SSI-rapport 94-08

Hans Ehdwall, et al.

The content and environmental impact from the waste depository in Sillamäe

ISSN 0282-4434

Pris: 50 kronor

Statens strålskyddsinstitut
Swedish Radiation Protection Institute

Nummer / Number: 94-08

ISSN: 0282-4434

Datum / Date of issue: 19940822

Titelblad / Title page

Författare / Author:
Hans Ehdwall, Björn Sundblad, Vladimir Nosov, Henno Putnik, Raimo Mustonen, Laina Salonen, Henning Qvale

Avdelning / Division:

Huvudenheten för kärnenergi

Dokumentets titel / Title of the document:

The content and environmental impact from the waste depositor in Sillamäe.

Sammanfattning / Abstract:

The studies of the waste depository in Sillamäe, Estonia, shows that the content as well as the wall material is typical tailings from chemical enrichment of uranium ore.
The environmental impact from radioactive substances as well as heavy metals has been estimated.
Results show the major radiological impact to the population in the Sillamäe town is the exposure to radon and its daughter products emanating from the depository. The impact on the Gulf of Finland is limited to a few hundred metres outside the coast-line.

Nyckelord (valda av författaren) / **Key words** (chosen by the author):

Sillamäe, uranium, waste deposit, thorium, loparite, environmental radiation, modelling.

Antal sidor / Number of pages: 40

The Sillamäe project - Final Report

The content and environmental impact from the waste depository in Sillamäe

Foreword

In spring 1992, it was decided that a project investigating radiological and other hazards from the waste depository in Sillamäe, Estonia, should be initiated. The objective for this project was to quantify the environmental impact of the depository from the radiological point of view as well as risks from heavy metals at present and in the future. Two scenarios should be studied, the first one was that the integrity of the waste depository remains as it is today and the second one if, of some reason, the whole deposit suddenly at one instant moment would to slide down into the Gulf of Finland. These two cases are to be considered as extreme cases and would thus cover all other thinkable scenarios.

In addition the project should also propose measures to be taken to reduce present environmental impact and, in form of new projects, investigations and measures, propose the continuation of how to remediate the waste deposit area.

A project group with members from Finland, Sweden, Estonia and later from Norway was established and the first meeting, June 1992, was held in Sillamäe at the RAS Silmet plant.

Financing of the project has been secured by founds from the Finnish, the Swedish and the Norwegian governments. The contribution from Estonia has been in the form of manpower, without which, this project would have been impossible to fulfil.

This report is the result from many different contributers. The first initial investigations, 1992, were made by staff from the Swedish Radiation Protection Institute (SSI) and from the Finnish Center for Radiation and Nuclear Safety (STUK) and the results have earlier been presented in a pre document (1).

In 1993, the Norwegian Institute for Energy Technology, IFE, was given the assigment to make a more detailed investigation of the depository. This investigation was made in cooperation with the Norwegian Geotechnical Institute, NGI, and the Geotechnical

Engineering Bureau in Estonia (GIB). The results from this investigation are in detail presented in an special report (2).

Studsvik EcoSafe was assigned to make the modelling of the radiological environmental impact for two differnt scenarios where the first one was the present situation and the second if, of some reason, the content of the deposit suddenly was released to the Gulf of Finland. Results from this modelling are also presented in a report (5).

The original plans were that this first project should be finished by the end of 1993. However, the project group had to postpone that to a later date. As we today deliver our report to our orders we have behind us a lot of interesting work and good companionship. It have been of great value to us to have had this opportunity to work together in this international group and we hope that our work will be the input for the future restoration work at Sillamäe.

