



**Historical Survey  
of Nuclear Non-Proliferation in Estonia,  
1946-1995**

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The opinions and statements published in the  
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## **THE AIM OF THE REPORT**

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In 1992 Estonia became a member of the International Atomic Energy Agency (IAEA) and joined the Treaty on the Non-Proliferation of Nuclear Weapons, which was the first nuclear-related treaty for the newly independent Estonia. The Treaty-based Safeguards Agreement between the Republic of Estonia and IAEA was signed in 1997 and it obliges the state to introduce a state system of accounting for and control of nuclear material, present regular declarations to IAEA on the nuclear material in the country and host IAEA inspections checking the data presented. More detailed instructions for the agreement compliance are included in a technical document (Subsidiary Arrangements to the Safeguards Agreement) and are related to the specific nature of the facilities under safeguards.

The present report presents a historical survey on two of the nuclear facilities under the IAEA safeguards in Estonia – Sillamäe Uranium Extraction Factory and the Paldiski Submarine Training Centre. These facilities were a Soviet legacy and shall be decommissioned and it is only through a close international co-operation and technical assistance that it would be possible to solve all the problems arising at these facilities. The historical survey represents the best available information we are able to give on the nuclear facilities, which have functioned on the territory of Estonia. The historical survey was a joint co-operation initiative by the Estonian Radiation Protection Centre and the Swedish Nuclear Power Inspectorate.

In 2000 Estonia signed the Additional Protocol to the IAEA Safeguards Agreement, which has to be ratified by the Parliament. The following historical survey will be presented to IAEA as a volunteer supplement to the State Declaration according to the Additional Protocol.

## **ACKNOWLEDGEMENTS**

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# General background

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## 1. Introduction

Despite the fact that a huge uranium extraction factory had been constructed at Sillamäe after World War II, for various reasons, the actual part Estonia has played in the recorded history of the development of the atomic bomb is rather small. Very often the topic – the development of the atomic bomb – is focused on political issues, the clash of interests between the two blocks in this field, the role of individuals, including top statesmen (Stalin and Hitler, Truman, Churchill, Roosevelt, etc.) and scientists (Werner Heisenberg, Otto Hahn, Robert Oppenheimer, Niels Bohr, Enrico Fermi, Lisa Meitner, etc.) in the birth and use of the bomb. Sometimes even the slightest details have been explored, regarding the key persons involved in the development of the bomb. One can also find books with the exclusive aim to study the history of physics or technology, which explore even the times, when people had absolutely no idea of bomb-making and were still busy with studying the material substance. Various spy topics are also popular because of the readers' high interest in them. Rather widespread are also materials covering nuclear proliferation and the respective legislation. As a rule, the authors of either shorter or longer surveys are historians. But also persons directly connected with the development of the bomb, even the former agents of special services have started to talk and write. There are also some former militaries, who have been involved in this field and who have now started to publish themselves, mostly basing their articles on memoirs.

It is a relatively complicated topic for a research work. Documents are strictly classified (this is true in the whole world, by the way) and a considerable part of the documents concerning us are kept outside of Estonia. Researchers, even the local ones, have no access to these documents stored in the archives in Russia now. Since the late 1990s the archives in Russia have gradually started to limit researchers' access to materials concerning complicated political topics. Sometimes it is not even possible to review the material already used in order to check the references made. In addition, it is very difficult to find a necessary document out of the endless heaps of papers, because, instead of existing place names, only codes (numbers) were used for factories and enterprises in the correspondence. One can presume that, as a rule, the name of Sillamäe cannot be found there. This is due to the strictest measures of classification valid at that time. To our knowledge it is only David Holloway in his book "Stalin and the Bomb",<sup>1</sup> who refers to the US-located archive sources in connection with Sillamäe.<sup>2</sup> This author, who is well-known both in the USA and Russia, has referred to the archives he had used in his work in the notes printed at the end of his book. These archives include those in the USA, Russia (Archive of Foreign Policy of the Russian Federation (Архив внешней политики Российской Федерации); Archive of the Russian Academy of Sciences (Архив Российской Академии Наук [mainly the notes by academician Vladimir Vernadsky]), Russian Centre of Storage and Research of the Documents of Recent History

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<sup>1</sup> Holloway, David. *Stalin and the bomb: the Soviet Union and atomic energy, 1939-56* / New Haven: Yale University Press, 1994, p.176.

<sup>2</sup> CIA, National Intelligence Survey, 73-15.

(Российский центр хранения и изучения документов новейшей истории (РЦХИДНИ)); Centre of Storage for Contemporary Documentation (Центр хранения современной документации (ЦХСД)). It is interesting to note that none of the Russian central national archives are included in this list despite the fact that the author has been a frequent guest both in the Soviet Union and Russia, a well-known specialist with good contacts.<sup>3</sup>

As for Estonian researchers, the topic of uranium extraction at Sillamäe has been studied more than once by Endel Lippmaa and Ello Maremäe (look page 35).

**Sources. Archival materials.** Documents of the Sillamäe uranium extraction factory, used in the present report in the part concerning uranium production (Uranium Production Research at Sillamäe, Estonia, in 1946 – 1989), are stored in the archive of the AS Silmet at Sillamäe. The materials with the then-time stamp “Classified” – *секретно (с)* and “Strictly classified” – *совершенно секретно (сс)* have lost their previous status by now and at present all the historic documents are available to researchers. The materials on uranium production have been collected in one sc. Uranium room. All the existing materials have been indexed in the card file. Beside the materials concerning the Sillamäe factory, one can find there also studies on various uranium production technologies made by various USSR research centres, including those not applied at Sillamäe. The archive of AS Silmet is a valuable source for research work for the researchers of different fields (general historians and historians of science, chemists, physicists, technologists, etc.), including students. According to AS Silmet specialists, the archive covers a complete set of the Soviet-time documentation in the forms of copies, while the originals, as a rule, have been sent to the former “headquarters” in Moscow.

Nevertheless, the topic of uranium production at Sillamäe is of an absolutely secondary importance in the major context of the development and history of the Soviet atomic bomb. Tõnis Kaasik (Minister of the Environment in 1991 – 1992) says, “The first atomic bomb of the Soviet Union was obviously built of the uranium extracted at Sillamäe”,<sup>4</sup> the authors of this survey have no information to confirm it. According to the specialists from Sillamäe, the uranium extracted at Sillamäe might have played some role in the development of the bomb, nevertheless, they were pretty confident that the quantity of the output of Sillamäe was far less than it was necessary for the first bomb (oral opinion of the former specialists of the factory). One of the leading Russian specialists in the archival sciences – Aleksandr Bezborodov from Moscow, who has also studied the issue of nuclear weapons, could not recall coming across the name of Sillamäe, at least. Even in the Estonian State Archive no documents about Sillamäe are available, which means that the period of almost forty years has not been reflected in any public documents. Within this project Ello Maremäe (PhD, Senior Researcher, National Institute of Chemical Physics and Biophysics) and Iige Maalmann (Estonian Radiation Protection Centre) visited the archive of AS Silmet in January and February 2003 in order to obtain additional information on the uranium production at Sillamäe and check the data already available. A great number of new archive documents have been brought onto circulation by professor David Vseviiov Most of the material presented in his work has been collected from the funds of a special branch of the State Archive of Estonia – Communist Party Archive (Partarhiv) as well as from the archive of the Sillamäe factory – the present AS Silmet.<sup>5</sup>

<sup>3</sup> Kuznetsova, N. I. Atomnyi sled v VIET. In: Istoria sovetskogo atomnogo proyekta. Dokumenty, vospominania, issledovania. Moskva, 1998. Vyp. I, 1998, otv. red. V.P.Vizgin (IIET), p.68.

<sup>4</sup> Kaasik, Tõnis. Uraaniimpeeriumi rõhuvad varem. Luup, 1999, January 11, No. 1, p. 8-14.

<sup>5</sup> Vseviiov, David. Sillamäe – A Secret Uranium Town in Estonia. From 1944 to mid-eighties. The publication was available in internet: <http://www.undp.ee/iviru/silla.html>.

**Glasnost and the classified status of the materials.** Despite the general policy (glasnost) proclaimed by M.Gorbachev, the authorities did not succeed in accomplishing it. Materials concerning the factory at Sillamäe as well as other documents interesting for us are mainly stored in Russia (mostly in Moscow) – in the archives closed for the public and never managed by archivists and to which nobody has any access, not even archivists or local researchers. The probability of obtaining a research permit is by far higher for Russian researchers with a high-ranking military background. This is the case in Russia with all complicated classified political themes. Very often the purpose of their archive research is not a publication, but just the quest for exploring the history of their particular field in their senior age. Among them there are relatively many persons, who have worked in that particular field and beside that have even studied history. For example, extramural studies in history at Tartu University were rather popular among the local Russian officers during the Soviet time.

**Uranium supplies and Soviet Union.** From the point of view of the Baltic States, the hegemonic policy of the Soviet Union designated not only their appropriation, but also the intrusion of the Soviet Army into the territories of their countries and the development of a military-industrial complex there. The favorable geographic position of Estonia, Latvia and Lithuania made them soon one of the most significant regions for the Soviet military machine.

The formation of the US and Soviet atomic industries turned uranium pretty soon into the most significant strategic raw material. First the Soviet Union was far behind its competition in developing the atomic weapon. The USA had started their all-out effort to build the atomic bomb in the summer of 1942 already<sup>6</sup> and made a public use of the atomic bomb at the end of World War II already – in August 1945 in the attacks against Japan. Though by that time the Soviet Union had started its national programme already, nevertheless, a major nuclear research project was initiated by Stalin at the beginning of 1943,<sup>7</sup> but success was hard to come. Despite the ongoing tough war with Germany, money was lavishly spent on the project; there were highly-qualified researchers in the Soviet Union, who were relatively well-informed about the similar research in other countries and also the secret service NKVD had woven a well-functioning web in the West around the persons involved in the development and building of the atomic bomb and had succeeded in obtaining valuable information from them.<sup>8</sup> The initial progress in the development of the bomb in the Soviet Union was pretty fast, it was supported both by the government and indirectly by the success of the Red Army on the front; the Stalingrad battle ended with the surrender of the German forces on 2 February 1943.<sup>9</sup> Nevertheless, those involved in the Soviet bomb project, faced a lot of problems – the intelligence information from abroad was irregular and was greatly delayed, only selected few could review it (only Igor Kurchatov under Viacheslav Molotov's surveillance in the Kremlin); it was difficult to gather all the researchers during the tough war time, because some of them were serving in the army and therefore the progress made in the research work was rather slow; a special cyclotron, designed for the bomb project, went into operation no sooner than in September 1944, researchers lacked the graphite of the right purity for a nuclear pile, heavy water, etc.<sup>10</sup>

One of the greatest problems in the development of the Soviet bomb was the lack of uranium. In 1940 two well-known scientists, the geologist Aleksandr Fersman and the radiochemist Vitali Hlopin made an expedition to Central Asia and evaluated the deposits there to enable to

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<sup>6</sup> Holloway, D. *op. cit.*, 80.

<sup>7</sup> Holloway, D. *op. cit.*, 90.

<sup>8</sup> Holloway, D. *op. cit.*, 15-48, 82-84, 90-91, 127-138, etc.

<sup>9</sup> Holloway, D. *op. cit.*, p. 84-90.

<sup>10</sup> Holloway, D. *op. cit.*, p. 64, 85, 91, 100-103.

extract 10 tons per year, regarding the 1942 – 1943 extraction capacities.<sup>11</sup> Fersman painted a gloomy picture about the uranium extraction possibilities at Tjua-Mujun in Central Asia. The first step would have been the construction of a mine and roads.<sup>12</sup> At the end of 1943 new uranium deposits were found in Kirgizia.<sup>13</sup> On 13 March 1943 academician Vladimir Vernadsky wrote a letter to the President of the Academy of Sciences in which he wrote that for the use of atomic energy it was first necessary to find uranium ore in sufficient quantity. Reality turned out different. Extraction was out of the question at that time and in spite of the government order for 100 metric tons of uranium metal in 1943, only one kilogram had been produced by August 1945.<sup>14</sup> Though in 1943 Kurchatov had 2 – 3 tons of uranium at his disposal, it was not enough for the project.<sup>15</sup> The Soviet Union succeeded in buying a small quantity of uranium oxide and uranium nitrate and only one kilogram of impure metal also from the United States.<sup>16</sup> The aim of the Americans was to prevent the Soviet military industry from obtaining great quantities. By the way, in 1945 the United States controlled over 97 per cent of the world's uranium output.<sup>17</sup>

By the time the war was coming to its end and especially after its end the situation for the Russians improved through obtaining several greater quantities of this valuable strategic material in Germany, though a considerable part of it was lost, because the Americans succeeded in removing more than 1,200 tons of uranium ore, the bulk of the German stock, from the salt mine near Strassfurt, which was due to fall within the Soviet zone of occupation. Nevertheless, Julij Hariton and Isaak Kikoin managed to track down over 100 metric tons of uranium oxide that had been hidden away. This saved a year in building the first experimental reactor.<sup>18</sup>

It was not until September 1945 that field expeditions began full-scale exploration, and then they concentrated on the Fergana Valley in Central Asia.<sup>19</sup> The formation of the Socialist block brought important benefits for the Soviet atomic project and uranium possibilities. In March 1945 the Czechoslovak government in exile traveled from London to Moscow to sign a secret agreement giving the Soviet Union the right to mine uranium ore in Czechoslovakia and transport it to the Soviet Union. Before World War II the uranium mines in Jachymov<sup>20</sup> had been the world's main source of uranium, yielding about 20 metric tons of uranium oxide a year.<sup>21</sup> After the war the Soviet Union could also benefit from the valuable uranium deposits in East Germany<sup>22</sup> and later on from some other countries in the Socialist block, including China, nevertheless, these deposits were of minor importance.<sup>23</sup>

Despite the fact that by the end of the 1940s uranium supplies were not a problem any more for the Soviet Union, there was still a need for a local raw material. In September 1945 a commission went to Central Asia to explore the uranium deposits and organize mining there.

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<sup>11</sup> V. Hlopin, by the way, was a son of a former professor of Tartu University and became famous by being the first to obtain radium from the Soviet ore.

<sup>12</sup> Holloway, D. *op. cit.*, p. 66.

<sup>13</sup> Holloway, D. *op. cit.*, p. 102.

<sup>14</sup> Holloway, D. *op. cit.*, p. 174.

<sup>15</sup> Holloway, D. *op. cit.*, p. 100.

<sup>16</sup> Holloway, D. *op. cit.*, p. 101-102.

<sup>17</sup> Holloway, D. *op. cit.*, p. 174.

<sup>18</sup> Holloway, D. *op. cit.*, p. 111.

<sup>19</sup> Holloway, D. *op. cit.*, p. 102.

<sup>20</sup> Holloway, D. *op. cit.*, p. 174.

<sup>21</sup> Holloway, D. *op. cit.*, p. 109.

<sup>22</sup> Holloway, D. *op. cit.*, p. 111.

<sup>23</sup> Holloway, D. *op. cit.*, p. 177.

