL technology has been used at sites in the GDR (Konigstein), Czechoslovakia (Straz, a large ISL facility), and Bulgaria (Plovdiv). Evaluation of the environmental impact resulting from ISL technology utilization is being conducted in both Czechoslovakia and Bulgaria (see Subsects. 3.2.2.2 and 3.2.2.3 respectively).

3.2.2 Specific Information on the Sites

3.2.2.1 The German Democratic Republic

In 1990 Wismut AG, the company that ran the uranium production operation in the GDR, began planning a cleanup program to fill mine shafts and to clean up the mountains and lakes of radioactive and hazardous waste. They estimated cleanup time and costs at 10 to 15 years and DM 5 billion to DM 6 billion (\$3.5 billion to \$4.1 billion). In early 1991 Paul Robinson, an American environmental scientist (who is also executive director of the Southwest Research & Information Center, Albuquerque, N.M.) toured uranium mining and milling facilities in Germany and Czechoslovakia. He estimated that the cost of cleaning up Wismut could be as high as DM 15 billion (\$10.3 billion), about 2.5 times the estimate of the Wismut AG officials. In addition, he further stated that the large waste sites will take decades to remediate, perhaps longer to clean up than they took to accumulate. This estimate is consistent with that of an Interuran AG representative who put the cleanup cost at \$9 billion to \$12 billion.³⁷ Interuran AG and its French parent Cogema have formed a joint venture with Wismut AG for the cleanup effort of this area.

One reason stated for the higher estimate is that criteria designed to isolate and to stabilize hazardous materials for the thousand-year time frame, as demanded by U.S. federal standards, were not applied to the earlier estimate. Another reason is that they have to assess the costs of remedies to the extensive groundwater problems and structural

deficiencies associated with the dams containing uranium mill tailings. German officials have stated that their standards are indeed getting stiffer and now approach those of the United States; they may even be tougher.³⁷

As a result of the above-mentioned 1991 tour, Robinson noted specific site problems. These include:

1. Koenigstein—an underground mine and mill complex converted to underground leaching. At this site years of neglect may result in long-term contamination of aquifers in the Elbe Valley upstream of Dresden “unless major new concepts are developed for protection of these water supplies.”
2. Crossen—a mine and mill complex where 50 million metric tonnes of mill tailings are deposited. This site “has seepage problems in three areas, in addition to problems related to the geologic fault and an associated broken rock zone underlying the tailings pile and dam.” German attention is focused on a large 60-m-deep (197-ft) pool with uranium mining and milling wastes that are one-third under water. The site has not yet been inventoried to determine all that is there. The Federal Ministry of Research and Technology (BMFT) has funded work to study the cleanup of Crossen.
3. Sellingstaedt-Treunzig—a mine and mill complex where more than 150 million MT of waste are located. This site includes an unidentified volume of industrial liquid waste dumped in the Treunzig tailings pile and “has seepage problems in several areas around each of the two tailings piles, both of which overlay fault zones.”
4. Schmirchau—an open-pit mining complex that has accumulated over 160 million MT of waste. At this site “perpetual groundwater contamination problems” have resulted, “including possible overflow of pit waters into surrounding streams in the Weisse Elster River watershed.” In addition, the quality of groundwater contamination detection is “very poor” for all sites and needs to be addressed.³⁷

3.2.2.2 Czechoslovakia

Although significant information was found on these sites, specific information was found for only 2 of 17 sites in Czechoslovakia.

Hamr District

The Straz pod Ralskem site has both conventional and ISL mining. In areas with favorable geologic and hydrogeologic conditions, conventional mining methods are used; in other parts ISL methods are employed. The main concerns have been the landscape and the treatment of radioactive waters before discharge into public water supplies.²⁷

