
NORM-related Mining in Nordic Countries: Legislation, practices and case studies

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Abstract

The aim of the project was to explain and compare the current state, legislation and practices concerning naturally occurring radioactive material (NORM) -related mining in the Nordic countries. The focus was on the mines that are aiming at off-taking of uranium as a co-product or a by-product, or are processing ores, which contain high levels of NORMs. The project concentrated on investigating how the environmental factors and different origins of radionuclides affected their activity concentrations and transfer factors in ore, soil, water and vegetation.

Key words

NORM, mining, uranium

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Final Report from the NKS-B NORMIN

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1. Introduction

The aim of the project was to explain and compare the current state, legislation and practices concerning naturally occurring radioactive material (NORM) -related mining in the Nordic countries. The focus was on the mines that are aiming at off-taking of uranium as a co-product or a by-product, or are processing ores, which contain high levels of NORMs. The project concentrated on investigating how the environmental factors and different origins of radionuclides affected their activity concentrations and transfer factors in ore, soil, water and vegetation.

The economic and social importance of mining industry in the Nordic countries is growing fast, as international mining companies are focusing their attention on the unexploited mineral resources of northern areas. Currently, the most important metals produced in the Nordic countries include iron, lead, zinc, copper, gold and silver¹. The mines are often important employers in areas where other employment possibilities are limited via employing directly but also through subcontracting. It is estimated that in the near future the employment figures of Nordic mines will continue to grow as new mines are launched.^{2, 3a} In addition to their economic impacts, the mines have long-lasting environmental effects and can affect large areas also outside the actual mining site^{3a-b}. If the processed ores contain uranium or other NORMs, the radiation safety issues have to be addressed. The radiation safety issues have to be dealt with even if no uranium is produced. For example, gold-bearing ores are usually rich in uranium; thus, even if uranium is not extracted the mining waste will be radioactive. The mining of ores that contain NORM and their waste stacks may change the levels of naturally occurring radionuclides in the adjacent nature^{4,5}. Because of these harmful effects, the mines in the Nordic countries are strictly controlled by mining and environmental protection laws, and if NORM-bearing ores are processed, the radiation and nuclear energy laws have to be taken into account.⁶ Currently, there is no uranium mining or take-off in the Nordic countries, however, there are potential uranium and thorium resources that could be recovered. The cost of the recovery would be relatively high, but as the price of uranium is increasing and more generous and cost-efficient resources are decreasing, the actors in nuclear technology are focusing their interest towards the Nordic resources.⁷ International mining companies are exploring the uranium resources in Nordic countries, and plans for the off-take of uranium or thorium, or for mining the rare earth elements (REE) in the northern areas are currently ongoing.

2. The current state, legislation and practices concerning NORM-related mining in Nordic countries

2.1 Finland

Exposure to natural radiation in mining activities is regulated under the Radiation Act and the Radiation Decree. However, if the aim is to produce uranium or thorium, the Nuclear Energy Act and the Nuclear Energy Decree are applied.

Only minor uranium-related exploration activities have been carried out in Finland. No uranium is currently mined and only small-scale uranium exploration projects have been underway. The known uranium occurrences are small, low-grade and uneconomic. Finland's reasonably assured conventional uranium resources are only 1 500 tU in two deposits, Palmottu and Pahtavuoma-U. Unconventional by-product uranium resources of the Talvivaara black schist deposit are approximately 22 000 tU (measured and indicated) in the total mineral resource of 2053 Mt.⁸

The Finland Mining Act regulates exploration and mining of uranium and thorium. An exploration permit given by Tukes (the surveillance and permit consideration authority in Finland) is always needed if the exploration is targeted at locating and exploring a deposit containing uranium or thorium. A mining permit application concerning the production of uranium or thorium and the permit application concerning the same activity under the Nuclear Energy Act shall be handled together and decided on in the same decision. The Government shall decide on mining permits related to the production of uranium and thorium. The decision to terminate mining activity in a NORM-bearing deposit needs the approval of the Radiation and Nuclear Safety Authority for appropriately completed termination measures.

2.2 Norway

Currently, neither radioactive waste generation nor radioactive pollution have so far been identified at existing mining sites in operation in Norway. The NRPA is working on mapping all the mining sites (existing and legacy) where radiation protection and radioactive pollution to the environment could be potential issues for consideration. NRPA is also working to communicate the information of need to conduct the initial investigation and screening for elevated levels of radionuclides in excavated rocks has been given to companies which are in start phase of mining. The initial screening is necessary to obtain the insight into the possible issues related to radiation protection and radioactive waste generation and consequent, proper steps with respect to legislation.

All the permits for investigations and mining are given by the Directory of Mining after the Norwegian Mining Act. Mining and processing of NORM rich rocks will cause discharges of radioactive elements to air and water, which would require a permit after the Pollution Control Act. Discharge permits, based on the Pollution Control Act, are issued by the Norwegian Radiation Protection Authority (NRPA). The advantages and disadvantages of giving the permit must be assessed. Permits given after the Pollution Control Act include

terms and conditions. One such condition may be that the discharge water must be filtered or otherwise purified prior to discharge.

Uranium and thorium are defined as a nuclear material after the regulations on nuclear materials and cannot be exported without a permit from the Ministry of Foreign Affairs.

Large quantities of REE rich minerals in Norway have recently been public and professional topics for discussion regarding possible extraction. These rocks are rich in NORM, especially Th-232. Mining and extraction of REE will cause a large amount of tailings, which will, most likely, be regarded as radioactive waste that must be deposited properly. Thorium that may follow the REE is usually separated from the minerals at a specific step in the extraction process and then creation of ^{232}Th concentrate is possible. The concentrate will most likely be considered nuclear material after the Regulations on nuclear materials. The enterprise does not need a permit for ^{232}Th concentrates with non-nuclear purposes. However, it must notify the NRPA of the existence of the concentrate. The license holder must also accept supervision of the facility and the concentration by both Norwegian authorities and international inspectors.

Radioactive waste that must be deposited are today placed in mountain halls or in near surface facilities with permits of accepting radioactive waste. Establishing a waste depository or tailings dam requires a risk assessment after the Planning and Building Act. In terms of IAEA Safety Guide RS-G-1.7 and IAEA Safety Reports Series No. 49 radioactive materials between 1 and 10 Bq/g could be considered for exemption by the regulatory body. Even if the waste would be exempted from terms and conditions other radioactive waste, the permit from the NRPA after the Pollution Control Act must also include a permit to handle radioactive waste.

2.3 Denmark

Denmark, Greenland and the Faroe Islands are part of the Kingdom of Denmark. As the main principle, the Danish Constitution stipulates that the foreign and security interests for all parts of the Kingdom of Denmark are the responsibility of the Danish government. Denmark is part of the European Union and has adopted EU Directives on ionising radiation and radioactive substances into Danish legislation. Since there is no mining industry in Denmark, there is no mining-specific legislation related to NORM. Greenland, however, is not part of the EU, and has no legislation related to ionising radiation and radioactive substances. Danish legislation on these matters does not apply in Greenland.

2.4 Sweden

Historically many of the Swedish iron and pyrite ore could contain uranium mineralizations, as uranite, pitchblende, thucholite or orthite. Several uranium mineralized dump heaps has since been found at old mining areas, mainly from investigations during the years 1968-1986, with uranium mineralizations from tenths of % up to about 10% (SSM 2009). Today, none of

the operating Swedish mines contain any known uranium mineralizations, e.g. the iron ore mined hold uranium levels well below 1kBq/kg. Although, enrichment may occur in the ore slag and reach uranium levels at the order of 1kBq/kg.

Other historical mining activities of importance to NORM are alum shale mining for uranium production; the Kvarntorp mining area, where uranium mining and processing was performed in 1953-1966 (a total of 50 tons U was mined), and the Ranstad mining area, active uranium mining and processing during the years 1965-1969 (a total of 215 tons of U mined). The Ranstad mining history will be described in more detail in Section 6: case studies.

A specific NORM waste problem is the burnt shale produced as a rest product in various industrial processes in the past; e.g. alum shale (oil) for burning of lime stone, manufacturing of alum, alum cement and concrete. This has left several heaps of millions of cubic meters of waste, with uranium concentrations up to about 5 kBq/kg (SSM 2009) .

Permits for mining exploration and exploitation (concessions) are handled and issued by the Mining Inspectorate of Sweden (Bergsstaten), following the Minerals Act (SFS 1991:45) and the Mineral Ordinance (SFS 1992:285). Granting of a concession also requires environmental assessments, following the Environmental Code (1998:808), and permits based on the Planning and Building Act (2010:900). Radiation protection legislations are dealt with in Section 4.4.

Since the 1970's there has been extensive prospecting for uranium undertaken in Sweden. In the 1970-1980's's the SGU (Geological Survey of Sweden) and the SKB (Swedish Nuclear Fuel and Waste Management, formerly SKBF) performed intensive prospecting using geophysical and geochemical methods, including drill testing, mainly in the northern part of Sweden. Two areas, Lilljuthatten and Pleutajokk, were identified as candidates for uranium mining, where extensive prospecting, including drilling and processing trials, were undertaken. However, the local communities opposed and were inclined to use their communal veto. Therefore the SKBF decided to withdraw from mining in the areas. In recent years there has been numerous exploration permits issued for uranium alone and combined with other minerals/metals, but the activities has decreased the last few years. In 2014 there were 3 valid exploration permits for uranium alone and 36 permits for alum shale, figures given by the SGU (www.sgu.se), however, uranium permits combined with other minerals are not published.

3. Current NORM related mining activities

3.1. Finland

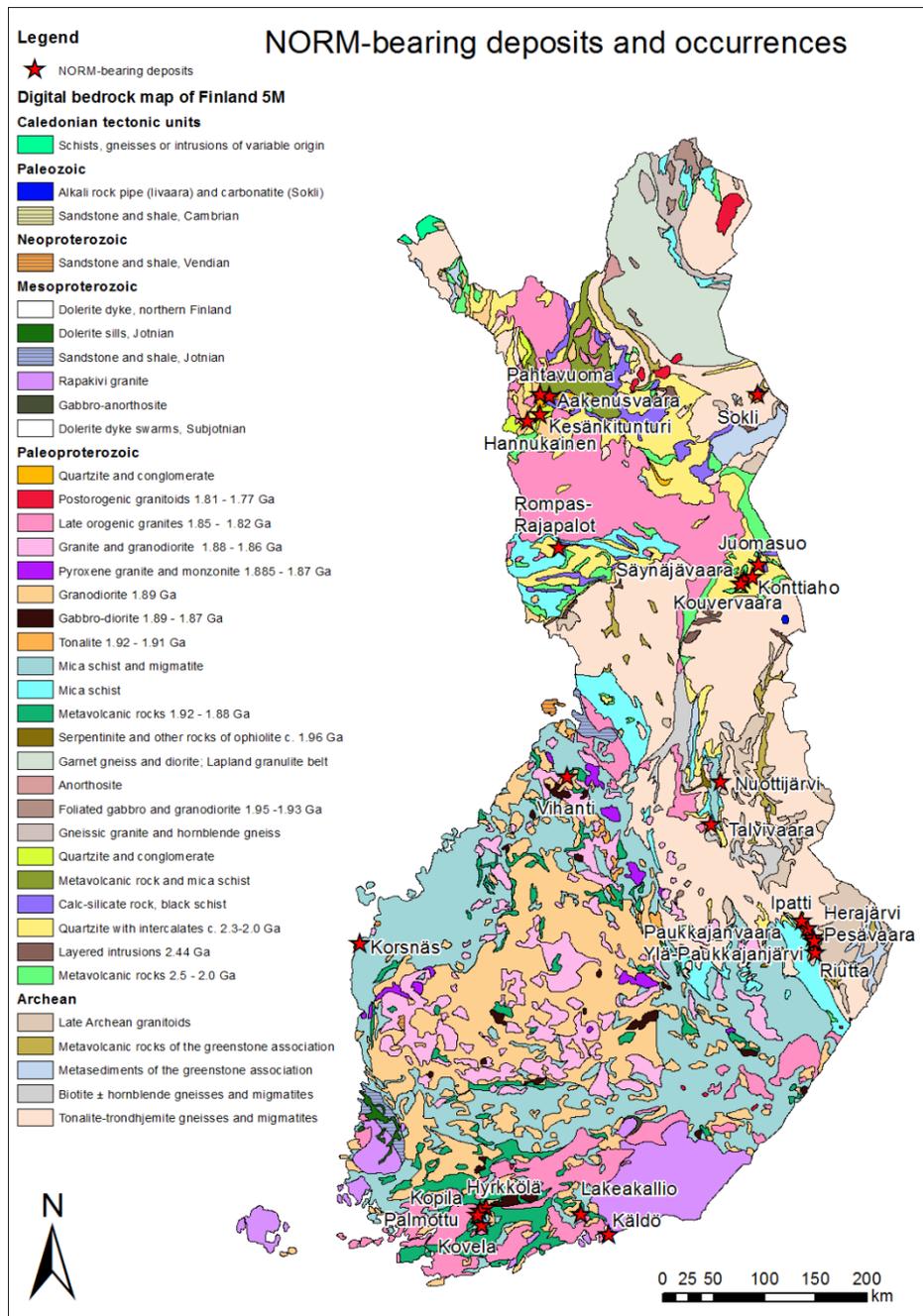


Figure 1. NORM-bearing deposits and occurrences discussed in the report. Geological map 1:5 000 000 © GTK.

3.1.1. Introduction

The bedrock contains several radioactive substances, i.e. radionuclides or radioisotopes, which have existed since the forming of the Earth. These elements are called Naturally

Occurring Radioactive Materials, NORMs. The most common NORMs are uranium (^{238}U , ^{235}U), thorium (^{232}Th), potassium (^{40}K), carbon (^{14}C) and their daughters, such as thorium (^{234}Th), radium (^{226}Ra), polonium (^{210}Po), lead (^{210}Pb) and radon (^{222}Rn). As the radionuclides are unstable elements they decay spontaneously, causing emission of alpha, beta or gamma radiation. NORMs may pose a risk to the environment due to the increased radiations levels and the chemical toxicity of substances like uranium. [Tornivaara, A., Kauppila, P., 2011]

The global average concentration of uranium in the upper crust is 2.7 ppm. In the bedrock of Finland the average uranium concentration (2 ppm) correlates with the global average, but, for example, in the areas where the dominant rock type is granite, the uranium content can be considerably higher. The highest uranium and thorium contents in the bedrock of Finland are found in the southern parts of the country as well as in the eastern and central Lapland. International uranium resource evaluation project (IUREP) has estimated the uranium ore resources of Finland to be somewhere between 8000 - 18 000 tons. [STUK 2/2005; Lauri L., Pohjolainen, E. and Äikäs, O., 2010; Uraani – ydinvoiman energiametalli; Vuokko, J., 1988]

The concentrations of NORMs migrating in the environment may be increased by human activities, such as mining and milling of ore containing NORMs. In Finland, the mining companies are required to investigate the possible risk of their actions, before the environmental and mining permits are granted. It is mandatory to conduct the Environmental Impact Assessment (EIA)-report, which evaluates the alternative ways of implementation and their effects on the affected area. If the ore contains more than 0.1 kg/t of uranium it falls under the supervision of the Nuclear and Safety Authority of Finland (STUK). [EIA procedure for projects; STUK 2/2005; Tornivaara, A., Kauppila, P., 2011]

The purpose of this literature review is to describe the mining activities related to radioactive materials in Finland. It includes information about previous and current NORM related mining operations and about the exploration target areas which are rich in NORMs. [STUK 2/2005; Uraanikaivokset]

3.1.2. Previous NORM-related mining activities in Finland

Currently, there are no uranium or thorium mines in Finland. In the end of 1950s uranium was mined in Finland for several years from the Paukkajanvaara mine in Eno municipality in eastern Finland.

Paukkajanvaara uranium mine

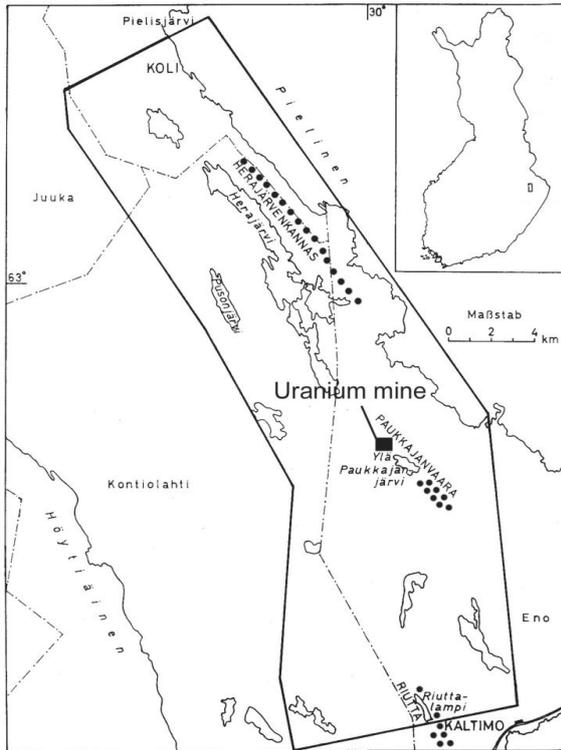


Figure 2. The location of the uranium mine in Paukkajanvaara [Colpaert A., 2006]

The uranium ore deposit in Paukkajanvaara was found in 1957 by two local part-time prospectors. During further field investigations the radioactive boulders in the area were sampled and analyzed to contain 1.5% uranium – a concentration 10 000 times higher than the average uranium content of the earth's crust. These findings led quickly to a claim, and in 1959 a small mine started to operate in the area. The mine was a kind of a test facility where the ore was milled both in an open quarry and in underground mine (called as Mårtenson mine), and enriched at the site. [Colpaert, A. 2006]

The mine employed several tens of workers who worked without any protective gear but were carrying dosimeters. No negative health effects on the workers have been reported, but both the number of workers and the operating period of the mine were limited. It is estimated that the radiation in Paukkajanvaara is relatively low, in the range of 1 – 9 $\mu\text{Sv/h}$, and dust and other hazards related to normal mining would be more important health issues than the radiation itself. [Colpaert, A. 2006]

During its 3-year operating period, approximately 30 700 tons of uranium ore was extracted from the mine (uranium content between 0.075-0.143%) and 27 tons of uranium ore concentrate was produced with a purity of 20-30% (uranium oxide). The concentrate was sold to Sweden. The ore in the underground mine was exhausted in 1961, the mining became economically unprofitable and the site was abandoned. It was not until 1970s when the last ore concentrate was removed, the production buildings demolished and the entrance of the

mining shaft covered. All tailings, containing about 12 000 m³ fine-grained materials and about 7 300 m³ waste rock, and waste-water ponds were left uncovered and unprotected. In 1985, a new claim was made, but no new mining operations were started. [Colpaert, A. 2006]

STUK studied the Paukkajanvaara site systematically in 1980s with a geologically similar undisturbed area as a reference site. It was estimated that due to the mining activities the radiation level in the mining site was increased by approximately 0.5 µSv/h. The radon levels in the air above the mining site were exceptionally high. The tailings were considered to be the main reason for the increased radon levels. The surface waters in the mining site were also contaminated by dissolved uranium. The radiation levels in the water of a ditch flowing through the area were between 0.2-0.4 Bq/l, considerably higher than in the reference site (0.002-0.003 Bq/l). Two kilometers downstream from the mine, the radiation level of the water was normal. Similarly, the uranium contents in the water and in bottom sediments were considerably high near the mining site but they were normal some two kilometers downstream, where the ditch reached the lake Saarilampi. The vegetation in the mining site and adjacent area had only slightly increased levels of radioactive isotopes, but the fish were found to contain relatively high concentrations of radioactive isotopes even in the lake Saarilampi. [Colpaert, A. 2006]

STUK concluded that the area should be rehabilitated in order to the radiation levels to be decreased to their natural levels. The rehabilitation was implemented in 1991-1994, when the mine shaft was demolished with dynamite and the whole area covered with 30 centimeters of clay and 1.2 meters of till. The area was landscaped and pine trees were planted. After the rehabilitation, the area was seen as safe for outdoor use without any restrictions but any residence activities remained prohibited. The measurements of STUK showed that the radiation levels were only slightly increased close to the enrichment station site, otherwise the radiation levels coincided with the normal Finnish averages. In 2000s, some quarry areas are still distinguishable but mostly the site looks like any other planted pine forest. The radiation is in the normal background level except on one specific site, where the gravel showed slightly increased values. [Colpaert, A. 2006]

Korsnäs lead mine

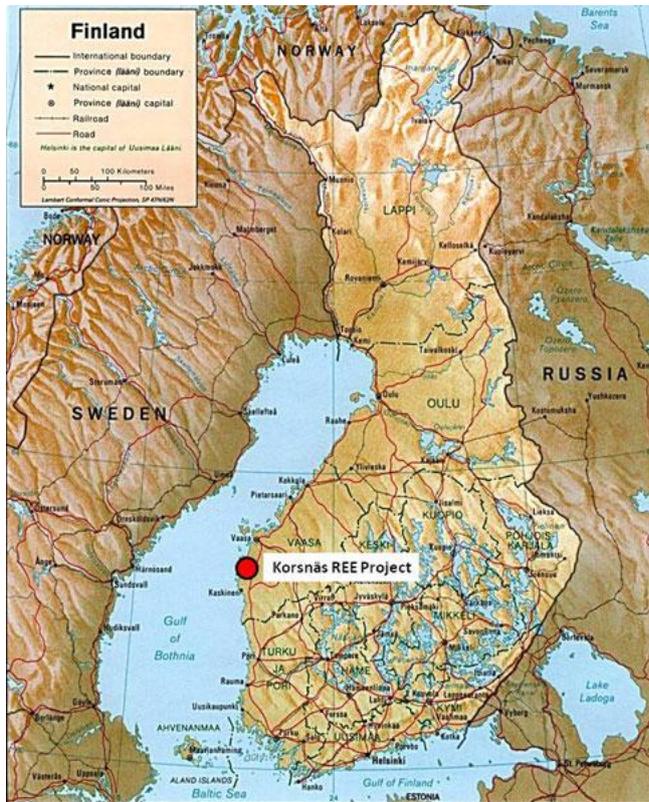


Figure 3. The location of the Korsnäs Project [Tasman Metals Ltd.]