There was little experience in uranium exploration and the evaluation of production capacities, nevertheless, these active steps led to the discovery of significant new reserves.<sup>24</sup> By 1948 the Soviet Union had started mines in a number of uranium deposits, among others, in hardly accessible regions in Central Asia, but also in the Krivoi Rog region of the Ukraine, at Slantsy in Leningrad province, near Piatigorsk in the Caucasus, in the gold-producing areas along the Kolyma river and at Sillamäe. In 1948 the Soviet Union's uranium output had reached the level sufficient for the development of its atomic weapon.<sup>25</sup> In 1945 – 55 twenty-two new explorable uranium deposits were found, at that time the overall reserves mounted to 28 thousand metric tons in the Soviet Union. At the same time mining was started in more than 50 deposits in Eastern Europe with the total reserves of 84 thousand metric tons.<sup>26</sup> Sillamäe with its relatively favorable geographic position and well-developed infrastructure was one of the most suitable options for uranium extraction. As the authorities had already passed the decision in favor of Sillamäe and considerable investments had been made for its development, Sillamäe did become somewhat more important than other regions. It is unclear why Holloway has not included Sillamäe in the map "Soviet Nuclear Facilities" published in his book "Stalin and the Bomb".<sup>27</sup>

For years scientists have been interested in the Estonian Dictyonema shale. The first attempts to make use of it, first, as a fertilizer, were made in the 19th century already, but failed. In the northern coast of Estonia, near the islands of Pakri and in the Paldiski Bay, the Dictyonema is covering the seabed. Waves are breaking off fractions from it, piling them up in beach ridges. The shale attracted attention also by its self-ignition. The first researcher to study this phenomenon was obviously August Mickwitz (1849 – 1910), who had studied in Tartu University and Zurich Polytechnic Institute.<sup>28</sup> He has written in his notes that at the beginning of the 20th century (1909) the shale ignited in the Paldiski beach ridge and the town dwellers feared that it was a volcano. In 1901 A.Peli, a physician from St.Petersburg, published a piece of information stating that the shale found in the Tsarskoye Selo is radioactive. Dmitri Mendeleev, who also took up this topic, pointed out that the ground in the vicinity of St.Petersburg, dating back to the Silurian period, was radioactive and exercised a considerable influence on the growth of vegetation and the health of people. More thorough studies of the Dictyonema shale located in the Leningrad oblast started in the 1920s. Before World War II this rare mineral resource was given no military importance.<sup>29</sup>

In the early 1920s August Tammekann, who later on became a professor of geography in Tartu University, wrote rather detailed surveys on the former research work carried out in Estonia and the application possibilities for the Dictyonema shale – at that time mainly as a fuel or oil-production tests.<sup>30</sup> The then-time option was that the best places for shale-mining were the areas near Aseri and Purtse, but as those areas were important agricultural regions, then it was suggested to start mining near Paldiski and Keila-Joa as well as at Iru near Tallinn.<sup>31</sup>

<sup>24</sup> Holloway, D. *op. cit.*, p. 175.

<sup>25</sup> Holloway, D. *op. cit.*, p. 176.

<sup>26</sup> Памятники науки и техники отечественной атомной отрасли: Альбом. М. 1999, p.12 (Hallmarks of Soviet atomic branch).

<sup>27</sup> Holloway, D. *op. cit.*, p. 179.

<sup>28</sup> Hasselblatt, A., Otto, G. Album Academicum der Kaiserlichen Universität Dorpat. Dorpat, 1889, p. 626, (Nr. 8526).

<sup>29</sup> Aare, Juhan. Fosforiidisõda. 1971-1989. Tallinn, 1999, p. 13-14.

<sup>30</sup> Tammekann, A. Eesti Diktüoneemakihi uurimine tema tekkimise, vanaduse, levimise ja majandusliku tähtsuse kohta. (*Research work on the origin, age, spread and economic significance*). Tartu, 1924 (Prize-winning survey, manuscript in the Library of Tartu University).

<sup>31</sup> Tammekann, A. *op. cit.*, p.61.



This is a short background to the history of the Soviet uranium prospecting. These were the conditions under which the town of Sillamäe and its mine appeared. The construction of the uranium extraction factory at Sillamäe was of paramount importance for the Soviet Union.

## 2. Sillamäe as a town

The town of Sillamäe is situated on the southern coast of the Gulf of Finland, at the mouth of the Sõtke river. According to the Statistical Office of Estonia its population was 17,199 in 2002.

Sillamäe's status was changed in 1957, when its status as a town-like settlement was changed into that of a town of republican subordination by the resolution of the presidium of the ESSR Supreme Soviet.<sup>32</sup> As a tavern location, Sillamäe has been mentioned in 1502 already, Tüksamäe – the present location of Silmet – has been first mentioned in 1520. In the 17th century there was a fishing village and the Tüksamäe (Türsel) Manor at that place. In the 19th century the beautiful coasts at Sillamäe and Tüksamäe made them popular summer resorts, which were visited by numerous intellectuals from St. Petersburg.<sup>33</sup> Even the Estonian Encyclopedia describes Sillamäe only as a summer resort.<sup>34</sup> In 1928 – 29 an oil shale retorting factory, a power station and a landing pier were constructed at Tüksamäe.<sup>35</sup>

**Foundation of the town.** Sillamäe settlement was destroyed during the war and it was only near the coast that a few private houses were left intact, but their owners were not allowed to come back and inhabit them any more. Only ruins and a nettle-covered ash heap were left from the pre-war Tüksamäe oil shale retorting factory. A new factory was constructed on the ruins of the former retorting factory.<sup>36</sup> Since 1946 all larger constructions in the town were built by the prisoners of war and soldiers of construction battalions. Among the prisoners there were many Estonians, Latvians and Lithuanians, who had served in the German Army.<sup>37</sup> At the construction sites in Ida-Virumaa worked inmates of camps No. 289, 279 and 135. In April 1947 the number of inmates in those camps was nearing 20,000. The total number of the prisoners of war on the territory of Estonia may have been up to 40,000.<sup>38</sup> No doubt, the construction work at Sillamäe was the largest one in that time Estonia.<sup>39</sup> During the first winter people lived in 30-men textile tents, afterwards – mainly in 4-men tents. Later on these were replaced by circular tent-houses. The first living houses were two-family wooden barracks, the first stone houses at Sillamäe were completed in 1948.<sup>40</sup> After the war the situation and living conditions of all the prisoners of war kept in Russian prison camps were extremely bad and the cases of a severe violation of the Geneva Convention on prisoners of war were rather frequent in those camps.<sup>41</sup> Nevertheless, many of the prisoners could not

<sup>32</sup> Branch of the State Archive of Estonia Tallinn, former Estonian Communist Party Archive (henceforth Partarhiv), Collection (C) 1, Roll (R) 19, Document (D) 9, p. 54-55.

<sup>33</sup> Raukas, A. *Tundmatu Eesti – Sillamäe – nõukogude sõjatööstuskompleksi ehe (Unknown Estonia – Sillamäe – a Beauty of the Soviet Military Industrial Complex)*. <http://www.kes-kus.ee/02/ilumets.htm>.

<sup>34</sup> *Eesti Entsüklopeedia*, vol. 7, Tartu, 1936, p. 779.

<sup>35</sup> Raukas, A. *op. cit.*

<sup>36</sup> Kallas, V. *Sillamäe sünnilugu (The Story of Sillamäe)*. <http://www.hot.ee/vaikal/sillamae.htm>.

<sup>37</sup> Kallas, V. *op. cit.*

<sup>38</sup> Partarhiv, C 1, R 5 – special items, D 40, p.71, 96.

<sup>39</sup> Vseviiov, D. *op. cit.*

<sup>40</sup> Kallas, V. *op. cit.*

<sup>41</sup> Kallas, V. *op. cit.*

survive under those difficult working conditions.<sup>42</sup> Sillamäe might have been the beginning of a major plan. It is known that during the 1950s there existed a plan to found a huge new town – Slantsegorod – with the population of several millions and which would have extended from Kiviõli to Narva. Fortunately, Stalin's death and various other circumstances saved the northern part of Estonia from ruining its nature and destroying the homes of Estonians living in the area.<sup>43</sup>

**Population.** After the completion of the factory the town started to grow rather rapidly. The first civilian inhabitants there were the 14-18-year-old homeless brought in from Leningrad. They had to be trained to become factory workers. These were aggressive youngsters, who were also skilful thieves and burglars. Shops and warehouses at Sillamäe fell immediately their victims. A special armed guard duty was formed on the basis of the work battalion to protect the property. After several encounters the militia unit brought in from Leningrad succeeded in taking the situation under its control.<sup>44</sup> Discipline, in general, was a great problem at Sillamäe. In 1951 a fierce brawl between the bullies from Combine No. 7 and the workers of the Leningrad "Lenpromenergmontazh" Company, ending with the death of two men, arose a big scandal and the Central Committee of the Communist party of Estonia had to inflict several penalties to the management of the combine.<sup>45</sup>

Until 1951 the number of those workers at the construction site of the Sillamäe enterprise, who had been moved in from Russia, remained relatively insignificant. A more considerable inflow of Russian workers to Sillamäe started mainly in the early 1950s, when the first houses built by work battalions were completed. After that the population started to grow very fast.<sup>46</sup>

In September of 1950 the population of Sillamäe was already over 10,000.<sup>47</sup> Relatively favorable living conditions contributed to the rapid growth of the town.

**National composition of the population.** According to the census data, the majority of the population at Sillamäe was Russians. Out of 542 members and candidates of the Communist party organizations in June 1952 445 were Russians, 29 Ukrainians and 1 was an Estonian.<sup>48</sup> The number of factory workers increased also as a result of the growth of the Party organization of the town. In December 1970 its membership was 923 persons, out of whom 844 were Russians, 13 Estonians and 25 of other nationalities. By the way, there were almost 200 persons with higher or incomplete higher education among more than 900 Communist party members.<sup>49</sup> This data indicates a low percentage of Estonians at Sillamäe.

Employment problems at Sillamäe were partly solved in 1960 by founding there a clothing factory, producing mainly on-the-line-made special-purpose clothing. Employment problems were especially acute among women.<sup>50</sup> In the mid-seventies the factory processed mainly the loparite concentrate and gave the concentrate-related output. At that time a new task was given to the factory – to extract metallic niobium of nuclear purity for the production of zirconium niobium alloys for power engineering. This was something completely new for the

<sup>42</sup> Partarhiv, C 1, R 4, D 18, p. 9.

<sup>43</sup> Kaasik, Ago. Miks ei kaevandata diktüoneemakilta? (*Why don't they Extract the Dictyonema Shale.*) [http://lepo.it.da.ut.ee/~mrattas/EMKTwebsite/Referaadid/kaasik\\_dikt.htm](http://lepo.it.da.ut.ee/~mrattas/EMKTwebsite/Referaadid/kaasik_dikt.htm)

<sup>44</sup> Kallas, V. *op. cit.*

<sup>45</sup> Partarhiv, C 1, R 5, D 48, p. 82-102.

<sup>46</sup> Kallas, V. *op. cit.*

<sup>47</sup> Vseviiov, D. *op. cit.*

<sup>48</sup> Partarhiv, C 6388, R 10, D 1, p. 102, D 9, p.37.

<sup>49</sup> Partarhiv, C 6388, R 49, D 4, p. 9.

<sup>50</sup> Partarhiv, C 6388, R 26, D 4, p. 75-76.

factory, as rare metals had not been dealt with before. A considerable part of the output was exported and the classified nature of the enterprise was lost.<sup>51</sup> Notwithstanding the importance of that production, the enterprise itself had its ups and downs. The worst problems occurred in 1984-85 because of the notably reduced amount of the loparite raw material supplied as well as the decreased content of rare components, especially since 1985.<sup>52</sup> Changes in the enterprise production profile forced the Sillamäe residents to look for the job also outside of the facility – in the vicinity of Sillamäe. For example, a great number of local people were employed in one of the units of the Estonian Oil Shale Company (Estoslanets) by the end of 1975.<sup>53</sup> On the other hand, gradually the demand for the workforce increased also in the town itself. For example, in 1983 the Sillamäe factory needed 150 – 300 additional workers, in May 1985 a pertinent application was sent to Moscow.<sup>54</sup> A completely new enterprise was founded at Sillamäe by the 1979 Decree of the USSR Council of Ministers – a branch of the Tallinn-based electrotechnical enterprise named after H.Pöögelmann producing hearing aids.<sup>55</sup>

**Restricted access area.** Classified activities at Sillamäe were one of the reasons, why the USSR Council of Ministers proclaimed a great part of the Estonian northern and western coast to be a border area under special regulations the access to which (even for the residents in that area) was authorized only by special permits issued by the ESSR Ministry of Internal Affairs.<sup>56</sup>

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<sup>51</sup> Partarhiv, C 6388, R 56, D 1, p. 53.

<sup>52</sup> Partarhiv, C 6388, R 72, D 1, p. 85.

<sup>53</sup> Partarhiv, C 6388, R 56, D 1, p. 80.

<sup>54</sup> Partarhiv, C 6388, R 68, D 1, p. 58-59.

<sup>55</sup> Partarhiv, C 6388, R 62, D 2, p. 82.

<sup>56</sup> Partarhiv, C 1, R 5, D 24, p. 1.

### 3. Other fields, concerning nuclear activities in Estonia

There existed plans to build a research reactor in Tartu after 1953 – 54. The envisaged location was in the central part of the town – on the territory of the Maarja (St. Mary's) Church in the vicinity of the sports complex of the present Estonian Agricultural University. In view of this plan, a group of young students was sent to Moscow to study physics there. They would have had to major in nuclear physics in 1956. As Latvians outmaneuvered this project from Estonians and built a reactor in Salaspils, the fate of those students from Estonia was of nobody's concern any more and they had to find jobs on their own. At least two of them are well-known physics and Dr. Sc. at present.<sup>57</sup>

In addition, a number of Estonia-based enterprises (i.e. Dvigatel, Baltiets, enterprises with a postal box address, etc.) were manufacturing products for the Soviet nuclear or military industry. Sometimes even the manufacturers themselves did not know the actual purpose of their production, because quite often these enterprises manufactured only isolated parts, which were assembled elsewhere, as a rule, outside of Estonia.

According to the National Report of Estonia to UNCED 1992<sup>58</sup> there were about 20 rocket bases within the Estonian territory during the Soviet period while tactical nuclear weapons were deployed in almost every republic of the USSR. We do not have any original information about the number of tactical nuclear weapons located in Estonia. Some information sources indicate the number 270.<sup>59</sup> The Soviet leadership had moved nuclear weapons from Baltic republics prior to the end of 1991.<sup>60</sup>

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<sup>57</sup> Oral information received by H. Tankler, anonymity was requested.

<sup>58</sup> National Report of Estonia to UNCED 1992, United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3-14 June 1992, Tallinn, Estonia, 1992, p. 32-33.

<sup>59</sup> Belous, Vladimir. Takticheskoe yadernoe oruzhie v novykh geopoliticheskikh usloviyakh, Yadernyj kontrol, No. 14, February 1996, p. 2.

