Uranium Occurrence, Deposits and Mines in Poland

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Abstract

Satisfying energy needs of the society and economy while preserving the principles of sustainable development and price competitiveness is the main objective of the state's energy policy. This aim can be achieved through the use of modern zero-emission technologies, including the nuclear power. A research paper titled "The Program of the Polish nuclear power" from 2014 included an assumption of the construction of nuclear power stations by 2030. This will be connected with the necessity of securing the uranium supplies.

The uranium ore was extracted in Poland in the years 1948–1968. Nearly all mines were located in the Sudeten mountains. Uranium was also extracted in the Staszic pyrite mine in Rudki (the Świetokrzyskie Mountains, also referred to as the 'Holy Cross' Mountains). The total production of uranium in Poland amounted to 650 Mg.

During the research done in the late 50's of 20th century, a concentration of uranium was discovered in layers of sandstone in the area of the Vistula Spit (Middle Triassic sediments in the Peribaltic Syneclise) and in bituminous shales in Rajsk in the Podlasie region (the Ordovician Dictyonema Shales in the Podlasie Depression). Concentrations of uranium were also detected in bituminous shales in the Carpathians (Oligocene Menillite shales), coals of the Upper Silesian Coal Basin (Carboniferous) and as admixture in copper-bearing shales.

The article analyzes locations of uranium deposits in Poland's territory, the history of search and prospects for uranium mining.

Keywords: occurrence of uranium in Poland, uranium mines in Poland, uranium deposits and prospects for uranium mining

Introduction

Fulfilling energy needs of the society and economy while preserving the principles of sustainable development and price competitiveness is the main objective of the state's energy policy. In order to achieve this aim, investments in up-to-date productive infrastructure are necessary. It is connected with a gradual departure from high-emission sources towards low-emission ones (clean coal technologies among others) and zero-emission ones (nuclear energy and renewable energy sources). It is especially important to pay attention to the nuclear energy production which can be distinguished by the lack of emission of carbon dioxide, dust (Particulate Matter), sulphur dioxide (SO_2), nitric oxides (NO_2) and other dust and gaseous pollution. In addition, it can be characterized with stable supplies of electrical energy. According to the data included in an analysis titled "EU Energy, Transport and GHG Emissions: Trends to 2050, EU Reference Scenario 2013" [4], the pace of building new energy-producing blocks will increase after 2025 and in 2050 the capacities of nuclear power plants will grow substantially in the European Union (from 96,9 GWe in the year 2025 to 122 GWe in the year 2050). By contrast, in a research paper titled "Program of Polish Nuclear Energy Production" published in 2014 it has been stated that the planned amount of energy produced by nuclear power plants in Poland will grow from seven percent share in the domestic electrical energy output in 2025 through 13 percent (equal to 23 TW-h) in 2026 to 19 percent stake (equal to 35 TW-h) in the domestic electrical energy production in 2030. This will involve the necessity of securing the supplies of fuels for the three planned electric power stations.

History of Search

The Sudeten mountains

The first mentions on the occurrence of uranium in the Sudetes go back to the latter part of the XIX century. In 1853 M. Websky described a new mineral of uranium type – uranophane – for the first time when he was doing research on copper deposits in Miedzianka. Uranium also accompanied other deposits, such as: fluorspar, iron ore and arsenic ore. It was also seen as a detrimental admixture to ores of other metals. Uranium was partially used in the production of uranium-based paints and as an addition to the glass (so-called uranate glass). At the turn of the XIX century medicinal properties of radium were discovered (this heavily radioactive metal is an output of uranium decay and it always accompanies the ores of uranium in small amounts) and the search for the uranium began. Uranium ores, so far treated as waste accompanying the mining of other minerals, suddenly became a precious raw material from which the radium was retrieved [2]. In the years 1927–1929 9 Mg (megagrams) of the uranium ore was mined which contained 689,3 mg of