The Korsnäs Pb-REE deposit was first discovered in 1955 by the Geological Survey of Finland (GTK). The deposit is located 50 kilometers southwest of the Baltic seaport town of Vaasa. The Pb-REE ore body measured 300 m by 20 m with a vertical depth of 175 m. The main REE bearing minerals in the deposit were apatite, monazite and allanite. Based on the studies, 80-90% of the REEs constitute of Ce, La and Nd, which were extracted from the REE concentrate by Typpi Oy in the 1960s. In 1975 GTK performed radiological studies on the boulders at the mine site and found increased concentrations of NORMs from the samples collected on the south-southeastern side of the deposit – the concentrations varied between 6-3100 ppm U and 10-2240 ppm Th. [Korsnäs - rare earth element project; Appelqvist, H. 1977]

Outokumpu Oy claimed the deposit and a mixed open pit and underground mine started in 1961. Due to the low market price of the lead in 1962 the mine was shut down, but when the economics emerged two years later the mine was reopened. The production continued until 1972, when the lead ore was exhausted from the mine. Mining of copper and nickel continued until 1973 and after this the site was abandoned. The total amount of ore mined is 860 000 tonnes from which 45 000 tonnes of lead concentrate was produced. The process produced 760 000 tonnes of waste material and 36 000 tonnes of concentrate tailings with increased concentrations of REE. The radioactive element concentrations in the lanthanide waste are

relatively higher than in the other waste fractions. [Korsnäs – the history of the mine; Korsnäs - rare earth element project; Markkanen, M, 1992]

The rehabilitation of the area has been made under supervision of STUK. The tailings have been lightly covered and the mining equipment removed. Lanthanide concentrate waste was sprayed with 0.5% sulphuric acid in order to prevent the dusting of the soil. After the rehabilitation the average activity concentrations for the waste were 700 Bq/kg for ^{238}U and 250 Bq/kg for ^{232}Th . The corresponding concentrations for the lanthanide waste area were 3000 Bq/kg for ^{238}U and 1000 Bq/kg for ^{232}Th . Over the waste area the measured radiation dose rate was 0.13-0.27 $\mu\text{Sv/h}$. No further rehabilitation process is required. The estimated annual external gamma radiation dose is around 0.1 mSv/a. [Korsnäs – the history of the mine; Korsnäs - rare earth element project; Markkanen, M., 1992]

At the moment the exploration rights on the Korsnäs deposit are owned by Tasman Metals Ltd, who investigate the possibility of exploiting the REEs from the enrichment waste material area at the mine site and possible even from the soils. Tasman Metals Ltd is not aiming to produce uranium as a main product or a by-product. If ores that contain NORMs are processed it has to be taken into account in the process, safety instructions and waste handling procedures. [Korsnäs - rare earth element project]

Vihanti zinc mine

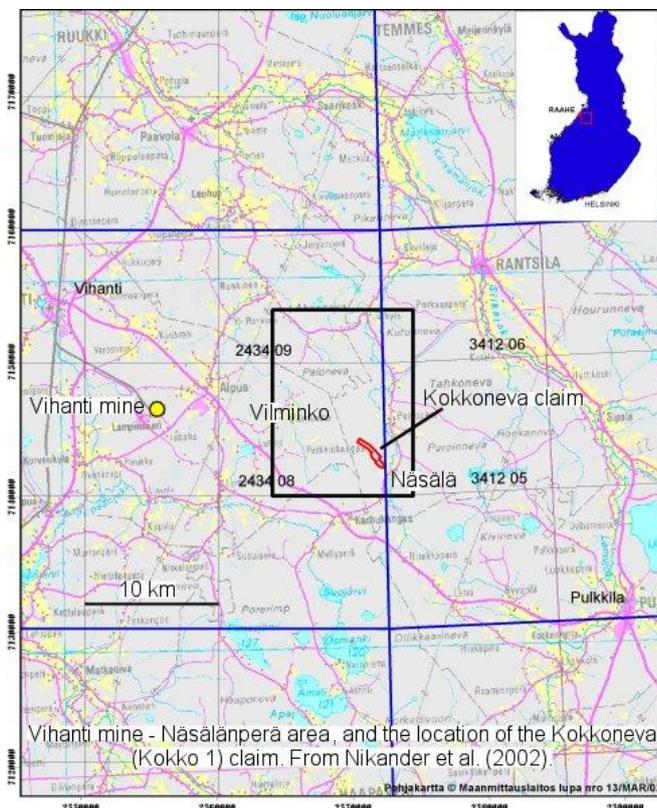


Figure 4. The location of the Vihanti mine. [Vihanti – zinc database]

GTK began to investigate the Vihanti region after receiving samples from amateur prospectors in 1936 and 1939. Ore deposits were found shortly afterwards and GTK continued to explore the area until 1950, when the rights were transferred to Outokumpu Oyj. The deposit is located 70 km south-southwest from Oulu and consists of three major zinc ore bodies (Ristonaho, Välisaari and Lampinsaari). The major ore minerals found in the Vihanti deposit are sphalerite, pyrrhotite, galena, chalcopyrite and pyrite. [Vihanti – Uranium database]

Based on previous studies (diamond drilling, ground magnetic, gravimetric and electric surveys) Outokumpu Oyj considered the zinc deposits to be sufficient for economically profitable mining. The underground mine started production in 1954. At the beginning of the 1970s the awareness of the health risks of indoor radon grew and due to this Outokumpu Oy started measuring the Rn concentrations at the mine site. The radon particle concentrations proved to be over the threshold level. The ventilation had to be improved and the search for the cause of the elevated Rn levels started. They were revealed to be caused by uranium-phosphate rich mineralization, which is mainly found on the eastern side of the deposit. The main uranium-bearing mineral is uraninite, but small U concentrations were also found in apatite. The estimated quantity of ore in the bedrock is 2.59 Mt with the average uranium concentration of 0.03% (max 0.15%), which is too small to be economic. In 1977, the uranium-bearing ore became part of the process plan as its mining was restrained. [Vihanti – Uranium database; Pelkonen, K. 1992]

The production in the mine continued until 1992. The total amount of ore produced was 28 Mt with average zinc content of 0.36 %. The mine also produced approximately 24 Mt of tailings with an average uranium concentration of 30 ppm. After the site was abandoned the mine was allowed to fill with water. It is believed that the radon concentrations inside the mine are increasing over time. The tailings sand has been covered in order to rehabilitate the site. At the moment there are no plans to utilize the Vihanti deposit, and the exploration rights remain open for acquisition. [Vihanti – Uranium database; Pelkonen, K. 1992]

STUK studied the different exposure pathways for radiation in the Vihanti area in 1992. The highest risk comes from external gamma radiation. Mostly the radiation levels varied between 0.06-0.11 $\mu\text{Sv/h}$, but for the tailings area the values were slightly higher at 0.12-0.16 $\mu\text{Sv/h}$. The NORM concentrations of the waste areas were also measured – uranium 400 Bq/kg, radium 300 Bq/kg, thorium 10 Bq/kg and potassium 200 Bq/kg. When compared to the Finnish averages the radiation levels do not differ much. Only the high concentrations of radium may pose a risk if the area is taken into permanent use. [Markkanen, M., 1992]

Käldö

Uranium occurrences at the Käldö island were found in the 1950s by GTK. Shortly afterwards Oy Perno Ab claimed the area and started investigating the mineralization with Suomen Malmi Oy. During the 1950-1960 they performed various diamond drillings going as deep as 70 meters. Most of the largest uranium-bearing vein was excavated and sent to the pilot

concentration plant in Askola run by Imatra Voima Oy. In 1979 GTK performed further studies at the site, leading to the conclusions that the uranium-bearing host rock was microcline granite and radiation levels were fairly low. The uranium concentration in bedrock varied between 25-1280 ppm and thorium concentration between 10-50 ppm. The site was abandoned as the major uranium ore bodies were exhausted. [Appelqvist, H, 1988]

Lakeakallio

In 1957, Imatran Voima Oy (IVO) discovered uranium rich lodes in the municipality of Askola in southern Finland. The findings led to claim and a pilot mining operation started later in the same year. The project consisted of two different test pit areas and a concentration facility. The results for the concentration tests were promising, but after some years the deposit was found to be too small to be economic. IVO abandoned the site in 1960 with no rehabilitation efforts. [Appelqvist H., 1982; Larsson N., 1958; Äikäs O., 2006]

The two open test pit areas, located 7 kilometres apart, are called Monninkylä and Lakeakallio. The concentration plant was placed at Lakeakallio. The ore was hosted by granitic gneiss and the total uranium resource was estimated to be 0.63 tons. In 1958, IVO measured the radiation over the mineralization to be 2.6 $\mu\text{Sv/h}$, and inside the drill holes 5.2 $\mu\text{Sv/h}$. The concentration plant was also used to process boulders from the Luhti occurrence and ore from the Källdö deposit. In total, 1000 tons of ore was processed over the three year period and the total yellow cake production is estimated to be no more than a few litres. [Larsson N., 1958; Mineral deposits and exploration]

GTK continued the exploration in 1978-80, in order to find extensions for the known mineralization. The data collected, including various drill core samples, was analysed, but the results showed no new anomalies. Overall, the radioactive materials are scattered widely around the area. [Appelqvist H., 1981, 1982]

STUK started the monitoring of the radiological state of Lakeakallio in 1985. Signs of the former mining operations could still be seen including the concentrate silo and waste rock area. The area was also visible in the GTK aeroradiometric map - a swamp at the northeastern side of the plant was clearly radioactive due to the spreading waste material, as was the road leading to the mine site, as it was built using the waste rock. The rehabilitation process of the area started in 1991 – the contaminated sediments were moved, the frame of the concentration plant was buried in one of the test pits and the test pits were covered. The final investigation was done in 1992, and it showed that the rehabilitation was sufficient. STUK concluded that the mining operations had increased the external radiation of the site, especially over the old concentration plant. There are no restrictions for outdoor use, but permanent activities remain prohibited. [Appelqvist H., 1982; Jakobsson K., 1992; Äikäs O., 2006]

Nuottijärvi

The Nuottijärvi deposit is located in the municipality of Paltamo, central Finland. It was discovered in 1959 by Outokumpu Oy through systematic radiometric surveys in the quartzite belt of Kainuu. Outokumpu Oy performed various surveys at the site and was the holder of the exploration rights until 1998. Subsequently claims were granted for Namura Finland Oy in 2007-09, Mawson Resources Ltd in 2010-12 and Euro Scandinavian Uranium AB in 2013. [Mineral deposit and exploration; Nuottijärvi - Uranium deposit]

The Nuottijärvi deposit is located in the Kainuu schist belt. The bedrock of the occurrence consists of mica schist, black schist, tremolite skarn some of which is mineralized, conglomerate and quartzite. The NI 43-101 compliant inferred resource is 3.2 Mt of ore with 0.053 % U_3O_8 and 3.5 % P_2O_5 (no cut-off value used). The main uranium mineral is uraninite and it occurs as separate grains in the ore. The size of the known deposit is 400 m by 50 m in horizontal extent and 150 m in depth. The deposit is listed in the Red Book of IAEA with a resource class of RAR>USD 130/kg U. The deposit is located on top of second class ground water reservoirs which run in a chain of eskers across the area, bending from northwest to southeast. [Nebocat J. and Reed G., 2010]

In 1965, pilot concentration tests were performed at the Nuottijärvi deposit. In total, 867 tons of ore were treated on-site and the results were poor. In 1969, Outokumpu Oy ran acid and alkaline leaching tests for Nuottijärvi ore in their laboratories at Pori. The Department of Geology and Mineralogy and the Department of Microbiology of the University of Helsinki conducted studies in the area between the years 1978-1983. The aim was to study bacterial leaching of phosphatic rocks. The site has not been restored afterwards. The ore was relatively low grade, but elevated radiation levels can be seen at the exposed outcrops and around the waste rock heap. It is suggested in the Red Book of IAEA that the Nuottijärvi deposit should be taken under supervision for the radiation levels. [Nuottijärvi - Uranium deposit]

3.1.3. Currently operating mines

Currently there are no mines producing NORMs as their main or by-product in Finland. However, the Talvivaara mine is producing base metals and processing minerals, which contain elevated levels of uranium. The process creates waste products and tailings with increased levels of NORMs. The company is obliged to take this into account in their processes, safety instructions and waste handling procedures.

Talvivaara



Figure 5. The location of the Talvivaara mine. [www.talvivaara.com]

The Talvivaara nickel sulphide deposits are located in the municipality of Kainuu in eastern Finland ca. 350 km from the Arctic Circle. The deposits were found by GTK in 1951. Various Finnish companies explored the area in 1951-1962. The Kuusilampi and Kolmisoppi polymetallic deposits were discovered during bedrock mapping of the area. The known size of the Kuusilampi deposit is 2600 meters in length, 40-1000 meters in width and 600 meters in depth. For the Kolmisoppi deposit the respective values are 1500 meters, 30-350 meters and 300 meters. The Kuusilampi and Kolmisoppi deposits are located approximately 3 kilometers apart and the distribution of metals in the bedrock seems to be homogeneous. [Riekkola-Vanhanen, M., 2013]

The ore is hosted by black schist (90%) and metacarbonate rocks (10%). The main ore minerals are pentlandite (Ni, Co), pyrrhotite (Ni, Co), chalcopyrite (Cu), sphalerite (Zn), pyrite (Ni, Co) and thucholite (U). The Australian JORC (joint ore reserves committee) compliant mineral resource at Talvivaara is 1004 Mt with 0.23% Ni, 0.51% Zn, 0.13% Cu, 0.02% Co, 0.0017% U, 0.3% Mn, 10% Fe, 9% S, 8% C and 50% SiO₂ using a cut-off 0.07% Ni. The Talvivaara nickel sulphide deposit is one of the largest in the world, but it is not easily attainable due the high graphite concentration in the ore. [Riekkola-Vanhanen, M., 2010, 2013]

Outokumpu Oy acquired the claims to the deposits in 1985 and applied for a mining license, which was granted in 1986. The geological and metallurgical work was continued and the deposit was defined as low grade, meaning that it would not be economically profitable for

mining with traditional methods. The Talvivaara Project acquired the mining licence from Outokumpu Oy in 2004 and together with Outotec came up with an idea to extract metals from the ore by using microbes – this process is called bioheapleaching. This process is relatively cheap as it only needs microbes, water and air to work. The Talvivaara Project started a pilot bioheapleaching experiment in 2005 at the mine site with smaller trials being performed in laboratory. The produced pregnant leach solution (PLS) was further processed at the OMG plant in Kokkola. The trial was successful and the mining and leaching of ore started in 2008. Talvivaara was the first mine in Europe to use bioheapleaching as an ore extraction process. [Riekkola-Vanhanen, M., 2010, 2013]

Talvivaara is primarily a nickel mine and the annual nickel production is anticipated to be 50 000 tonnes. In addition, 90 000 tonnes of zinc, 15 000 tonnes of copper and 1800 tonnes of cobalt will be produced as by-products. PLS also contains a high concentration of uranium as it dissolves when the pH of the solution is kept low. In 2012 the Regional state administration agencies granted a permit for Talvivaara to collect the uranium as one of the by-products, with annual production of 350-500 tonnes. However, the permit was later rejected due to the bad economic situation of Talvivaara. At the moment most of the dissolved uranium ends up in the gypsum ponds, where its activity concentration varies between 300-900 Bq/kg. The average activity concentration of uranium around the mine site is 20 ppm or 250 Bq/kg. [Riekkola-Vanhanen, M., 2010, 2013]

At the end of 2012 Talvivaara suffered a leakage in one of the gypsum ponds and the waste water entered the environment along the mine site. Due to heavy rain the acidic water from the mine site was directed to the gypsum ponds and this caused an overflow. When the pH decreased in the ponds the gypsum dissolved, leading to a high concentration of metals in the waste water, including uranium. After the leakage, areas of water around the mine were badly contaminated and the radioactive concentrations were increased. Salmisen järvi, Kalliojärvi and Kivijärvi lakes still remain unusable. [Vesterbacka, P., 2014]

Part of the uranium in the PLS ends up in the final products. The main purchaser of the nickel is Norilsk Nickel Harjavalta Oy. The average uranium concentration in the nickel sulfide material from Talvivaara is 19 ppm. At the factory the uranium accumulates in the leachates of the cobalt and calcium extractions and finally ends up in the Kokemäenjoki River. In 2010, Norilsk Nickel Harjavalta Oy was granted a permit to trial separation of the uranium as a byproduct from the leachates. The trial was successful and the process for getting a permanent permit was launched. At the moment, Norilsk Nickel Harjavalta Oy is allowed to extract and store 10 000 tons of uranium per year. [Norilsk Nickel Harjavalta Oy, 2011]

3.1.4. Exploration

Several companies are doing exploration or are planning for mines in areas where the bedrock contains NORMs. However, the production of NORMs as a main or a by-product has yet not been considered as suitable deposits are missing. If the processed ores contain uranium or other NORMs it is mandatory for the companies to take the radioactivity into account in their processes, safety instructions and waste handling procedures.

Rompas–Rajapalot

NORMs related to mining are currently a controversial topic in the public debate in Finland. This is partly due to the environmental releases of uranium in soluble form from mines in 2012-2013, and partly due to the plans for the recovery of uranium as a by-product in metal mines. There are several exploration and mining projects at various stages where the ore or related rocks contain significant amounts of natural radionuclides (e.g. Juomasuo, Sokli, Rompas–Rajapalot).

Rompas–Rajapalot is an Au-prospect in northern Finland, in the municipalities of Ylitornio and Rovaniemi. Exploration in the area is currently undertaken by Mawson Resources Ltd (hereafter ‘Mawson’). According to the news releases from Mawson the rocks in this area contain variable but sometimes very high contents of uranium, up to 27% U_3O_8 in grab samples. Originally the area was investigated as a potential uranium deposit.

Rompas–Rajapalot was chosen as a target for this case study, as it is a large area under active exploration with uranium-rich rocks and limited first-hand knowledge on the distribution of natural radionuclides in the environment. Environmental samples were taken and analysed for the main uranium and thorium series nuclides.

Background

The Rompas occurrence was discovered in 2008 by AREVA Resources Finland Oy and many separate showings with high uranium and extremely high gold contents in a 6 km by 300 m zone were located during exploration activities in 2008-2009. Mawson purchased the property from AREVA in 2010. The Rajapalot occurrence on the E side of Rompas was discovered by Mawson in 2012. Gold grades up to 3200 g/t Au (native gold) and uranium contents up to 27% U_3O_8 have been measured in grab samples.

Geologically the Rompas–Rajapalot occurrence is situated within the Peräpohja Belt, which is a sequence of Paleoproterozoic supracrustal rocks including quartzites, mafic volcanic rocks, carbonate rocks, black schists, mica schists and greywackes. The metamorphic grade in the Peräpohja Belt varies from greenschist facies in the southern parts to amphibolite facies in the northern margin, but no migmatization is observed within the belt.

There are at least two different mineralization styles in the Rompas–Rajapalot occurrence; these are, vein-type and disseminated ore. The classification and formation mechanism of the ore-type(s) in the Rompas–Rajapalot area is still unclear.

The Rompas–Rajapalot occurrence is in a region, which contains protected areas belonging to the Natura 2000 biodiversity programme of the EU. In addition to the Natura 2000 network, there are nature reserves that are part of the mire conservation programme and herb-rich forest conservation programme (e.g., Romppaat and Mustiaapa-Kaattasjärvi), in which the regulations are more binding than in the Natura 2000 areas. The mineralizations are partly found within these areas. There has been legal action against Mawson with claims of harm to endangered species caused by exploration activities inside protected areas. According to the decision of the Kemi-Tornio court in December 31st, 2014, the company got a fine for trenching and sampling within the protected areas, but no harm to endangered species could be proved.

The area has extensive glacial cover and very limited outcrop (estimated 2%). The terrain is predominantly swampy, mainly consisting of forests and flat mires. There is a reasonable network of forestry roads, which is typical in Finland. The surface waters from Rompas drain roughly northwest into the Tengeliö river system and eventually into the Tornio River, which is the border between Sweden and Finland and the most important breeding river for the Baltic Sea salmon. The surface waters from Rajapalot drain southward into the Loue river, which then joins the large Kemi river. The Kemi river has been harnessed for hydroelectric power.