<sup>60</sup> Woolf, Amy F. CRS Issue Brief, 91144: Nuclear Weapons in the Former Soviet Union: Location, Command, and Control Updated November 27, 1996. <http://www.fas.org/spp/starwars/crs/91-144.htm>.

# Uranium Production Research at Sillamäe, Estonia, in 1946 – 1989

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## Introduction

After the World War II there was a situation in the world that USA already possessed the atom bomb in 1945, while Soviet Union only started looking for raw material to make it. The nearest place where geologists had reported to have found large quantities of uranium ore was in Northeast Estonia, and so the foundation of uranium processing facility was started in the Estonian town Sillamäe, situated on the southern coast of the Gulf of Finland, 172 km east of Tallinn and 25 km from the Russian border. Processing of Dictyonema shale at Sillamäe was started immediately after the World War II. The plant at Sillamäe was operating as a top-secret institution until 1991. The plant was privatized in 1997 and renamed “AS Silmet”. They are currently producing rare metals, rare earth metals, their compounds and alloys.

## First Part

### 1. Organization and Naming of the Facility [1-4]

In 1927 – 1928 the Swedish company “Estonian Oil Consortium AS” constructed an oil-shale processing plant in the location of the present plant at Sillamäe. The same Consortium was the owner of that oil-processing plant until WW II. This Plant together with all the 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 the Baltic States with the Baltic gold deposited in the Swedish banks and some Baltic ships lying in Swedish ports. However, in 1941 representatives of the company restored the plant jointly with the Germans. At the end of the war (since August-September 1944 until 1945) the further restoration of the oil-shale processing plant was carried out by the Estonian Construction and Assembly Trust. In 1945 the Glavgastopprom Oil Shale Processing Plant at the USSR Council of Ministers was founded on the basis of the before mentioned plant.

Following the classified Decree No. 1626-718cc/оп (cc/оп meaning top secret operative) of 27 July 1946 of the USSR Council of Ministers, the Head of the First Main Directorate of the USSR Ministry of Internal Affairs at the Council of Ministers issued a classified Decree No. 0282cc of 6 August 1946

to establish a diversified enterprise “Combine No. 7 “ at Sillamäe within the First Directorate of the same Main Directorate for the mining and industrial processing of the Baltic Dictyonema shale on the basis of the Glavgastopprom Oil Shale Processing Plant.

Following the Regulation No. 11684 PC of 29 September 1946 issued by the USSR Council of Ministers, an Decree No. 0313cc of 2 October 1946 of the above mentioned First Main

Directorate was issued to take over the Oil-Shale Processing Plant at Sillamäe, including the staff, equipment, living quarters, means of transportation and other material and technical assets from the Glavgastopprom of the USSR Council of Ministers for temporary exploitation. In addition, the Decree obliged Pjotr Andropov (Deputy Head of the First Main Directorate) to start pilot production of product A-9 (uranium) from the Dictyonema shale by 1 December 1946.

“Combine No. 7” was constructed by military construction units, mostly prisoners of the war and the assembly divisions of Glavpromstroï of the USSR Ministry of Internal Affairs, as ordered in the Appendix No. 2 of the Decree No. 0282cc/op of 6 August 1946.

In 1947 “Combine No. 7” was assigned the code name “Military Unit No. 77960” by the regulation No. 7428/2cc of 17 December 1947 of the First Main Directorate Second Division. According to the Decree No. 18 of 20 May 1948 of the Main Directorate a Register of the Reservists of this Military Unit was introduced in the combine.

In 1953 a regulation by the Ministry assigned the plant a new code name “Oil-Shale Processing Equipment Plant of the Ministry of Medium Machine Building of the USSR” for the purpose of using the name in their correspondence during their financial and economic activities up to second quarter of 1954. In March 1954 the assigned code name with the subordination to the Ministry of Medium Machine Building of the USSR was cancelled and it was never applied.

For the purpose of recruitment, issuance of service records, certificates and other document for the workers, engineers, technical workers and other employees, a code name “Enterprise P.O.B. 22” was assigned to the “Combine No. 7” following the Regulation No. YK/49 of 6 May 1955 of the Ministry.

Due to the simplification of the management structure of the industry, “Combine No. 7” was renamed as a “Factory No. 7” by Ministerial Decree No. 0460c of 9 December 1960.

For the internal use and contacts with the local institutions included on the list approved by the minister, a code name “Oil-Shale Processing Plant” was given to the plant by the letter of K.V. Borovkov No. PC/2220 of 8 September 1961.

In 1968 the plant was renamed as an “Enterprise P.O.B. P-6685”, later “Sillamäe Metallurgical Plant” and “Sillamäe Chemical Metallurgical Production Association”, now “AS Silmet”.

#### Moscow office of material and technical supplies of Combine No. 7

Foundation of the Moscow office of the Combine No. 7 took place by the Decree No. 0282cc/op of 6 August 1946 of the First Main Directorate. Liquidation of this Moscow office followed soon – in December of the same year, maintaining to representatives to fulfill special tasks. Full liquidation of the office was carried out by Decree No. 113c of 25 May 1951 of the Second Main Directorate.

## 2. Uranium Production from the Local *Dictyonema* Shale at Sillamäe

### 2.1. Estonian *Dictyonema* shale – occurrence in nature and chemical composition [5-7]

The Estonian Early Ordovician (Tremadoc) graptolitic argillite, known as the *Dictyonema* shale, crops out on the southern coast of the Gulf of Finland in northern Estonia. The shale correlates with the Ordovician Alum Shale of central and southern Sweden and belongs to the extensive formation of the Cambrian-Ordovician black shales extending from Lake Onega in the east to the Jutland Peninsula in the west.

The supplies of Estonian black *Dictyonema* shale are enormous – more than 60 billion tons forming about a quarter of the territory of the republic (Fig. 1). That is far more than those of the well-known brown oil shale (kukersite). The thickness of the *Dictyonema* stratum varies between 1 to 8 meters, it lies in the depth of some meters up to 300 meters. The origin of the *Dictyonema* shale goes about 500 million years back. Its popular name originates from the fossils found in the shale formed from the remains of graptolite *Dictyonema flabelliforme*. Being accumulated in quarry dumps, *Dictyonema* shale has a tendency due to rain, wind and sun to split into the sheet-like plates, and in contact with atmospheric oxygen and water it is a subject to spontaneous ignition.

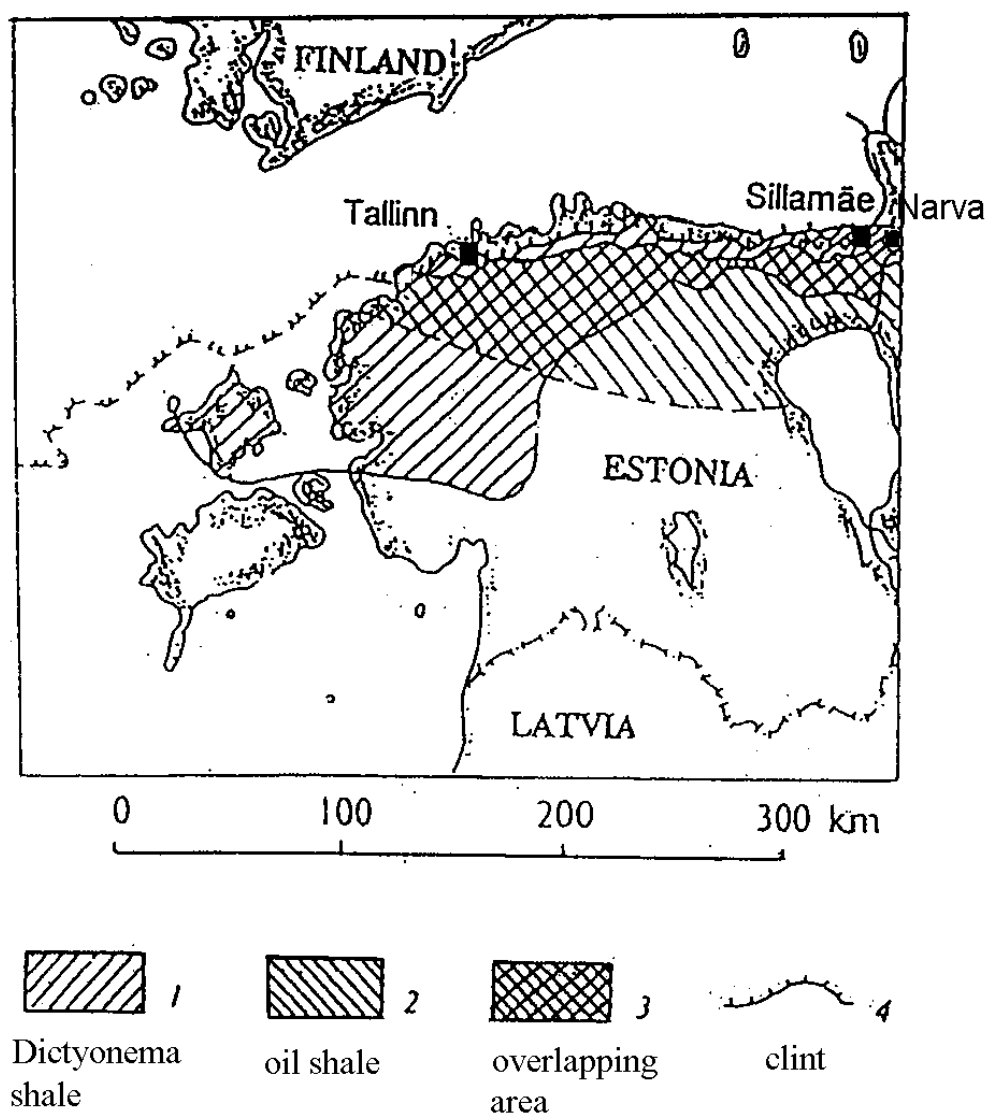


Fig.1. *Dictyonema* shale and oil shale (kukersite) supplies in Estonia

The Dictyonema shale is a low-grade oil shale. It contains 80 to 90% mineral matter and 10 to 22% (on average 15%) organic matter and is characterized by enhanced concentration of several microelements (Table 1).

The Dictyonema shale is a potential multi-mineral resource. The commercially important elements are uranium (35 to 300 ppm), molybdenum (50 to 400 ppm), vanadium (350 to 1,000 ppm), and rhenium (0.1 to 0.2 ppm). The maximum contents of these elements in the Estonian Dictyonema shale are as follows (in ppm): U – 1,038; Mo – 1,990; V – 1,910; and Re – 3. Uranium content in the Dictyonema shale, low as it is, induced the foundation of the uranium plant at Sillamäe in 1946.

Table 1. Chemical composition of the Dictyonema shale from the Sillamäe deposit

Component	wt %
SiO <sub>2</sub>	49.54-54.68
Al <sub>2</sub> O <sub>3</sub>	7.98-9.10
Fe <sub>2</sub> O <sub>3</sub>	7.82-10.77
K <sub>2</sub> O	4.74-4.97
CaO	3.30-5.82
Na <sub>2</sub> O	0.37-1.47
MgO	0.91-1.07
NiO	0.02-0.03
CuO	< 0.01 7
P <sub>2</sub> O <sub>5</sub>	0.87-0.93
V <sub>2</sub> O <sub>5</sub>	0.11-0.30
MoO <sub>3</sub>	0.03-0.080
CO <sub>2</sub>	< 1.72
SO <sub>3</sub>	0.33-1.80
Sulfides	< 4.38
Uranium	0.01-0.09, av.0.025
Others	0.5-1.20

## 2.2. Structure of Combine No. 7

Decree No. 85c of 8 March 1948 of the First Main Directorate introduced the following production structure of the Combine:

- a) Mine No. 1
- b) Mine No. 2 – was never founded
- c) Pilot Plant in Narva
- d) Plant No. 1 at Sillamäe.

### 2.2.1. Mine No. 1 [4, 8-10]

For the purpose of executing construction activities of the Mine No. 1 and securing the output of ore planned by 1 February 1947, the management activities of the mining were concentrated in a separate unit – Mine Management No. 1 by the Decree No. 2cc of 27 January 1947 concerning Combine No. 7. As a result of restructuring, Mine Management No. 1 was terminated and renamed as “Mine No. 1 of Combine No. 7”.



The first shaft of the Dictyonema shale mine, situated alongside the planned uranium factory at Sillamäe (Fig. 2), was sunk in December 1946, just after the building of the Narva Pilot Plant was started. Deadline for the planned 400 tons daily shale capacity was 1 June 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. 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 10 June 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.

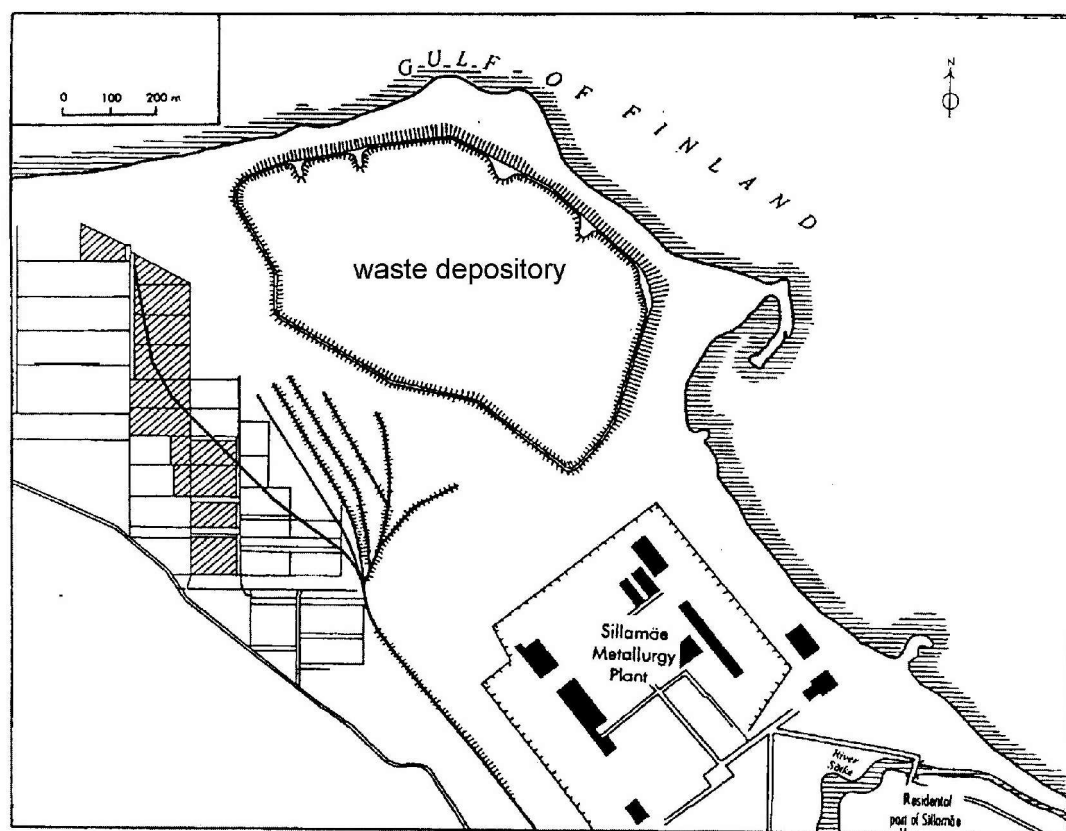


Fig.2. Sillamäe uranium plant (Plant No. 1), underground mine (striped area) and waste depository

Due to the fact that the processing of local ore was stopped, the mine was closed by 1 July 1952 by the Decree No. 141cc/on of 15 April 1952 of the Second Main Directorate and the Decree No. 65c of 11 August 1952 concerning Combine No. 7.