Ra – radium [1]. Until the phenomenon of chain reaction was discovered, uranium was treated as waste and then suddenly it turned into a strategic stock covered by the military secrecy. In the years 1943–1944 72 Mg (megagrams) of the uranium ore was extracted in the area of Kowary [2, 6, 10, 16] and then transported to Oranienburg (35 kilometers north of Berlin) in order to do research regarding the opportunities of use for military purposes. After the Second World War the search for uranium ore was resumed in the area of Lower Silesia. Initially the search began on mounds and available mining excavations (most of them were flooded and destroyed). During that event several sites of occurrence of uranium mineralization were found which provoked interest on the side of Russia. In 1947 a Polish-Russian agreement was signed on the manners of search, mining and processing of the uranium ore in Poland [2]. An enterprise called „Kuźnieckijie Rudniki", so Kowarskie Mines, was formed on the 1st of January 1948 which then changed its name to Zakłady Przemysłowe R-1 w Kowarach – Chemical Company R-1 in Kowary – in 1951. The research conducted by Russian geologists focused in the first period on revising of areas of old mining works, most of all old mining excavations, mounds and drifts. In case any radiometric anomalies were observed, the search work was started. By acting in this way deposits of uranium were detected in Miedzianka and in the surrounding area of Klodzko in the years 1948–1949 [6, 7]. The next stage was the search with use of geophysical, geological, geochemical, drilling and mining methods (including: aero-radiometric method – the content of radioactive isotopes in the air, eradiation method – isotopes in the soil, and radio-hydrological method – isotopes in the water) [2, 5. 16]. This work continued till 1956 and was conducted not only in the Sudetes. The Carpathians, the Silesian and Czestochowa coalfield [2, 6] and the Swietokrzyskie mountains (the 'Holly Cross' mountains) were also examined [10, 16]. All warehouses with drill cores were checked as well as well logging was done to holes made by other units [6, 7].

The result of the done research was pointing to [10]:

- Two deposits qualified for mining: Radoniow and Podgorze (exploitation was commenced).
- Three deposits of the uranium ore coexisting in deposits of non-radioactive minerals in Kowary, Miedzianka and Kletno-Kopaliny.
- 14 occurrences of mineralization from which 0,04 to 12 Mg (megagrams) of uranium was obtained during the mining research work.
- Three deposits of poor uranium ore in Okrzeszyn, Grzmiąca and Radków-Wambierzyce (with the uranium content from 0,01 up to maximum of 0,1%).
- In the area of the Swietokrzyskie mountains the uranium ores were found in Rudki (as a mineral accompanying the deposits of iron sulphide, haematite and siderite).

Due to the discovery of big deposits of the uranium in the Ural mountains and poor and close-to-exhaustion deposits in Poland, Russian started to withdraw gradually from the searches beginning from 1954 and ended up in leaving finally in 1957. From that year the search for deposits of uranium was conducted only by Polish geologists and geophysicists. Virtually all easily accessible uranium deposits were exploited. In the majority of mines the uranium had a form of thin veins within tectonic fractures which made their mining very low efficient. The authorities of Poland restricted a range of activities of works of R-1 Companies to the extraction in three mines – Podgórze in Kowary, Radoniów (42 km away from Kowary) and Staszic in the Świętokrzyskie mountains. Radiometric anomalies detected during former research in Okrzeszyn, Wambierzyce and Kopaniec [2, 16] were also recognized. Because of the decline in extraction, works of R-1 Companies changed their activity profile. A liquidated mine of Wolnosc was replaced by ore enrichment works in the years 1963–1966. In this place a concentrate with high amounts of uranium was produced made of poor ore (formerly not exploited) and materials retrieved from old mine drifts. In 1973 the activity of R-1 Company came to an end and the works was formally closed down. Over the 15 years of mining activity in Poland an estimated 1000 Mg (megagrams) of the natural uranium was extracted from ore of concentration of 0,2 percent. After the uranium processing plant was founded, some 120 Mg (megagrams) of the uranium concentrate was obtained which contained over 50 percent of the natural uranium [6]. The figure 1 below presents amounts of uranium ore extracted by R-1 Company in the years 1948–1960.