For the project group

Hans Ehdwall

THE SILLAMÄE PROJECT
Project group members

Mr. Hans Ehdwall	Swedish Radiation Protection Institute (SSI)
Mr. Björn Sundblad	Studsvik AB, Sweden
Mr. Vladimir Nosov	RAS Silmet, Estonia
Mr. Henno Putnik	Institute of Meteorology and Hydrology, Estonia
Mr. Raimo Mustonen	Finnish Centre for Radiation and Nuclear Safety (STUK)
Mrs. Laina Salonen	Finnish Centre for Radiation and Nuclear Safety (STUK)
Mr. Henning Qvale	Institutt för energiteknikk (IFE), Norway

Table of contents

The content and environmental impact from the waste depository in Sillamäe

1 Summary

During 1992 and 1993, investigations of the waste depository in Sillamäe have been made. Samples for the evaluation of radioactive substances as well as heavy metals have been taken from the deposit and its surroundings.

The major radiological impact to the population in the town of Sillamäe comes from the inhalation of airborne radon and its daughter products. The environmental impact to the Gulf of Finland can be observed only to the immediate coast line just outside the depository.

Collective committed radiation doses during 50 years for the present release and in the case of a sudden release of the whole content of the depository into the Gulf of Finland are in both cases estimated to be in the order of 1 manSv. Individual committed doses are estimated to be 1 and 2 µSv, respectively .

The results of the study indicate that the isotopic enrichment of ^{235}U has not been performed at the Sillamäe plant. Also there were no indications of dumping other kinds of radioactive waste in the depository.

The project group proposes that the Sillamäe project continues. Its task should be to investigate the possibilities for the restoration of the area. But before that the stability has to be investigated further and the limitation of erosion of the coast line must be considered.

2 Introduction

2.1 Background

Sillamäe is a small town in north east Estonia, some 185 km east of Tallinn. It has about 20 000 inhabitants and has been developed around the Sillamäe Metallurgy Plant, today the state joint-stock company called RAS Silmet. Until recently, the plant belonged to and was managed by the USSR Ministry of Medium-Scale Engineering and its production was uranium for military and civil use.

The Sillamäe Plant was built in 1948 as a top secret facility, originally for processing alum-shale (about 0.03% of U) from Estonia. Later uranium ore from eastern Europe (up to 1% of U) was processed. As a total, 4 013 000 tons of uranium ore were processed at the plant. Most of the ore was brought from Czechoslovakia (2.2 million tons) and from Hungary (1.2 million tons). Minor amounts of uranium ore were brought from Poland, Romania, Bulgaria and DDR. Until 1970, only uranium ore and alum-shale were processed at the plant. In the beginning of the 1970s the plant switched to processing of loparite - a mineral from the Kola Peninsula rich in niobium, tantalum and rare earth metals. In addition loparite also contains elevated concentrations of uranium (about 0.03%) and in particular thorium (0.6%). Since 1977, no uranium ore has been processed at the plant. Today the plant is operating only about 15-20% of its production capacity due to shortage of raw material and chemicals for the process.

The waste from the uranium processing was transported to the first marine terrace of Päite cape near the plant and stored at the surface until 1959, when a waste depository was established. The depository has been reconstructed a couple of times in the last decades and in 1969-70 it was expanded to its present size. Waste material from inside of the depository was then used for the construction of the walls of the impoundment. From 1977 to 1989 the depository has been used for the disposal of oil-shale ash and wastes from loparite processing. The annual volume of disposal of loparite waste in recent years had been about 20 000 tons per year, and oil-shale ash has been disposed over neighbouring area in west from the main depository during the last years.
Today, the depository is an oval retention impoundment on the waterfront of the Gulf of Finland with an overall area of about 330 000 m^2, containing some 8 million m^3 (about 12 million tons) of wastes, the top of the dam being

about 25 meters above sea level. About 30% of its area is covered by a sedimentary pond containing some 150 000 m^3 of acid waste water (pH ~ 2-3) with a depth of 0-3 meters.