Due to the foundation of a pilot plant at Sillamäe and the preparations for the production from local Dictyonema shale, the mine was reopened on 1 February 1962 by the Decree No. 9c of 14 March 1962 concerning Combine (this time named Factory) No. 7.

### 2.2.2. Pilot Plant in Narva [4, 11-14]

Pre-war Narva was best known for its famous textile factories and thus it was quite natural to name the uranium production pilot plant in Narva “Dyeing Factory” (official name “Enterprise P.O.B. No. 2”). The Pilot Plant, founded by the Decree No. 0282cc/оп of 6 August 1946 was built round the clock from 27 November 1946 to 1 June 1947. By then it comprised separate units for ore beneficiation, burning, hydrometallurgical treatment, research laboratory, and power station with boiler.

The Dictyonema shale beneficiation included crushing, sieving, classification through grading and flotation. A rotary 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 (unburnt) or burnt shale. The research laboratory was fairly well equipped for the mid-forties. It had all the necessary apparatus for spectral, luminescence and radiometric analysis.

At that time the Pilot Plant employed 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\*, the workers and even most chemists were unaware of what they were doing (the word “uranium” was taboo) and the occupational safety was not applied.

The research and development was not confined only to the black local shale. Already in 1949 beneficiation of Bala-Sauskandyk ore had been studied. In 1956 – 1957 quite an interesting ore from Tastykol containing 0.15% U, 1.2% Zr and 23% P<sub>2</sub>O<sub>5</sub> in concentrate was investigated. The Utch-Kuduk ore with 0.13% U content was countercurrent-extracted with dilute sulfuric acid and AN-2F anionite was used for uranium concentration from leachate. Imported ores from Metchek, Chudonovichy, Prschibrani and others were also processed.

Since much richer imported ores had become available, the Narva Pilot Plant was transferred from the Sillamäe factory (Combine No. 7) to the State Union Project Institute No. 12 (ГСПИ-12) on 15 April 1957 by the Ministerial Decree No. 162 from 30 March 1957. The new owner continued the acid leaching experiments.

### 2.2.3. Plant No. 1 at Sillamäe [4, 9, 15, 16]

Construction of the pilot-scale chemical plant for uranium production (Plant No. 1) at Sillamäe was started in 1946. According to the Decree No. 340-150cc of 1 March 1947 of the USSR Council of Ministers the Plant had to start its operations since 1 July 1947 by the Decree No. 8cc of 3 April 1947 concerning Combine No. 7.

At first the full-scale uranium production at Sillamäe was scheduled already by 1 March 1947. It was not a realistic deadline at all 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 new uranium-extraction factory or Plant No. 1 of Combine No. 7 was built close to the seashore. The mine, the prison camp, the factory and the barracks for workers were all located

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\* The wastes were stored in the “second zone” of the Pilot Plant situating on the boundary of the town Narva. Later the wastes were transported by vehicles to the waste depository at Sillamäe.

at the territory of the present-day AS Silmet factory. The shale was transported to the factory in small 0.81 m<sup>3</sup> electric cars of the local railway.

The first echelon of the Plant No. 1 was completed about a year after the deadline, in June 1948. It started uranium production in the fourth quarter of 1948 producing 99 kg 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 overrun high.

The factory started to use richer ore from the other sources, which were known only by codenames such as the Volohov object (0.12% U), the Maltsev object (0.17% U), the Ermolayev object (0.27% U), etc. For the use of much richer ore a new producing unit Complex 4 was completed and launched in 1950, and uranium production increased rapidly. All the use of Dictyonema shale was discontinued from 1 July 1952, and Plant No. 1 was reconstructed for the use of richer ore. 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. Sillamäe remained a closed city up to 1991, despite that all the activities with extracted and enriched uranium were discontinued there since January 1990.

### **2.3. The first research institutions of the Soviet Union ordered to carry out research on Dictyonema shale [11]**

The decree of 27 July 1946 issued by the USSR Council of Ministers ordered twelve well-known research institutions of the Soviet Union to carry out research on shale in the following areas:

1. Chemical composition:
  - All-Union Institute of Mineral Raw Materials (ВИМС)
  - V.G. Hlopin Radium Institute of the USSR Academy of Science (РИАН)
  - Leningrad Mining Institute (ЛГИ)
  - Scientific Research Institute of Processing Mineral Resources (Механобр)
2. Beneficiation:
  - Scientific Research Institute No. 9 (НИИ-9)
  - State Scientific Research Institute of Nonferrous Metals (Гинцвтмет)
  - All-Union Institute of Mineral Raw Materials (ВИМС)
  - Scientific Research Institute of Processing Mineral Resources (Механобр)
3. Hydrometallurgical extraction of uranium:
  - Scientific Research Institute No. 9 (НИИ-9)
  - All-Union Scientific Research Institute of Hydrometallurgy (ВНИИГ)
  - All-Union Institute of Mineral Raw Materials (ВИМС)
  - N.S. Kurnakov Institute of General and Inorganic Chemistry of the USSR Academy of Science (ИОХ АН)
  - All-Union Scientific Research Institute of Geology (ВСЕГЕИ)

#### 4. Uses of shale organic matter:

Institute of Combustible Mineral Resources of the USSR Academy of Science  
(ИГИ АН)  
Moscow Division of the Mendeleev Chemistry Association  
Institute of Industrial Research of the Estonian Academy of Science

As can be seen from the directive of 4 June 1948 of the First Main Directorate of the USSR Council of Ministers titled "The results of the scientific research on the Dictyonema shale", the results achieved by the institutes differed widely and did not meet the expectations at all. The most important objective, extraction of uranium from the shale into the final product was, instead of the expected 70 – 80% extraction, as follows: All-Union Institute of Mineral Raw Materials – 20%, Scientific Research Institute No. 9 – 44%, All-Union Scientific Research Institute of Hydrometallurgy – 57%. A year later, the second directive of the First Main Directorate was issued on 7 May 1949. It stressed the importance of developing a new technology for efficient uranium extraction from the black Estonian shale and announced unheard of bonuses, up to one million roubles for the task. The best USSR equipment and new highly qualified staff were to be provided.

At the same time (in 1949) preparation works for processing higher grade imported ores were started in Combine No. 7. It was justified as a temporarily undertaking until the elaboration of effective technology for Dictyonema shale would be completed. So far the technology was missing and in 1950 – 1951 at Sillamäe the maximum uranium extraction percent from the local Dictyonema shale was only 40%, which was insufficient for any premiums to be paid. The Estonian black alum shale turned out to be a rather non-uniform ore with unpredictable properties not being subject to technologies used at that time.

### **2.4. Extraction of uranium from the local Dictyonema shale**

#### 2.4.1. The period 1946 – 1952 [7, 11, 17-20]

The very first scheme of Sillamäe Plant No. 1 for uranium production – carbonate scheme with previous combustion of shale (later also unburnt shale was processed) – proposed by the Scientific Research Institute No. 9 included in 1948 the following stages: underground mining of Dictyonema shale, crushing, grinding, combustion in Gerreshof kilns, soda leaching of burnt shale, precipitation of ammonium diuranate, drying and calcination in electrical furnaces. The final product was 40% concentrate.

As determined by the First Main Directorate, since the fourth quarter of 1949 chlorate-acid-soda scheme was used. In 1950 the improved scheme included (Fig. 3): crushing, grinding, burning in ten-bottom Gerreshof kilns, treatment with 1% solution of potassium chlorate and sulfuric acid, neutralization, leaching with 20%  $\text{Na}_2\text{CO}_3$  solution, double filtration on drum filters, pulp hydroremoval to waste depository, filtration of commercial solution on plate-and-frame filters, precipitation of the 1st chemical concentrate U-I (sodium diuranate), filtration, U-I repurification with 20%  $\text{NaOH}$ , filtration on plate-and-frame filters, drying the 2nd chemical concentrate U-II in electrical furnaces for the formation of the commercial product, the yellow cake. Insoluble  $\text{U}^{\text{IV}}$  in the native shale was thus first converted into soluble  $\text{U}^{\text{VI}}$  salts, which were precipitated as insoluble sodium diuranate [7].

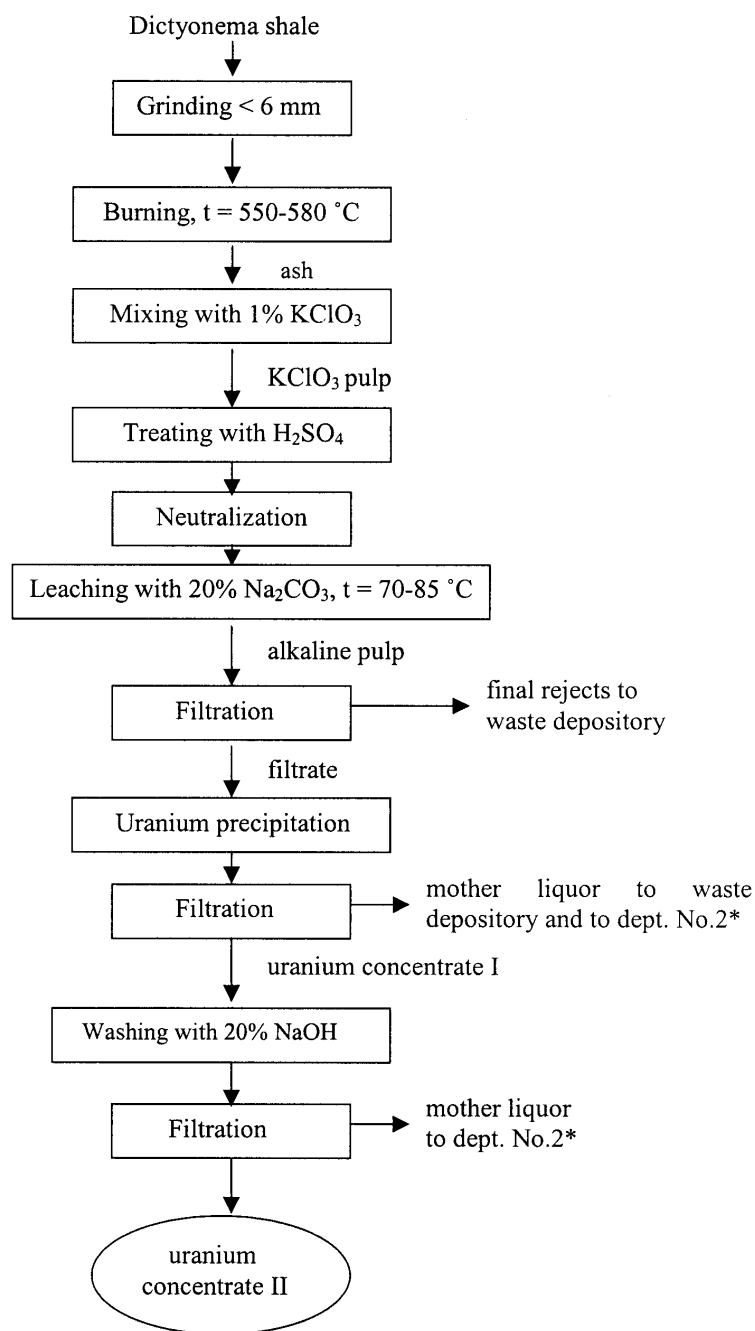


Fig.3. Flow sheet of uranium processing from local Dictyonema shale in Combine No. 7 in 1950

\* Mother liquor was directed back to the burning department (dept. No. 2) to moisten the Dictyonema shale before burning. It reduced dust and raised the uranium extraction level.

By the end of the 1st quarter of 1951 for the first time the extraction degree over 40% was reached. In spite of the desired 50% extraction degree was reached in 1952, the processing of local shale was stopped and replaced with treating imported ore much richer in uranium.

The total quantity of the Dictyonema shale mined in 1948 – 1952 was 271,500 tons. Uranium production from this shale was 22.4 tons of elemental uranium (while the final product was 40% concentrate) (Table 2).

Table 2. Uranium production from the local Dictyonema shale at Sillamäe in 1948 – 1952

	1948 4th quarter		1949		1950	
	planned	actual	planned	actual	planned	actual
Quantity of shale mined, 10 <sup>3</sup> tons		6.6	114.9	68.3	86.6	80.3
Moisture, %		12.0	13.0	12.0	13.0	11.9
Average uranium content in dry shale, %		0.025	0.025	0.025	0.023	0.028
Total uranium in shale, tons		1.5	25.0	14.5	17.5	19.6
Uranium extraction yield, %		6.8	40.0	25.5	40.0	31.6
Total uranium produced*, tons	1.5	0.1	15.0	3.7	7.0	6.3
	1951		1952		Total	
	planned	actual	planned	actual	planned	actual
Quantity of shale mined, 10 <sup>3</sup> tons	76.5	77.3	39.5	39.0	317.5	271.5
Moisture, %	12.0	12.5	12.5	12.5	12.6	12.2
Average uranium content in dry shale, %	0.026	0.027	0.026	0.027	0.025	0.027
Total uranium in shale, tons	17.5	17.8	8.5	9.2	68.5	62.6
Uranium extraction yield, %	40.0	43.3	49.7	50.0		
Total uranium produced*, tons	7.0	7.7	4.2	4.6	34.7	22.4

\* In 40% chemical concentrate

### Central laboratory

In 1949 there were four groups in the central chemistry laboratory for analyzing the following materials: initial raw material, solutions, uranium production and end product. The laboratory staff consisted of 7 engineers, 8 technicians, and 69 technical assistants – 84 persons altogether.

Among the laboratory staff only three engineers and ten assistants had a three-year-long experience and were skilled professionals. The others were mostly young untrained people with no knowledge of chemical reactions occurring during uranium treatment. The

unknowing was even preferred. However, mechanical following of analysis protocols caused incorrect and even wrong results.

### Security

Every operation of uranium production at the Combine No. 7 was kept secret from the very first days of operation. Use of the word “uranium” was strictly forbidden in inner and outer correspondence, in reports, in official and personal talks of employees. In 1946 – 1947 uranium was called “A-9”, a designation introduced by the Research Institute No. 9, which led to rather transparent formulas like  $(A-9)_3O_8$ . Uranium was also called metal, pitch, carbon, aluminum etc. Beginning from 1950 mostly carbon and metal were used. Moscow preferred the names silicon, lead and tin. Uranium enrichment degree was called metal moisture degree.