Riutta

In 1958, Atomienergia Oy discovered high-grade uranium boulders approximately 30 kilometres southeast of the Koli area in eastern Finland. The findings lead to the discovery of uranium-bearing bedrock exposures that are now known as the Riutta deposit. Various different companies have explored the area since the discovery: Atomienergia Oy in 1958-59, Outokumpu Oy in 1960-63, GTK in 1983-88, AREVA Resources Finland Oy in 2008-09 and Mawson Resources Ltd in 2010-2012 [Mawson Resources Ltd 2011; Äikäs O., 1987]

The Riutta deposit consists of three main ore lodes, which are called Ristimonttu, Unimonttu and Kolmosviuhka. The bedrock in the area is composed of sericite-quartz schist, felsic and intermediate gneiss, granodiorite and tonalite. The main ore minerals found are uraninite, pyrite, chalcopyrite, magnetite and molybdenite. Uraninite occurs in veins that cross-cut the host rocks. There are no reliable resource estimates available due to insufficient drilling data. The highest concentrations of uranium in drill core samples were 3.6 m @ 1.10 % from 42.0 m at the Unimonttu lode, 1.0 m @ 0.35 % from 63.3 m at the Kolmosviuhka lode and 11.3 m @ 0.68 % from 20.2 m at the Ristimonttu lode. [Mawson Resources Ltd 2011; Äikäs O., 1989]

AREVA concluded a baseline study in the area in 2007-09. The chemical analyses suggested that there are no significant changes in the chemical composition of water, sediments or moss that could be caused by exploration work in the Riutta area. [Heikkinen P., 2009]

Euro Scandinavian Uranium AB obtained the claims for the Riutta deposit in 2013. Their main focus was finding uranium. The municipality of Kontiolahti and several other organizations were against the project, but the claims were granted despite the objections. The company recanted the rights in the latter part of 2013. One of the reasons stated was that the Finland Mining Act denies the possibility of gaining the mining permit if the municipality is against the granting of the permit. [TUKES: Riutta 1, 2013; TUKES: Malminetsintäluvan raukeaminen, 2013]

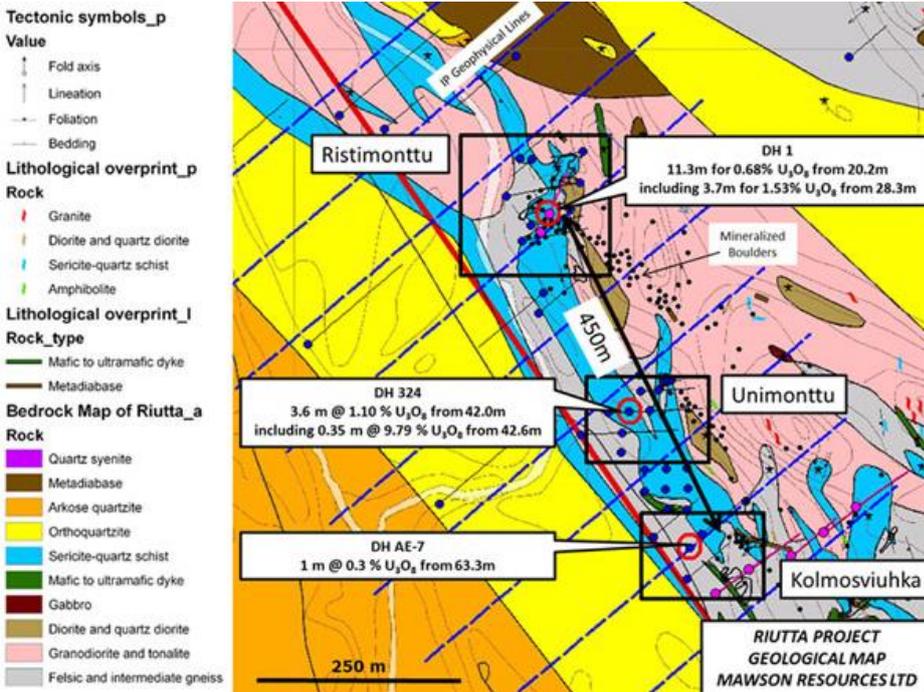


Figure 6. The geological map with drill holes and boulders of Riutta deposit. [Mawson Resources Ltd, 2011]

Ipatti

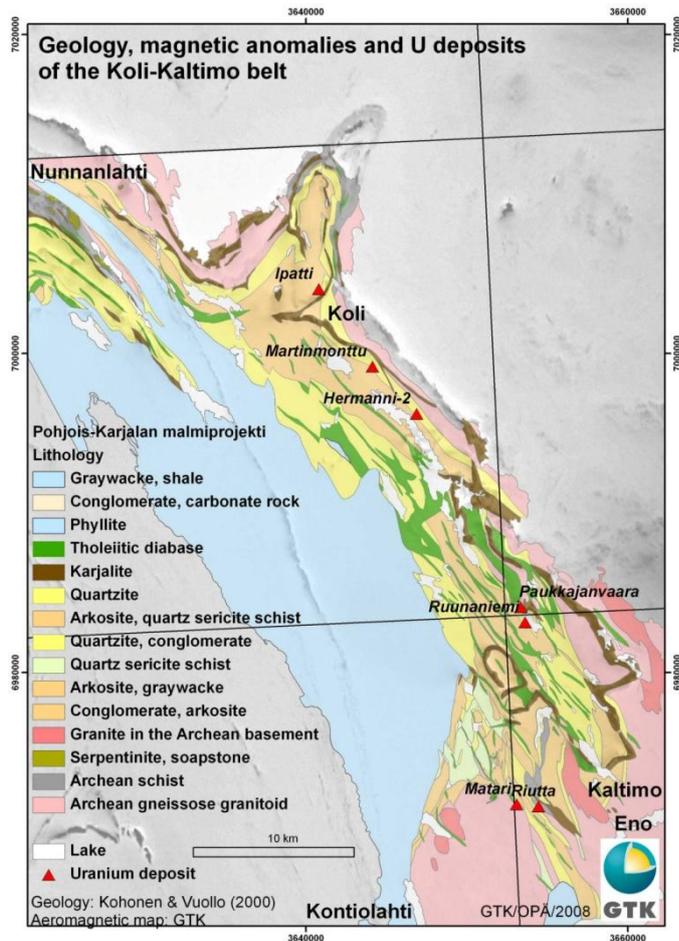


Figure 7. The locations of the Koli deposits, including Ipatti. [Äikäs O., 1989]

The quartz-pebble conglomerate-hosted Ipatti uranium occurrence is located in the municipality of Lieksa, eastern Finland. The small occurrence was discovered in 1967 by Outokumpu Oy, through a systematic ground scintillation survey. Outokumpu Oy investigated the area up to 1972. Geophysical measurements, trenching, percussion drilling and diamond drilling revealed the ore body to be approximately 300 m long. The ore body was estimated to hold 71 000 tons of mineralized rock, with uranium concentration of 0.083%. The evaluated dimensions for the ore body are 6 m x 50 m x 300 m. The major ore minerals are uraninite and magnetite, but also uranophane can be found as a secondary mineral in the uraninite matrix. The uranium content was too low to be economic. The exploration rights remain open for acquisition, but as the Ipatti occurrence is within the Koli national park the geological sampling is only allowed for educational or scientific purposes and with a special permit. [Ipatti – Uranium database; Äikäs O. 1987, 1989]

Hannukainen, Rautuvaara



Figure 8. The location of the Hannukainen deposit. [YVA Hannukainen, 2013]

The Hannukainen Iron oxide-Copper-Gold deposit is located approximately 12 km west of the Ylläs fell, in the municipality of Kolari, in northern Finland. Iron ore was mined from the deposit in 1978-1992 by both Rautaruukki Oy and Outokumpu Oy, and the ore was processed at the nearby Rautuvaara iron mine. Northland Mines Oy claimed the area containing both the Hannukainen and Rautuvaara deposits in 2005, as the ore resources remaining in the deposits are still considered as economic. [STUK 2014]

Northland Mines Oy is planning to operate two different ore lodes (Hannukainen and Kuervittikko) in the Hannukainen area. These two occurrences represent Iron oxide-Copper-Gold (IOCG) type ores, which occur within the Pajala-Kolari shear zone in Finland and Sweden. The ore is hosted by hornblende-diopside skarn and magnetite skarn. The resource is estimated to be 114.8 Mt of ore with 30.5 % Fe, 0.185 % Cu and 0.112 g/t Au. The uranium content of the ore is estimated to be between 7-13 ppm. The deposit will be mined with open pit mining methods, and the ore mined will be transported to the former Rautuvaara iron mine for processing. The estimated amount of quarried ore per annum is 6.5 Mt, amounting to 2.0 Mt of iron concentrate and 50 000 t of copper concentrate. Uranium production as a by-product is not in the company's interests. [ELY lausunto, Hannukainen 2014; Hannukainen PEA report 2010; TUKES Hannukainen 2013]

The disposal location of the tailings will be the existing tailings pond of the Rautuvaara mine. In the past, 6.6 Mt of tailings from several different mines were disposed in Rautuvaara, including uranium-bearing waste from the Juomasuo deposit in Kuusamo. According to GTK,

the uranium concentration in the tailings can be as high as 500 ppm and the corresponding levels in the water around it 100-500 µg/l. Northland Mines Oy informs that the existing tailings pond is sufficient for storing tailings for the operation period of 10 years, after which an additional tailings storage will be needed. The tailings from the Hannukainen deposit will contain high levels of sulphur, and part of it may be characterised as acid-generating waste. [Hannukainen PEA report 2010; STUK Hannukainen 2014; TUKES Hannukainen 2013]

The Environmental Impact Assessment (EIA) for the Hannukainen project was completed in 2013 and a radiological baseline study and Natura-statement made by the Centre of Economic Development, Transport and the Environment are due to commence. The studies are needed for applying the environmental and mining permits. According to the original plan of Northland Mines Oy the production was supposed to start at the earliest in 2014. Currently this seems unlikely due to the economic recession. [YLE uutiset, 2014; YVA Hannukainen, 2013]

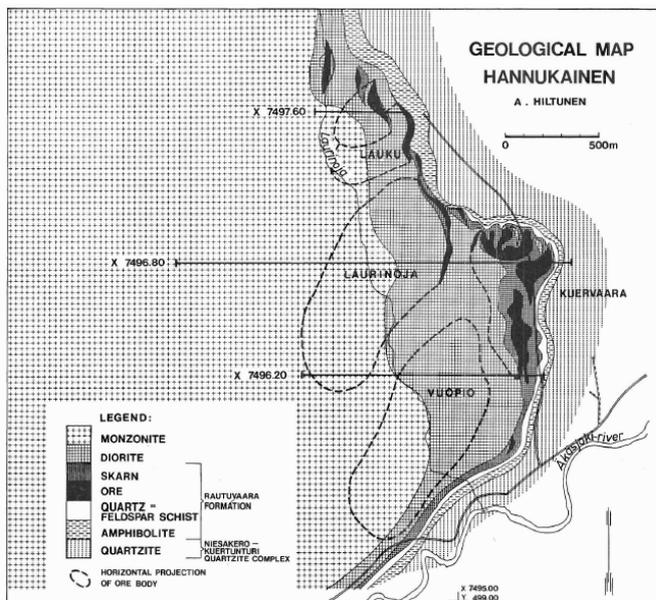


Figure 9. The geology of the Hannukainen area. [Niiranen T., Eilu P., 2007]

Pahtavuoma (copper, zinc and uranium showings)

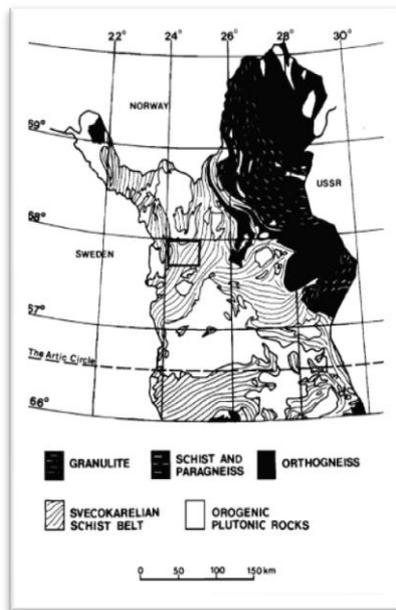


Figure 10. The location of Pahtavuoma deposit [Inkinen O., 1979]

The Pahtavuoma deposit is located in the municipality of Kittilä, about 150 kilometers north of the Arctic Circle. In 1970, after 10 years of exploration, Outokumpu Oy discovered copper anomalies in the Central Lapland greenstone belt. In the following year radiation was detected from drill core samples drilled for copper exploration. Outokumpu Oy has been the owner of the mining permit since the 1970s. [Inkinen O., 1979; Pahtavuoma-U – Uranium deposit]

The Pahtavuoma deposit consists of four separate copper ore bodies, six zinc ore bodies and three uranium ore bodies. The estimated ore resources are 144 318 tons of zinc, 67 776 tons of copper and 546 tons of uranium. Bedrock in the Pahtavuoma area is composed of greenstones and sedimentogenic schist. The greenstones are amphibole-albite rocks that contain also biotite. The sedimentogenic schist is a heterogeneous unit of chlorite and mica schists, phyllites, graphite phyllites, cherts and graywackes. The copper, zinc and uranium ore bodies are found within the sedimentogenic schist. Phyllite is the dominant host rock for all ore types, but copper and uranium lodes are also found within mica schists [Inkinen O., 1979; Korkalo T., 2006; Mineral deposits and exploration; Pahtavuoma-U – Uranium deposit]

The four copper ore bodies are called the Western orebody, the Central orebody, the A orebody and the Ulla orebody. The largest ones are the A and Ulla bodies, which do not contain anomalous concentrations of uranium. The main Cu ore mineral is chalcopyrite-pyrrhotite and the ore bodies are situated close to the greenstones. The three uranium ore bodies are UI, UII and UII and the main ore minerals in the uranium lodes are pyrrhotite, uraninite and molybdenite. The zinc ore bodies are separate from the copper and uranium lodes. The locations of the different ore bodies are presented in the figure 11 . [Inkinen O., 1979; Pahtavuoma-U – uranium database; Pahtavuoma – ZINC deposit]

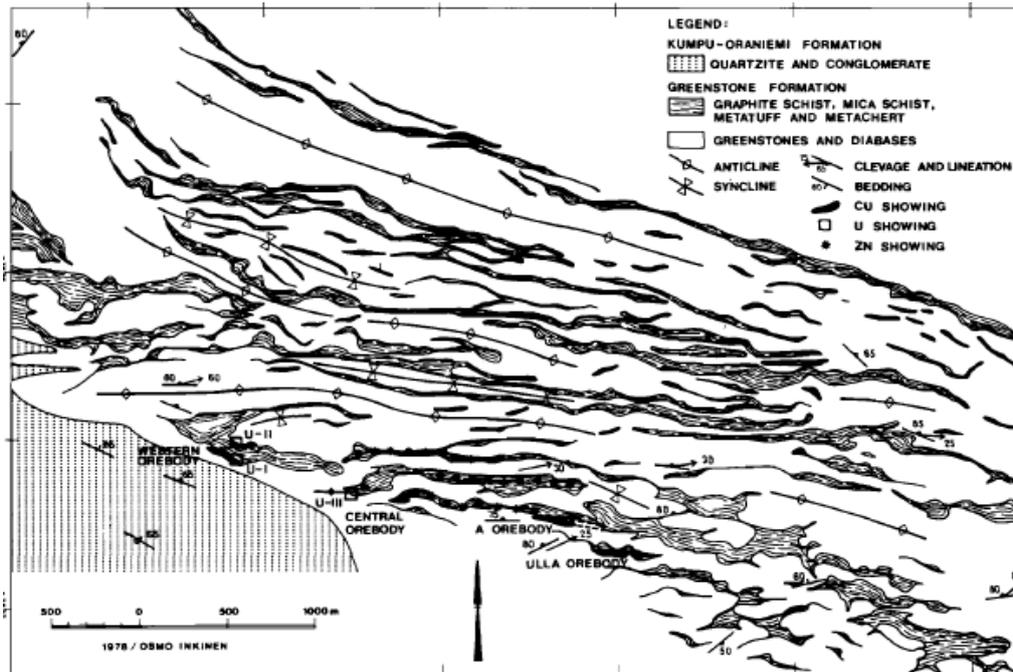


Figure 11. Pahtavuoma ore bodies. [Inkinen O., 1979]

The uranium ore bodies are different in composition from the zinc and copper lodes, as the uranium and molybdenum concentrations are higher and the base metal contents are lower in them. The uranium concentration in the UII and UIII lodes is higher than in the UI lode. The in situ evaluated resource for UII and UIII lodes is 0.14 Mt of ore with 0.39 % of uranium. For the other metals the average in situ estimates are 0.24 % Cu, 0.08 % Zn, 0.09 % Pb, 0.02 % Ni, 0.01 % Co, 9.17 % Fe, 0.02 % As, 0.024 % Mo, 2.82 % S, 24 ppm Ag and <0.01 ppm Au calculated along a 33 m drill core section. [Korkalo T., 2006]

The mining licence was granted to Outokumpu Oy in 3.11.1977. In 1989-1993, two of the copper lodes were mined until they were exhausted, concurrently with operations at the adjacent Saattopora gold mine. The ore from both mines was enriched at the plant in the Rautuvaara iron mine. After the mining operations were concluded the site was abandoned. According to the Lapland Centre of Economic Development, Transport, and the Environment (ELY centre) the signs of the former mining activities are still visible at the site e.g. open pit mine that has been filled with water. Outokumpu Oy has been supervising the state of the environment by observing the waterways around the mine site. [TUKES Pahtavuoma, 2014]

In 2005, the Pahtavuoma mining site was included in the Ylläs-Aakenus Natura 2000 area and the Pallas-Yllästunturi national park conservation area. The area of the mining concession has been excluded from the national park. The conservation areas have to be taken into account when looking at the rehabilitation of the mine site. The ELY centre of Lapland has declared that the termination of the mining concession should be taken into account as well. [TUKES Pahtavuoma, 2014]

Juomasuo gold mine, Kuusamo (gold, ore contains uranium)



Figure 12. The operations of Dragon Mining Oy in Finland and Sweden. [Kuusamo EIA 2014]

Dragon Mining Oy is currently investigating the possibility of opening a gold mine in the Kuusamo municipality, eastern Finland. The Au-Cu-Co-U deposits in Kuusamo were found in the middle 1980s by the GTK. In 1990 Outokumpu Oyj acquired the prospecting rights for the five deposits (Juomasuo, Hangaslampi, Pohjasvaara, Sivakkaharju and Meurastuksenaho) discovered from the area and continued exploration until 1994. In 2003, Polar Mining Oy purchased the rights and in 2011 started an environmental impact assessment (EIA), which evaluated the Kuusamo mine project from an environmental, sociological and social perspective. This was done in order to get the information required for environmental permits and mining licenses. Based on the EIA process no notable effects influencing the area around the Kuusamo mining region are expected. Furthermore, in 2012 the Finnish Radiation and Safety Authority commenced the radiological baseline study of the Kuusamo mine region which was completed in 2014. At the moment, Dragon Mining Oy is performing test work with samples from the Juomasuo and Hangaslampi deposits in the ALS-Ammtec laboratory in South Australia. [Kuusamo EIA 2014; Kuusamo Gold Project]

At the end of 2012 the estimated ore reserves of the Kuusamo gold deposit were 3.4 million tonnes of ore grading 4.2 g/t gold. Cobalt, copper, uranium and some rare earth metals are found in the ore. The most significant uranium mineral is uraninite. In the Kuusamo deposit the uraninite mainly occur as discrete grains, which are scattered within the gold lodes and the cobalt mineralisation. According to an intern report of the radiological baseline study the radioactive concentration of the deposits indicates that it is similar to other Au-Cu-Co-U deposits in the Kuusamo region. The main concern with the process is that uranium may end up in the tailings sections and to the gold product slurry. The process does not increase the concentrations of uranium as the concentrations in the tailings and slurry were equivalent to

those in the ore. The total radiation rates in the tailings varied between 1000-5000 Bq/kg and the main radiators were U-238 (42 %) and Ra-226 (45 %). The corresponding percentages for thorium and potassium were 1 % and 15 %. All the radionuclides found in the Kuusamo mining region are naturally occurring. [Kuusamo EIA. 2014]

Dragon Mining Oy is planning to collect uranium from the tailings using gravity separation. This would create low-level radioactive waste with the uranium concentration around 0.1% or 1 kg/t, and the process would fall under the supervision of STUK. All the mining activities where the concentration levels of radioactive elements exceed the limit of 0.01 % or 0.1 kg/t are controlled by STUK. Processing of the low-level radioactive waste does not require any special, radiation-related precautions. The final disposal of the tailings with elevated uranium levels is still under consideration. Either it will be disposed with inactive tailings waste or separately to improve the controllability. [Kuusamo EIA. 2014; Malminetsintä ja kaivokset.]

At present, Dragon Mining Oy is not planning the production of uranium as a by-product. Kuusamo mine project is going to be predominantly a gold mine. Processing other metals would not be economically possible since the deposits are fairly low grade. [Kuusamo EIA. 2014]

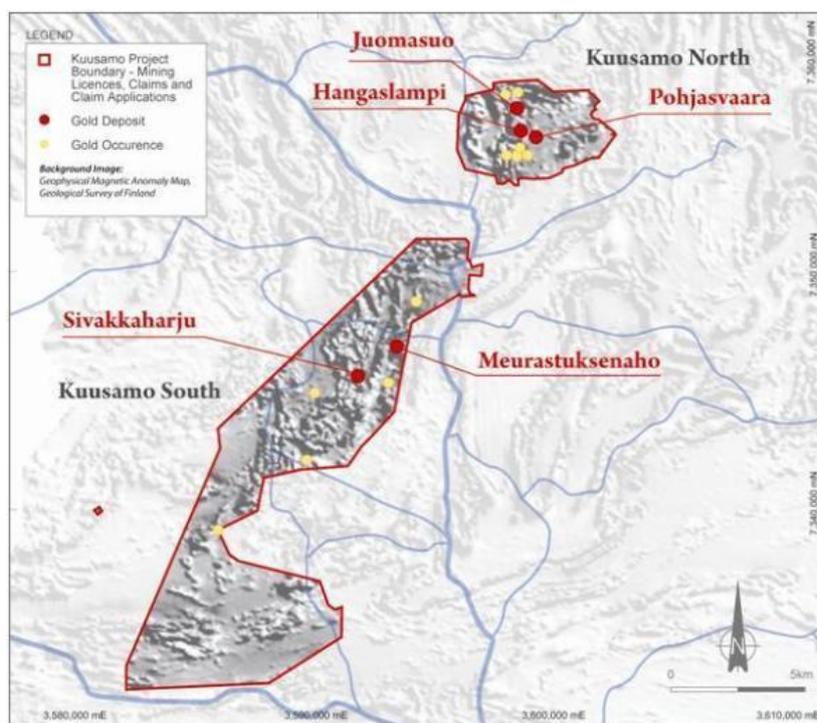


Figure 13. The gold deposits at the Juomasuo area. [Kuusamo gold project]

Konttiahho (gold, uranium)

GTK discovered the Konttiahho deposit in 1985 by ground radiometric measurements performed in a gold exploration project. Konttiahho is located 25 kilometres from the Kuusamo town center, on the western side of the Ruka ski resort. It is situated within the

Paleoproterozoic Kuusamo volcano-sedimentary belt with several other similar Au-Cu-Co-U-bearing deposits (Juomasuo, Sivakkaharju, Pohjaslampi, Hangaslampi) occurring in the vicinity. GTK worked in the area in 1985-90. Subsequently, the exploration rights were held by Outokumpu Oy in 1993-98 and Polar Mining Oy in 2003-08. Currently the Konttiahho deposit is under an exploration permit application by Dragon Mining Oy. [Mineral deposits and explorations; Vanhanen E., 1991]

The Konttiahho deposit consists of several hydrothermal breccia pipes occurring in carbonate rocks, albite diabases and sericite quartzites that are heavily albitized. Gold is primarily found in the larger pipes and there is a strong correlation between gold and uranium. The pipes enriched in gold are also rich in sulfides. The smaller pipes are enriched only in uranium. The most common ore minerals are pyrite and pyrrhotite. The main uranium mineral is uraninite. The metal concentrations in grab samples and drill cores fall in the range of 0.1-0.3 % Co, 0.1-0.2 % Cu and 0.5-10 g/t Au. The uranium concentration of samples analyzed varies from 0.05% to several percent. Thorium concentrations are low. In the uranium rich part the Ag concentration is as high as 10-20 g/t. A non-compliant geological resource estimate for the Konttiahho deposit is a few thousand tons of ore, which is too small to be economic. [Pankka H., 1989, 1991; Vanhanen E., 1991]

Säynäjävaara (gold, uranium)

The Säynäjävaara occurrence is located in the municipality of Kuusamo, in north-eastern Finland, and it is situated in the Kuusamo schist belt. GTK discovered the occurrence in 1983 and performed various surveys in the 1990s. In 2002 Belvedere Resources Ltd acquired the prospecting rights and has been investigating the occurrence since then. The focus of the company is on finding gold, copper and cobalt. [Säynäjävaara – Gold database; TUKES Säynäjävaara, 2011.]