Conventional Mining. A system for monitoring the groundwater contamination resulting from the settling pond at the Straz site has been reported based on hydrogeologic and geophysical methods. Geoelectric methods allow for monitoring the movement of contamination in the whole area and not just at borehole points. By July 1990, after 9 years of operation, contamination movement was found to be a maximum of 400 m (1312 ft) to the south and east of the settling pond. Based on the results, a system of

boreholes was designed to prevent further movement of contaminated water toward the Ploucnice River in the North Bohemian area. Dose rates measured on the soil surface showed half of the permissible dose rate in Czechoslovakia for permanent residence. The monitoring consisted of four chemical composition tests per year for groundwater, two geoelectrical tests per year on eight sites, and one radiometric test per year for the presence of radium isotopes on the soil surface.^{38, 39} In further monitoring reported, radon dosimetry samples were taken in ambient air near the shafts of uranium mines at Straz. In addition, problems of transport roads for uranium ore were also reported to have been studied.³⁹

In Situ Leaching. Reference 24 reports that a re-evaluation of the environmental effects of ISL is ongoing and that a decision by the Czechoslovak government relating to continuing this approach is under consideration. A similar concern for ISL technology has been expressed in Bulgaria (see Subsect. 3.2).

Pribram District

In December 1990, members of the Austrian branch of Greenpeace told journalists in Prague that results of investigations made over several months in Czechoslovakia led them to recommend the immediate closure of the Mape plant in Mydlovary (South Bohemia). Mape is a uranium mill that has been of concern with respect to its surroundings, according to Greenpeace. The ecologists supported their claims by film, photographs, polluted samples, and evidence of an expert who had conducted measurements at Mape. Greenpeace claimed that they had drawn attention to the situation at Mape earlier this year, but their assertions were dismissed as unfounded by representatives of the plant and other officials.⁴⁰ This site was subsequently shut down by the government following the 1991 decision to reduce uranium production to levels that support home production of nuclear energy.

3.2.2.3 Bulgaria

Bukhovo Uranium Production Center

Only limited information concerning the environmental status of specific sites in Bulgaria was found in this survey. Three references concerning two subjects were found. The first expressed a concern about the radiation exposure to the public at the Bukhovo site where uranium mining began shortly after World War II.⁴¹ In addition, this location was the site (until 1966) of the only uranium mill in Bulgaria. In 1990 this site was closed for environmental reasons (see Subsect. 2.3 for details of the Bukhovo site).

It appears that minimal attention was paid to waste management at uranium production sites in Bulgaria until the very recent past.⁴¹ The first signs of contamination of three villages near the mine are reported as early as the 1950s. The first measures to control contamination were also taken at that time by building an area for the uranium tailings. Also, the worst contaminated land was expropriated, fenced, and afforested. However, the residents were apparently not adequately informed and continued to use contaminated water for irrigation and to cultivate the expropriated land. In addition, the population was

not given regular medical examinations. Only in recent years have the children been examined—and then only for heavy metal contamination.

During the last half of 1990, the Ministry of the Environment held two meetings to discuss the radioactive pollution at the Bukhovo site. As a result of these meetings, an offer was made to relocate families with children under 15 years of age living in this area.⁴¹ No mention of the result of this offer was found in the survey; however, the fact that the government made such an offer indicates one of two things: either the government felt a real problem existed, or the offer was made for political reasons. Since this occurred at the end of 1991, when political pressure was possible, it is unknown which reason is the most likely.

Plovdiv Uranium Production Center

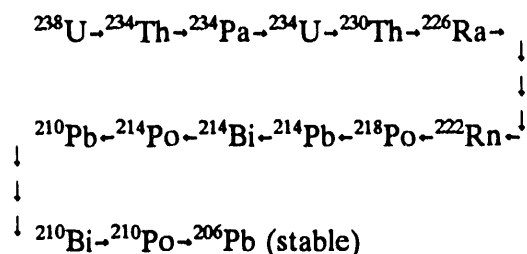
Two environmentally oriented references discuss the advantages and disadvantages of ISL mining technology.^{42, 43} The Plovdiv site is the only Bulgarian area found in this survey where this technology is used. ISL involves dissolving uranium in situ belowground using sulfuric acid solutions (see Subsect. 2.3 for more details concerning ISL technology). Of the uranium mined in Bulgaria, 68% is obtained by the ISL process. In order to use ISL, the uranium ore must be impermeable to water from above or below to prevent groundwater contamination.⁴² An advantage of this process is stated to be that workers "mining" it are exposed to significantly less radioactivity, particularly airborne activity.