Operations, products, links of equipments and also chemicals were called by code names. The names of the technological processes were changed as well (for example, uranium ore was named sand, filtration – separation, enrichment – moistening, etc.), and the chemicals (soda, sulfuric acid, ammonia, etc.) were named as products 1, 2, 3, etc., and these numbers were often changed. A special decree about the use of the required terminology included a special paragraph for the department heads informing them that every offender will be severely punished. The First Department (State Security) was the instance that controlled indisputable submission to this decree. An operator of the Narva Pilot Plant who in 1948 leaked data on Combine No. 7 was convicted by the Supreme Soviet Presidium of the Soviet Union and sentenced to eight years imprisonment.

Strict requirements were established for storing the concentrates. However, a control raid made in October 1950 on the Central Laboratory found there precious samples of uranium concentrate to lay in an open wooden locker in an unlocked basement room where employees of another department were working. Neither the head of the laboratory nor anyone else had any idea about the number of the samples. After this inspection a correct booking was introduced, and a special person appointed to be responsible for correct accountancy. The samples were to be kept in a guarded room in a locked and sealed strongbox.

### 2.4.2. The period 1953 – 1973 [11, 21-23]

In this period various other methods for uranium producing from Dictyonema shale were tested. In 1950s the Leningrad Technological Institute in collaboration with Combine No. 7 made numerous draft proposals to process 100, 000 t of black shale per day in the Combine No. 7 according to the four technological versions given in the Table 3. From the proposed schemes, version No. 1 (considered the best) described the planning of pilot operation in 1959 and allotment of capital resources to build the installation in Combine No. 7 in 1960.

In 1960 – 1963 bacterial leaching experiments with the Estonian black shale were carried out at Sillamäe. A 50% uranium yield was achieved in a large 2,000-ton concrete percolator with up to 25 mm crushed shale. In a two-year run (23 months) in open-air heaps, and the wooden percolators with shelves and added bacterial cultures, a 55% uranium yield was achieved with up to 25 mm crushed shale.

Table 3. Proposals of the Leningrad Technological Institute for processing Estonian black Dictyonema shale in Combine No. 7

Version No.	Proposal	Uranium Extraction yield, %	Calculated factory cost of 1 t uranium, th. roubles
1	Leaching of black shale using the percolation method	49	724
2	Leaching of black shale in heaps on special stands or in a quarry	42	900
3	Underground leaching of shale	34	1,010
4	Combined scheme, where 70% of the shale goes to direct percolation and 30% for leaching after roasting	59	665

Some other approaches to achieve better uranium extraction yields from the local black shale were also tried, such as extraction under pressure. The 30 m<sup>3</sup> stainless steel autoclave was installed at Sillamäe in 1965. The next year experiments with acid leaching at 140 – 150 °C under oxygen-vapor pressure of 15 – 20 atm were carried out and up to 65 – 70% (max. 76%) uranium leaching yield was achieved. However, results were not good enough for such an expensive apparatus and process. The financing of the pilot plant at Sillamäe was terminated in 1973 and work with the Estonian Dictyonema shale ceased at about the same time.

## Second Part

### 3. Uranium Production from Imported Raw Material at Sillamäe

#### 3.1. Chlorate-acid-soda scheme. 1949 – 1954 [16, 24-26]

In 1949 in Combine No. 7 a special Complex No. 4 (Shop No. 4) for processing of imported uranium ores was organized. The shop was launched in April 1950. The process was characterized by throughput rate of 100 t of ore per day using chlorate-acid-soda leaching with gravity concentration at the process head. After the ending of the gravity concentration application in 1951, the flow sheet included the following operations: grinding, thickening of ore pulp, potassium chlorate treatment, acid treatment, neutralization and then leaching with soda, thickening of soda pulp, double filtration on vacuum filters, soda repulping of cake, treatment of the final cake with sea water and its hydroremoval to depository, prethickening of filtrates, control filtration, precipitation of uranium (using acid and ammonia), filtration, drying, separation and packing of the precipitate. The final product was 40% chemical concentrate. By the end of 1951, extraction of uranium from ores into chemical concentrate reached 80%.

In 1951 the shop was reconstructed to process both the second- and third-grade ores. The line of processing the richer second-grade ores was launched in September 1953.

The process of chemical concentrate repurification by salting ammonium uranyl tricarbonate (AUTC) crystals out with ammonium carbonate was introduced in 1952. The regeneration process of ammonium carbonate was mastered as well as calcination of AUTC crystals in rotary tube electric furnace to obtain a new product – mixed oxide U<sub>3</sub>O<sub>8</sub>. The latter operation



enabled in 1953 to produce high-quality  $U_3O_8$ . In this respect the designed capacity of the shop was not only reached but even surpassed next year.

The technological flow sheet of processing imported ores using chlorate-acid-soda scheme is given in Fig. 4.

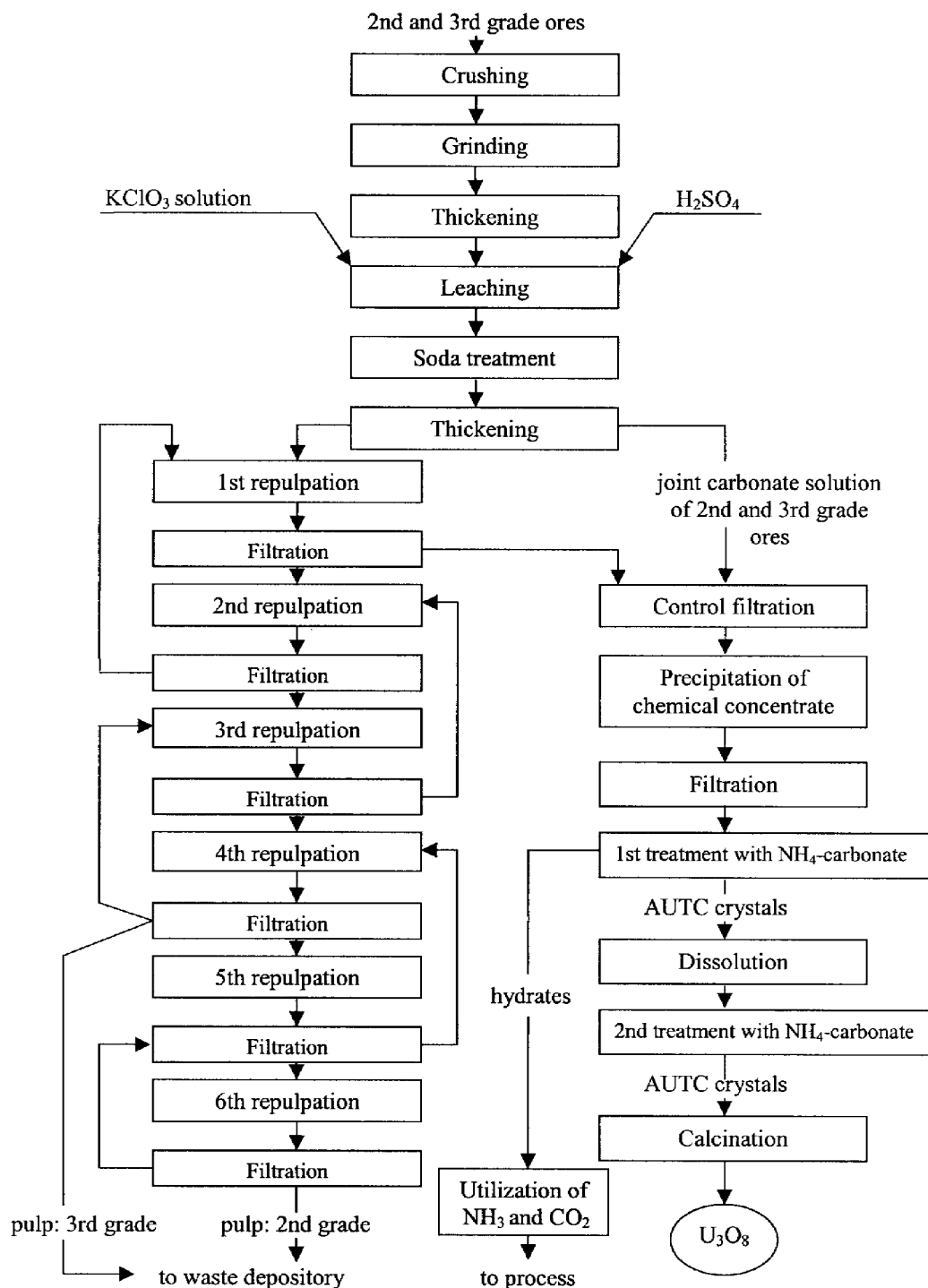


Fig. 4. Technological flow sheet of reprocessing of imported ores using the acid chlorate-soda scheme

### 3.2. Acid-sorption scheme. 1955 – 1985

#### 3.2.1. The period 1955 – 1959 [21, 26]

The Ministerial decree from October 1954 obligated the Combine to design and to mount a full-scale unit for testing the possibility to obtain uranium from acid pulp by sorption, i.e. to use a more progressive acid-sorption scheme. In 1954 – 1955 Combine No. 7 was one of the first uranium production plants of hydrometallurgical industry introducing the acid-sorption scheme without filtration.

During the trials from November 1955 continuously up to 1958 many steps of the flow sheet were elaborated and both the technology and equipment were considerably improved. In the desorption process a more economic and less labor-consuming flow-scheme of wash water was accepted. This scheme without filtration enabled to exclude six plate-and-frame filters and to liberate 31 employees from hard physical labor. Elaboration and introduction of sorption extraction scheme, a novel route in uranium hydrometallurgy, enabled to enhance the productivity, to reduce reagent requirements and the cost price of processing markedly.

The situation in waste depository was improved as well. The dikes were reconstructed by covering with dumped sand and planting greenery. The electric lighting was established. Construction and employment of overflow wells stopped ingress of tailings silt into the Gulf of Finland.

#### 3.2.2. The period 1960 – 1969 [26-28]

In 1960 the sorption process was modernized again, this renovation included installation of twelve ion-exchange column-reactors (“pachuks”\*) and five desorption columns. Already in 1961 the new unit of “pachuks” was put into full-scale operation. Thanks to the sorption process flow sheet became much shorter due to omitting precipitation of the 1st chemical concentrate and filtration on plate-and-frame filters.

In 1961 – 1962 the mixtures of ores with average uranium content of 0.51 – 0.52% were processed. The ores imported from different foreign countries were as follows (the number in brackets indicates the grade of the ore):

- Poland – 0.22% (III) and 2.34% (II)
- Czechoslovakia – 0.39% (III); 0.81% (III) and 1.95% (II)
- Romania – 0.41% (III)
- Hungary – 0.21% (III)
- East Germany – 1.58% (II) and 3.50% (II)
- Bulgaria – 2.32% (II)

In 1965 – 1966 a more original version of the sorption scheme, so-called “sorption leaching” using a new resin AMP was suggested. The following processes were developed (Fig. 5): sorption leaching of pulp in “pachuks”, regeneration of AMP using the method of chloride conversion, sorption repurification of chloride solutions on SG-1, neutralization of spent pulp with oil shale ash from thermal power plant (TPP). Ammonium carbonate purification process of commercial solution in salting out of AUTC crystals was mastered, and the output, which met more strict requirements concerning the additives, was guaranteed.

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\* Russian term for special equipment used for both leaching and sorption.

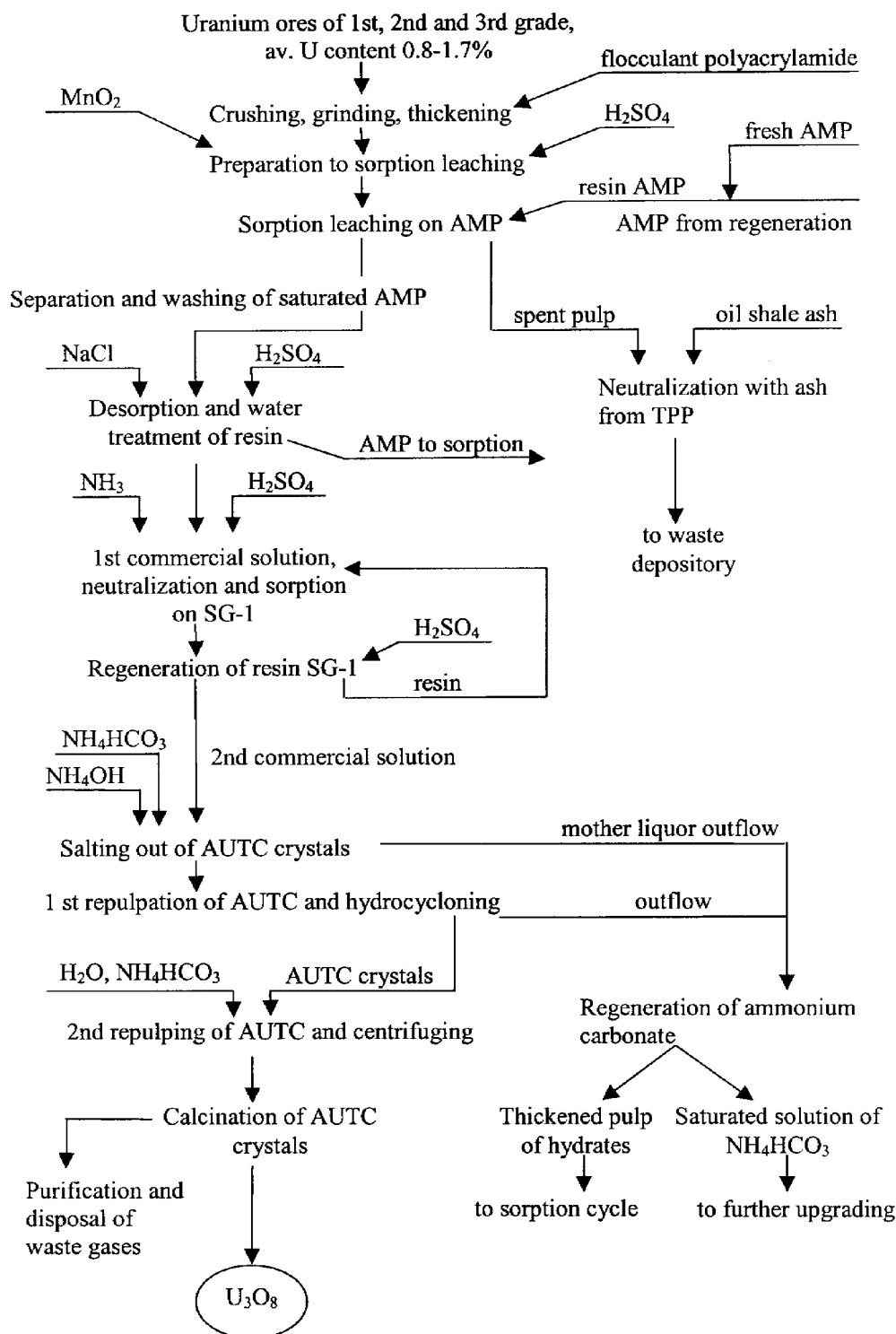


Fig. 5. Flow sheet of combined processing of 1st, 2nd and 3rd grade ores using sorption leaching on AMP (1967-1970)

The new method fully substituted the previous one in 1967. In 1968 the strongly alkaline anion exchanger AMP was finally introduced. Realization of the combined process in acid medium enhanced the extraction degree and enabled to avoid the labor-intensive treatment of ore sand fraction in a separate unit. Upon that the use of AMP enabled to use the same

equipment for ore leaching and uranium sorption on AMP (i.e. to create the so-called “sorption leaching”) and to introduce its large-scale use for the first time in the world practice.