The inferred resources of the occurrence are 450 000 tons of ore with 1 g/t of Au. The average contents of ore based on drill core data are 3.70 ppm Au, 276 ppm Co, 220 ppm Cu, 69 ppm Ni, 5.7 ppm Th and 4 ppm U. Au is present as selenides, tellurides and native gold and the main sulphide mineral is pyrrhotite, but also pyrite, Co-pentlandite, chalcopyrite and uraninite are found. [Säynäjävaara – Gold database]

In late 2011 Belvedere Resources Ltd applied for an exploration permit and the application is still under consideration. If the permit is granted Belvedere Resources Ltd will perform a pilot concentration study for 300 kilograms of ore collected from the diamond drill cores. The company also plans to apply for mining and environmental permits. [Kaivosrekisterin karttapalvelu; TUKES Säynäjävaara, 2011]

Kouervaara (uranium and sulphide deposits)

The Kouervaara deposits are located in the municipality of Kuusamo, in north-eastern Finland, within the Kuusamo schist belt. The two known deposits in Kouervaara comprise a

sulphide deposit and uranium deposit, which are located ca.1200 metres apart. The ore potential of the Kouervaara area has been extensively studied over the years, 1957-69 by Atomi Suomi Oy, 1970-80 by Outokumpu Oy, 1995-2002 by GTK and since 2002 by Belvedere Resources Ltd after claiming the prospecting rights for the Au-Cu-Co deposit. The Kouervaara uranium occurrence was claimed for a short period in the 2000s by Namura Oy. [Kouervaara – Gold database; TUKES: Kaivosrekisterin karttapalvelu.]

The Kouervaara uranium deposit was discovered in 1978 by GTK. The sericite quartzite-hosted uranium rich ore body is 3 km long with variable thickness, bending in NE-SW direction. A non-compliant resource estimate is 0.3 Mt of ore with average uranium content of 0.04%. [Mineral deposits and explorations; Vuokko J., 1988.]

After the discovery of the Kouervaara occurrence GTK conducted detailed geological mapping and radiological surveys at the site. The average uranium concentration in drill core samples was 385 ppm. Thorium concentrations were low in all samples. The main uranium mineral was pitchblende. The more rare secondary uranium minerals found in Kouervaara include brannerite and coffinite. [Mineral deposits and explorations; Vuokko J., 1988.]

The Ministry of Trade and Industry granted a claim for Namura Finland Oy in 19.01.2007. The permit only covered radon and gamma radiation surveys, which took place during the summer 2007. Namura Finland Oy applied for an extension of the claim, but due to the economic recession they pulled out of Finland before receiving the reply. The other long handling times of the applications also contributed to the decision to relinquish the claim application. [Eerola T. 2010; Namura Finland Oy:lle uraanivaltaus Kuusamossa.]

The Kouervaara uranium occurrence is the largest in the Kuusamo area and one of the largest in Finland. However, the average uranium concentration is too low for a mining project to be economical. The exploration rights remain open for acquisition. [Mineral deposits and explorations; Vanhanen E., 1989.]

The Kouervaara sulphide deposit, located 1200 m NE of the uranium occurrence, is estimated to contain 1.58 Mt of ore grading 0.1 % Co (cut-off 400 ppm), 0.2 % Cu and 4 g/t Au. The deposit is 900 metres long, 200 metres wide and 240 metres deep. The main ore minerals are pyrrhotite, chalcopyrite, cobaltite and cobalt-pentlandite. The ore is hosted by sericite quartzite, with irregular micaceous and albite-rich beds. The uranium and thorium concentrations are relatively low, but an increase can be seen in albite-rich rocks (uranium up to 20 ppm and thorium up to 5-50 ppm). [Kouervaara – gold database; Vanhanen E., 2001.]

Sokli

The P-Nb ore deposit of Sokli is located in the municipality of Savukoski, in north-eastern Finland, 12 kilometres from the Finnish-Russian border. The Urho Kekkonen national park

and the Värriö nature reserve are situated ca. 10 km from the Sokli deposit. The deposit was found in 1967 and has been under study ever since. In the 1970s, Rautaruukki Oy conducted a pilot leaching operation of the phosphate ore. The mining rights were subsequently transferred to Kemira Oy, which continued to investigate the different mining possibilities until 1989. Processing the niobium ores as one of the products has been studied since the 1990s. STUK has measured the radioactivity levels at the deposit and adjacent areas. At the moment, Yara Suomi Oy holds the mining rights of the Sokli deposit. An environmental impact assessment (EIA) -report was finished in the spring 2009. EIA-report evaluated the Sokli mine project from an environmental, sociological and social perspective. [Sokli EIA. 2009; Siirama, L. 2009]

The quaternary cover in the Sokli area mainly consists of till. Outcrop conditions in the area are very poor. The Sokli carbonatite complex is deeply weathered, with the lateritic weathering zone (regolith) extending down to ca. 20 m. The main phosphate ore is situated in the regolith and the main ore mineral is apatite. The deposit can be divided in four different ore types, which are lateritic phosphate ore, silicate-apatite-ore, niobium ore and weathered bedrock ore. Niobium ore contains high levels of naturally occurring radioactive materials (NORMs) mainly within the pyrochlore mineral. [Sokli EIA. 2009]

At the moment Yara Suomi Oy is planning to process the phosphate ore (apatite) and the iron minerals. In the future, the production of vermiculite and manganese as by-products may be possible. The company does not plan the production of uranium or thorium as by-products. The estimated annual ore production will be around 7 million tonnes. The selected concentration process in Sokli will be flotation fractionation and iron will be separated by using magnetic separation. The annual production is evaluated to be 1.54 million tonnes of phosphate concentrate and 0.3 million tonnes of iron concentrate. [TUKES Sokli, 2013]

STUK has commenced a radiological baseline study of the Sokli region. The study indicates that the radioactive concentration levels at the deposit correspond to those of Lapland and rest of Finland, apart from niobium ore. The average radiation rates in niobium ore are 1000 Bq/kg for ^{238}U and 4000 Bq/kg for ^{232}Th (the maximum rates were up to 2500 Bq/kg for ^{238}U and 10 300 Bq/kg for ^{232}Th). The corresponding values for the phosphate ore are 310 Bq/kg for ^{238}U and 533 Bq/kg for ^{232}Th . The average activity concentration for the bedrock in Finland varies between 10-70 Bq/kg. The exploration activities have not induced any substantial change in the radiological baseline, when compared with the survey results from 1980s. By global comparison, the average concentration of uranium is fairly low whereas the thorium concentration is higher than the average. [Solatie et al., 2010]

Palmottu (uranium deposit)

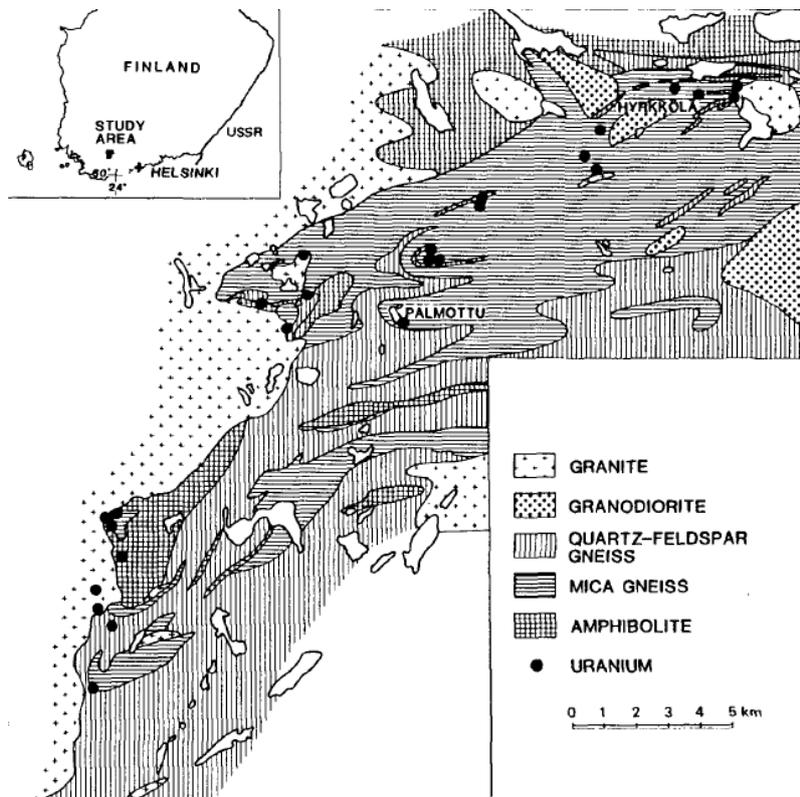


Figure 14. Geological map of the Palmottu area. [Räisänen E. 1989]

The small uranium and thorium deposit of Palmottu is located in the municipality of Nummi-Pusula, in south-western Finland. GTK discovered anomalies in the airborne geophysical data collected in the late 1970s. The investigations were continued with ground follow-up, geophysical ground radiometric measurements and drilling, which lead to the discovery of the deposit. The Palmottu uranium deposit is situated at the south-eastern corner of the lake Iso-Palmottu, in the boggy area at the lakeside. The deposit was claimed by GTK in 1980-1988 and 1993-2001 and subsequently by AREVA in 2005-2006. [Blomqvist R., 1987; Palmottu – Uranium database]

The Palmottu deposit is located in the Uusimaa schist belt, approximately 4 kilometres away from a microline granite massif. The bedrock in the western part of the area consists of Svecofennian schists and in the eastern part of microline granite. The geological in situ ore estimate is 1.018 Mt of ore with 0.01 % of uranium (1083 tons). Uranium is found in two lodes, which consist of coarse-grained feldspar-quartz-biotite pergamite and sheared granitic dyke rich in quartz and biotite. The primary uranium mineral found in both lodes is uraninite. Elevated concentrations of molybdenite occur sporadically within the uranium mineralisation. The U/Th ratio is typically 2:1, but Th concentrations are higher on the granite dykes located on the eastern and western side of the deposit. Overall the uranium ore body is discontinuous with a length of 400 metres and thickness varying from 1 to 15 metres. The deposit is not economically interesting, but due to the large number of drill holes it is an ideal place to study

the transport of uranium and thorium in the rock matrix and the groundwater. [Blomqvist R., 1987; Palmottu – Uranium database; Räisänen E., 1991]

The Palmottu deposit has been a research target in international and national projects. GTK performed intensive field investigations in 1981-1984. After this the site became a research target for nuclear waste management, focusing on the possibilities of disposing nuclear fuel deep in the bedrock. Similar studies have been made in Australia, Brazil and Canada, amongst others, but the results are not compatible with Finland, due to the different bedrock composition. [Blomqvist R., 1987; Palmottu – Uranium database; Räisänen E., 1989, 1991]

In the vicinity of the Palmottu deposit there are several other small uranium occurrences. These are called Hyrkkölä, Kopila and Kovala. The Hyrkkölä occurrence is located 10 km northeast from Palmottu. It was discovered in 1980 by car-borne radiometric measurements made by GTK. The measured uranium concentrations in the boulders varied between 0.05-0.2 %. The Hyrkkölä deposit is also too small to be economic. The Kovala occurrence is a monazite-bearing granite intrusion situated within the supracrustal rocks of the Uusimaa belt ca. 10 km SE of Palmottu. GTK has studied the Kovala occurrence in 2010-2014 as a potential REE target, however, the amount of ore is too small to be economic and the presence of NORM in the ore is quite high (up to 1.29 wt% Th). [Räisänen E., 1989; Grönholm et al., 2014]

In 2014, Oy Fennoscandian Investment Group Ab submitted a reservation for an area called Suomensjärvi 1, which contains the Palmottu, Kovala and Hyrkkölä occurrences. The company is exploring for Au, Zn, Fe, Cu, Ag, Pb and W. The reservation is valid until March 2016. The reservation area is presented in figure 15. [TUKES: Varauspätös, Suomensjärvi 1]

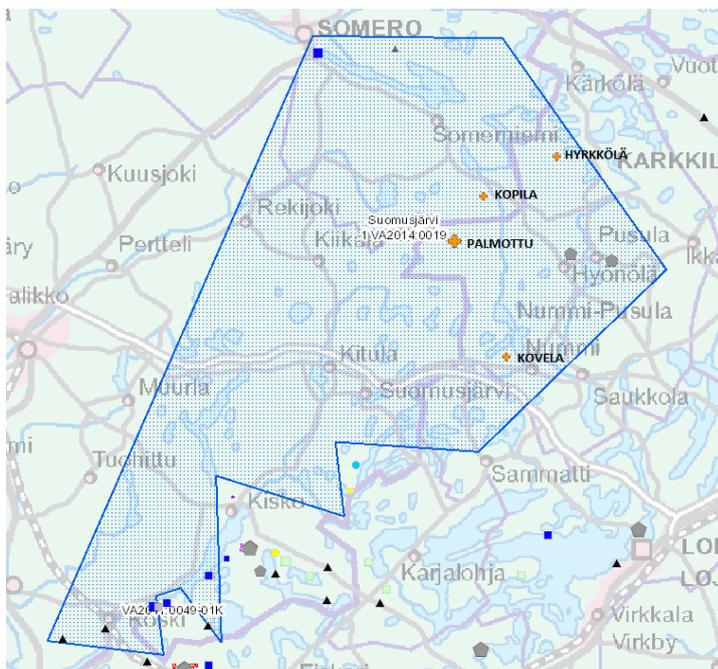


Figure 15. Reservation area Suomensjärvi 1. [Mineral deposits and exploration]

Kesänkitunturi (uranium)

Kesänkitunturi (Kesänki fell) is located in the municipality of Kolari, in northwestern Finland. In 1965, Outokumpu Oy discovered radioactive boulders at the southern side of the fell and concluded several studies in order to evaluate the mineral resources in the area. In 1970s Outokumpu Oy applied for a mining concession at the Kesänki fell area. The bedrock mainly consists of sericite quartzite where the main ore minerals are pyrite and chalcopyrite. Increased uranium concentrations are found in two zones, UI and UII, which are lying 200 metres apart along the quartzite layering. Copper anomalies with concentrations of 0.2-0.5 wt% were also found, and a positive correlation between U and Co can be seen. A non-compliant resource estimation for the Kesänkitunturi occurrence is 1.45 Mt grading 0.065% U (950 t). The main uranium mineral is uraninite. Secondary uranium minerals are rare, torbernite (hydrated U-Cu-phosphate) is found in some samples. [Anttonen R., 1992; Korkalo T., 2006; Mineral deposit and exploration; Sarikkola R., 1970, 1973]

The Kesänki fell is part of the Pallas-Yllästunturi national park, which complicates the exploration work due to the permits needed. At the moment there are no reservation applications for the area. [Pallas-Yllästunturin kansallispuiston hoito- ja käyttösuunnitelma; Söderholm K., 2006]

Aakenusvaara (gold, copper and uranium showings)

Aakenusvaara is located in the municipality of Kittilä, only 3 kilometres east of the Saattopora gold deposit. In the early 1970s, Outokumpu Oy discovered boulders with high uranium concentrations during a till geochemical survey. GTK continued the investigations in the late 1970s and concluded that the boulders came from the western margin of the Aakenusvaara hill, where an N-S-trending uranium rich zone was found. The Aakenusvaara occurrence comprises weak gold, copper and uranium showings. Uranium is found in biotite schist sections. [Anttonen R., 1992; Korkalo T., 2006; Pääkkönen K., 1989]

GTK submitted a reservation application for the Aakenusvaara occurrence in 1981, but renounced it as the uranium showings turned out to be uneconomic. Dragon Mining Oy became the holder in 2009, but no investigations were conducted as the main target of the company was in the Saattopora deposit. The claim expired on 13.7.2014. The area remains open for acquisition. [Aakenusvaara – Gold database; Pääkkönen K., 1989; TUKES: Kaivosrekisterin karttapalvelu]

Ylä-Paukkajanjärvi deposits

The uranium occurrences of Ylä-Paukkajanjärvi comprise the Paukkajanjärvi, Ruunaniemi and Sikovaara ore bodies. They are found within an area of 0.5 km by 1 km. The Ylä-Paukkajanjärvi area is located on the S-side of the Paukkajanvaara deposit. The ore bodies are enriched in uranium, vanadium and iron. The bedrock in the area consists of orthoquartzite. The main uranium minerals found are pitchblende, uranophane and coffinite. In the IAEA

classification the Ylä-Paukkajanjärvi occurrences are classified as sandstone-type deposits. They are small and low grade and thus uneconomic. Agricola Resources Plc and Namura Finland Oy submitted reservation and claim applications for the Ylä-Paukkajanjärvi area in the 2000s, but currently the area is open for acquisition. [Paukkajanjärvi – Uranium database; Ruunaniemi - Uranium database; Sikovaara - Uranium database]

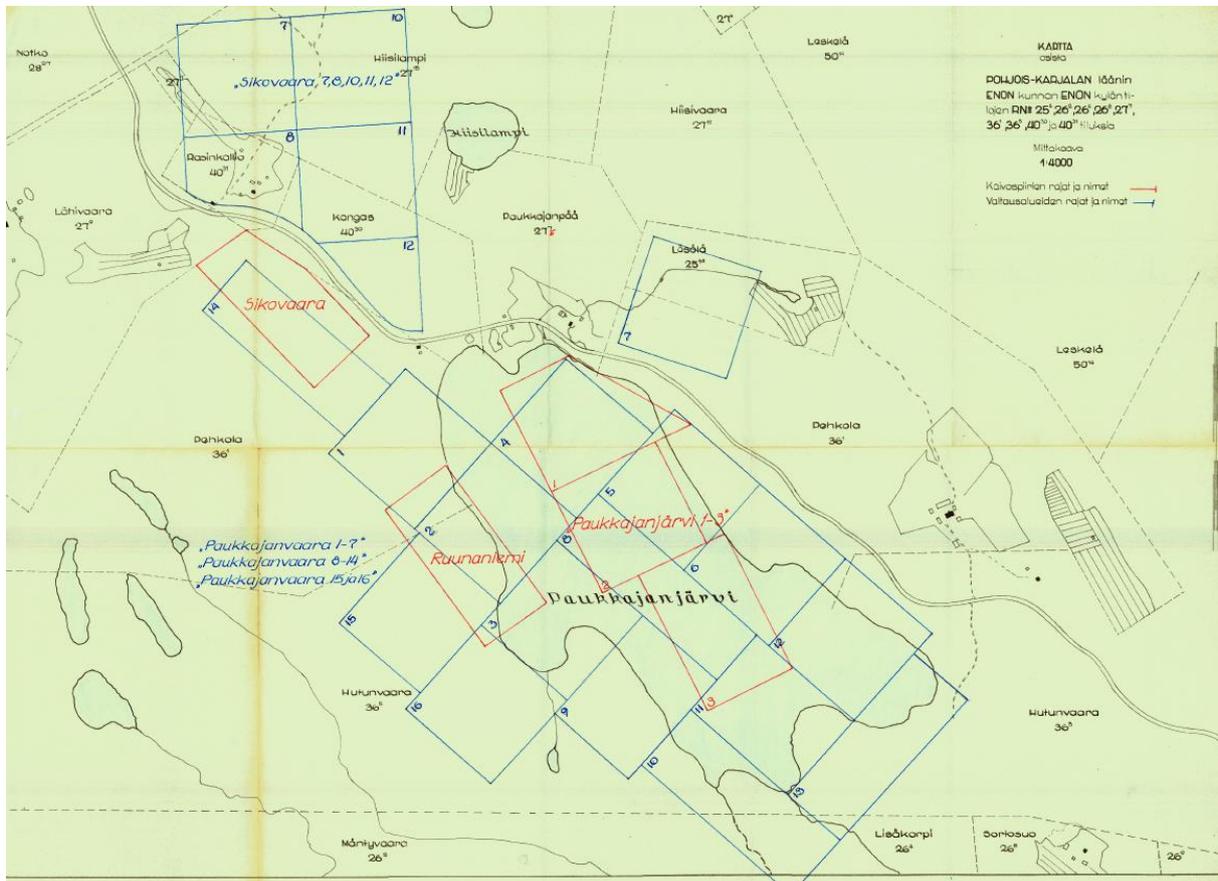


Figure 16. Map of the Ylä-Paukkajanjärvi deposits. [Valtausraportti, Outokumpu Oy]

Herajärvi occurrences

The Herajärvi area comprises three uranium occurrences, Hermanni, Martinmonttu and Myllykorpi. In 1958, Atomienergia Oy discovered boulders with high uranium concentration between Lakes Herajärvi and Pielinen. These boulders lead to the discovery of several uraniumiferous lodes, of which Hermanni, Martinmonttu and Myllykorpi are the largest. All three have been drilled and the first two were targets of small test pit operations. The ore mined was transported to the Paukkajanjärvi uranium mine. The locations of the three main occurrences are presented in Figure 16. Currently the Herajärvi occurrences are located in the Koli National Park. Sampling is allowed with a special permit and for educational or scientific purposes only. [Hermanni – Uranium database; Martinmonttu - Uranium database; Myllykorpi - Uranium database; Äikäs O., 1987]