An estimation of the substances disposed in the depository, given by the plant, indicates the following:

4 million tons of uranium processing residuals, 1.5 million tons of oil-shale ash, and waste from processing about 140 000 tons of loparite. These wastes contain totally some:
1.2 thousand tons of uranium, 0.8 thousand tons of thorium, and 4.4 x 10^{15} Bq (1.2 x 10^5 Ci) of naturally occurring radioactive elements (decay products of U and Th) of which about 3 x 10^{14} Bq (7000 Ci) is ^{226}Ra.

2.2 The main geological features of the area surrounding the Sillamäe waste depository[1)]

The main geological units underlying the Sillamäe waste depository are shown schematically on the geological profile (Fig. 2.1) to a depth of approximately 200 m. Above crystalline basement rest 200 m of Vendian sandstones, silts and clays of Vendian to Lower Cambrian age (600 - 550 million years). These strata are virtually horizontal and parallel and overlain unconformably at low angle by Lower Ordovician sandstones, siltstones and alum shales (age ca. 500 million years), and on top, Lower and Middle Ordovician carbonate rocks, forming the notable escarpment behind the depository.

The depository itself rests on Quarternary sediments, silts, sands and gravel, 3-6 m thick, covering the Lower Cambrian bedrock. The Lower Ordovician dictyonema shale, served in very early times as raw material for the production of uranium in the Sillamäe plant.

There are four main aquifers in the area: Cambrian - Vendian, Ordovician - Cambrian, Silurian - Ordovician and Quarternary. The Quarternary aquifer acts as a feeder to the Ordovician aquifers. The Cambrian - Vendian aquifer, which is the economically important of the four, is mainly fed through ancient vallies and tectonic dislocation zones, of which one easily recognisable is located below the depository and is traced south-eastwards below Sillamäe town.

In the last years the consumption of water (7000 m^3/day) from Cambrian - Vendian aquifer has significantly exceeded the natural supply. This has generated a depression of the Vendian - Cambrian aquifer system in the Sillamäe area, creating a possibility for conditions for migration of polluted water from the depository and the upper aquifer systems.

---

1) (Summarized from Valter Petersell)

Fig 2.1 Geological map (scale 1 : 25000) and profile

1-3. Vendian sedimentary rocks: 1. Gdov Formation, 2. Kotlin Formation. 3. Voronka Formation

4-5. Cambrian sedimentary rocks: 4. Lontova Formation, 5. Lükati & Tiskre Formation

6-8. Ordovician strata: Öland series 68.7, including Pakerord Formation (8)

9-11. Quarternary sediments: 9. Glacial sediments, 10. sediment from various stages of the Baltic Sea, 11. Mill tailings

12. Basement rocks

13. Sandstones and siltstones

I4 Siltstones and clays (argillites)