In 1960 – 1970 the share of the 1st-grade ores began to grow as the raw material was imported mainly from the Soviet-German joint-stock company “Wismut”.

The data characterizing the rise in production output were as follows (Table 4).

Table 4. Uranium production at the Sillamäe uranium plant in 1967 – 1970

	1967	1968	1969	1970
Uranium output, t	1,320	1,357	1,409	1,465
Uranium content in the ore, %	0.703	1.085	1.480	1.828
Extraction, %	97.12	97.74	98.02	98.07
Number of workers	529	482	301	266
H <sub>2</sub> SO <sub>4</sub> consumption, t/t uranium	36.05	28.84	25.22	23.87

### 3.2.3. The period 1970 – 1979 [28, 29]

In 1970 it was decided to decrease ore import in 1971 – 1975, simultaneously starting to import a 50% uranium chemical concentrate from Germany. This time two types of uranium-containing raw material were processed at Sillamäe:

- a) 1st- and 2nd-grade ore concentrates (gravity concentration products, uranium percentage 1.6 – 7%, supplier – Soviet-German joint-stock company “Wismut” from German Democratic Republic), and 2nd-grade concentrates (1.5 – 2%) from Czechoslovakia,
- b) chemical concentrates (45 – 55%) provided by “Wismut”.

Ore concentrates were transported in railway wagons in bulk, chemical ones in special wooden containers.

In 1973, designing the technology for processing ore concentrates and chemical concentrates together, it was decided to use soda-ammonium carbonate in the applied sulfur acid-sorption scheme. However, in 1974 – 1975 great drawbacks of this scheme were discovered: calcination of the second crystals of ammonium uranyl tricarboxylate yielded the off-grade U<sub>3</sub>O<sub>8</sub>. Then, application of the scheme was discarded and in 1976 – 1977 the efforts were directed at improving only the chemical concentrate processing technology. As the sorption technology using an anionite of high capacity to uranium had many advantages, in 1977 a high-efficient sorbent VP-IAP, more effective than anionite AMP, was elaborated and tested. The corresponding flow sheet is given in Fig. 6.

Both technology and equipment were continuously improved. In 1979 series of innovations were introduced into the technology for desorption of uranium from anionite. Better desorption conditions and reutilization of ammonium carbonate and ammonia allowed to reduce the consumption of reagents and gave an essential economical effect.

In this time new tasks were performed also in technical fields: monitoring and automatic control equipment was taken into use for the first time. The first line of the control system “Yantar” was put into full-scale operation. The system had three subunits: for central control, for calculating main technical and economic parameters of the work of the department, and for controlling the process run.

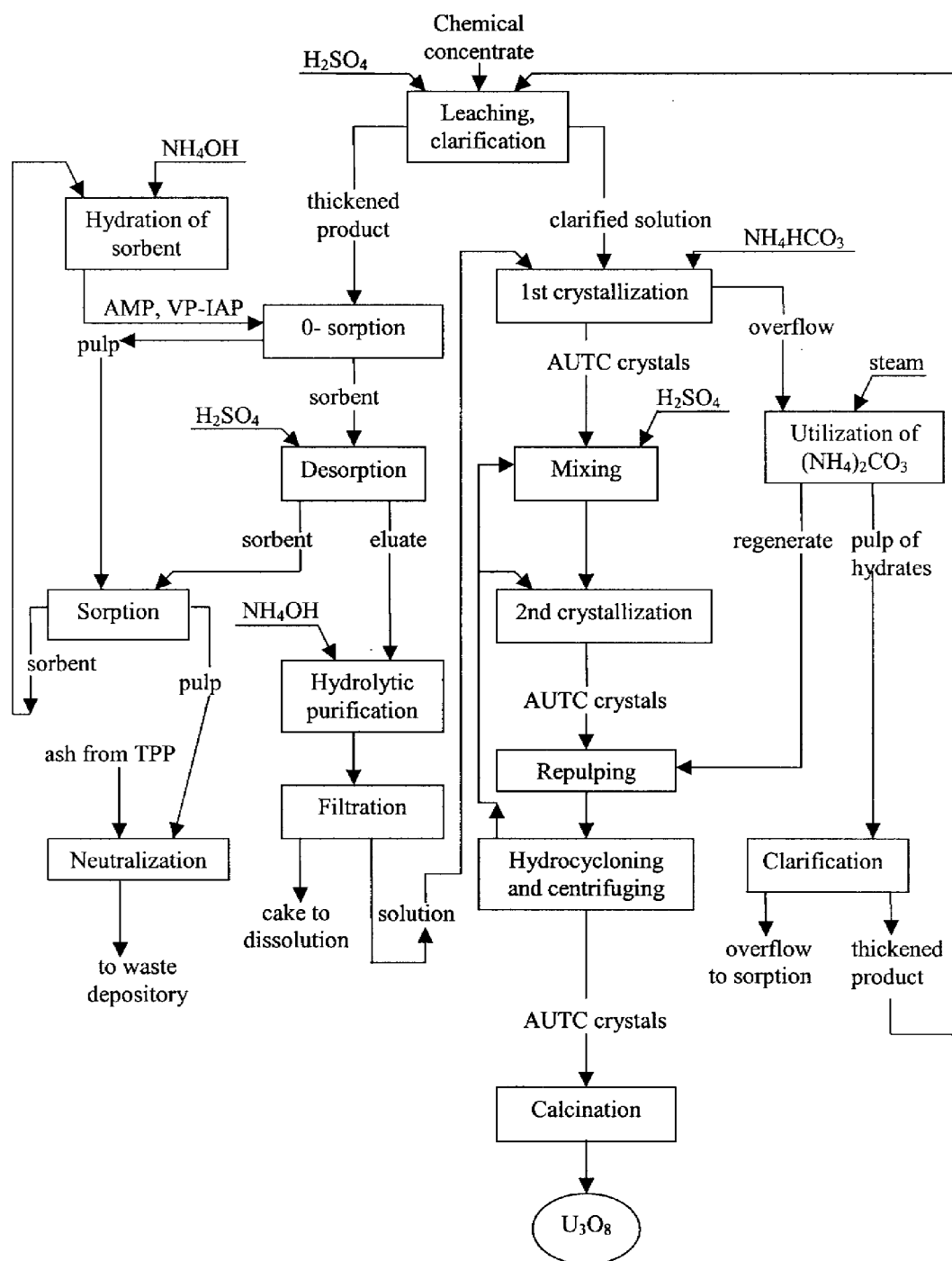


Fig.6. Technological flow sheet of processing of chemical concentrate using acid-sorption scheme

### 3.2.4. The period 1980 – 1985 [29, 30]

Processing of chemical concentrates imported from Czechoslovakia was mastered in 1980. The concentrates were relatively poor in uranium (up to 50%) but rich in admixtures (potassium, sodium, iron, aluminum). In spite of the initial matter poor quality the production characteristics met the heightened requirements designed for the year 1982. During the years

1981 and 1982 chemical concentrates both from Czechoslovakia and Germany were processed using the sorption technology. The department worked steadily and efficiently giving high-quality production.

In 1983 a two-stage counter-flow scheme for washing off admixtures from sorbent saturated with uranium was worked out and taken into use. It enabled to diminish water supply and stabilize the quality of the end product regarding iron, aluminum and silicon.

In 1980 – 1985 the attention was paid also to diminishing the amount of harmful waste and reutilization of expensive reagents ammonium carbonate and ammonia. Successful large-scale experiments were made to test a new device ARTKM for thermal decomposition of ammonium carbonate in mother liquor from the crystallization unit. Ammonium carbonate regeneration based on the mentioned ARTKM was considerable as the new node enabled significantly to enhance the utilization coefficient of ammonium carbonate as one of the biggest tonnage reagent needed in uranium industry. At the same time in 1984 the process to reach complete re-extraction of ammonia from still bottom after crystallization of AUTC was introduced.

Improvement of the sorption equipment was a continuous process. In 1985 the “pachuks” used to extract uranium from pulp were replaced by pulsating columns packed with KRIMZ. The first from a four-column assembly was installed in the same year.

In November 1983 the second line of automatic control was put into operation. It gave a considerable economical effect.

Further efforts to enhance the economic efficiency of uranium production included preparations to start with processing of rejected fuel elements (discussed in detail in the Chapter 3.3).

The present report does not reflect the period 1986 – 1989 about sorption process at Sillamäe uranium plant, as the corresponding data were not available.

### **3.3. Processing of rejected fuel elements**

Preparations to start with a new production line at Sillamäe – the recovery of significantly more radioactive enriched uranium products from the utilizable waste of the fuel elements supplied by the other 3rd Main Directorate enterprises – began in the 1980s. There were three kinds of processes elaborated: 1) production of low-enriched uranium dioxide 2) production of granulated microfuel and 3) production of spherical fuel elements.

#### **3.3.1. Production of low-enriched (2.0. – 3.6% U-235) uranium dioxide from rejected fuel elements [31, 32]**

The feasibility study for starting the production of low-enriched uranium dioxide from rejected fuel elements was carried out on the basis of the order No. MG-548c by the Head of the 3rd Main Directorate from 24 March 1980.

In 1981 – 1982 a new Building No. 1b was constructed and radiation resistant equipment for two production lines installed. The start-up, adjustment and alignment of the lines started in

December 1982. The full output rate of novel products – low enriched  $\text{UO}_2$  powders were reached in 1983 (U-235 content then 2.0; 3.0; and 3.3%).

Uranium dioxide was produced from technical-grade  $\text{U}_3\text{O}_8$  (2.0 up to 3.6% U-235 enrichment) manufactured through oxidation of rejected pellets of  $\text{UO}_2$  in the Machine Building Plant in Elektrostal, Ulbinsky Metallurgical Plant in Ust-Kamenogorsk and Novosibirsk Plant of Chemical Concentrates. Source material was transported to Sillamäe by railway in 330-liter stainless steel containers. The standard end product was delivered to consumers – to the enterprises where the rejected fuel elements initially had come from – in the same containers in the same way.

The technology of enriched  $\text{UO}_2$  production was analogous to the schemes implemented at the other enterprises of the Main Directorate. The scheme included the following basic operations (Fig. 7): dissolution of  $\text{U}_3\text{O}_8$  in nitric acid, extraction with 25 – 30% solution of tributyl phosphate (TBP) in kerosene, re-extraction with water, precipitation of ammonium diuranate, its thermal decomposition and the following reduction in the hydrogen flow to get  $\text{UO}_2$ . The extraction degree was 99.15%.

The total production in pure uranium terms at Sillamäe within 1983 – 1989 was about 1,355 tons (Table 5).

Table 5. Enriched uranium dioxide production at the Sillamäe uranium plant in 1983 – 1989

Uranium in enriched $\text{UO}_2$ , t	1983	1984	1985	1986	1987	1988	1989	1983-1989
2.0% U-235	34.623	79.109	98.606	53.489	103.547	No data	40.119	
2.4% “	0	0	0	0	74.036		150.569	
3.0% “	13.190	25.504	0	0	40.347		66.082	
3.3% “	68.025	52.056	71.492	88.342	22.571		0	
3.6% “	0	0	0	19.026	0		0	
Total	115.838	156.669	170.098	160.857	244.501	249.936	256.770	1,354.669

Powders of uranium dioxide obtained were applied to produce nuclear fuel for nuclear power stations and for various other power units.

### 3.3.2. Production of granulated microfuel from rejected 21 – 90% enriched uranium dioxide [33, 34]

Granulated microfuel was produced from rejected enriched uranium dioxide with 21, 36, 45 and 90% U-235 enrichment. The raw material – enriched uranium dioxide powder – was transported to Sillamäe by railway in 7-liter containers (net weight 15 kg). The supplies were transported into the warehouse which was equipped with cadmium-plated racks. From the warehouse the containers were transported to the Building No. 1b where the dioxide powder was stored in a steel safe. When needed for processing, the material was reloaded into a sealed hood and grinded there in a ball mill. Grinded  $\text{UO}_2$  was mixed with plastizing agent for making microcores by way of mechanical rolling. After quality control standard cores were mixed with aluminum oxide powder and sintered. The final sintering to the designed density was carried out after removal of aluminum oxide powder. Sintered microcores were subjected to a thorough quality control as well as to their sphericity, size and also grading control. Their density, oxygen index and danger factor were determined.

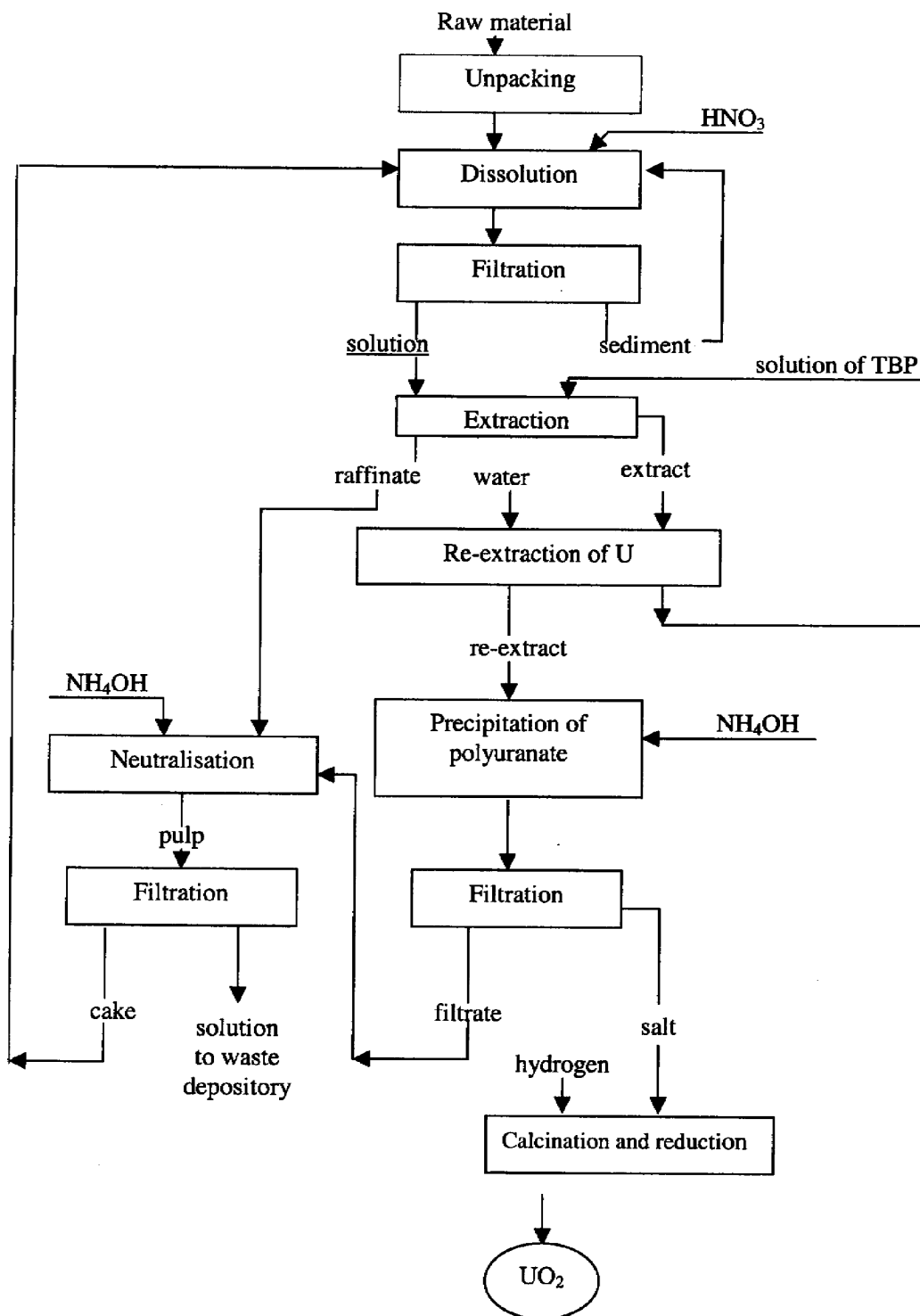


Fig. 7. Technological flow sheet of the recycling of rejected fuel elements

As follows, microcores were covered by protective pyrocarbon coating at a “fluidized – bed” unit. At the same unit the covered cores were tested for radiation leaks and packed into glass jugs stored in metal boxes or into dry metal containers of the capacity of 2.7; 5.0; 10 and 20



liters depending on the U-235 enrichment level. The pyrocarbon-coated fuel granules were stored and transported only in a packed form.