However, an expert commission suggested that utilizing ISL would contaminate the underground waters of the freshwater basin laying beneath the Thracian Plain, which is used for drinking water.⁴² Therefore, they recommended that this water not be used for drinking water if ISL is used in this area. The reference also stated that significant technical detail suggests that ISL cannot lead to contamination of these underground waters. A favorable report on the ecological risk in the Thracian Plain was written in 1989, prior to the recommendation of the state commission. No resolution of this point was found during this survey.

3.2.2.4 Romania

Only one reference was found concerning environmental control of uranium production wastes.⁴⁴ In this article the physical and chemical characteristics of the waste are discussed, and the behavior of radium and radon and the overall radioactivity of the liquid waste during processing are considered. It is pointed out that the waste from the uranium mills is the most hazardous because it not only contains equilibrium quantities of radionuclides that have built up in the ore over long time periods (as is also true of mining) but also contains them in a more concentrated form. However, both the mining and milling wastes continue to be surface radioactive sources after the mill or mine is shut down, and this is a primary concern from an environmental standpoint. This report further states that every ton of ore processed provides 1 kg (2.2 lb) of uranium product, and every ton of solid waste provides about 100 g (3.5 oz) of unrecovered uranium to the mill settling pond (based on an average ore quality of 0.1 wt % uranium, which is lower than western ores by a factor of 1.5 to 3).

The most significant concern in uranium mining occurs in the mines themselves and is due to ^{222}Rn gas and ^{226}Ra particulate, the concern in each case being inhalation by the miners. The decay chain for the formation of ^{226}Ra and ^{222}Rn from natural uranium (^{238}U) is as follows:



The most significant concerns resulting from uranium milling are (1) airborne exposure resulting from the release of radon gas from both solid and liquid waste, (2) potential release of liquid radioactive solutions from mill ponds (due to the solubility of the radioactive elements, primarily radium and uranium), and (3) potential release of chemical-processing reagents used during the milling process that would be poisonous if not contained and/or treated (see Subject. 3.2.1 for further discussion).

One ton of the Romanian uranium ore containing 0.1 wt % uranium contains about 0.3 mg of ^{226}Ra , which is insoluble in sulfuric acid and only slightly soluble in alkaline solution. Therefore, a large amount (about 98%) of the ^{226}Ra stays with the solid waste stream and is eventually removed to the waste pond. The danger of the radium stored in the pond is not significant as long as pond water is not allowed access to the public water supply and the waste pond is protected in order to prevent access.⁴⁴

Radium (^{226}Ra) is generated from the ^{238}U , and the radon gas (^{222}Rn) is generated from the radium solid in the waste as shown above. Radon gas (^{222}Rn) along with particulate ^{226}Ra (occurring from dust) pose the major radiological health risk to the public and the worker in the front-end of the fuel cycle. However, it presents a much smaller danger on the surface than in the mines. Radon is heavier than air, and once released it can settle in low areas where air circulation is poorer. It can also adhere to the surface of dust particles or water drops. Therefore, waste ponds should be located so that the direction of the wind is away from inhabited areas.⁴⁴

In addition to the gaseous release of ^{222}Rn , the radioactivity of the solid waste in the ponds can present a problem because of the mobility of the soluble effluents. Therefore, it is important to control the release of the radionuclides contained in these liquid wastes.⁴⁴ Release of ^{226}Ra along with ^{222}Rn presents the major radiological health risk to both the general population and the worker.

The major chemical steps in uranium recovery from the ore are leaching, purification (ion exchange in this Romanian case, solvent extraction in much of the world), and precipitation. During the leaching step, the uranium is dissolved from the ore by exposure to sulfuric acid (for the acid flowsheet) and sodium carbonate-bicarbonate solutions (for the alkaline flowsheet). The waste to the mill pond exits the process between the leaching and purification processes.