15. Alum shale (dictyonema)

16. Limestone (dolomite)

17. Waste depository

18. Fault/fault zones

19. Boundary between geological units

20. Klint

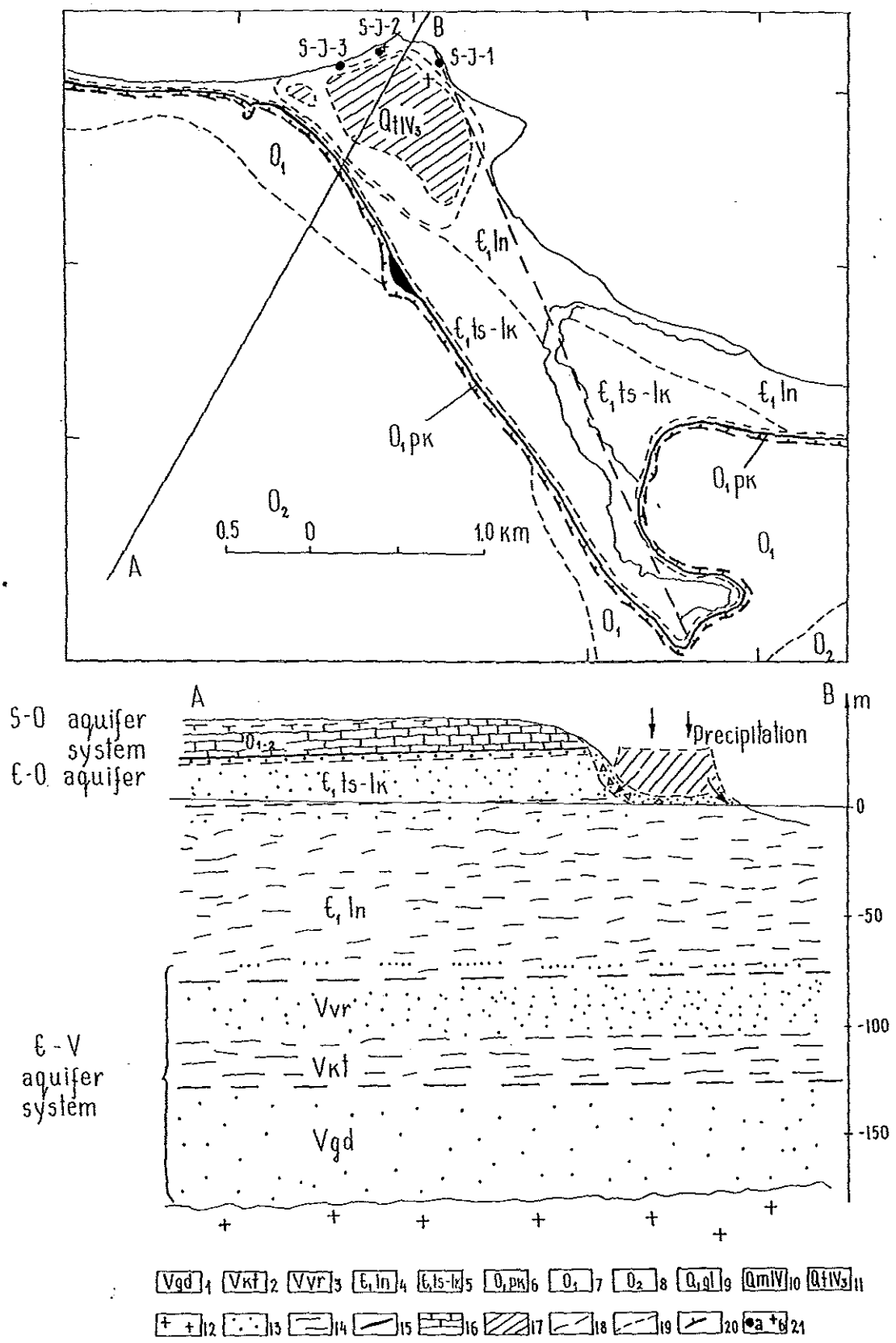


Fig 2.1 Scematic geological profile of the Sillamäe waste depository

3. MATERIAL AND METHODS

3.1 Pond

3.1.1. Radioactive elements

In September 1992, the first radiation measurements and sample collections were performed at Sillamäe by the project group. Samples of solid waste were taken from the surface of the impoundment wall at 25 different places. The samples were taken from the depth of about half a meter in the wall. The external dose rate, in μSv/h, was also measured at each sampling pit by a portable dosemeter. Two solid samples were taken outside the wall of the depository and these samples represent the older waste deposited in the beginning of the industrial operation at Sillamäe. Two samples were collected from the top of the depository to represent the waste of the present production of the plant. The sampling places of these samples are shown in Fig. 3.1.

In September 1993, samples from the inner parts of the depository were collected by drilling nine bore holes through the depository. The drillings were performed on the temporary road built across the top of the depository. The road was built out from each sidewall along an E -W profile (shown in Fig. 3.1) thus crossing areas anticipated to represent a wide range of steps in the history of the Sillamäe depository. Eight drilling sites were selected along the profile in order to be able to sample the major sections of the depository. The ninth site was selected near the southern rim where the records indicate a very early small depository. Totally 47 solid samples from the drilled cores were selected for measurements of radioactive elements. Two solid samples were collected outside the main depository (samples S-2 and S-3 in Fig. 3.1).