The production areas of the pilot shop belonged to the increased fire hazard category. In order to avoid a spontaneous chain reaction, the transportation routes of the enriched material were designed ruling out any cross transportation, i.e. the line production was applied. The entire equipment used for technological operations or for storing the enriched material was made to be radiation resistant.

The pyrolytic-carbon-coated uranium dioxide granules were to be used in the cores of the fuel elements of the water-cooled reactors in the composition of uranium dioxide + aluminum alloys, as well as in the spherical graphite fuel elements of the high temperature gas cooled type reactor VGR-50 and other reactors, and for the research work.

### 3.3.3. Production of spherical fuel elements by way of adding pyrolytic graphite [35-39]

Spherical uranium-graphite fuel elements were produced from uranium dioxide of various enrichment degrees and high-density fine-grained graphite of the brand ARV-1. The production of these elements included two relatively independent processes: 1) granulated microfuel production from the enriched uranium dioxide and 2) spherical fuel element production thereof.

Making granulated microfuel, the microcores after driving off the binder were sintered and – unlike the process described in 3.3.2 – covered with protective multilayer from pyrocarbon and silicon carbide. For making spherical fuel elements the double-covered microfuel obtained were mixed with graphite moulding powder and loaded into a pyrolysis unit to be bound with pyrolytic carbon and thereafter mechanically worked into the required size and surface finish.

The final product – spherical uranium-graphite fuel elements were stored and transported in a packed form. They were packed into not less than 0.2 mm polyethylene film and stored in layers in wooden boxes, or in metal boxes with the max. gross weight of 60 kg.

Special requirements for the equipment and conditions concerning features of industrial safety measures, sanitation and fire protection were demanded in this production process. Emergency ventilation was installed to avoid emission of fuel gas from the pyrolysis equipment and elsewhere into the workspace. It was activated by fuel gas sensors at the gas concentration over 5% of the lower explosion limit.

Spherical fuel elements were used for tests in neutron physics and other experiments in the assembly “Astra”, in reactors and likewise in ring tests simulating the work of fuel elements in the high-temperature gas reactor VGR-50. Since 1980 an enlarged laboratory-scale plant “Uglerod” was operating at the enterprise in order to elaborate the technology of manufacturing of spherical fuel elements of monolithic type for HTGR reactors.

In 1981 650 mock-up models and 31 standard spherical fuel elements were produced. A pilot shop with the annual capacity of 30,000 spherical fuel elements was under construction. Initial data were collected to carry out the feasibility study to start a pilot production with the annual capacity of 200,000 spherical fuel elements.

Since 1982 the output of the pilot production in the facility “Uglerod” was the following:

- 1982 – 600 pieces (pcs) of mock-ups (without fuel cores)
- 1983 – 1,000 pcs of mock-ups
- 1984 – 1,000 pcs of mock-ups
- 1985-86 – 1,000 pcs of mock-ups, 100 pcs of fuel elements with 21% enriched  $\text{UO}_2$  and fuel microelements containing 100 g  $\text{UO}_2$ .

As the enterprise had not received any orders for 1987 and the following years to produce mock-ups and standard fuel elements, the technical meeting of the enterprise held in 21 January 1987 passed a resolution to discontinue the activities concerning the production of HTGR spherical fuel elements of monolithic type at the Sillamäe enterprise as the similar production line existed at another enterprise.

#### 4. Total Uranium Production at Sillamäe in 1948 – 1989 [10]

Uranium production from Dictyonema shale mined in 1948 – 1952 was only 22.5 tons of elemental uranium (final product – 40% concentrate). Uranium production from imported uranium ores and concentrates (mostly as  $\text{U}_3\text{O}_8$ ) was, however, enormous: an amount equivalent to about 98,681 tons of elemental uranium was produced in 1950 – 1989.

In 1982, processing of low-enriched uranium fuel (2.0 to 3.6% U-235) from rejected fuel elements was started. Altogether 1,354.7 tons of uranium was processed (Table 6).

Table 6. Total uranium production at the Sillamäe uranium plant in 1948 – 1989

Production of uranium	Duration of production	Production	
		planned	actual
Uranium in 40% chemical concentrate, produced from local Dictyonema shale, t	1948 – 1952	34.7	22.451
Uranium in 40% chemical concentrate, produced from imported ore, t	1950 – 1952	187.0	207.0
Uranium in $\text{U}_3\text{O}_8$ , produced from imported ore, t	1953 – 1977	23,628	24,514.5
Total from imported ore, t	1950 – 1977	23,815	24,721.5
Uranium in $\text{U}_3\text{O}_8$ , produced from imported chemical concentrate, t	1971 – 1989	73,591	73,959.3
Total uranium produced from Dictyonema shale, imported ore, and imported concentrate, t	1948 – 1989	97,440.7	98,703.251
Uranium in enriched $\text{UO}_2$ (2.0 to 3.6% U-235), produced from rejected fuel elements, t	1983 – 1989	1,476.9	1,354.669

## 5. Liquidation of Uranium Processing at Sillamäe [40, 41]

Uranium processing at Sillamäe was liquidated according to the Decree No. 077 of 7 June 1989 of the Ministry of Medium Machine Building. The decree “Reprofiling of the specialized production of the Sillamäe Chemical-Metallurgical Production Association (PA) for civil production” ordered the following:

1. To stop processing of the chemical concentrates and rejected enriched uranium at the Sillamäe Chemical-Metallurgical PA from 1 January 1990.
2. To transfer the processing of imported chemical concentrates planned for the 3rd Main Technological Directorate to Pridneprovsk Chemical Plant (in Dneprodzerzhinsk) from 1 January 1990.
3. The Head of the 3rd Main Technological Directorate is obliged to:
  - a) Reduce the supplies of chemical concentrate and rejected enriched uranium arriving to Sillamäe Chemical-Metallurgical PA to the level needed for the fulfillment of the production plan of 1989 only.
  - b) Redirect the supplies of recycled enriched uranium and guarantee their processing at Machine Building Plant (Elektrostal, Moscow) and Ulbinsky Metallurgical Plant (Ust-Kamenogorsk, Kazakhstan).
4. As the changes in the production profile will free manpower, the Head of the 3rd Main Technological Directorate and the Deputy Head of the Main Economical Directorate have to reconsider economic specifications of the Sillamäe Chemical-Metallurgical PA to be engaged in development of machine building and production of consumer goods, and to guarantee the processing of loparite concentrate as well as to solve the ecological problems.

To obey the above-mentioned decree, the Decree No. 8 from 3 April 1990 “About changing the production profile” was issued by the administration of the Sillamäe plant. For the period till 1 July 1990 the decree foresaw to remove the technological solutions and middling from the equipment, to deactivate the equipment and to dismantle the equipment not needed in the future. The decree included a complete reorganization of the works at Sillamäe, as well as the workforce retraining and reduction.

The decree No. 077 provided that the Sillamäe Chemical-Metallurgical PA was exempted from production funds taxation in 1990 – 1995 because of low lucrativeness and sharp decrease in profits.

The plant made corresponding preparations to rearrange its work and to proceed with new production. However, the changing political situation and new economic development did not allow to effect these future plans in the reborn in 1991 Estonian Republic.

## Acknowledgements

I would like to express my gratitude to Professor Endel Lippmaa who has reviewed the First Part of my report, and Doctor Ille Johannes who has read and commented the Second Part of the text.

## Literature

The archive of the present AS Silmet (Sillamäe, Estonia) was the main information source to give an overview about the uranium production activities in Estonia in 1946 – 1989. In the following Literature the used archival documents are listed in Russian and the relevant records numbers (Архив, Д. №) are given.

In the First Part of the report Literature items No. 1 – 23, and in the Second Part – Literature items No. 24 – 41 were used. Figures 4 – 7 in the report have been taken from Sillamäe archives without any corrections and alterations by the author of the report.

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# **The former Soviet Naval Nuclear Training Center at Paldiski**

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## **1. Introduction**

During the incipient stages of the Second World War, and immediately after the non-aggression pact between Germany and the Soviet Union, Estonia was forced to accept a similar pact with the Soviet Union. According to that pact the soviets had the right to establish six military bases within the territory of Estonia. One of those bases was located at Paldiski. Consequently, Paldiski was completely transformed into a military town, a situation that continued until 1994.

During the Cold War, there were a number of military units located at Paldiski and on Pakri peninsula:

- a brigade of diesel-powered submarines;
- two tactical missile hangars;
- a division of missile boats (Project 205, Osa I class);
- anti-aircraft missiles;
- boarder guards;
- a training center for boarder guard troops;
- temporary units dealing with pilot projects such as mini submarines;
- a naval prison camp.

There is no available information that clearly indicates that these military units on the Pakri peninsula have been equipped with nuclear weapons. However, the first three of the above mentioned units might have been armed with nuclear warheads at certain periods of time. The reason for this suggestion is that the whole Soviet Baltic fleet had a common security system that meant that not every naval base was all the time equipped with nuclear weapons. A secret rotation program was in operation where nuclear warheads were moved to several base locations in the area. In the late eighties and in the beginning of the nineties, the Baltic Fleet of the former Soviet Union were composed of 575 ships, including 49 principal surface combatants, 50 auxiliaries, and 46 submarines. Naval aviation in the Baltic Fleet was assigned some 270 nuclear and non-nuclear aircrafts, 105 bombers and fighters and 45 anti-submarine aircraft. The headquarters for the Baltic Fleet was Kaliningrad. The Baltic naval bases were located at: Baltiysk, near Kaliningrad; Klaipeda in Lithuania; Liepaja and Riga in Latvia; Paldiski and Tallinn in Estonia and; Lomonsov, Kronshtadt and Vysotsk in the Leningrad area.<sup>61</sup> Unfortunately, there is no data available on how these warships were shared between these bases during different time periods.

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<sup>61</sup> J. Handler and W. M. Arkin. Nuclear Warships and Naval Nuclear Weapons 1990: A Complete Inventory. Neptune Papers No. 5. Greenpeace 1990.

## 2. Soviet Navy nuclear training center at Paldiski

In the early 1960's, construction work began on a land-based training center for nuclear submarine crews of the Soviet Navy at Paldiski. In 1968, the first training unit was commissioned – a prototype of the first generation Soviet submarine (Project 658, Echo II class) with a VM-A type nuclear reactor (70 MW<sub>t</sub>). The second training unit went critical in 1983 – a prototype of the second generation of Soviet nuclear submarine (Project 667, Delta I-IV class) with a VM-4 type reactor rated at 90 MW<sub>t</sub>. The reactors with all shipboard systems for energy production and propulsion were situated in scaled submarine hulls, located in the high bay area of the Main Technological Building. The reactor at the first training station was refueled once in 1980. Both reactors were shut down in 1989. The operational data of the reactors is presented in Table 1.

Table 1. Key characteristics of nuclear training stands in Paldiski naval training center

Parameter	Unit 1	Unit 2
Project no / NATO Class	658 / Echo II	667 / Delta I-IV
Reactor type	PWR / VM-A	PWR / VM-4
Thermal Power	70 MW	90 MW
Enrichment of fuel in U-235	21 %	21 %
Approx. qty of Uranium / U-235 [kg] <sup>62</sup>	250 / 50	350 / 70
Encasement (submarine hull segment)	diam. 7.5 m length about 50 m	diam. 9.5 m length about 50 m
First criticality	April 1968	February 1983
Last criticality	January 1989	December 1989
Refuel and maintenance	1980-81	never
Operating time	first load 13 781 h second load 7 040 h	5333 h

The training center at Paldiski was located within the territory of supervision of the Baltic Fleet of the former Soviet Union, but in fact it came under the direct control of the Soviet Navy Headquarters in Moscow. The main aim of the training center was to educate crews in the operation of strategic ballistic missile submarines. The training covered all theoretical and practical aspects in the operation of submarines in peace and war situations including navigation, means of communication, computer technology, use of weapons (missiles and torpedoes), operation of submarine reactors, etc.

In 1989, both reactors were temporarily shut down due to an overall revision of the nuclear safety concepts in the former Soviet Union after the Chernobyl accident. However, the training process continued until 1993 but without practical training of reactor operations. In eighties, the training center at Paldiski also provided training to the crews of the third generation soviet nuclear submarines (Project 941, Typhoon class). After the breakdown of the Soviet Union, the Soviet Navy Headquarters started to move training away from Paldiski to the Obninsk training center in Russia.

<sup>62</sup> T. Nilsen, I. Kudrik, A. Nikitin. The Russian Northern Fleet Nuclear-powered vessels. Chapter 2.3.7. Russian submarine fuel. <http://www.bellona.no/e/russia/nfl/nfl2-1.html#O5>.



### 3. The nuclear site of the Paldiski training center

The Paldiski training center was actually located in two places; the headquarter with huge training facilities at Paldiski town, and the nuclear training site with two operational ship reactors some 4 km outside Paldiski in the middle of Pakri peninsula. The nuclear site occupied 26 hectares and consists of the Main Technological Building (MTB) and seven relevant auxiliary facilities which were: a Liquid Waste Treatment Facility (LWTF), a Liquid Radioactive Waste Storage (LWS), a Solid Radioactive Waste Storage (SWS), a Ventilation Facility, a Laundry Facility, a Radiochemistry Laboratory, Cooling Towers, as well as several conventional supporting facilities like remote boiler with oil tank farm, workshops, stock houses, etc.