In the table 1 there is a list of deposits which were exploited in the years 1948–1968 [own research, 22].

The Swietokrzyskie mountains

The Swietokrzyskie mountains were the only place in Poland, apart from the Sudetes, where the

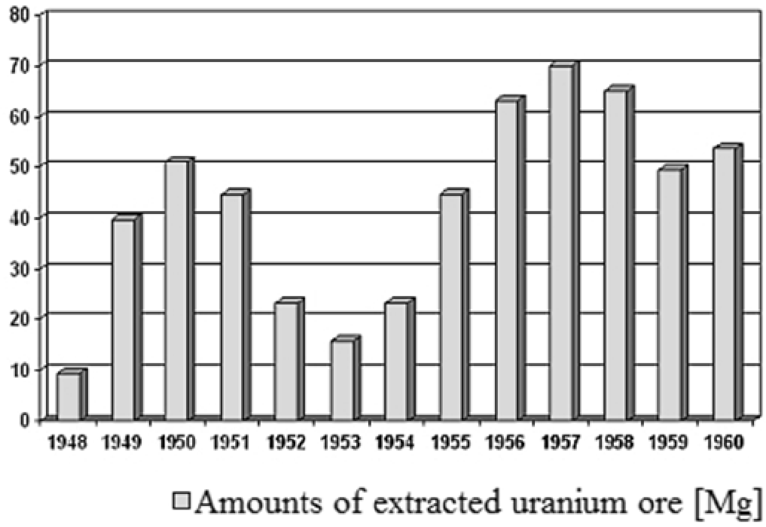

Fig. 1. Amounts of extracted uranium ore in the years 1948-1960 (source: [23])

Rys. 1. Ilości wydobytego uranu w latach 1948-1960 (źródło: [23])

Tab. 1. Deposits of uranium ore in the historical perspective – exploited from 1948 to 1968

Tab. 1. Złoża uranu w perspektywie historycznej – wydobywane w latach 1948-1968

Deposit	**Estimated uranium resources (Mg)**	**Exploited uranium resources (Mg)**	**Remaining (Mg)**
Wolność	94,0	94,0	-
Miedzanka	14,7	14,7	-
Podgórze	280,0	199,0	81,0
Rubezal	0,5	0,5	-
Mniszków	4,5	4,5	-
Wiktoria	0,28	0,28	-
Majewo	0,96	0,0	0,96
Wołowa Góra	2,5	2,5	-
Radoniów	345,0	214,0	131,0
Wojcieszyce	14,4	12,3	2,1

uranium was extracted. The uranium ore was extracted as an accompanying mineral in the Staszic pyrite mine in Rudki. In 1958 the uranium resources were at 40 Mg [20]. The uranium ore was extracted until 1968. In 1973 the Staszic mine was closed down with an estimated 10 Mg of uranium remaining in an inefficient deposit [16, 20].

The Polish Lowland

The recognition of occurrence of uranium deposits within structures of Poland's Lowland was one of the primary objectives of Department of Radioactive Elements founded in 1956 in the Geological Institute. The research was focused on:

1. Radiometric measurement of rocks and water in mining excavations.
2. Analysis of geophysical well loggings in all boreholes drilled in the country.
3. Examination of rocks in which radiometric anomalies were observed.

The outcome of the conducted research was the discovery of concentration of uranium in forma-

Fig. 2. Distribution of uranium ore in Poland (source: author's own research)

Rys. 2. Występowanie uranu w Polsce (źródło: opracowanie własne)

tions of colorful sandstone in an area ranging from Paslek to Krynica Morska in the late 50's of the XX century [16]. That research was continued in the years 1975–1984 and extended to the region of Vistula Spit. 23 boreholes were drilled and the occurrence of mineralization in sandstones was observed. The features of that mineralization were similar to deposits existing in the USA, Niger and Kazakhstan [9].