Chemical compounds in the waste solution from the acid flowsheet are:

1. from leaching—excess sulfuric acid, sulfates of iron, copper, aluminum, manganese, magnesium, chrome, uranium, vanadium, cobalt, nickel, thorium, rare earths, sodium, potassium, and calcium;
2. from ion exchange—sulfuric or nitric acid, ammonium sulfate or nitrate, sulfates or nitrates of various metals (in smaller quantities than leaching), and remnants of degraded ionic resin; and
3. from precipitation—ammonium and uranyl sulfate, ammonia, and other soluble hydroxides.

Chemical compounds in the waste solution from the alkaline flowsheet are:

1. from leaching—carbonate and bicarbonate and sodium sulfate;
2. from ion exchange—sodium carbonate and sodium chloride; and
3. from precipitation—sodium carbonate, sodium hydroxide, and uranyltricarboxylate.

These chemical compounds in the waste streams cause problems when the mines/mills operate in a manner where there is release from the waste pond to waterways or leakage to a drinking water aquifer. In this case they must be treated such that they are removed to acceptable levels before release. No reporting of such treatment was found.

Reference 44 concludes that effluents from uranium-processing plants do not present a danger to the population or the environment if Romanian laws dealing with the discharge of radioactive liquid effluents are obeyed. The age of the report (1975) makes the conclusion suspect in that most data from Eastern European countries before the current revolutions away from communism conclude with such a statement and then, after the revolutions, reverse the position to say significant problems exist. However, the general nature of the data quoted above seems to be valid.

3.2.2.5 Hungary

No environmental information was discovered in this survey of literature. It is assumed that environmental concerns at the Hungarian uranium production sites were treated similarly to those of other Eastern Bloc countries (i.e., only minimal environmental control was exhibited) (see Subsect. 3.1 for general discussion).

3.2.2.6 Poland

Minimal information was found concerning the environmental practices at uranium production sites in Poland. Only one reference was found, and that concerned the mining and mill site at Kowary. At this site, because of concerns raised, a special commission was formed to investigate this area of Jelenia Gora province. Investigation showed that the premises, machines, and equipment used by the plant continued to be used for 16 years before they were finally decontaminated. The commission appointed two teams of experts to examine the health risk to former miners and to determine radiological and toxic contamination in Kowary.³³ No reference to the results of this 1991 investigation was found, and it is assumed that it is still ongoing.

According to the chairman of the Polish Atomic Agency, the heaps no longer pose risk to local residents. This is a very suspicious statement, however, because the sources of the concerns (i.e., uranium isotopes and ^{226}Ra) are still there, yet no discussion on any type of remediation of the heaps is given.

3.2.3 Potential Health Problems at the Sites

3.2.3.1 The German Democratic Republic

Because of the above problems (see Subsect. 3.2), the federal government sent teams of physicians and other experts to study disease rates and map the polluted areas, but they found few areas where they felt dangers to health existed from uranium mining wastes. They did acknowledge, however, that potentially greater dangers loom from the presence of other toxic materials, like arsenic in the wastes,³⁵ some of which are there from nonuranium production sources such as silver mining.

Wismut, the company that ran the mines for the government, reported through its director that in the early years, employee medical care was deficient. Later, the company reported organizing health care services exclusively for its workers that were far above the level enjoyed by most East Germans. The company reported that about 5400 cases of lung cancer had been recorded in secret medical data that the company had kept over the years on some 450,000 employees, roughly the same as the national average. However, data from other sources indicate that illnesses due to exposure to radioactivity have been occurring at these sites.³⁵

Wismut further stated that other health conditions such as silicosis, a lung ailment marked by shortness of breath common among miners, and rheumatic ailments of the joints and back (that resulted from measures taken to reduce the inhalation of radioactive dusts by miners) were much more common. Recently Wismut opened its medical records for research.³⁵

3.2.3.2 Czechoslovakia

The only reference to potential health problems at Czechoslovak uranium production sites found in this survey was a study of lung cancer in Czechoslovak miners. The cause of the lung cancer is exposure to daughter products of ^{222}Rn . Results indicated a definite correlation between airborne exposure and lung cancer (with frequency of lung cancer increasing with increasing exposure time).⁴⁵ This conclusion was stated to be consistent with U.S. data.