The concentrations of gamma-emitting radionuclides in dried solid samples were measured at STUK with high energy resolution gamma spectrometers. Both Li-drifted and high-purity germanium detectors were used. From natural radionuclides, concentrations of ^{238}U, ^{235}U, ^{226}Ra and ^{232}Th were measured. The concentration of ^{238}U was determined from the 1001 keV gamma line of ^{234}Pa, the ^{226}Ra concentration as a mean value of the results from the 295 keV, 352 keV and 1765 keV gamma lines of the short-lived radon daughters, and ^{232}Th concentration from the 911 keV gamma line of ^{228}Ac. The ^{235}U concentration was determined from the 186 keV gamma line after subtracting the proportion of ^{226}Ra in the gamma peak. The dried samples were measured in gas-tight aluminium containers after the ^{226}Ra, radon and its short-lived decay products were in radioactive equilibrium in the containers. The activity concentrations in the samples were calculated by using the computer software GAMMA-83 developed at the STUK. Concentrations of artificial gamma-emitting radionuclides in solid samples (if detected) were calculated with the same software.

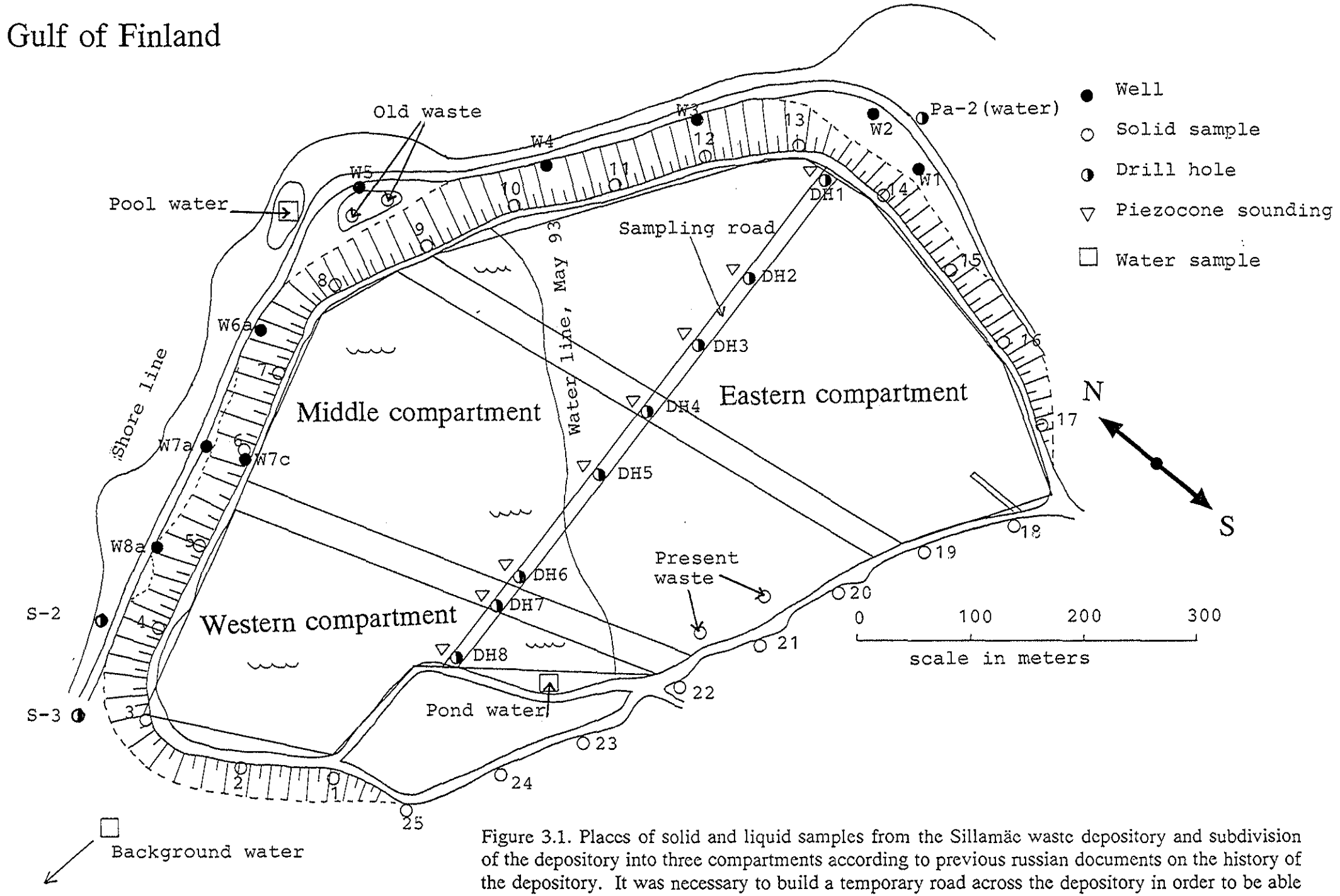


Figure 3.1. Places of solid and liquid samples from the Sillamäe waste depository and subdivision of the depository into three compartments according to previous russian documents on the history of the depository. It was necessary to build a temporary road across the depository in order to be able to drill samples from the inner parts of the depository and to make piozocone soundings.

Nine water samples were collected from the sampling wells drilled into the wall of the depository or into the soil outside the wall. These water samples were assumed to represent the radioactivity content of the liquid effluent migrating from the depository to the Gulf of Finland.

Three additional water samples were collected. Two of them were taken from the liquid waste in the depository and the third one was taken from a little pool between the depository and the Gulf of Finland. The same pool was sampled also in June 1992. The sampling places in the depository and in its nearby environment are shown in Fig. 3.1 The location of the wells in the wall or in the soil outside the wall are also shown in Fig. 3.1. The water level in the wells varied from a well to another but it was not recorded.