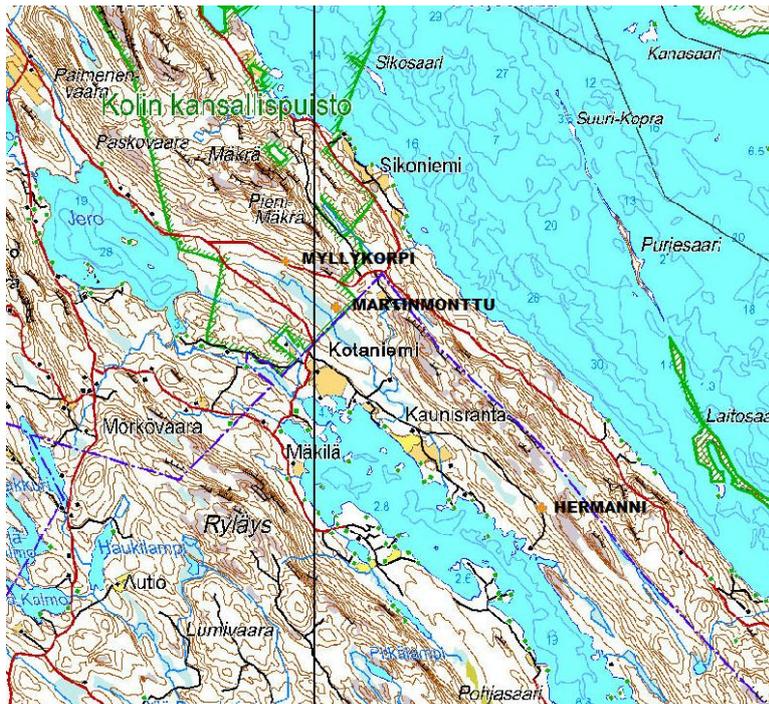


Figure 17. The locations of the Herajärvi occurrences. [Mineral deposits and exploration]

Hermanni, also known as Hermanninmonttu, and Martinmonttu occurrences were discovered in 1958 through ground radiometric and soil radon surveys performed by Atomienergia Oy. A non-compliant resource estimation for the Hermanninmonttu occurrence is 20 000 tons of ore grading 0.08 % U. The corresponding figures for the Martinmonttu occurrence are 20 000 tons of ore grading 0.10 % U. [Hermanni – Uranium database; Martinmonttu – Uranium database]

The exploration activities carried out by Atomienergia Oy in 1958-61 included boulder hunting, geological mapping and radon surveys. In the winter 1960, Atomienergia Oy concluded a pilot pit at the Hermanni and Martinmonttu sites. Outokumpu Oy claimed the occurrences in 1960 and continued the diamond and percussion drillings until 1970. GTK continued the studies in 1983-84 by taking 40 samples across the occurrence for an IAEA-based study focusing on the uranium deposits in Proterozoic quartz-pebble conglomerates. [Hermanni – Uranium database]

The bedrock of the Herajärvi area consists of orthoquartzite. The main ore minerals are pitchblende, goethite and hematite. Pitchblende has altered to secondary uranium minerals. Sulphides such as pyrite, pyrrhotite and chalcopyrite are found as accessory minerals. In high-grade samples collected by GTK the metal contents were in the range of 0.90-2.21 % U, 0.80-1.55 % Fe and 0.018-0.06 % V. Thorium concentrations were low. In the samples from Martinmonttu the metal content has been as high as 0.61 % U and 32.92 % Fe. The Hermanninmonttu occurrence is a tabular mass 100 metres long and 2 metres wide. [Hermanni – Uranium database; Mineral deposits and exploration]

The Hermanni occurrence has been intensively studied as the ore composition has similarities to the Paukkajanvaara uranium deposit. The pilot mine site has not been rehabilitated and slightly increased gamma radiation levels are found around the uncovered test pits and on outcrops of the uraniferous lenses. The area remains open for acquisition, but the occurrence is situated in the Koli National Park and may be sampled only for scientific or educational uses. [Hermanni – Uranium database]

Pesävaara

The Pesävaara deposit, also known as Mutkajuoni, is a small uranium occurrence located approximately 10 kilometres away from the Hermanni deposit and 40 metres away from the Taka-Aarnio nature reserve. [Pesävaara – Uranium database]

Atomienergia Oy discovered the occurrence in 1958 through ground radiometric surveys and claimed the area from Pesävaara to Rekilampi. They continued investigating the mineralization by diamond drilling, geological mapping, and radon surveys until 1960. A shallow trench was excavated for mining test purposes. The site has not been rehabilitated and traces of the previous operations can still be seen. The documentation made by Atomienergia Oy is no longer available. [Pesävaara – Uranium database]

Agricola Resources Plc reserved the area in 2003 - 06, but did not apply for claims. Namura Finland Oy had a claim application pending in 2007, but due to the economic recession they pulled out of Finland before receiving the reply. The area is open for acquisition. [Pesävaara – Uranium database]

4 Current regulations

4.1 Finnish Regulations

4.1.1 General

In Finland, provisions concerning exposure to natural radiation are laid down in the Radiation Act (592/1991) and the Radiation Decree (1512/1991). Other requirements are presented in Guide ST 12.1 Radiation safety in practices causing exposure to natural radiation. However, if the purpose is to produce uranium or thorium, the Nuclear Energy Act (990/1987) is applied to the practice.

According to the Radiation Act (section 45) the responsible party must investigate the radiation exposure caused by natural radiation if it is discovered or there is reason to suspect that practices or circumstances are such that the exposure of human beings to natural radiation causes or may cause a health hazard. If necessary, the exposure shall be limited.

STUK must be notified of the commencement of mining operations before the practice is commenced. The notification must also be made of extensive utilisation of natural resources that contain uranium or thorium in excess of 0.1 kg per ton.

The responsibility has to ensure that radioactive waste poses no hazard to human health or to the environment (the Radiation Act, section 50).

4.1.2 Action levels

The action level for the radon concentration in inhaled air is 400 Bq/m³ in workplaces where people work on a permanent basis (the Radiation Decree, section 27). Radon concentration refers to the annual mean of the radon concentration during working time. If the working hours are less than 600 hours per year the action levels are higher (see the Table below).

Table 1. Action levels for the radon concentration in inhaled air for different working times.

Annual working time	Action level for radon concentration in inhaled air (Bq/m ³)
Work performed on a permanent basis (more than 600 hours per year)	400
Max. 600 hours	1000
Max. 300 hours	2 000
Max. 100 hours	6 000

The action level for the radiation exposure of workers caused by sources of natural radiation other than radon is 1 mSv per year (the Radiation Decree, section 27). When assessing the dose, both the dose caused by external radiation and the dose from naturally occurring radionuclides entering the body through the mouth and along with inhaled air are taken into account. Before the dose received in this way can be compared with the action level, the proportion of natural background radiation and the dose caused by radon and its short-lived decay products is deducted from the total dose.

Functions of STUK

On the basis of notifications, investigations and plans presented, STUK sets requirements for the radiation safety of the practice. If the action levels are exceeded, STUK gives orders on limiting radiation exposure. The impact of the measures taken to reduce exposure must always be ascertained by appropriate measurements, unless the impact can be verified by other means.

For the purpose of regulatory control, STUK is authorized to inspect practices giving rise to natural radiation exposure, to conduct the necessary measurements, and to obtain the notifications, data and documents needed for the control.

STUK carries out periodic radon inspections in underground mines, in principle, every second year. When necessary, the inspection interval may be shorter.

Monitoring of the radiation exposure and medical surveillance

The monitoring of the radiation exposure of workers must be arranged if, even after actions taken to limit their exposure, the action level is exceeded. The monitoring of exposure may be ordered, for example, in the case that the radon concentration in the first measurement was exceptionally high.

Radiation exposure is generally determined on the basis of working hours and the results from measurements conducted in work sites or in their vicinities. According to the circumstances, the measured object may be e.g. the radon concentration in inhaled air, the dose rate of external radiation, or the activity concentration in inhaled air caused by radioactive substances in dust. The measurements shall be made in working conditions that are normal with respect to exposure conditions.

Before the practice or the monitoring of radiation exposure is begun, the exposure from natural background radiation shall be investigated in the workplace in order to make it possible to correctly assess the exposure due to the practice.

All operations must be arranged so that dose limits are not exceeded. If necessary, the exposure must be limited through limiting working hours.

If the radiation exposure caused by sources of natural radiation other than radon might exceed 6 mSv per year, a personal dosimeter must be used. Furthermore, in such a case, the responsible party must arrange medical surveillance for the workers. If the operation causes exposure to radon only, medical surveillance is not needed.

Public exposure

The responsible party must investigate the radiation exposure of persons other than workers if there is reasonable cause to suspect that the dose will exceed 0.1 mSv per year. In such a case, however, the dose from radon is not taken into account. The investigation must cover an individual representing the population group whose exposure is estimated to be the highest.

If it is probable, that the exposure of the public will be higher than 0.1 mSv per year, the responsible party must

- submit to STUK a plan describing the measures by which radiation exposure is to be kept as low as is reasonably achievable
- organise a radiological baseline study
- arrange environmental radiation monitoring after the operation has commenced.

Radiological Baseline Study and Environmental Radiation Monitoring

Radiological baseline studies in the environment chart the baseline before the commencement of practices so that the effects of the practice on the environment and the respective exposures can be assessed after operations have started. The extent of the baseline study and the required sampling and measurements shall be estimated with regard to the nature of the practice and the operational environment. Generally, it is necessary to determine the uranium and thorium concentrations in the samples as well as the concentrations of their decay products. It may be necessary to conduct measurements at different times of the year or in different years, because there may be natural variation in the concentrations.

For example, the baseline study may include radiation measurements and the determination of radioactive substances in the following objects:

- external radiation
- radon in the outdoor air
- radioactive substances in the particle form in the outdoor air
- soil
- household water
- groundwater
- aquatic environment (water, sediment, water plants, benthos, fish)
- gathered products/game (berries, mushrooms, venison etc.)
- foodstuffs and pasture plants (grain, gardening products, grass, milk, meat etc.)

The purpose of environmental radiation monitoring after the commencement of a practice is to ensure that the radiation dose to the public is kept as low as is reasonably achievable and that the practice poses no hazard to the environment. Environmental radiation monitoring takes place with the same measurements as the baseline study. When possible, sampling should take place in the same places as in the baseline study.

Environmental radiation monitoring must be regular and well-defined. The extent of radiation monitoring and the frequency of sampling may be revised, if necessary, once the practice has been in operation for a longer time.

Waste and Releases Caused by the Practice

The responsible party must ensure that radioactive waste and releases due to practices utilising natural sources pose no hazard to health or to the environment (the Radiation Decree, section 50). Discharges of radioactive substances to the environment shall be restrained effectively irrespective of the magnitude of the exposure.

If a waste area containing naturally occurring radioactive substances or a comparable area in which a practice has already ceased, causes or is suspected of causing long-term radiation exposure to the public, then the responsible party must, when appropriate and according to the radiation hazard, do the following:

- delineate the area
- limit the use of the area and the buildings in the area
- restore the area and prevent the spread of radioactive substances into the environment
- investigate the radiation exposure of the public and act in accordance with the results of the investigation in order to reduce the radiation exposure.

References

The Radiation Act (592/1991), especially Chapter 12

The Radiation Decree (1512/1991), especially Chapter 7

Guide ST 12.1 Radiation safety in practices causing exposure to natural radiation

Uranium mining in Finland from a regulatory perspective

General

Uranium and thorium mining in Finland is currently regulated under the Nuclear Energy Act 990/1987 (NEA) and Nuclear Energy Decree 161/1988 (NED). A new decree and related STUK's regulatory guide for uranium and thorium mining are currently under preparation.

In Finland mines are divided into regular mines regulated under Mining Act, and U or Th mines regulated both under Mining Act and Nuclear Energy Act. Permits under

Environmental Protection Act are also required. To be considered an uranium or thorium mine requiring a licence from the Government, the annual production of U or Th has to be greater than 10 000 kg and for which a licence according to NEA is needed. If the annual production is less than 10 000 kg, a licence for operations is given by STUK. If the U and Th contents of the products are above 0.5 kg per metric tonne regardless of the annual production, the mine needs a licence under NEA. Uranium deposits in Finland are not of high quality, and mining only uranium is not economically viable. The most probable form of U mining in Finland is by-production of U in a regular mine.

Licensing

An application for a licence to carry out mining or milling operations with the purpose of producing uranium or thorium is submitted to the Government. The licence given under Nuclear Energy Act is processed jointly with the licence to be given under the Mining Act 621/2011 (NEA Section 23 & Mining Act Section 44). The details of the licensing procedure for U or Th mining and milling activities is given in NED Chapter 9.

The applicant has to describe in their mining licence application to the Government e.g.

- the radiation protection arrangements and the technical features and other arrangements which are used to ensure the safety of the mine and the enrichment plant,
- a description of the effects of the mine or the enrichment plant on the environment and a description of the design criteria that will be observed by the applicant to avoid environmental damage and to restrict the burden on the environment,
- a description of the applicant's financial prerequisites and the economic viability of the project,
- a description of the quality and quantity of the ores, nuclear materials and nuclear waste that will be produced, handled and stored,
- a description of the arrangements required for the transportation of ore, nuclear materials and nuclear waste needed for the operations, and
- a description of the applicant's plans and available methods for arranging nuclear waste management, including the decommissioning or demolition of the mine or the milling plant and the disposal of nuclear waste, and a description of the timetable and costs of nuclear waste management, and the arrangement of the provision referred to in chapter 7 of the Nuclear Energy Act.

The applicant needs to provide STUK with several documents simultaneously with its mining licence application. These documents include e.g.

- a safety analysis report, which shall include the general design and safety principles of the mine, a detailed description of the mine, a detailed description of radiation protection arrangements, waste management and environmental impacts,

- a radiological monitoring programme for the environment,
- plans for the arrangements for security and emergencies, and
- a plan for arranging the nuclear safeguards control that is necessary to prevent the proliferation of nuclear weapons.

The licence is granted for a fixed term. When the length of the term is considered, particular attention is paid to ensuring safety and to the estimated duration of operations. The licence may include a provision that the licence will expire if operations are not started within a certain period from the granting of the licence. Licences can also be cancelled if implementation of the general principles for the use of nuclear energy as laid down in NEA is essentially endangered.

The required prerequisites for an operating licence for a Uranium or Thorium mine are (NEA Section 21) that

- the use of nuclear energy meets the safety requirements laid down in NEA, and appropriate account has been taken of the safety of workers and the population, and environmental protection,
- nuclear waste management has been arranged appropriately and provision for the cost of nuclear waste management has been made in accordance with the provisions of chapter 7 of NEA,
- the applicant's arrangements for the implementation of control by the Radiation and Nuclear Safety Authority (STUK) as referred to in NEA are sufficient; and
- the applicant has sufficient expertise available and the operating organisation and competence of the operating staff are appropriate.

In addition, the following aspects need to be catered to:

- the site of the mining or milling activity shall be appropriate with respect to the safety of the operations intended, and the activity shall be in line with the overall good of society.
- In addition a responsible manager shall have been appointed by the licensee and approved for the role by STUK. It is the responsible manager's task to ensure that the provisions, licence conditions and regulations issued by the Radiation and Nuclear Safety Authority (STUK) concerning the safe use of nuclear energy, the arrangements for security and emergencies, and the control of nuclear materials are complied with.

Operation and regulatory oversight

Currently there are no U or Th mines in Finland. Mines licenced as U or Th mines are under STUK's oversight. Being the regulatory authority, STUK is responsible for the supervision of safe use of nuclear energy. STUK participates in processing licences pursuant to NEA and supervises the observance of licence conditions. STUK can set detailed requirements based on

a mandate given in NEA. STUK is prepared to give detailed guidance for U and Th mining if such mines are licenced in the future by the government.

A mining and milling operation shall not be initiated on the basis of a granted licence until STUK has ascertained that the activities are in accordance with the safety requirements set by the law and regulations.

The mining operations and the mine have to be planned to that release of radioactive substances in all forms (liquid, gaseous, solid, dust) to the environment is minimized. The waste generated in the mining operations has to be disposed of in a way that releases of radioactive substances are at an acceptably low level. Radiological monitoring of both workers and the environment is required in addition to all monitoring requirements set under Mining Act and Environmental Protection Act.

Closing a mine

The actions to be performed after a mine is closed are described in the Mining Act. No later than within two years of the termination of mining activity, the mining operator shall restore the mining area and the auxiliary area to the mine to a condition complying with public safety; ensure their restoration, cleaning, and landscaping; and perform the measures specified in the mining permit. The regulators inspect the site after the mining area has been restored.

4.2 Norwegian regulations

4.2.1. General

Norwegian legislation for radiation protection has been revised and new legislation put in force from 1st of January 2011. The public consultations with industry, ministries, competent authorities and NGOs have preceded and feedback has been implemented in the final regulation.

The main change was the implementation of radioactive waste and pollution in the Pollution Control Act. With new regulations, a holistic approach to the protection of human health and environment has been created regarding regulatory practice in Norway. All radioactive waste in Norway is now regulated alongside hazardous waste in an integrated, ecosystem based approach; for instance radioactive waste has since then been declared in joint declaration scheme with hazardous waste. A tiered, prescriptive approach has been adopted for regulation of radioactive waste in Norway. A set of radionuclides activity levels is defined in the regulation for when material is considered radioactive waste and requires a permit (e.g., 1 Bq/g of Ra-226 in case of NORM waste), and for when radioactive waste is subject to obligatory final disposal (e.g., 10 Bq/g of Ra-226 in case of NORM waste). All the activities that lead or may lead to radioactive pollution or produce radioactive waste must have a permit issued by NRPA. Handling of radioactive material must be proper and practices that generate waste have a duty to deliver radioactive waste to authorised companies at least once per year.

The radioactive waste must be declared in defined way. The same declaration form is used for radioactive and hazardous wastes. This form includes the European waste list for hazardous waste and a Norwegian waste category number that makes it possible to specify whether waste is hazardous and radioactive, only radioactive or only hazardous. This simplifies the process for operators and gives a better overview to competent authorities. An online reporting system (E-declaration system) is implemented in spring 2015. Furthermore, quantities, activities of waste handled and the management options chosen must be reported annually to the NRPA.

The Act on Radiation Protection and Use of Radiation constitutes the legal basis for regulating the use of ionizing and non-ionizing radiation and radiation protection requirements, both in the medical/ non-medical fields and contingency planning. The Act applies to any manufacture, import, export, transport, transfer, possession, installation, use, handling and waste management of radiation sources. The Act also applies to human activity giving increased levels of naturally ionising radiation from the environment. Radiation protection regulations establish requirements on authorizations, notifications, internal control, competence, safety equipment, emergency preparedness etc. for users of radiation sources.

Furthermore, certain recommendations and agreements of the international conventions (OSPAR, London, IAEA Joint convention) are implemented in regulations. In addition, the Norwegian Radiation Protection Authority (NRPA) has developed guidance documents for the different areas of radioactive waste management and application of radioactive sources.

4.2.2. Legislative aspects of mining activities in Norway

Environmental concerns of mining are addressed under the Mining Act, Pollution Control Act and Planning and Building Act.

Permits for investigations and mining must be given by the Directory of Mining after the Mining Act.

The Pollution Control Act (from 1981; with amendments concerning radioactive waste and radioactive pollution from 2011) requires pollution permits for mining and contains rules concerning waste. The Government Regulation on Waste (Waste Regulation) under the Act contains a separate chapter on mining waste.

Mining and refining REE will most likely cause discharges to air and water, which requires a permit after the Pollution Control Act, given by the NRPA. The advantages and disadvantages of giving the permit to must be assessed. Permits given after the Pollution Control Act include terms and conditions. One such condition may be that the discharge water must be filtered or otherwise purified prior to discharge. Environmental monitoring programs must be considered and terms concerning radiation protection of the environment must be approved by NRPA. Requirements for workers at mining sites related to radiation protection are given as general requirements (optimization, justification and dose limits as basic principles) for occupational

exposure in the Act of Radiation Protection and Use of Radiation and Radiation Protection regulations.

Mining and extraction of different NORM rich minerals usually cause a large amount of tailings which will most likely be regarded as radioactive waste which must be deposited. Radioactive waste which must be deposited are today placed in mountain halls at facilities with permits of accepting radioactive waste which must be deposited. Establishing a waste depository or tailings dam requires a risk assessment after the Planning and Building Act.

4.3 Danish Regulations

NORM-related legislation in Denmark and Greenland

Greenland and the Faroe Islands are part of the Kingdom of Denmark. As a main principle, the Danish Constitution stipulates that the foreign and security interests for all parts of the Kingdom of Denmark are the responsibility of the Danish government.

Denmark is part of the European Union and has adopted EU Directives on ionising radiation and radioactive substances into Danish legislation. Since there is no mining industry in Denmark, there is no mining-specific legislation relating to NORM.

Greenland, however, is not part of the EU, and has no legislation related to ionising radiation and radioactive substances. Danish legislation on these matters does not apply in Greenland.

4.4 Swedish Regulations

In order to undertake exploration and exploitation/mining of mineral deposits in Sweden several legal requirements needs to be considered. However, geological mapping/search of minerals is normally allowed without permits using the legal right of access to private land. The Mining Inspectorate of Sweden (Bergsstaten), headed by the Chief Mining Inspector, is the official body in Sweden responsible for issuing permits for prospecting (exploration permits) and mining (exploitation concessions), following the Minerals Act (SFS 1991:45) and the Mineral Ordinance (SFS 1992:285). The Mining Inspectorate is also the legal body for carrying out inspections of mines. The Environmental Code (1998:808) lays down the general environmental framework, and environmental assessments are made by the county administrative board and by the Land and Environmental Court. The Environmental Code is applicable in matters concerning the granting of a concession. Therefore an Environmental Impact Assessment must be appended to an application for a concession. A permit for exploitation must always be granted under both the Minerals Act and the Environmental Code. Other relevant legislation is the Planning and Building Act (2010:900) that contains provisions regulating building and construction, for which the local municipality is responsible for permissions. Also the government may be involved in decisions in matters of public interest.