Between the years 1967 and 1972 62 boreholes were made in the Podlasie region (the Rajsk deposit). An increased amount of uranium, vanadium and molybdenum was found in bituminous shales (especially in black ones) [10].

The Carpathians

Within the frames of parallel research, examination work was conducted in the Carpathian Mountains. In the years 1956–1962 the search for uranium was focused on bituminous shales of Menilite layers of the Carpathians in the Bezmiechow-Monaster region [16]. The concentration of uranium in shales in that region amounted to 620 ppm (average 110 ppm). By contrast, in all other areas the amounts of uranium were significantly lower and in enriched parts reached around 30–100 ppm (and their geochemical background was determined at about 12 ppm) [9]. The re-examination conducted in the 70's of the XX century showed that the mineralization did not have a value for production because of too low uranium amount as well as technological problems connected with the enrichment of such poor ore [9, 10, 16].

Upper Silesia Coal Basin

Immediately after the war period manifestations of the uranium mineralization were observed in the coals of the Upper Silesia Coalfield during the radiometric examination of mines. It is present mainly in upper levels of productive Carboniferous (the Libiąż, Lazisk and Orzesk layers) in the east part of coal basin [11]. Those were mainly zones of tectonic and sedimentary intermittence as well as connection zones of coal layers in sandstone beds which underwent the mineralization process [9]. Concentrations of natural radioactive isotopes in rocks adhesive to coal are several times higher than concentrations observed in the coal [8, 15]. The source of radioactivity of coal and coal-adhesive rocks is the aggregation of derivative phosphates and uranothorite (ThU) [SiO_4] in a form of dispersed radiation centres. The uranium present in coal is concentrated in more oxidized elements of the organic matter and reaches its maximum values in fractions the density of which amounts to 1,7–2,0 g/cm^3 [11]. Radioactive elements were also found in the coalmine water [12].

The maximum values of uranium content in the area of Upper Silesia Coal Basin is 0,26 percent. During the research no bigger ore-related bodies were found and this is why the region was not recognized as prospective [9].

In figure 2 sites of occurrence of uranium ore are indicated.

In publications regarding the categorization of uranium deposits two basic categories of conventional reserves are distinguished: known recoverable

Tab. 2. Division of conventional uranium reserves (source: author's own research based on: [5])

Tab. 2. Podział zasobów uranu (źródło: opracowanie własne na podstawie [5])

Conventional resources	Known Recoverable Resources	Reasonably Assured Resources
		Inferred Resources
	Undiscovered Resources	Undiscovered Prognosticated Resources
		Undiscovered Speculative Resources

Tab. 3. Marginal values of parameters defining a uranium deposit and its borders (source: [14])

Tab. 3. Wartości marginalne parametrów definiujących złoże uranu i jego granice (źródło: [14])

Parameter	**Unit**	**Marginal value**
Maximum depth for documenting the deposit	m	1000
Minimum amount (U) in sample outlining the deposit	%	0,01
Minimum average amount (U) in the deposit profile along with gangue overgrowth	%	0,01
Minimum deposit abundance (U)	kg/m^3	0,8

Tab. 4. Identified resources of uranium ore in Poland (source: author's own research based on: [22])

Tab. 4. Zidentyfikowane zasoby uranu w Polsce (źródło: opracowanie własne na podstawie [22]

Deposit/Region	**Resource (Mg)**	**Amount of uranium in ore (%)**	**Amount of uranium in ore (ppm)**
Okrzeszyn (Sudetes)	937,6	0,05-0,11	500-1100
Grzmiąca (Sudetes)	792	0,05	500
Wambierzyce (Sudetes)	217,5	0,0236	236
Rajsk (Podlasie)	5 320	0,025	250

resources and undiscovered resources. Table 2 presents a division of conventional uranium reserves.