3.2.3.3 Bulgaria

No specific health problems were found in this survey, but problems were alluded to at the Bukhovo site.⁴¹ The reported offer to move people (see Subsect. 3.2.2.3) would certainly make one believe that some health problems may exist for the public at this site. The discussion concerning ISL technology indicates a significant amount of concern by some people concerning utilization of the technology that has been in use at the Plovdiv site.^{42, 43}

3.2.3.4 Romania

No information concerning potential health problems at Romanian uranium production sites was found in this survey.

3.2.3.5 Hungary

No information concerning potential health problems at the Hungarian uranium production site was found in this survey.

3.2.3.6 Poland

Only one reference was found that allowed potential health problems at Jelenia Gora uranium production sites to be inferred. This reference concerned the mining and mill site at Kowary. As mentioned in Subsect. 3.2.2.6, a special commission was formed to investigate concerns. The commission appointed two teams of experts to examine the health risk to former miners and to determine radiological and toxic contamination in Kowary.³³ No reference to the results of this 1991 investigation was found, and it is assumed that it is still ongoing.

4. CONCLUSIONS

4.1 OVERALL ENVIRONMENTAL STATUS OF EASTERN EUROPE

Because of the seriousness of the environmental problem in Eastern Europe, focusing on environmental issues will not be easy. The short-term costs of environmental cleanup, such as investments in pollution control and jobs lost because of plant shutdowns, will be more readily apparent than the economic and quality-of-life benefits. However, death rates appear to be higher as a result of pollution. In the dirtiest parts of the region, life expectancies are far lower, and rates of cancer, reproductive problems, and a host of other ailments are far higher than in cleaner areas.^{3, 4, 34} Therefore, remediation will likely occur in the near-term and continue over the next 40 to 50 years.

Complicating this issue is the fact that Eastern Europe missed out on the rebuilding that occurred after World War II in the western part of the country. Because of this, the whole energy production industry is energy inefficient compared with the West and is a major contributor to the air pollution problem. Energy reform in this area will require large sums of money. An example of just how large is taken from ref. 20, which estimates that Bulgaria, Czechoslovakia, Hungary, Poland, and Romania collectively would need to spend \$40 billion, \$100 billion, and \$60 billion (U.S. dollars) over the next 20 to 30 years to retrofit existing power plants, to build new environmentally clean power plants and networks, and to modernize energy use respectively.

To this the cost for environmental restoration, as well as other problems, must be added. The estimated cost for environmental restoration in the former GDR recently became available.⁵ This report spells out the environmental problems in detail and concludes that the remediation cost will be \$55 billion to \$205 billion through the year 2000. This report also makes the statement that 40 years of ecological damage cannot be corrected in a short time but can only be reduced gradually over many years. Also, this report indicates that priorities must concentrate on areas of acute environmental impairment or imminent threats to health.

4.2 IMPACT ON ENVIRONMENTAL RESTORATION

Primary funding for cleanup of environmental problems must come from governments with significantly less revenue than that of the United States. Therefore, the enigma facing Eastern European countries today is how to institute resolution of such problems, many of which exist as a legacy from the past, when they do not have the financial resources necessary for such a massive environmental cleanup. The sum of the energy reform and environmental restoration areas alone results in a very large total indeed, and other significant costs exist as well (e.g., the cost of upgrading the rest of industry to current environmental standards). The energy reform costs alone are so large that they evidently exceed financing and logistic possibilities, even assuming an upsurge of business.²⁰

For all of these reasons, prioritization of sites for cleanup will be an absolute must and will be harder to accomplish than in this country. However, many Western European

countries are also significantly affected by pollution that originates in Eastern Europe. Therefore, these countries, along with the United States, have begun to support environmental cleanup of Eastern Europe.^{3, 4, 20, 34} But even with this help, the funding of this cleanup is a difficult task because of its magnitude and because of all the additional problem areas beyond the environmental area. However, Eastern European countries are committed to changes that increase the possibility for strong economic growth for both Eastern Europe and U.S. business.⁴⁶

4.3 URANIUM PRODUCTION SITES IN EASTERN EUROPE

The information reported in Sect. 3 represents all data found concerning the environmental status of these sites. This information represents only a small number of the total sites discussed in Sect. 2, but since many of the problems at the sites are common, it is felt that most of the environmental problems have been generically covered in Subsect. 3.2.1 concerning the physical status of the sites. However, the level of remediation effort required for each specific site has not become apparent from this survey, nor can the potential health risk from each site be determined.