The radiation protection regulations regarding NORM was revised in 2011 and put into force in 2012 (SSMFS 2011:4). The background to this revision was, in brief; at the time of EU membership the Swedish Radiation Protection Act (RPA) (1988:220) was harmonized with the EU BSS directive 96/29/Euratom regarding general radiation protection requirements. The Act did not specifically include NORM but revisions of the Act in year 2000 led to requirements for authorizations/permits for a large number of businesses handling NORM-material, including mining operations. The main purpose with the new regulations (SSMFS 2011:4) is to fully or partly exempt NORM from the requirements in the RPA and the Act on Nuclear Activities (ANA) (1984:3). In this context NORM is defined as material in natural conditions or material being processed or enriched for purposes other than extraction of radionuclides. In order to make exemption from the RPA the NORM handled must not exceed 1 kBq/kg of each nuclide of the uranium and thorium series radionuclides, and 10 kBq/kg for ⁴⁰K. Further, no license is required e.g. for handling, processing of NORM (uranium and thorium series radionuclides) of concentrations less than 10 kBq/kg of each radionuclide. It also includes the possibility to deposit NORM waste without consideration of radioactivity properties. However, the authority (SSM) have made room for invoking both RPA and ANA if needed, i.e. override the regulation SSMFS 2011:4.

Uranium mining

Mining of uranium minerals are included in the list of minerals for which exploration permits and mining concessions are regulated and may be granted under the Minerals Act (SFS 1991:45) and the Mineral Ordinance (SFS 1992:285) as well as environmental issues by the Environmental Code (1998:808) (see above). Mining of uranium is a nuclear activity and therefore regulated by Act on Nuclear Activities (ANA) (1984:3) and the Ordinance of Nuclear Activities (ONA) (1984:14). In the process from prospection, exploration to mining the following radiation protection regulations needs to be considered:

Prospection work:

Undertaking prospection work, e.g. drilling tests, sample analysis, is exempted from regulations in the Act on Nuclear Activities (1984:3). However, a permit is required from the SSM, an assessment particularly addressing waste issues, including provisions for transport of radioactive material according to ADR transport regulations. As uranium series radionuclide concentration are expected to exceed the exemption levels of 1 kBq/kg (uranium in secular equilibrium with daughter radionuclides) (Radiation Protection Ordinance (RPO), 1998:293), prospection work normally fall under the RPA.

Exploration work:

Uranium exploration in the context of mining tests/trials is defined as nuclear activities (see <http://www.stralsakerhetsmyndigheten.se/start/Karnkraft/Sa-fungerar-ett-karnkraftverk/Karnbransle/Uranbrytning-sker-i-tre-steg/>) and therefore regulated by the Act on Nuclear Activity (ANA) (1984:3), and it also falls under the Swedish Radiation Protection Act (RPA) (1988:220). A license from the SSM or the government is required, which licensing body depends on the quantities of uranium to be handled. SSM will also make an

assessment whether an Environmental Impact Assessment is required. The SSM is the responsible authority for the supervision under the ANA and RPA.

Mining:

Mining of uranium at commercial scale is defined as nuclear activities and fall under the same regulations as for exploration work (see above). Application for uranium mining will be investigated by SSM, including issues of special conditions attached to a permit. The final assessments and permits are made by the Swedish government. As for NORM-businesses Environmental Impact Assessment must be appended the concession application, which needs approval of both the Land and Environmental Court and the Government. Finally approval from the Municipal Council is needed, having the possibility to use their Municipal Veto for uranium mining. Their decision also involve provisions regulating building and construction (Planning and Building Act (2010:900)), which is particularly important regarding handling of waste products of the mining activities.

5. Intercomparison

Introduction

In the NKS-NORMIN project meeting in 12th March 2014 it was decided that in addition to the environmental samples of the case studies, suitable NORM-samples would be analysed as an intercomparison exercise using gamma-spectrometry. Antti Kallio (STUK) prepared the instructions for the intercomparison (Appendix I), and collected the results. Rajdeep Sidhu (IFE) sent the samples to the participants.

Samples

The samples chosen for the gamma intercomparison were two IAEA reference materials, IAEA-RGU-1 and IAEA-RGTh-1. These samples have been prepared for the IAEA from uranium ore BL-5 and thorium ore OKA-2, respectively, by diluting with silica powder. Both ores BL-5 and OKA-2 have been estimated to be in radioactive equilibrium for the uranium and thorium series. IAEA-RGU-1 contains 400 mg/kg uranium and IAEA-RGTh-1 contains 800 mg/kg thorium. (IAEA, 2014)

Results

Three laboratories returned results for the gamma-intercomparison. The main results are shown in Table 1. Detailed results from participants are listed in Appendices II-IV. The

results from LAB 1 and LAB 3 are within uncertainty of the IAEA reference values, as is the ^{235}U in uranium ore from LAB 2. The results of ^{238}U in uranium ore and ^{232}Th in thorium ore from LAB 2 are 15-20% lower than the IAEA reference values. The largest discrepancies from IAEA reference values are the LAB 2 results for ^{238}U and ^{235}U from thorium ore, which are deviant by a factor of ten.

Table 2. Results of the NKS-NORMIN gamma-spectrometry intercomparison, shown at the 95% confidence level. IAEA reference values from IAEA, 2014.

Nuclide	Sample IAEA-RGU-1 (Bq/kg)				Sample IAEA-RGTh-1 (Bq/kg)			
	LAB 1	LAB 2	LAB 3	IAEA ref.	LAB 1	LAB 2	LAB 3	IAEA ref.
^{235}U	245±25	228±21		226-230	<6	39±11		3,3-3,9
^{238}U	4681±470	4210±200	5374±650	4910-4970	*	840±235		72-84
^{226}Ra	4606±460	4600±510	4876±280		73±9	75±16		
^{210}Pb	4067±410	4000±310	3825±540		61±10	80±35		
^{228}Ra	<5	<25			2914±350	2460±150		
^{228}Th	4±1,4	<4			2848±340	2750±150	3189±145	
^{232}Th	<5	<4			2869±290	2600±400	3318±180	3160-3340

* unable to determine ^{238}U from $^{234\text{m}}\text{Pa}$, the result for ^{226}Ra can be used if radioactive equilibrium is certain. Alternatively MDA of ^{235}U can be used to obtain $^{238}\text{U} < 130$ Bq/kg, assuming normal isotopic abundances.

Discussion

The results for uranium and radium isotopes from uranium ore and thorium from thorium ore were acceptable for the most part (better than 20% accuracy overall). The results for uranium isotopes from thorium ore are more variable. It is important to remember that the matrix composition can affect the reliability of certain gamma energy peaks. The $^{234\text{m}}\text{Pa}$ 1001 keV peak is usually considered a relatively interference-free energy in the uranium series. However, when the Th-content is high relative to uranium, for example the otherwise minor peak of ^{228}Ac at 1001 keV becomes large enough to give erroneous results for $^{234\text{m}}\text{Pa}$ (and therefore ^{238}U). The error in ^{238}U is then propagated to ^{235}U if it is calculated from ^{238}U using the natural isotopic abundances. This is probably at least a part of the reason for the too large uranium results from thorium ore from LAB 2.

Because the radionuclide reference values of the samples IAEA-RGU-1 and IAEA-RGTh-1 are calculated from elemental concentrations with assumed isotopic abundances, it is not meaningful to look at the measured isotopic ratios in great detail. A more detailed understanding of the reference materials would be required for that kind of investigation.

References

IAEA, 2014 <http://nucleus.iaea.org/rpst/ReferenceProducts/ReferenceMaterials/Radionuclides>, accessed 26.11.2014.

Intercomparison exercises

ICP-MS

Samples: Two samples were collected for the Intercomparison exercise with ICP-MS, one from the River Palokkaanjoki, Rovaniemi (Sample 1) River water and one from Talvivaara, Sotkamo (Sample 2) Open-pit mine water. The samples were acidified with conc. HNO₃ (10 ml HNO₃ to 1000 ml water) in the laboratory of STUK. The samples were delivered from STUK to Linköping University, DTU, IFE and FOI CBRN (FOI is external i.e. not a partner of the project).

Analytical results of 2 samples: partner from DTU and STUK participated in the analysis of two samples. STUK sent also the samples to the Finnish independent accredited laboratory (accredited by the Finnish Accreditation Service) for ICP-MS analysis. STUK has a new ICP-MS equipment and the validation process is still going on. Results for uranium are shown in Table 3.

Table 3. Intercomparison exercise results for uranium with ICP-MS.

ICP-MS	Sample 1, Palokkaanjoki	Sample 2, Talvivaara open pit
	Uranium µg/l ± uncertainty	Uranium µg/l ± uncertainty
Laboratory 1	0,02 ± 0,003	3800 ± 160
Laboratory 2	0,02 ± 0,003	4200 ± 630
Laboratory 3*	0,03 ± 0,0045	4600 ± 690

* Finnish independent accredited laboratory.

In general a good agreement of the analytical results for uranium was obtained from three laboratories taking into consideration also uncertainties of the results. More detailed analysis of the intercomparison exercise could be obtained if all partner laboratories participate in analysis of the samples.

6. Case studies

6.1 Case study: Rompas-Rajapalot, Finland

Introduction

Materials and methods

Environmental and ore samples from the Rompas-Rajapalot region were collected in the summer of 2014. Sample information is listed in Table 1 and sampling locations shown in Figure 1. Water samples were taken directly into plastic bottles. Stream bottom samples were taken with a pipe-corer. Soil samples were taken with a small shovel from the vertical soil profile of an exploration pit. Ore samples were taken from rock outcrops with a geological hammer. Care was taken to use clean containers and sampling equipment to avoid cross-contamination of samples.

Table 4. Samples taken from the Rompas-Rajapalot exploration area.

Sample ID	Sample type	Location	Municipality	X (WGS84)	Y (WGS84)	Ref.Date
NR 1/14	stream water	Palokkaanjoki	Rovaniemi	24,99603	66,42082	10.6.2014
NR 2/14	stream water	Kuusijoki	Rovaniemi	24,97756	66,39071	10.6.2014
NR 3/14	stream water	Pohjasenoja	Ylitornio	24,88783	66,39384	10.6.2014
NR 4/14	stream water	Kahilajoki	Ylitornio	24,77267	66,41422	10.6.2014
NR 5/14	stream water	Rompaanoja	Ylitornio	24,73210	66,47907	10.6.2014
NR 6/14	stream bottom	Kuusijoki	Rovaniemi	24,97756	66,39071	10.6.2014
NR 7/14	stream bottom	Palokkaanjoki	Rovaniemi	24,99603	66,42082	10.6.2014
NR 8/14	stream bottom	Kahilajoki	Ylitornio	24,77267	66,41422	10.6.2014
NR 9/14	soil	Rompas N	Ylitornio	24,73841	66,48108	11.6.2014
NR 10/14	soil	Rompas N	Ylitornio	24,73841	66,48108	11.6.2014
NR 11/14	ore	Rompas N	Ylitornio	24,73841	66,48108	11.6.2014
NR 12/14	ore	Rompas N	Ylitornio	24,73841	66,48108	11.6.2014

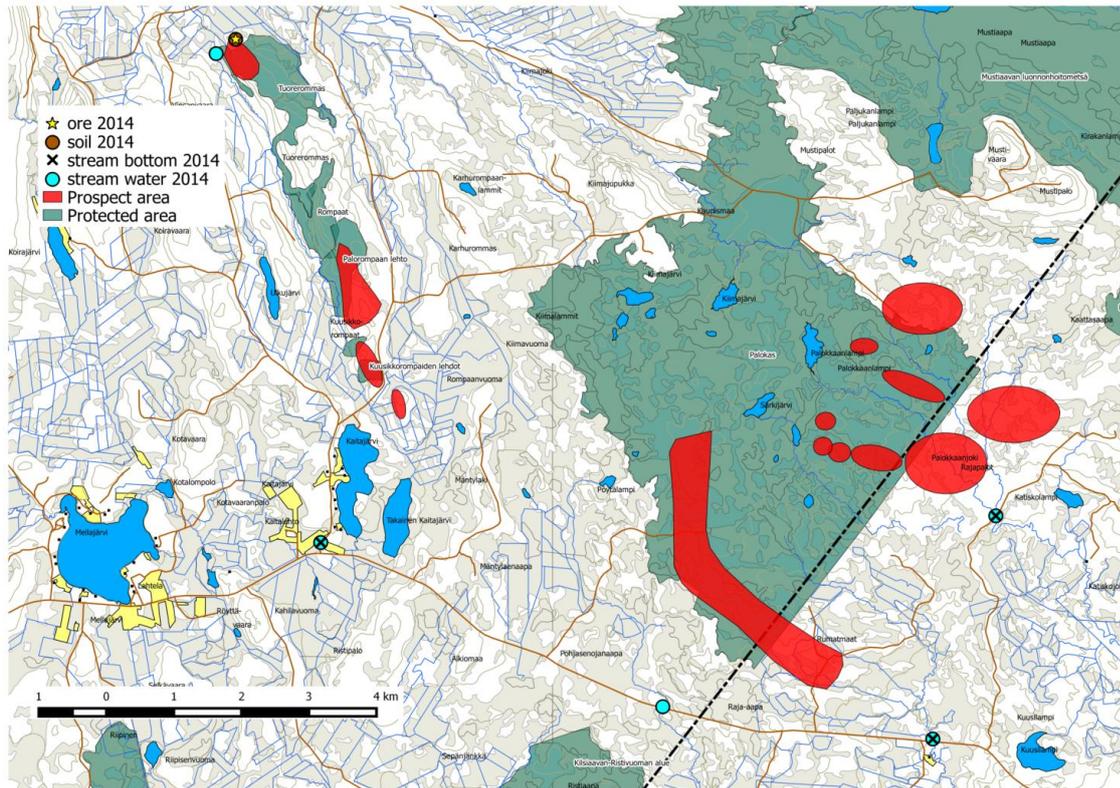


Figure 18. Locations of environmental samples taken from the Rompas-Rajapalot area.

^{238}U , ^{235}U , ^{226}Ra and ^{232}Th from solid samples were analysed using gamma-spectrometry. Soil and stream bottom samples were dried in 105°C , homogenized, and vacuum-packed in Al-foil for three weeks to make sure the daughter nuclides of ^{222}Rn were in equilibrium. Ore samples (small cm-size pieces of rock) were directly vacuum-packed without prior sample preparation. Measurements were made using electrically cooled HPGe-detectors inside low-background lead shields.

^{210}Po and ^{210}Pb from solid and water samples were analysed using radiochemical separation and alpha-spectrometry. Some unknown substance(s) in the soil samples (other metals?) caused the analyses to fail and therefore no radiochemical results could be obtained for ^{210}Po and ^{210}Pb from soil. ^{226}Ra and ^{228}Ra from water samples were analysed with the total-alpha method and gamma-spectrometry, respectively. Uranium from water samples was analysed using a newly installed ICP-MS at STUK.

The laboratories at STUK are accredited and meet the standard EN ISO/IEC 17025:2005.

Results

The analytical results from stream water samples are given in Table 5. The ^{210}Po activity concentrations are 5-17 mBq/l and ^{210}Pb 2-9 mBq/l. The highest concentrations of both nuclides are found in Pohjasenoja and Kahilajoki. The concentrations of ^{226}Ra were below 10 mBq/l, and ^{228}Ra not detected at all. Uranium concentrations in stream water were analysed with ICP-MS and the concentrations of U are below 1 mBq/l.

Table 5. Radionuclide activity concentrations in stream water samples from the Rompas-Rajapalot area. Results are given at the 95% confidence level.

Sample ID	Location	²¹⁰ Po mBq/l	²¹⁰ Pb mBq/l	²²⁸ Ra mBq/l	²²⁶ Ra mBq/l	total-alpha mBq/l	²³⁸ U mBq/l
NR 1/14	Palokkaanjoki	5±1	3±1	<70	<10	<20	<1
NR 2/14	Kuusijoki	5±1	2±0,3	<50	<10	30±20	<1
NR 3/14	Pohjasenoja	17±3	6±1	<50	<10	50±25	<1
NR 4/14	Kahilajoki	10±2	9±1	<30	<10	<20	<1
NR 5/14	Rompaanoja	8±3	3±1	<50	<10	<20	<1

The analytical results from solid samples are given in Table 6. The stream bottom samples have 25-60 Bq/kg ²³⁸U and similar amounts of ²²⁶Ra, ²¹⁰Po and ²¹⁰Pb, exhibiting secular equilibrium of the uranium series in these samples

The soil samples show variation in uranium series nuclides by a factor of ten, with ²³⁸U concentrations of 14 and 150 Bq/kg and ²²⁶Ra concentrations of 25 and 260 Bq/kg, respectively. The variation is even larger in the ore samples as one ore sample shows 2 MBq/kg ²³⁸U while the other contains 1300 Bq/kg ²³⁸U. The contents of ²²⁶Ra in the ore samples are of the same order as ²³⁸U.

The contents of ²³²Th in all analysed solid samples, except the uranium-rich ore, are in the range 10-25 Bq/kg. The concentrations of ²²⁸Th and ²²⁸Ra (not shown) are very similar to ²³²Th for these samples, indicating that the Th-series is in secular equilibrium.

Table 6. Activity concentrations of selected natural radionuclides in ore, soil and stream bottom samples from the Rompas-Rajapalot area. Analyses were done with gamma-spectrometry, except ²¹⁰Po was analysed with alpha-spectrometry. Results are given at the 95% confidence level.

Sample ID	type	Location	²³⁸ U Bq/kg	²²⁶ Ra Bq/kg	²¹⁰ Po Bq/kg	²¹⁰ Pb Bq/kg	²³⁵ U Bq/kg	²³² Th Bq/kg
NR 6/14	stream bottom	Kuusijoki	58±21	32±4	32±3		2,0±0,8	18±2
NR 7/14	stream bottom	Palokkaanjoki	25±14	22±2	33±4	27±3	0,9±0,3	18±2
NR 8/14	stream bottom	Kahilajoki	28±12	22±2	37±4	26±3	1,2±0,3	26±3
NR 9/14	soil	Rompas N	151±21	264±28			6,6±0,8	12±1
NR 10/14	soil	Rompas N	14±10	25±3			0,6±0,3	10±1
NR 11/14	ore	Rompas N	2E6±2E5	2E6±2E5				2E3±1E3
NR 12/14	ore	Rompas N				282±3		25±3
			1278±128	1628±178		0	48±4,8	

Discussion

The stream bottom samples and one of the soil samples show amounts of uranium series nuclides (10-60 Bq/kg ^{238}U) comparable to typical Finnish soils and bedrock (20-70 Bq/kg ^{238}U). The remaining soil sample has slightly more uranium and radium (150 Bq/kg ^{238}U , 264 Bq/kg ^{226}Ra), but these levels are not unusual in Finland. Despite the presence of high uranium concentrations in the ores of Rompas-Rajapalot, the environmental samples of this study show typical values of natural radionuclides for the Finnish environment. As has been shown also in previous studies, it is evident that uranium and thorium series radionuclides are not very easily mobilized under natural conditions in Finland.

The ore samples from Rompas-Rajapalot analysed by Mawson show a very large range of uranium concentrations from 0.1 ppm uranium to 27% of U_3O_8 . This type of variability is also evident in the two ore samples of this study. The uranium minerals are very heterogeneously distributed in this ore type.

If the development of the Rompas-Rajapalot project goes further than exploration a radiological baseline survey will be required in addition to other environmental surveys before permits can be acquired. Also due to the high content of uranium series nuclides in the ore, plans will be required for the radiation protection of workers and public and safe storage of mining waste.

6.2 Case-study: Kvanefjeld, Denmark/Greenland

Kvanefjeld is a low altitude mountain (690 m.a.s.l.) situated 8 km NE of the town of Narssaq in south Greenland at $60^\circ 59' \text{ N}$, $46^\circ 00' \text{ W}$. Kvanefjeld is part of the Ilimaussaq intrusive complex which hosts a variety of unusual rock types and which holds one of the world's largest rare earth element deposits. An estimated amount of 56 million tons of mineralized material with an average grade of 365 ppm uranium has been found there. The surrounding landscape is characterized by deep fiords (down to 600m depth) and high mountains (up to 1400 m.a.s.l.). The geology of Kvanefjeld area has been investigated since the early 20th century and the focus on uranium mining in the area started in 1955 when the late president of the Danish Atomic Energy Commission (AEK), Niels Bohr, initiated radiometric exploration within the area. After drilling and mapping programmes 180 tons of ore was mined in 1962 for the purpose of metallurgical studies. The Kvanefjeld Uranium Project (financed by the Ministry of Energy) was started in 1978 in order to study uranium extraction at a pilot plant at Risø National Laboratory. For this purpose 4000 tons of ore was mined in 1979-1980 from a 1000m long adit and brought to Risø. Exploration continued until 1982, at which time political and economic forces determined that continued exploration would be infeasible due to low market prices for uranium and a new zero-tolerance uranium policy. Greenland Minerals and Energy Limited, an Australian exploration company, today has the licence of exploration over the northern ilimaussaq intrusive complex in Greenland.

The mine material brought to Risø is today placed in three heaps (see picture 19) with grass, bushes and trees growing on and around them. The ore heaps and water-covered uranium

tailings have been exposed to weather for more than 30 years. Three water ponds are located some 20m east of the heaps.

Sampling at the Kvanefjeld rock deposits at Risø

Water from two of the ponds were sampled (the third one was partially dried out) and samples from birch, grass, pine, fern and rowen growing directly on the heaps were collected together with raw rock material. The water was analysed directly without any further processing (except dilution) while biological samples were dried, ashed and analysed by gamma spectrometry before being dissolved and analysed by ICP-MS.



Figure 19. Kvanefjeld rock deposit at Risø. Vegetation such as grass, birch, pine and fern are growing directly on or next to the rock heaps.