On the basis of the article 97 paragraph 1 point 1 of the Act on Geological and Mining Law (Journal of Laws No 163, item 981) [21], the Ordinance of the Minister of the Environment (Journal of Laws No 291, item 1712) [14] was introduced on the geological documentation of a mineral deposit. The marginal values of parameters defining a uranium deposit were determined In the appendix 11 (Table 3).

A report titled 'Uranium 2014: Resources, Production and Demand' [22], published in 2014, included identified resources of the uranium ore in Poland (Table 4).

The mineralization of uranium is connected with sedimentary formations from late Carboniferous and early Perm. One can distinguish three mineralization types [9]:

1. Sandstone type – Grzmiaca deposit,
2. Schistose – Wambierzyce deposit,
3. And mineralization in coals – Okrzeszyn deposit.

Characteristics of particular deposits are shown in the table 5.

Forecasted uranium resources in Poland are shown in the table 6.

The richest uranium mineralization of sandstone type is located in the Vistula Spit. In the Ptaszkowo IG-1 borehole an average content of

Tab. 5. General characteristics of the uranium deposits: Grzmiąca, Wambierzyce and Okrzeszyn (source: author's own research based on: [9, 16].)

Tab. 5. Ogólna charakterystyka złoż uranu: Grzmiąca, Wambierzyce oraz Okrzeszyn (źródło: opracowanie własne na podstawie: [9, 16])

Deposit	**Deposit profile**
Grzmiąca	**Mineralization of deposit**: uranium oxides with small amounts of pyrite, zinc blend and chalcopyrite. **Thickness**: around 20 meters. **Amount of uranium in deposit**: 0,05% (500 ppm). **Metal resources**: around 792 Mg. According to the authors of the research [16], good recognition of the deposit and favourable geological conditions make the exploitation possible
Wambierzyce	**Thickness**: 0,2-1,5 meters (in this area there are 12 levels with an increased uranium content). **Amount of uranium in deposit**: 40 – 200 ppm (0,004-0,02%). Low amounts of uranium and strong relationship with organic matter pose a serious technological problem. Large distances between uranium-bearing levels also make the area of low economic value. On the other hand, the place has tourist and environmental advantages - the Stolowe Mountains National Park is nearby.
Okrzeszyn	**Mineralization of deposit**: it is connected with layers of coal and coal shales and partially with sandstone and conglomerates. It is in a form of bars and layers congruous with the lamination of coals. It is also in a form of irregular aggregations alongside crevices which intersect the coals. **Amount of uranium:** goes up to 0,2%, average: 0,13%. **Resources**: 938 Mg. **Thickness**: 0,2 m Low thickness and the irregularity of mineralization distribution in coal layers may pose a serious problem during the exploitation. The next trouble is the course of state border which does not allow for enlarging the resources.

Tab. 6. Projected resources of the uranium ore in Poland (source [22])

Tab. 6. Perspektywy zasobów uranu w Polsce (źródło: [22])

Region	Forecasted resources located deeper than 1 000 meters (Mg)
Peribaltic Syneclise	20 000

uranium was observed which amounted to 0,26 percent in a layer 4,43 meters thick [9]. The uranium is accompanied by high volumes of vanadium, selenium, molybdenum, lead and arsenic. In addition, ore-related bodies were found in the area of Krynica Morska. They are located in the Vistula Spit at the depth of 750 to 800 meters. During the research conducted in the area of Frombork, Młynary i Pasłęk the occurrence of uranium was noticed at the depth of 950 to 1170 meters. Its concentration, however, is much lower than required [19]. Because of high costs of drillings (at such greats depths) and environmental and recreational advantages of areas in question (the Nature 2000 area), the exploitation of those deposits does not seem possible.

