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HISTORICA

URANIUM PRODUCTION FROM THE LOCAL DICTYONEMA SHALE IN NORTH-EAST ESTONIA

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The Sillamäe uranium factory processed in 45 years more than 100,000 tons of uranium. The first 22.4 tons were produced from the local ore, the black Dictyonema shale, overabundant in North-East Estonia.

Preamble

The presence of moderate amounts of uranium in the abundant black Paleozoic Ordovician Dictyonema shale deposits in Northern Estonia was well documented before WWII. Nuclear energy and feasibility of the Bomb were likewise matters of intense and animated scientific debates that got reflected in at least one satirical wartime *Penguin* book about nuclear politics [1] and a cartoon in *Eesti Sõna*, the main local newspaper published by the German occupation forces. The Godfather of the first US nuclear device was shown sitting on a fairly good likeness of the real thing and stuffing nuclear fuel into it with a large funnel.

It was thus not surprising that immediately after Soviet reoccupation of Estonia a geological survey and uranium prospecting team headed by one of the founders of Soviet uranium industry, prof. M. Althausen, was sent to Estonia and a first small demonstration batch of soluble uranium salts was rapidly extracted from the local black shale during the last wartime winter 1944–1945. The strategically important jar was duly presented to the Politburo in Moscow [2] and the chain of events, eventually leading to the production and processing of more than 100 million kilograms of uranium at Sillamäe, was initiated. Uranium production was the main activity of the plant for 45 years from 1946 to 1991, but local ore was used only at the very beginning from 1948 to 1952 [3].

First Steps

Active prospecting for uranium started in the spring of 1945 with the participation of ESSR Central Institute of Industrial Research [4]. The

institute was given the task to drill 1500 m of boreholes between the towns of Narva and Paldiski, but first of all in the Saka-Aseri region where a detailed survey had to be carried out over a 35 km^2 mining area. By November 1945, 950 m of drillcores were produced and a 31.8 km^2 area surveyed. Chemical analyses gave the expected encouraging results and the Chief of the First Chief Directorate of the USSR Council of Ministers B. Vannikov issued the top secret Decree No. 0282cc of August 6, 1946 establishing within the First Directorate of the same Chief Directorate a diversified enterprise "Combine No. 7" for the mining and industrial processing of the Baltic Dictyonema shale.

This decree required the Combine to develop a suitable industrial technology for uranium extraction from the shale, to carry out all the necessary field work in uranium prospecting and survey of the mining area, and last but not least – to actually build all the necessary mines, factories, laboratories, housing, roads, prison camps and cemeteries, but at least not during the first phase of operations – waste dumps for the unavoidable radium-rich radioactive waste. All these operations were supervised by the Deputy Chief P. Antropov and the Chief of the Combine, MGB major-general M. Tsarevski. While officially the management of the new enterprise resided in the premises of the pre-war private commercial Scheel Bank in the center of Tallinn, the activities actually never left Narva and the Tallinn address was used as a cover.

Pre-war Narva was best known for its famous textile factories and thus it was quite natural to name the uranium production pilot project in Narva "Dyeing Factory". The pilot plant, founded by the same Decree No. 0282cc, was built round the clock from Nov. 27, 1946 to June 1, 1947, when it started to process no less than 10 tons of shale per day, enough for about 1 kg of uranium. By then it comprised separate units for ore beneficiation, burning, hydrometallurgical treatment, research laboratory, and power station with boiler.

The black shale beneficiation included crushing, sieving, classification through grading, and flotation. A rotary 1 by 8 m kiln was used for thermal pretreatment and leaching could be carried out by column percolation. The end product was a concentrate of uranium salts produced through sulfuric acid or soda leaching of the as mined or burnt shale concentrate. The research laboratory was fairly well equipped for the mid-forties. It had all the necessary apparatus for spectral, luminescence and radiometric analysis. Most common elements such as U, V, Mo, Zr, Li, Ti, as well as Na, K, Ca, Mg, Al, Si and Fe were routinely determined and by 1949, 4250 uranium determinations per month were carried out, most of them (68 %) by wet chemical methods.

The pilot plant employed at the time 219 workers including 116 industrial equipment operators and 45 engineers. The staff of the research laboratory was 101 persons. All operations were carried out without a waste depository and since the workers and even most chemists were unaware of what they

were doing (uranium was variously dubbed as carbon, aluminum, pitch, metal or some code number such as A-9, etc.) and workplace safety was non-existent. Both beneficiation and enrichment were known as moistening.