Figure 20. One of the three tailing dams located at Risø. Rock deposits in the background.

Results

Table 7. Results of ICP-MS measurements of the pond water next to the rock heaps.

Sample	^{238}U [Bq/kg]	$^{235}\text{U}/^{238}\text{U}$ (atom)	$^{234}\text{U}/^{238}\text{U}$ (atom)
Pond No1	0,096 (+/- 5%)	0,00723 (+/- 3%)	5,80E-05 (+/- 5%)
Pond No2	1,1 (+/- 5%)	0,00726 (+/- 3%)	5,47E-05 (+/- 5%)

Table 8. Results of radioactivity concentrations in biological samples collected at the rock heaps. Associated standard deviations are about 10% for the gamma measurements and 5% for the ICP-MS measurements.

Sample type	Dry sample ^{232}Th [Bq/kg]	Dry sample ^{238}U [Bq/kg]	Dry sample ^{228}Ra [Bq/kg]	Dry sample ^{228}Th [Bq/kg]	Dry sample ^{210}Pb [Bq/kg]
Birch	0,051	0,088	53	28	ND
Pine needles	0,084	0,463	6,0	3,2	30
Fern	0,343	6,010	125	20	56
Grass	1,041	1,464	50	4,8	67
Rowan berries	0,017	0,010	21	10	1,2
Rowan leaves	0,190	0,220	250	90	ND
Rowan twigs	0,043	0,097	141	108	22

Table 9. Calculated transfer factors for ^{238}U , ^{232}Th and ^{228}Ra assuming a homogeneous ^{238}U and ^{232}Th concentration in the rock material of 4.2 and 3.5 kBq respectively and secular equilibrium between ^{228}Ra and ^{232}Th .

Sample type	Uranium (^{238}U) transfer factor	Thorium (^{232}Th) transfer factor	Radium (^{228}Ra) transfer factor
Birch	2,08E-05	1,46E-05	0,015
Pine needles	1,10E-04	2,45E-05	0,002
Fern	1,42E-03	9,93E-05	0,036
Grass	3,46E-04	3,02E-04	0,014
Rowan berries	2,42E-06	4,79E-06	0,006
Rowan leaves	5,20E-05	5,51E-05	0,072
Rowan twigs	2,29E-05	1,24E-05	0,041

6.3. A case study of potential mining activity in Fen, Norway

Norway is rich on geological resources. The main geological resource in Norway is oil. There are other potentially economically viable geological resources such as metal ores which may be mined. High wages and regulations make mining difficult for enterprises to keep viable, especially when the price of ore or refined metals is low.

The Fen Complex

The Fen complex is situated in Ulefoss, Nome municipality in Telemark County, in south-eastern Norway. It consists of an intrusion in the native gneiss of carbonatite and alkaline rocks enriched with Rare Earth Elements (REE), iron (Fe) and niobium (Nb). The intrusion is about 9 km² in diameter and is surrounded by a fenitised zone about 2-300 meters thick. The main types of rock is søvite (calcite carbonatite), rauhaugite (ankeritic or ferrodolomitic carbonatite) and rødbergite (hematite-ankerite carbonatite).

The highest concentrations of Lanthanum (La) and Yttrium (Y) are found in rødbergite and rauhaugite. The rødbergite and rauhaugite ores consist amongst other minerals REE carrying monazite, bastnasite, synchisite and parisite.

Transfer of radionuclides

The rocks rødbergite and rauhaugite are especially known to have high concentrations of thorium-232 (^{232}Th) and to lesser degree uranium-238 (^{238}U) and their daughter radionuclides. Furthermore, soil layers in the whole Fen Complex are also shown to have more elevated NORM levels (Dowdall et al., 2012; Mrdakovic Popic et al., 2012; 2014; NGI-UMB, 2010) than what was expected, considering the formation of soil layers through the long-lasting weathering of geological materials. Concentrations of ^{232}Th , ^{238}U , Radium-228 (^{228}Ra), Radium-226 (^{226}Ra), and Polonium-210 (^{210}Po) in soil of the Fen Complex area were in

ranges 60 – 16516, 36 – 2161, 134 – 7300, 77 – 250, and 38 – 76 Bq/kg, respectively (Mrdakovic Popic, 2014). Inhomogeneous spatial distribution of soil radionuclides (both vertical and horizontal) was found to be in statistically significant correlation with the distribution of rock type rødbergite.

Despite the enrichment of radionuclides in the soil, transport to wild forest plant species in the Fen Complex area, was in accordance with transfer factor (TF) values published in TRS-472 (IAEA, 2010). Ranges of geometric means of soil to plant (vascular plants, moss and lichens) transfer factors (TFs), based on pooled data, were as follows: 0,002 – 0,04, 003 – 0,12, 0,005 – 0,22, 0,005 – 0,19 and 0,02 – 1,63 for ^{232}Th , ^{238}U , ^{228}Ra , ^{226}Ra , and ^{210}Po , respectively. Higher TFs were calculated for the daughter radionuclides Ra and Po, what suggested their elevated mobilization in the environment in comparison to parent radionuclides of ^{232}Th and ^{238}U . Transfer of radionuclides to tree leaves was, on average, several orders of magnitude lower. Detailed analyses of the specific activity in plant parts showed that transport to different plant parts differed significantly, with transfer to roots being one order of magnitude higher than transfer to aboveground plant parts.

However, transfer of radionuclides ^{232}Th and ^{238}U to free living earthworms species was higher than to plants, with TFs ranges 0,03 – 0,08 and 0,09 – 0,25, respectively. Concentrations of ^{232}Th in the earthworms were up to 80-fold higher than the ^{232}Th concentration in earthworms living in the average background soil (Beresford et al., 2008). Results are most likely related to the earthworms specificity with respect to large quantities of soil processes in their bodies, but might also reflect a small soil residual in the earthworms bodies (although analyses of tissue were done after the gut depuration).

Mining and extraction of Rare Earth Elements

Rare Earth Elements (REE) are the lanthanides (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium) and yttrium. Scandium is by IUPAC also defined as a rare earth element. The term Rare Earth Oxides (REO) is also used, as REE often is found in oxide ores.

REEs are divided into light (LREE) and heavy (HREE). The LREE consist of lanthanum, cerium, praseodymium, neodymium, samarium and europium, while HREE consist of gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium and yttrium.

REEs are used as chemical catalysts, in metallurgy and alloys, for glass polishing, permanent magnets and phosphors. High technology is practically based on REE. REEs are used in cellphones, air pollution controls, batteries and windmills.

Mining and extraction of REE is more complex than mining of many other elements. For instance:

- a) There are two main types of REE minerals: the bastnasite and the monazite types. The bastnasite is a carbonate rock which has a significant amount of calcites. The

monazites are phosphate rich rocks. Rødbergite and rauhaugite have varying persistence against chemical attacks.

- b) REE ores usually include several elements which are of little or no economic value, such as thorium. These elements may be difficult to remove from the ore without losing too much of the desirable elements.
- c) The lanthanides have similar chemical properties to each other and it is difficult to separate one lanthanide from the others.

Points a) and b) cause different environmental impacts such as how much ^{232}Th will be placed in tailings, the magnitude of discharges and where the decay products may end up due to different processes using various chemicals. These factors will influence the potential of pollution from the enterprises and through this, the factors influence how the activities of enterprises may be regulated.

The process

There are two main steps in mining and extraction of REE; concentration and production.

The concentration starts with mining of REE ore. The ore is then crushed to gravel size (2-4 mm diameter), which is then grinded down to a slurry with grain size between fine sand (0,125 – 0,25 mm) and silt (0,002 – 0,063 mm).

This fine grain sized matter is then treated by flotation. Chemicals are added to the slurry, and air is pumped through it. The flotation chemicals form foam which carries the REE grains, while the heavier grains fall to the bottom of the separator.

The foam with the REE grains are removed from the slurry and then filtered and the result is a REE concentrate.

The concentrate is then treated with a series of chemicals in order to separate the elements from each other. Usually REE are extracted using a liquid-liquid extraction. The different types of ores need different extraction methods. Bastnasites are often treated with sulphuric acid in order to remove calcites, while monazites are treated with sodium hydride in order to remove phosphates.

One of the preferred methods of extracting REE from monazites is by “alkaline cracking” using sodium hydroxide (NaOH). The NaOH separates phosphates from a “mud”, leaving REE, ThO_2 , TiO_2 , ZrSiO_4 and other residuals. The residuals are then treated with hydrogen chloride (HCl), which separates the REE from the ThO_2 , TiO_2 and so on.

Radioactive waste and pollution could be produced at several of these steps. Runoff from the mine can carry radioactive substances to the environment and be a source of pollution, and stockpiling overburden and sub-ore are expected to also potentially carry radioactive substances to the environment.

The radioactive substances are expected to mostly end up in tailings from magnetic separation of the elements in the ore, or from liquid discharges in form of slimes (very finely grinded mineral grains) to the tailings pond. Radioactive waste may be formed after flotation and thickening and this waste may also be placed in the tailings pond.

ThO₂ can be extracted from REE in bastasites by solving the minerals in acid and adjusting the acidity. REE would stay in solution and ThO₂ would precipitate at about pH 1. This may cause the formation of a ThO₂ concentrate.

The separation of REE from the ores often utilizes chemicals such as ammonium bicarbonate, sulphuric acid and hydrochloric acids as mentioned earlier, magnesium oxide, kerosene and solvents such as trichloroethylene. These chemicals can influence how easily ²³²Th and other NORM is mobilized from tailings or how it may behave if discharged to water.

Evaluation of the REE resource in Fen

Rødbergite has a lot of iron and consist of up to 95 % hematite. This makes the material resistant to physical and chemical attacks, making it hard to process.

Earlier investigations performed by 21st North, showed that the physical and chemical forms of the REE mineral in monazite grains found in rødbergite varied. Some of it was fine grained with an average of 1 µm. This requires a fine grinding of the ore. The concentration was about 2,8 % REE. Samples of hematite rich carbonate ores from Gruveåsen showed a REE concentration of 1,6 %, but with 70-90 % of the grains above 43 µm (21st North, 2011a).

Samples of Rauhaugite (dolomite-ankerite carbonatite) had a REE concentration of 1,8 %, but far coarser grains, where the majority was larger than 43 µm. The REE mineral was found in Bastnasite grains.

Flotation surveys on fine grained monazite in Rødbergite, using sulphuric acid and an oxidant, gave a higher recovery at a higher cost. Treating the liquid with NaOH gave a pure concentrate of ²³²Th and the REE had a 90 % recovery (21st North, 2011b).

Investigations by 21st North show that the REE content of calcite carbonate was low and a positive correlation between hematite and REE was found in the samples. The amount of ²³²Th in the Søvites (calcite carbonates) is also less than in Rauhaugite and Rødbergite, so Søvite is not further discussed.

Samples with Rauhaugite showed REE > 1 %. The rock had REE in bastnasite, synchellite and parisite grains. Some aggregates had a size of several thousand µm. These large grains should be easier to separate from the surrounding gangue, and they had a higher percentage of light rare earth elements (LREE) compared to the heavy rare earth elements (HREE).

One sample of Rødbergite had 2,32 % REE in small Monazite grains, enriched with HREE, which is more coveted than LREE. The grain size was just a few µm (21st North, 2011a).

An estimation of the resource done in 2014 was that their area consisted of 900 000 – 2 000 000 tons REE. The ore appeared to be relatively homogenous (21st North, 2014).

Evaluation of potential mining of REE in Fen

The ore in the Fen complex which may be mined are bastnasite-dominated Rauhaugite and monazite-dominated Rødbergite. Extraction of REE from the two kinds of ores would be significantly different and this may cause difference in the amount of ^{232}Th in tailings, in a potential concentrate of ^{232}Th and also how mobile and bioavailable ^{232}Th and daughter nuclides may be. The case study will focus on Rauhaugite as it is probably the most economically viable ore. It is assumed that ^{232}Th will follow REE until specifically separated from the REE minerals.

Rauhaugite – bastnasite extraction

In order to extract REE, the ore would be crushed down to a coarse grain size. Optical sorting and gravimetric methods could produce a pre-concentrate of $> 4\%$ REE. The recovery rate is estimated to be 65% . As ^{232}Th is associated with the bastnasite minerals themselves, it can be assumed that approximately 45% of the ^{232}Th goes to tailings together with the lost minerals (21st north, 2014).

Flotation recovers 80% of the pre-concentrate. 20% of the remaining ^{232}Th will be lost at this stage. 58% of the ^{232}Th in the ore will have been removed from the concentrate and would go to tailings.

Assuming similar processes as used in the Bayan Obo mine, further processing of the concentrate will produce REE slag, waste water and REE. $96-98\%$ of the remaining ^{232}Th will go to the REE slag, some will be discharged to air ($0,1-0,5\%$) or liquid discharge ($0,6 - 2\%$). The remainder will be found as trace amounts in the products (Quifan, 2011).

Approximately between 98 and 99% of the original amount of ^{232}Th in the ore are finely grinded solids which would traditionally be placed in tailings dams.

Historical data from 45 samples taken in 1970 showed an average concentration of 938 ppm ^{232}Th in “carbonatite”, which is assumed to be rauhaugite (dolomite-ankerite carbonatite) as both søvite and rødbergite are named as such. This gives an average of $3,75$ Bq/g ^{232}Th in the ore. If between 98 and 99% of the ^{232}Th in the ore would go to waste, this will give an estimated average concentration of the tailings between $3,68$ and $3,71$ Bq/g, given an average ore concentration of $3,75$ Bq/g.

If we assume that no daughter products have alternative ways through the process and that the 10 times higher assumption as seen in the REE processing factory Lynas Advanced Materials Plant in Malaysia (LAMP) are valid for this kind of ore as well – then the total activity concentration of the tailings would be about 37 Bq/g for ^{232}Th and daughter nuclides. (Bell, 2012)

Discharges to water and air might be maximum 2% of the total thorium content in the ore, that is $7,5$ Bq/kg ore.

Environmental impact

The assessment of potential environmental impact must rely on assumption. It is assumed an annual production of 20 000 tons REE from Rauhaugite (bastnasite) ore, similar to the ore processed at Australian owned REE refinery Lynas Advanced Materials Plant (LAMP) in Malaysia.

With an average REE concentration in the ore of about 1,5 %, about 1,3 million tons of ore must be extracted each year. Using the historical data, and assuming that the tailings would have an average activity concentration of 3,7 Bq/g ^{232}Th and 0,36 Bq/g uranium-238 then 4,9 GBq ^{232}Th and 0,48 GBq uranium-238 would go to tailings each year. Assuming equilibrium and no loss due to dust, we can use ERICA assessment tool in order to evaluate the environmental impact of a land based tailings dam. Using a benchmark of 10 $\mu\text{Gy/h}$ and site specific activity concentrations, it was found that the benchmark was breached for Lichen and Bryophytes, Grasses and herbs.

Environmental impact of a dry, land based tailings heap

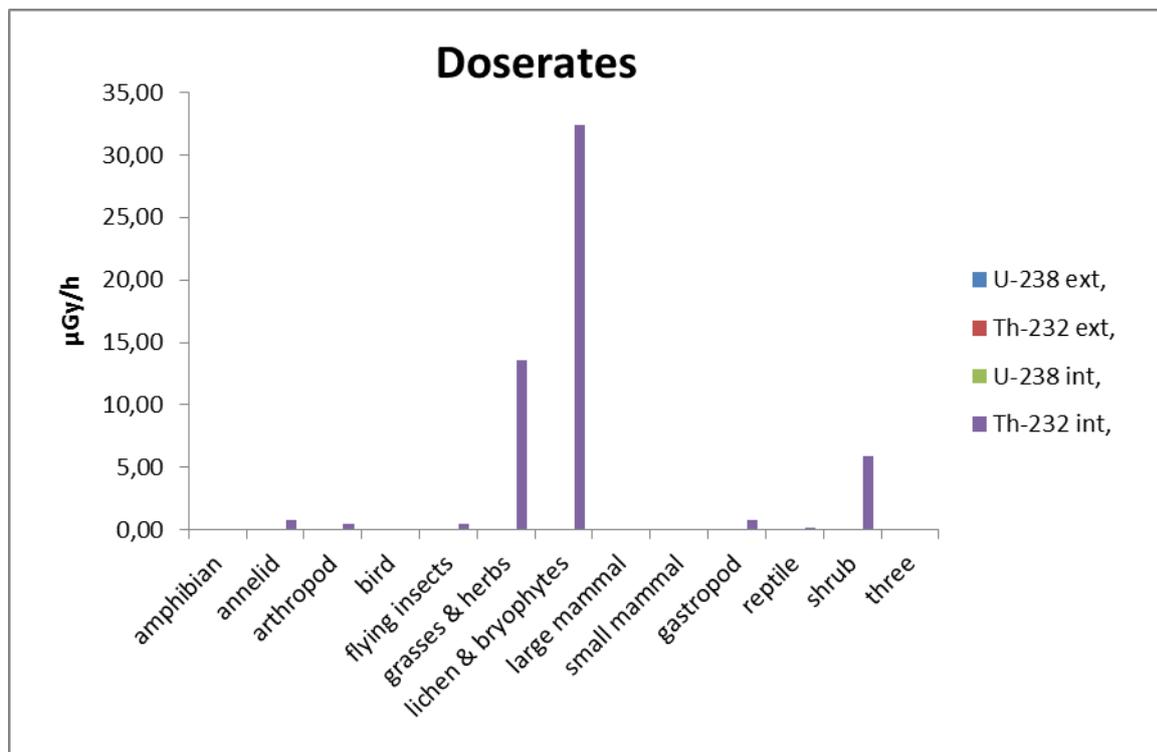


Fig. 21: Results of the ERICA tool assessment. Ext = external doses, int = internal doses.

The major exposure comes from internal ^{232}Th to lichen and bryophytes, grasses and herbs and to a lesser degree shrub. The maximum exposure to radiation other than internal ^{232}Th would be internal exposure to uranium-238, but as the highest exposure organisms (lichen and bryophytes) will get 0,01 $\mu\text{Gy/h}$ from ^{238}U , is this exposure negligible. All other dose rates were significantly lower than 0,01 $\mu\text{Gy/h}$.

The ERICA assessment tool estimates that lichen and bryophytes could accumulate up to 1400 Bq/kg ²³²Th fresh weight, while grasses and herbs could accumulate up to 590 Bq/kg ²³²Th fresh weight. Shrubs could accumulate up to 230 Bq/kg ²³²Th fresh weight. Other radionuclides show a negligible accumulation in organisms.

The ERICA assessment tool takes into account daughter nuclides from the naturally occurring radioactive isotopes and adds these doses to the parent nuclide. Daughter nuclides in equilibrium with parent nuclide will be represented in this assessment. Since the investigation previously mentioned concerning transfer of radionuclides in weathered soil showed a higher transfer factor for daughter nuclides as radium and polonium than uranium and thorium, the doses will most likely be higher.

However, it is not appropriate to give a more detailed evaluation of the exposure situation with a higher mobility of radium and polonium due to a too high intrinsic insecurity of such an assessment. If the assumption that the daughter nuclides give about 10 times higher activity concentrations in the tailings, as seen at the LAMP, then the exposure situation would be more severe than this modelling indicates.

Environmental impact of discharge to water

Assuming that the estimation that maximum 7,5 Bq ²³²Th would be discharged for each kg ore mined are correct, the discharges to water from a milling and refinery could be about 0,065 GBq ²³²Th each year. Assuming a daily discharge of water of 10 000 m³, again similar to LAMP, this will give a discharge of about 2 Bq ²³²Th per second, distributed in 115 l of water.

The standard ERICA assessment tool benchmarks of 40 µGy/h for terrestrial animals, birds and so on, and 400 µGy/h for aquatic animals and fish, the IAEA SRS-19 model marine environment was used. The discharge point was assumed to be at 50 m depth, 100 m from the shore, 500 m from the receptor, which was defined to be in the sea, and with a standard coastal current of 0,1 m/s.

The benchmark was not breached for any organisms. The highest dose would be to phytoplankton at about 0,2 µGy /h. The activity concentration in phytoplankton could reach 13 Bq/kg fresh weight.

The activity concentration on the sea floor could reach 145 Bq/kg dry weight.

Environmental impact of discharge to air

Assuming that the discharge of radionuclides to air are 1,8 Bq per kg ore mined, 1,3 million tons ore each year are processed, then the discharge rate would be 76 Bq/s. Varying discharge scenarios don't cause the benchmark of 10 µGy/h to be breached. With a release of 10000 Bq/s, the risk quotient with a conservative estimation for lichen and bryophytes are above 1, but the expected value is below 1. This leads to the assumption that the discharges to air must be far above what would be expected, even with an extremely increased production, for the discharge to air to have an environmental impact on a terrestrial environment.

How will Norwegian laws and regulations affect the mining and extraction of REE

Permits for investigations and mining must be given by the Directory of Mining after the Mining Act.

Mining and refining REE will cause discharges to air and water, which requires a permit after the Pollution Control Act, given by the NRPA. The advantages and disadvantages of giving the permit to must be assessed. Considering that phytoplankton might receive an internal dose from ^{232}Th and the potential for bioaccumulation are quite high, there might potentially be observable negative effects on higher trophic levels following discharges to water.

Permits given after the Pollution Control Act include terms and conditions. One such condition may be that the discharge water must be filtered or otherwise purified prior to discharge. However, this creates a new challenge. If filtration or purification removes all ^{232}Th from the discharged water, then about 0,065 GBq ^{232}Th rich concentrate needs to be handled each year. The product must be expected to have a high concentration of ^{232}Th and could theoretically be placed in a tailings pond or a separate storage for radioactive waste.

Mining and extraction of REE will cause a large amount of tailings which will most likely be regarded as radioactive waste which must be deposited. Radioactive waste which must be deposited are today placed in mountain halls at facilities with permits of accepting radioactive waste which must be deposited. Establishing a waste depository or tailings dam requires a risk assessment after the Planning and Building Act.