In general, it is the author's opinion, based on the referenced material, that the majority of the pollution and health problems discussed earlier come from sources other than uranium mining and milling although these are certainly included. The problems of air pollution, water pollution, and soil pollution (mostly coming from nonuranium production sources) are very large (as discussed in Subsect. 3.1) concerning environmental practices in Eastern Europe. It is the author's opinion that these large problems result in most of the health problems described in Eastern Europe.

If this perception is true, then it follows that uranium production sites will probably be ranked as lower priority items as listings are made for environmental cleanup. Information from ref. 5 states that highest priority for site cleanup will be given to those sites of acute environmental impairment or imminent threats to health. This gives credibility to the importance of prioritization. None of the above statements is intended to minimize the environmental or health impacts at the uranium production areas but rather to suggest that the environmental and health problems are significantly more widespread, in much greater number, and of higher immediate hazard for the other pollution sources.

In the former GDR a lot of activity in 1991 was directed at quantifying remediation of the problems at these sites. These estimates ran as high as \$10.3 billion to clean up all the Wismut sites. The statement was also made that the sites would take decades to clean up, perhaps longer than they took to accumulate.³⁷ The German government is committed to completing this cleanup by the year 2000; however, the budget for the total cleanup effort in Germany has been only \$0.83 billion thus far. This does not seem like a level that will accomplish cleanup at the uranium production sites in the next 10 to 15 years. This seems to confirm the feeling of assigning lower priority to the uranium production sites.

It appears that, whenever the environmental cleanup occurs, western technology will be involved. Western technology in this area is superior to that in the East and will be in demand in the cleanup of former Eastern Bloc countries.⁴⁷ In addition, since U.S. dollars

are, and will be, involved in the cleanup effort, it would appear that U.S. technology can be involved from this standpoint as well. For these reasons western technology will likely be heavily utilized during the environmental restoration efforts both from pure sales and technology transfer standpoints.³⁵ Technology transfer will most likely occur through joint ventures.

5. RECOMMENDATIONS CONCERNING INFORMATION GAPS

In this survey it has been shown that the uranium production sites, like most of Eastern Europe, have received very little attention from an environmental release standpoint. However, the author feels that the result of long-term neglect concerning air pollution, water pollution, and soil pollution has been more widespread both in area and numbers of people affected than contamination from uranium production. Therefore, this suggests that the priority for cleanup generated in each country, in the limited funding atmosphere that exists, may be lower for the uranium production sites. However, there is not enough data to substantiate the truth of such prioritization based on the information found in this survey.

The following are areas where more information is needed to proceed beyond the level of this survey. This information would be needed for all uranium production sites where further evaluation is required:

1. hazardous chemical handling and release;
2. liquid waste treatment and release;
3. status of mine shafts;
4. handling of tailings piles and waste ponds;
5. data on contaminants in waterways both past and present;
6. data on release of ^{222}Rn , particulate ^{226}Ra , ^{230}Th , and any others; and
7. data on ISL sites that would give an indication of leakage of sulfuric acid into groundwater.

Evaluation of radionuclide release could be estimated by a modeling approach. For example, the uranium production site radioactive health risk is primarily from ^{226}Ra and ^{222}Rn , both of which are generated from ^{238}U by decay. Specific information to determine the release of these radionuclides has not been found. However, their release from a site in the United States might be applied to Eastern European sites to attempt to bound the release of these radionuclides. This approach might provide confidence that the prioritizations for cleanup are correct.

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