The research and development was not confined to the local black shale. The first batch of imported ore came in July 1949 from Bala-Sauskandyk and by 1952 only nonlocal ores were studied. By then a new 26 meters long rotary kiln was in operation and the Narva pilot plant was turned into a testing ground for new uranium technologies developed elsewhere in the USSR.

The Mining of Dictyonema Shale

According to the Decree No. 0282cc, the Dictyonema shale mine and the uranium extraction factory were to be built at Sillamäe using the remains of the pre-war Swedish "Estonian Oil Consortium AS" brown (kukersite) shale retorting plant, built in 1936. This plant together with all other Swedish-owned property was ceded to the Soviet Union by the May 30, 1941 Moscow Agreement. Soviet Union paid for the expropriated Swedish property in Baltic States with the Baltic gold deposited in Swedish banks and some Baltic ships lying in Swedish ports.

The first shaft of the black shale mine situated alongside the planned uranium factory at Sillamäe was sunk in December 1946, just after building of the Narva pilot plant started. Deadline for the planned 400 tons daily shale capacity was June 1, 1947, when deliveries to the Narva pilot plant had to start. The mining conditions were near ideal – a dry 1.15 m thick seam of shale with 13 to 20 m of overlay.

Nevertheless, the planned production quotas were difficult to achieve in spite of the large workforce used at the building site (16,000 prisoners and convicts, and a 10,000 man forced labor unit consisting mainly of Baltic conscripts who had served in the German army). The workforce actually used in the mine thus consisted of prisoners of war and criminal convicts (79 %) and of soldiers serving various kinds of punishment (19 %) with only 2 % of free labor. Out of all these, 30 % were in normal health, 60 % weak and 10 % very weak. It is then not surprising that 203 prisoners of war died during the first four months of 1946 at the prison camp No. 393 alone. This camp was built close to the mouth of the mine shaft.

The planned final capacity of the mine was large indeed, because the Decree No. 0282cc required prospecting for certified reserves of shale in Toila-Sillamäe-Utria deposit to yield 5,000 tons of uranium. At the 0.025 % uranium content of shale and 40 % yield achieved, it would mean 20 to 50 million tons of Dictyonema shale. No wonder then that true slave labor methods were used to meet the target that nevertheless remained elusive up to the very end of Dictyonema shale mining. Much better ore was soon found elsewhere and local mining operations were discontinued as of June 10, 1952. Only a very limited production (30 to 35 tons per day)

remained for research purposes. The mine itself was not destroyed, but conserved for optional further use. So it has remained to this day. Just before the Soviet Army left Estonia, numerous boreholes were sunk into the dormant galleries. The drillcores were immediately shipped away and the purpose of drilling remains unknown.

The Uranium Extraction Factory

Full-scale uranium production at Sillamäe was at first scheduled for March 1, 1947. It was not a realistic deadline even with massive use of slave labor. The old Swedish oil shale retorting factory proved to be a good cover for uranium production, but technologically useless and was never actually used. The first echelon of the Sillamäe "Combine No. 7", the "Plant No. 1", was completed more than a year after deadline, in June 1948. It started uranium production in the fourth quarter of 1948 producing 99 kg of uranium, or 6.6 % of the planned 1.5 tons. The production targets were not met in the two following years either and it became clear that the shale-based technology used was inadequate for the task both technologically and economically. The uranium extraction yield remained low and the production cost overruns high (see Table 1).

The factory started to use richer ore from other sources which are known only by codenames such as the Volkhov object (0.12 % U), the Maltsev object (0.17 % U), the Ermolayev object (0.27 % U), etc. For the use of the much richer ore a new producing unit "Complex 4" was completed and launched in March 1950, and uranium production increased rapidly. About 207 tons of uranium were produced from imported ore in 1950–1952. All use of Dictyonema shale was discontinued from July 1, 1952, and "Plant No. 1" was reconstructed for use with rich (1.5 % U) ores. However, the factory, the mine and the town remained totally closed and were administratively an exclave of the Russian Federation in Estonian SSR from 1947 to 1957 where no Estonians could be employed. It remained a closed city up to 1991, when all activities with extracted and enriched uranium were discontinued.

The new uranium-extraction factory or "Plant No. 1 of Combine No. 7" was built close to seashore (the Figure), 3 km NW from the Vaivara railroad station, and connected to it by a side track. The mine, the prison camp, the factory and the barracks for workers were all located at the territory of the present-day "Silmet" factory. The shale was transported to the factory in small 0.81 m^3 electric tramcars of the local railway.