Uranium can also exist as an accompanying mineral. Such resources are referred to as unconventional. They comprise an important supplement to the conventional resources. The amount of uranium in phosphate rocks (they are used for the production of phosphoric acid and chemical fertilizers) is between 70 and 200 ppm (0,007–0,02%), yet it happens to be even 800 ppm [5]. The biggest number of phosphate rock deposits is in Morocco (over 90 percent of world's resources). Phosphates are also extracted in Brazil, the USA, Jordan, Tunisia, Egypt, Algeria, China, Israel, Russia, Syria and Vietnam. The deposits of phosphate rocks qualified for exploitation contain around 35 millions Mg (mega-grams) of uranium. The biggest number of uranium resources in phosphate rocks is possessed by Morocco (6,9 millions of Mg) and the USA (1,2 millions of Mg) [3].

The uranium can also come from the decommissioning of nuclear heads which is the secondary source. Another example can be depleted uranium which undergoes the enrichment process in modern ultracentrifuge installations [5].

In the region of Lubin-Sieroszowice the uranium is present as an admixture to copper layers. The amount of uranium in that ore is at around 60 ppm. As stated by Strupczewski [17], the uranium resources in that ore are estimated at around 144 000 Mg and can be obtained through energy input which is lower than 5 percent of the power earned from a nuclear power plant. The advantage of this solution will undoubtedly be the limitation of amounts of radioactive waste stored on mounds. It is estimated that the amount of uranium dumped to mounds is at 1700 Mg/year while an annual copper production rate at 569 000 Mg [18].

Summary

Relating to the data which has been presented in this article it appears that Poland for now does not have the possibility of fulfilling its fuel needs basing on its own resources for building nuclear power stations which are planned. It appears that further investigations in the area of Peribaltic Syneclise in the region of the Vistula Spit and Vistula Lagoon are necessary. Uranium deposits of sandstone type are present over there. Because of the fact they are located very deep (at least 800 meters) and the area is legally protected (Nature 2000 project), the extraction of the deposits may be problematic.

Due to Poland's geological structure one cannot have high hopes for the discovery of deposits easy for exploitation and with significant resources. However, there is a stimulus for further research on implementation of new technologies connected with obtaining the uranium from deposits of low concentration. It is the growing demand for the uranium and the exhaustion of deposits characterized with its highest concentration (so the lowest cost).

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Występowanie uranu, złoża i kopalnie w Polsce

Głównym celem polityki energetycznej państwa jest zapewnienie odpowiedniej ilości energii przy satysfakcjonujących kosztach oraz utrzymaniu zasad zrównoważonego rozwoju i konkurencyjności cen. Cel ten może zostać osiągnięty za pomocą zastosowania nowoczesnych technologii zero-emisyjnych, w tym za pomocą energii jądrowej. Artykuł naukowy pt. "Program polskiej energetyki jądrowej" z 2014 roku zawierał założenia konstrukcji elektrowni jądrowych do roku 2030. Będzie to połączone z potrzebą zapewnienia zasobów uranu.

Ruda uranu była wydobywana w Polsce w latach 1948-1968. Prawie wszystkie kopalnie były zlokalizowane w Sudetach. Uran był również wydobywany w kopalni pirytu Staszic w Rudkach (Góry Świętokrzyskie, również nazywane górami „Świętego Krzyża"). Ogólna produkcja uranu w Polsce wynosiła do 650 Mg.

Podczas badań zrealizowanych późnych latach 50. XX wieku, złoża uranu odkryto w warstwach piaskowca w rejonie Mierzei Wiślanej (osady środkowego triasu w syneklizie pery bałtyckiej) oraz w łupkach bitumicznych w Rajsku w rejonie Podlasia (łupki z ordowiku w depresji podlaskiej). Złoża uranu zostały również odkryte w łupkach bitumicznych zlokalizowanych w Karpatach (łupki oligoceńskie), węglach Górnośląskiego Okręgu Węglowego (karbon) oraz jako domieszka w łupkach miedzionośnych.

Artykuł przedstawia analizę umiejscowienia złóż uranu na terytorium Polski, historię ich poszukiwań oraz perspektywę górnictwa uranu.

Słowa klucze: występowanie uranu w Polsce, kopalnie uranu w Polsce, złoża uranu i perspektywy górnictwa uranu