Tailings dams used in conventional mining are open dams with or without linings which more or less hinders leaching of heavy metals and other chemicals. In terms of IAEA Safety Guide RS-G-1.7 and IAEA Safety Reports Series No. 49 could radioactive materials between 1 and 10 Bq/g be considered for exemption by the regulatory body and this may be considered in mining of REE. However, the evaluation of the potential dose rates and bioaccumulation of ^{232}Th in plants, show a potential for harm to the environment. Exemption for the waste should only be considered after a thorough investigation and risk assessment. No matter if the waste would be exempted from terms and conditions other radioactive waste which must be deposited, the enterprises permit from the NRPA after the Pollution Control Act must also include a permit to handle their radioactive waste.

Some processes in the extraction process may cause the creation of ^{232}Th concentrate. This will be considered as nuclear material after the Regulations on nuclear materials. The enterprise does not need a permit for ^{232}Th concentrates with non-nuclear purposes. However, it must notify the NRPA of the concentrate. The enterprise must also accept supervision of the facility and the concentration by both Norwegian authorities and international inspectors.

Thorium is defined as a nuclear material after the regulations on nuclear materials and cannot be exported without a permit from the Ministry of Foreign Affairs.

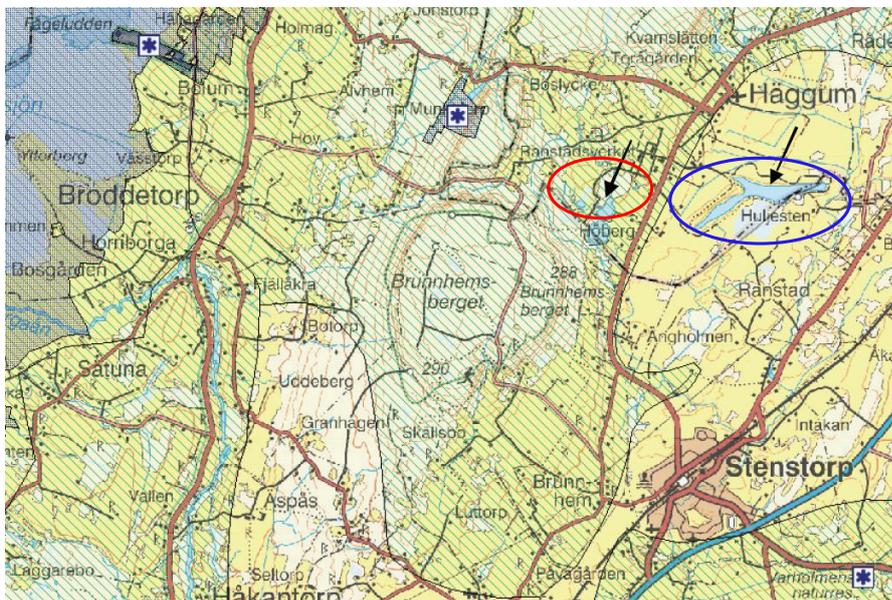
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A case study of the Ranstad uranium mine, Ranstadverken, Sweden

In this section a short description of the Ranstad uranium mining operations, the programs for remediation and published results from environmental studies will be shown; i.e. this case study will not include new data.

The uranium mining and milling facility Ranstadverken was constructed between 1960 and 1965 in the Billingen-Häggum district adjacent the Billingen mountain in the southern part of Sweden, 13 km from the town Skövde. The Billingen alum shale mineralizations hold a uranium ore grade of about 200-300 ppm and the total deposit is estimated at about 300 000 tons, considered to be one of the largest uranium resources in Europe. The alum shale is a clayish silicate (Al-SiO₂, K) including about 13% pyrite (FeS₂) and 15% organics.



○ Tailings waste area ○ Lake Tranebäresjön; former open-pit area

From: AB SVAFO. Rapport 10054177, 2005-04-15

The aim of mining was to make Sweden independent of uranium import, since both commercial nuclear power plants and research reactors were becoming established at the time, including the possibility to obtain Pu for nuclear weapons production. In 1965 uranium mining commenced and a total of 1.5 million tons of alum shale were excavated in an open-pit mine and processed (crushed and percolation leached with H₂SO₄ followed by uranium extraction by ion-exchange, liquid-liquid extraction and final precipitation as sodium uranate), extracting about 215 tons of uranium oxide. The sudden decision to put the operations on ice in 1969 was due to economical reasons and the fact that the Swedish government in 1968 decided to abandon the plans for nuclear weapons production and signing the Non-Proliferation Treaty and giving up the independence of uranium import. In the early 1970's, when the price of uranium increased dramatically, plans were made to resume production. However, protests from environmental organizations and municipalities (opting for using the communal veto) ended with a withdrawal. The Ranstad concession ended in 1984, and the

extraction plant and mine were closed down, after which restoration and remediation plans were made, described below.

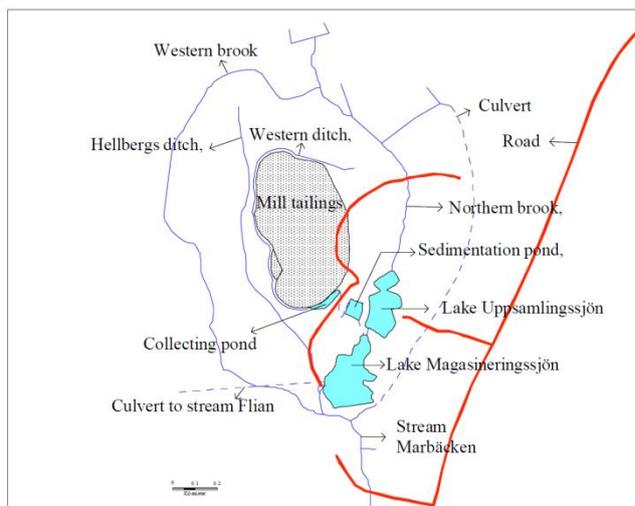
Remediation of the Ranstad mining site

The remediation plan, adopted by the County Council of Skaraborg county in 1990, comprised of (i) coverage of the mill tailings area with a multi-layer dry depository system, (ii) filling the open-pit with a wet depository (weathered shale and water), and (iii) restoration of the industrial site. The overall objective was to restore the environment to conditions where no maintenance work was needed in the future. Further, in 1997 the County Council decided on environmental goals on metal concentrations (As, Cd, Co, Fe, Mn, Ni, Pb, U, Zn) in one of the recipient lakes.

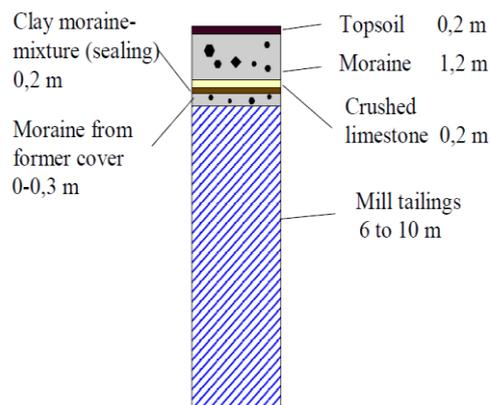
Mill tailing remediation:

The mill tailing waste, containing crushed alum shale and leached slag, amounts to about 1 million m³ and cover an area of 230 000 m² of 6-10 m mill tailings thickness. The radionuclide inventory is about 180 tons of U ($2.2 \cdot 10^{12}$ Bq of ²³⁸U), about $5 \cdot 10^{12}$ Bq of ²²⁶Ra together with daughter radionuclides (Sundblad, 2002; Stiglund & Aquilonius, 1999a). During the mining period the tailings was uncovered and due to weathering large amounts of acid and metals were released to drainage areas, including e.g. uranium and ²²⁶Ra. Therefore ditches surrounding the waste areas were constructed, where leakage water was collected and then further transported to an assembly pond, Lake Uppsamlingsjön/Lake Högberg. From this pond the water was pumped back to the mill and treated in a purification plant and then transported to a sedimentation pond and after sedimentation directed to the Lake Magasineringsjön/Lake Blackesjön. In recent time the leakage water was drained to the western ditch and the collecting pond, pumped for treatment in the purification plant and further to the sedimentation pond and the Lake Magasineringsjön, and finally pumped via a culvert across the Billingen mountain to the stream Hornborgaån and the Lake Hornborgasjön (see figure below). However, since year 2000 the water is allowed to flow directly from Lake Magasineringsjön to the stream Marbäcken (see figure below).

The produced sludge from the purification plant was disposed of on top of the tailings. In the 1970's the tailings were partly covered with a thin layer of till, which partly reduced the weathering, i.e. reducing oxidation of pyrite by O₂ to Fe(III) and SO₄²⁻ and release of other metals. During the 1970's and 1980's several studies were performed to find methods to reduce the leaching process, i.e. methods for reducing rainwater infiltration and oxygen entry into the tailings to obtain a sustainable solution for the environment. Different cover systems were tested and a detailed plan for the restoration was submitted in 1988. The County Council granted permission for the remediation site project in 1990. The components of the multi-layer cover is shown in the figure below; (i) a sealing layer of moraine and clay/moraine mixture (0.2-0.5 m) with proven low permeability, (ii) then a 0.2 m drainage layer of crushed limestone, (iii) a 1.4 m protective layer of moraine and topsoil, and finally a dense tree planting of birch and spruce. Later, in 1996, a new pond for collecting leakage water and a new leakage water precipitation plant was constructed near the disposal site together with a sedimentation pond to collect precipitates (see figure below).

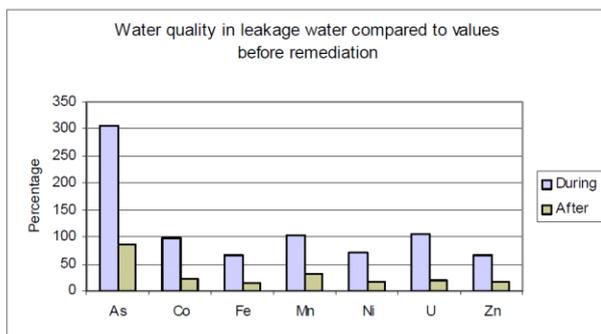


The mill tailing area and drainage recipient water courses and lakes. Stiglund & Aquilonius, 1999a.

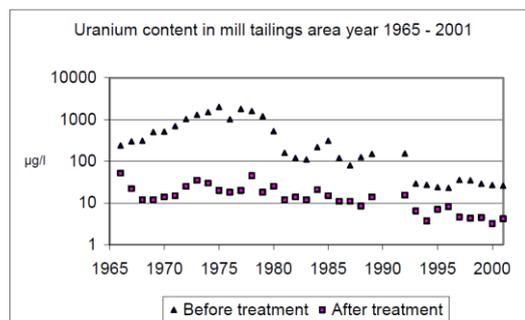


Cross section of the mill tailing cover system. From: Stiglund and Aquilonius, 1999a.

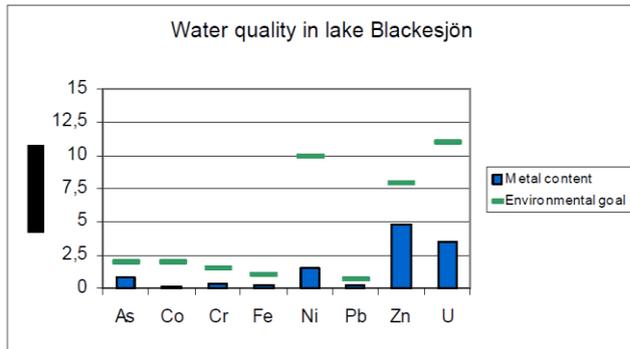
An environmental program was initiated with an extensive set of sampling sites for groundwater aquifers and surface waters, most of the results are reported by Sundblad, 1996 and more recent data can be found in SVAFO, 2005. The results show that the multi-cover system has significantly changed the water infiltration and oxygen diffusion into the tailings. The pyrite weathering has decreased based on increasing pH and sulphate content in the leakage water, as well as significant decrease in metal levels in the leakage water (see figure below). The effects of remediation on uranium release is significant (see figure below). The initial remediation work at the end of the 1970's and the next in the 1990's has resulted in an almost 100-fold reduction in uranium concentrations in the leakage water (before treatment). The environmental goals set by the County Council in 1997 involved metal concentrations in the lake Blackesjön/lake Magasineringsjön downstream the tailings area. Measurements from year 2001 show that the goals have been achieved (see figure below). From a radiological point of view, the mill tailing area is not considered to be a problem today. However, the SSM require continued monitoring of uranium and ^{226}Ra four times a year for samples from the southern part of the tailings area and in lake Magasineringsjön, typically showing ^{226}Ra levels of a few mBq/L.



Water quality in leakage water before and after remediation. Sundblad, B (2002).



Uranium concentrations in leakage water before respectively after treatment year 1965 to 2001. Sundblad, B (2002).



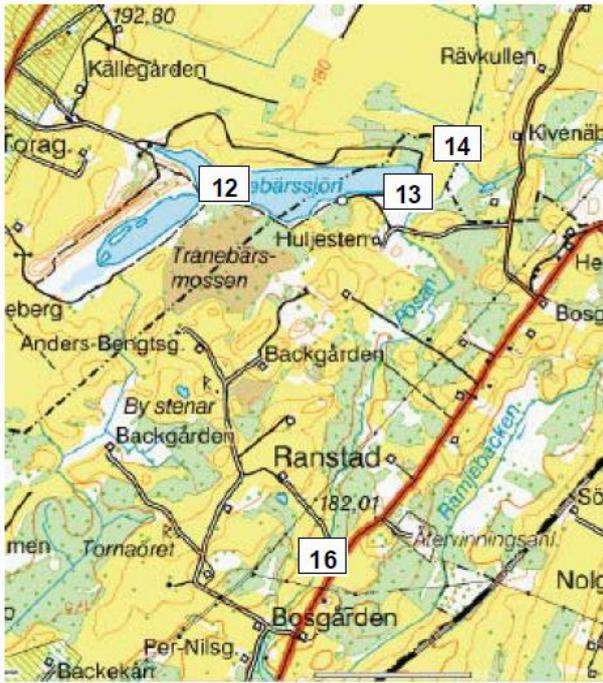
The water quality in Lake Blackesjön/Lake Magasineringsjön during year 2001 compared to the environmental goals. Sundblad,B (2002).

Lake Blackesjön/Lake Magasineringsjön in 2015.

Open-pit remediation:

The remediation of the open-pit started in 1990, with the aim of ending pumping of drainage water and creating a lake area. The bottom of the pit was partly backfilled with limestone and alum shale waste covered with moraine. The pit-area, total 1.5 km length and maximum width 200 m, gradually filled up with water dominated by groundwater arising from moraine and limestone aquifers. A connection to the Pösan stream via a ditch was created to maintain a stable water level, an outflow that started in 1993. Today the lake holds a water volume of about 1.3 million m³ with an average and maximum water depth of 4 m and 15 m, respectively. The average water outflow is about 25-40 l/s (SVAFO, 2005) resulting in a water exchange rate of about 1-1.5 year. Analyses have shown that the lake is strongly stratified in two layers, divided by a thermocline at 8-10 m depth. The lower layer show reducing and almost oxygen-free conditions with rather high levels of iron, nickel, uranium, Ca²⁺, SO₄²⁻, CO₃²⁻ and a pH close to neutral and low primary production. The upper layer show oxidizing conditions with high levels of Ca²⁺, SO₄²⁻, CO₃²⁻ and slightly basic pH. Normally the water is clear, but during spring and autumn sudden exchange between bottom and surface water occur, probably driven by a reduced thermocline. At these occasions large amount of iron and manganese is moving from the bottom layer to mix with surface waters (Stiglund, 1999b, SVAFO, 2005).

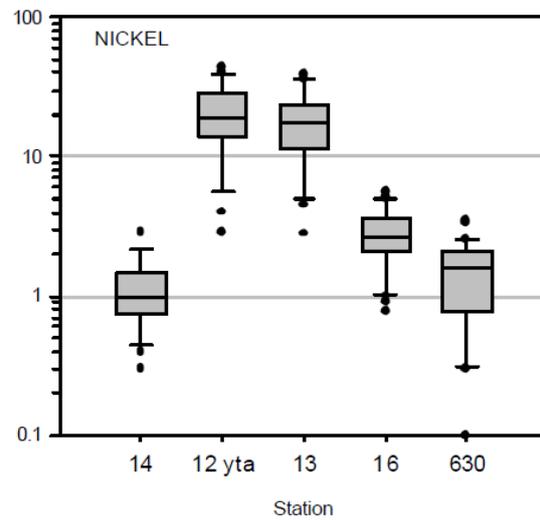
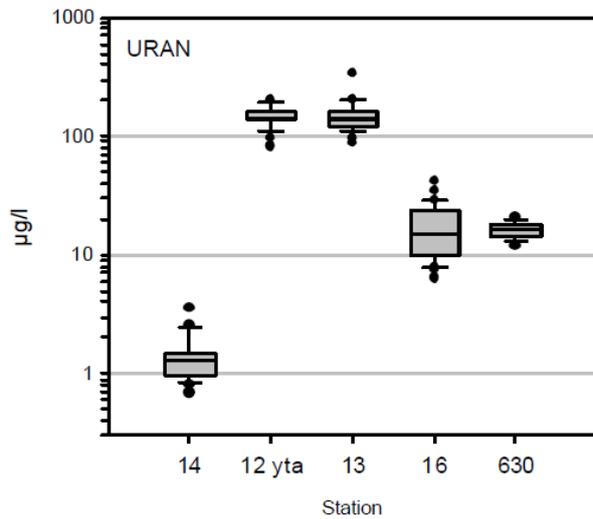
The concentrations of some metals (Ca, Mo, Mg, Ni, Sr, U) and sulphates are rather high in Lake Tranebärssjön compared to reference stations upstream the lake, and obviously not suitable for consumption, either by humans nor grazing livestock; see data on Ni, U in figure below. The uranium levels are much higher in the lake compared to both upstream and downstream stations, but uranium is considered to act conservatively, i.e. insignificant sedimentation in the recipient water bodies. The levels of uranium in Lake Tranebärssjön, in both surface and bottom water, has been rather constant over time (see figure below). However, uranium together with Ni is considered the most problematic in terms of environmental and health impact (SVAFO, 2005).



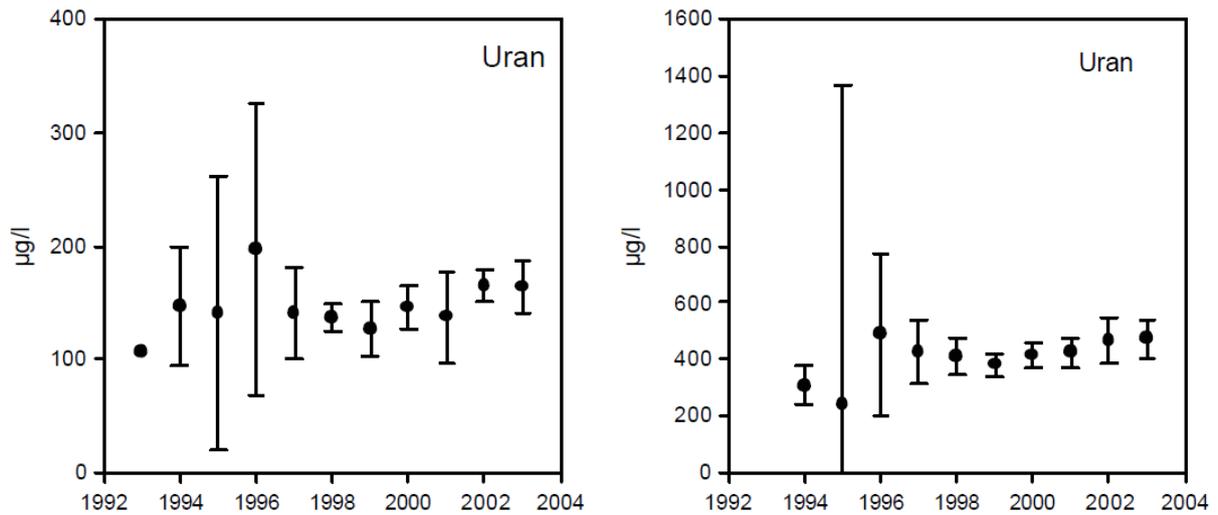
Sampling stations at Lake Tranebärssjön and its recipients. From: SVAFO, 2005.



Open-pit mining area before and after remediation. From: <http://nonuclear.se/sv/lindholm20070427.html> and <https://sv.wikipedia.org/wiki/Ranstad>



U and Ni concentrations in surface waters of Tranebärssjön and its recipient stream Pösan during the years 1999-2003 (10, 25, 75 and 90% percentiles and geometrical means). Station 630 is located in stream Hornborgaån 20 km downstream station 16. From: SVAFO, 2005.



Annual mean uranium concentrations in surface and bottom water of lake Tranebärssjön. From: SVAFO, 2005.

Radiological impact on environment and health:

A comprehensive radiological impact assessment of present radionuclide releases, in particular uranium, has been made by Stiglund and Aquilonius (Stiglund, 1999a, 1999b). The study is based on a compartment analysis including recent radiometric data. The study also includes exposure to chemicals/metals. They have assign farmers living in the vicinity of the Ranstad site to be the critical group. They have included consumption of locally produced meat and milk, fish captured in the lake Magasineringsjön and drinking water from groundwater drawn from limestone aquifer underneath the tailings.

Overall the radiological impact is rather insignificant, showing annual individual effective doses for the critical group of 0.04 and 0.01 mSv/year for the tailings site and lake Tranebärssjön effluents. The consumption of fish is the main source to the dose. Their model also includes long term assessment of collective dose. The main long term contribution to the dose is from uranium in groundwater from the tailings waste, i.e. long term leaching of uranium reaching the limestone aquifer. With the remediation performed until now, their model predict total collective doses of the order of 10 manSv within 500 years.

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Disclaimer

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Title	NORM-related Mining in Nordic Countries: Legislation, practices and case studies
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Abstract max. 2000 characters	The aim of the project was to explain and compare the current state, legislation and practices concerning naturally occurring radioactive material (NORM) -related mining in the Nordic countries. The focus was on the mines that are aiming at off-taking of uranium as a co-product or a by-product, or are processing ores, which contain high levels of NORMs. The project concentrated on investigating how the environmental factors and different origins of radionuclides affected their activity concentrations and transfer factors in ore, soil, water and vegetation.
Key words	NORM, mining, uranium