Figure 1. The nuclear site of Russian Navy nuclear training center at Paldiski in June 1995 <sup>63</sup>

#### Main Technological Building (MTB)

The MTB consists of the high bay area housing Units 1 and 2, two spent fuel storage pools (only one used) and an annex of offices, training areas, a machine shop, support equipment and other miscellaneous rooms.

#### Liquid Waste Treatment Facility (LWTF) and the Liquid Waste Storage (LWS)

Liquid radioactive waste was stored in the tanks of LWTF and LWS facilities. The LWTF contained the equipment used for treatment of the contaminated wastewater generated on site. Equipment included evaporators, flocculation tanks, ion exchange columns, six receiving tanks (total capacity 1020 m<sup>3</sup>) and two tanks for holding water prior to discharge.

The LWS consisted of six tanks (total capacity 2400 m<sup>3</sup>). These tanks were originally intended as a final depository for processed/concentrated liquid radioactive waste.

<sup>63</sup> The aerial photo of the site was taken by the Remote Sensing Laboratory during the US DOE funded project An Aerial Multisensor Survey of the Paldiski Naval Reactor Training Facility and the Sillamäe Waste Pond. EG&G/EM 11265-1169 UC-702, December 1995.

### The Solid Waste Store (SWS)

The SWS consists of a concrete structure divided into 10 compartments. The top of the storage was covered by concrete slabs, or poured concrete with removable plugs all of which had been covered with a layer of crushed gravel and asphalt. This facility was originally intended as a final repository for the radioactive operational waste from the site. All the waste in the SWS has been disposed off without any conditioning and packaging. According to data provided by the Russians, the total activity of the waste in the SWS was about 3.7 TBq. Only three compartments were used for disposal of waste. The waste included eight steam generators and a circulation pump from Unit 1 (which were replaced during the refueling operation in 1980), contaminated equipment and miscellaneous contaminated material, as well as twenty irradiated control rods and high level sealed radiation sources, totally about 100 m<sup>3</sup> of waste.

### Laboratory Building

The laboratory building is a three-floor building containing offices; health physics training rooms, environmental and radiochemical laboratories, and instrument calibration facilities.

### Laundry Facility

The laundry facility is a two-floor building that processed all the site laundry. The upper floor was reserved for non-contaminated clothing and the ground level for contaminated protective clothing.

### Ventilation Facility

The ventilation facility provided off-gas capability to all reactor operation facilities on site. Connected to the Main Technological Building were the Laundry Facility, the Liquid Waste Treatment Facility, and the Laboratory Building. The off-gas from all the buildings passed through a single stage set of HEPA filters before being discharge through a 100-meter chimney.

## **4. Negotiations with Russia on shutting down of the Paldiski training center**

After the collapse of the Soviet Union and Estonian declaration of independence in 1991, the Russian withdrawal of troops from Estonian territory, the closure of the Paldiski training center, and the decommissioning of reactors became a subject of intense negotiations between Estonia and Russia.

The first documented communication regarding time schedule for shutting down and liquidation of the training center was a letter of reply (No. 714/13/0103, 13.01.1992) from Admiral Tshernavin at the Russian Navy Headquarters to Edgar Savisaar, the Prime Minister of Estonia. In his letter, Admiral Thernavin informed the Government of Estonia that the two nuclear reactors at Paldiski were shut down and were in a safe condition. He also stated that the Russian side was carrying out preparations for dismantling the training units.

After two and half years of intense negotiations with Russia it was finally decided to shut down the Paldiski naval training center. An agreement was signed on July 30, 1994 between Mr. Raul Mälk, Deputy Secretary General of Ministry of Foreign Affairs of Estonia and

Mr. Igor Ivanov, Deputy Minister of Foreign Affairs of Russian Federation<sup>64</sup>. Article 8 of the Paldiski agreement stipulated that: “The site with two sealed reactor compartments and radioactive waste storages shall, after decommissioning, be transferred to the Republic of Estonia by September 30, 1995 together with the completion of all relevant documentation”. Accordingly, Estonia agreed to take full custody for the site and future decommissioning of both reactor compartments and waste facilities together with the waste generated during the site operations. Unfortunately, the agreement included neither a detailed technical specification of the site facilities status nor a requirement for documentation to be handed over to Estonia together with the site.

## **5. International support and assistance to Paldiski**

While negotiations with Russian Federation were in progress, Estonia sought parallel international assistance and support regarding the problem. While regaining independence, Estonia also recognized that domestic nuclear expertise was non-existent and the Government initiated an international campaign aimed at mobilizing assistance and support for the management and decommissioning of the Paldiski site. The IAEA, the Nordic countries, organizations, as well as the United States and other countries having nuclear submarine fleet, were all approached for assistance. At the initiative of the Swedish Minister of Foreign Affairs, and after consultations with other concerned countries, a meeting was held in Stockholm in January 1994, which was the beginning of an active international engagement on the issue of decommissioning the Paldiski facility. At a later meeting, in May 1994, the Paldiski International Expert Reference Group (PIERG) was established with participation of Estonia, Finland, Germany, Russian Federation, Sweden, USA, IAEA and CEC. Swedish Radiation Protection Institute (SSI) provided secretarial support for the PIERG.

The aim of the PIERG was to promote the safe and timely decommissioning of the former Soviet Union Nuclear Training Center at Paldiski, by advising and assisting the parties participating in the decommissioning work on technical, legal, organizational, financial, waste management and radiation protection matters. To achieve the overall objective, the PIERG was expected to discuss the progress and make recommendations on decommissioning work at the nuclear installation at Paldiski, as well as on specific issues and problems requested by the parties participating in the decommissioning work. The PIERG was also expected to promote, co-ordinate and prioritize international, technical, and financial assistance for the Paldiski nuclear installation.<sup>65</sup>

Prior to take-over of the site by Estonian authorities, the PIERG played important role in recognizing the nature and extent of the problem to be solved. It was also instrumental in bringing the Estonian and Russian parties to the table to discuss purely technical matters related to dismantling and decommissioning options and radioactive waste management issues.

One of the first tasks under auspices of PIERG was the preparation of a conceptual decommissioning plan for the Paldiski nuclear site. That task was financed by Sweden and implemented by SKB.

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<sup>64</sup> Agreement Between the Government of the Republic of Estonia and the Government of the Russian Federation on Procedures and Deadlines for the Decommissioning of the Nuclear Reactors and the Guarantee of Nuclear and Radiation Safety on the Pakri Peninsula of the Republic of Estonia. Published in daily newspaper *Rahva Hää* 01.08.1994 (in Estonian).

<sup>65</sup> Activities of the Paldiski International Expert Reference Group. Phase I; May 10, 1994 – September 26, 1995.

During the period of Estonia's taking over of the site, the PIERG co-ordinated several international assistance projects to Estonia aiming to support safe management and decommissioning of the Paldiski nuclear facility. This also included processing of liquid radioactive waste at Paldiski performed by IVO International, Finland, conducting an independent investigation of the site including the premises and the environment by US Department of Energy and peer review of the Conceptual Decommissioning Plan by the IAEA.

## **6. Decommissioning of the Paldiski nuclear facilities**

Actual decommissioning works of Paldiski nuclear facility started immediately after the July 30, 1994 Paldiski agreement in Moscow. On the morning of August 24 the following month, the lid of 90 MW reactor was opened and defueling started. The process of extraction of spent nuclear fuel from that reactor and loading onto the transport container lasted until September 7 that year. Defueling of the 70 MW reactor was carried between September 20 and October 11, 1994. On the early Saturday morning of October 15, 1994, a heavy railcar consisting of four TK-VG-18 type special cars, each loaded with three TK-18 type containers of spent nuclear fuel, started to move from the Paldiski site towards Russia. In the evening of the same day (at 18:05 hours), the railcar across the Estonian-Russian border in Narva. With this crossing, and in terms of non-proliferation, the nuclear history of the Paldiski training center came to an end. But actually that was only the beginning of longstanding and costly measures for cleaning up of the consequences of nuclear activities and restoration of the site.

After the defueling of reactors, intensive preparations for the site hand over to Estonia started. As part of preparing the site for the hand over, Russia removed non-contaminated and secret equipment of the training stations and dismantled the submarine hulls except the sections associated with the reactor vessels. The reactor compartments were seal-welded and the Russians built concrete sarcophagi around these remaining hull sections.

After the site take-over by Estonia, the new site operator A.L.A.R.A. AS that was established by Estonian government started to develop the plans for the safe management, clean-up and decommissioning of the site facilities. In order to achieve the goals drawn up in the Conceptual Decommissioning Plan, the following main tasks were addressed in the Site Management Plan:

- Rearrangement of site in tune with the need for decommissioning and radioactive waste handling;
  - construction of an on-site interim storage for conditioned radioactive waste;
  - arrangement of a waste handling and conditioning facility;
  - renovation of major service systems and site infrastructure;
- Radiological characterization and decontamination of facilities;
- Conditioning of solid operational waste in the Solid Waste Storage;
- Solidification of liquids and sludge in tanks of the former Liquid Waste Treatment Facility and Liquid Waste Storage;
- Decontamination and dismantling of other site facilities of no use in future (Ventilation Building, Laundry and Laboratory Buildings, etc.).

Below, a short information is presented on the radioactive waste management and decommissioning projects carried out by the A.L.A.R.A. AS after taking custody of the Paldiski site.

### Rearrangement of site in tune with the need for waste handling and decommissioning

These works included establishment of an on-site interim storage for conditioned radioactive waste as well as of the facility for waste treatment and conditioning. A decision was made to construct an interim storage and a waste treatment and conditioning facilities in the Main Technological Building. The interim waste storage is in operation since 1997. It provides space for 720 standard size (1.2 by 1.2 by 1.2 m) waste containers, consisting of two cells, each for 360 containers placed in 8 layers, 5 by 9 containers. The new waste treatment area also houses the office facilities, a mechanical workshop, the warerooms, and the facilities necessary for implementation of health physics and radiation protection programs.

### Project on conditioning of operational solid waste

During the site operations, the solid radioactive waste was disposed in an on-site storage facility, SWS, which consisted of a concrete structure divided into 10 cells. The former site operator had used only three of these cells for storage of radioactive waste. Waste had been dumped into the facility without any conditioning or packaging and without any recorded inventory. The estimated waste volume in the SWS was about 100 m<sup>3</sup>, including eight heat exchangers and twenty control rods from the repair and maintenance campaign of the Unit 1. The project started in 1996 with a radiological characterization of the waste and was continued with waste retrieval and conditioning. Depending on the radiological conditions, both remotely operated technique and manual retrieval was practiced. In summer 2000, the project was completed with demolition of the building after a full decontamination and declassification of the facility. During the project, a total dose of 0.04 manSv was received by 16 persons, the maximum dose burden for a single person being 7.6 mSv. A more detailed description of this project were summarized in papers presented at the international conferences WM'98<sup>66</sup> and ICEM'99<sup>67</sup>

### Project on dismantling of the Liquid Waste Treatment Facility (LWTF)

Dismantling work of the LWTF started in early summer 2000. The project plan followed the recommendations given in a relevant EC PHARE funded project<sup>68</sup>. Before the actual dismantling work, a detailed radiological survey followed by decontamination of all floor and wall surfaces was carried out. In addition, all asbestos insulation from equipment and pipes was removed. In 2000, the dismantling of conventional technological systems (heating, ventilation, conventional sewage, water supply, cables, etc.), both inside and outside of the radiological control areas was completed. Dismantling of conventional technological systems (heating, ventilation, conventional sewage, water supply, cables, etc.) and contaminated technological systems were completed in 2001, and decontamination in 2002. The project was completed with the demolition of the building in autumn 2002.

### Project on dismantling of the Liquid Waste Storage Building (LWSB)

Liquid radioactive waste is stored in the tanks of the Liquid Waste Treatment Facility (LWTF) and Liquid Waste Storage (LWS) facilities.

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<sup>66</sup> M. Varvas, H. Putnik, F. Hodson, S. Pettersson. Practical Experience and Future Plans for Radioactive Waste Management in the Former Soviet Navy Nuclear Submarine Training Facility, Paldiski, Estonia. WM'98 March 1-5, 1998, Tucson Arizona.

<sup>67</sup> M. Varvas, H. Putnik, B. Nirvin, S. Pettersson. Characterisation, Conditioning and Packaging of Solid Waste from Solid Waste Storage of Paldiski Nuclear Facility, Estonia., The 7<sup>th</sup> International Conference Proceedings on Radioactive Waste Management and Environmental Restoration, ICEM'99. September 26-30, 1999, Nagoya, Japan.

<sup>68</sup> Dismantling of the Liquid Waste Treatment Facility at Paldiski, Estonia – Phase I. PHARE Project PH4.03/95. Final Report, SGN and SKB, January 1999.

The LWS consists of six tanks (with a total capacity of 2400 m<sup>3</sup>). These tanks were originally intended as a final depository for the processed/concentrated liquid radioactive waste and sludge. Four of the six tanks in the LWS were emptied and decontaminated before the site take-over during the IVO International wastewater purification project. According to a sample of the residue in the tanks of waste material, the estimated total activity content in two tanks of the facility was about 230 GBq. The dominating radionuclides were Cs-137, Co-60 and Sr-90. Total volume of waste material was approximately 130 m<sup>3</sup>.

The project on decontamination and decommissioning of the LWS started in 1999 with installation of cementation equipment for solidification of the resins, sludge, sand, etc. in two tanks of the facility. The solidification project has been carried out under Swedish - Estonian co-operation program on radiation protection and nuclear safety. The Swedish counterparts, SKB and Studsvik RadWaste, were responsible for development, adaptation and delivery of equipment for solidification and instruction and training of A.L.A.R.A. staff. A.L.A.R.A. AS was responsible for manufacturing of waste containers, supply of expendable materials, operations during solidification etc. The solidification project was completed in summer 2002, and a total 124 waste packages (about 220 m<sup>3</sup> of storage space) was produced during the project. Currently, in Fall 2003, dismantling of contaminated equipment, pipes and steel lining is ongoing. According to project plans the building will be decontaminated and demolished by the end of 2004.

#### Decontamination and Dismantling of Other Site Facilities

In addition, other conventional buildings and facilities unfit for future use have been decontaminated and demolished, including Remote boiler (in 1997) with associated oil tank farm (1999/2000), storehouses (2001), but also buildings formerly classified as radiological controlled areas like Laboratory Building, Laundry Building (in 2002) and Ventilation Building (2003). According to plans, the site will consist only the Main Technological Building housing two reactor compartments surrounded by concrete sarcophagi and interim storage for radioactive waste, garage/workshop and the entrance building, which allow to release the most part of the territory of the site for unrestricted future use.

#### EC Phare project Safe Long-Term Storage of the Paldiski Sarcophagi and Related Dismantling Activities

The main objective of the project is to implement a series of well-defined actions that will guarantee the safe storage of the Paldiski sarcophagi for a period of at least 50 years by improvement of sarcophagi safety, designing and building of ventilation systems for both sarcophagi and interim storage for RW, dismantling of unnecessary parts of the Main Technological Building and improvement durability of it against weathering. The project started in November 2002 with environmental impact assessment and other necessary preliminary studies. The project should be completed by the end of 2005.