The shale was burned and the ash leached using much the same technology as at the pilot plant, i.e. oxidative acid and basic leaching using sulfuric acid with potassium chlorate and thereafter sodium carbonate for leaching, followed by precipitation and sodium hydroxide treatment for the formation of the commercial product, the yellow cake. Insoluble U^{IV} in the native shale was thus first converted into soluble U^{VI} salts which were precipitated as insoluble sodium diuranate.

Table 1. **Uranium Production from the Local Dictyonema Shale at Sillamäe**

	1948 4Q		1949		1950		1951		1952		Total	
	planned	actual	planned	actual	planned	actual	planned	actual	planned	actual	planned	actual
Quantity of shale mined, 10^3 tons		6.6	114.9	68.3	86.6	80.3	76.5	77.3	39.5	39.0	317.5	271.5
Moisture, %		12.0	13.0	12.0	13.0	11.9	12.0	12.5	12.5	12.5	12.6	12.2
Average uranium content in dry shale, %		0.025	0.025	0.025	0.023	0.028	0.026	0.027	0.026	0.027	0.025	0.027
Total uranium in shale, tons		1.5	25.0	14.5	17.5	19.6	17.5	17.8	8.5	9.2	68.5	61.1
Uranium extraction yield, %		6.8	40.0	25.5	40.0	31.6	40.0	43.3	49.7	50.0		
Total uranium produced*[1], tons	1.5	0.1	15.0	3.7	7.0	6.3	7.0	7.7	4.2	4.6	34.7	22.4
Cost of the mined shale, roubles/ton			104.00	96.47	79.00	91.33	79.0	75.18	70.00	66.32	83.00	82.30
Factory price of uranium*[1], roubles/kg	12400	92000	8280	13729	7100	8230	6500	5930	5237	5016	7903 6779*[2]	24981 8226*[2]
State Planning Committee price for uranium*[1], roubles/kg			8750		7340		6700		5300		7023	

*[1] In 40 % chemical concentrate.
*[2] Without 4Q of 1948.

Aerial photo of Sillamäe in 1951. The uranium factory "Plant No. 1 of Combine No. 7" is located in the centre of the picture (*1*). Just North of it is the waste disposal area at the sea (*2*), and the underground mine extends NW from the factory to the sea (*3*). The prison camp is the rectangle West of the factory (*4*). Living quarters and barracks for the workers are located South and SE (town centre) from the factory (*5*)

Table 2. **The Number of Workers at the Combine No. 7**

	Year			
	1949	1950	1951	1952
1. At Sillamäe Mine	418	288	214	156
Plant No. 1				
a) Industrial group				
Unskilled workers	1691	1969	2098	1993
Engineers	263	266	284	282
Office workers	116	140	145	142
Apprentices	0	0	0	3
Militia	15	19	10	26
Security guards and firemen	67	77	53	65
b) Non-industrial personnel	642	909	1105	829
Total number of workers	2794	3380	3695	3340
2. Narva Pilot Plant	320	323	360	

Table 3. **Factory Price of 1 kg of Pure Uranium in 40 % Chemical Concentrate from Dictyonema Shale**

	Year		
	1949	1950	1951
1. Shale from the local mine	1174	1169	763
2. Processing materials	1773	1110	1034
3. Energy (electricity and steam)	2531	1654	1092
4. Fuel	269	283	177
5. Wages of the production workers	876	634	504
6. Bonus payments	66	49	42
7. Security costs	126	6	–
8. Plant overhead costs	3043	1611	1290
9. Factory general expenses	3871	1714	1023
10. Commercial expenses	–	–	5
Total uranium factory price roubles/kg	13729	8230	5930

Table 4. **Average Consumption and Prices of the Processing Materials for 1 kg of Pure Uranium in 1949–1950**

Chemicals	Consumption, kg/kg	Price, roubles/ton
Soda Na_2CO_3	1113.6	380
Sulfuric acid H_2SO_4	649.6	295
Potassium chlorate $KClO_3$	53.4	2500
Sodium hydroxide NaOH	23.2	2150

The factory was huge, employing thousands of workers (see Table 2) and obviously destined to grow rapidly.

Although economical uranium production from the shale was not achieved (see Tables 3 and 4), the technical progress made was successfully used with other raw materials. The factory price of uranium produced from local shale was 5016 roubles/kg in 1952, but only 1087 roubles/kg in case of imported ore.

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