The pretreatment of the samples comprised preservation and filtration. All water samples were preserved by acidifying with concentrated hydrochloric acid (HCl) to pH 1 - 2. Water samples from the sampling wells were not clear, some suspended matter was precipitated in the bottom of the vials. Therefore those water samples were filtrated through 0.45 µm membrane filter and the two fractions, the filtrate and the suspended matter on the filter, were analysed separately. The water samples from the depository and the little pool were not filtrated.

The concentration of alpha and beta emitting nuclides were first screened by measuring their gross alpha and beta concentrations with a low background liquid scintillation spectrometer. This counting method allows the determination of gross alpha and beta but also uranium and ^{226}Ra contents in the simultaneous count. If the activity levels sufficiently exceed the background levels, the method usually gives sufficient accurate results for uranium and ^{226}Ra and does not call for the time-consuming radiochemical analyses. At present this method does not give exact values for uranium isotope ratio (^{234}U: ^{238}U) if the isotope ratio does not equal to1. Therefore uranium was also analysed by radiochemical methods.

The radiochemical analysis of uranium consisted the initial concentration of uranium with iron hydroxide, the purification of the uranium fraction by ion exchange and the precipitation of uranium with CeF_3 for the activity measurement with an alpha spectrometer. This method is very sensitive and allows the analysis of very low amounts of uranium and the uranium isotope ratio. No other radionuclides were analysed by radiochemical methods.

Gamma spectrometric methods, as described above, were used to measure the radioactivity in filters and in solid samples.

3.1.2 Chemical compounds

Before the analysis, the solid samples were dried (at 105 centigrades) for obtaining the dry-weight content. An amount of 0.5 grams of each solid

sample was dissolved in HNO_3. The metal content was determined by Plasma-emission spectrometry ICP-AES and Plasma-mass spectrometry ICP-MS at the Studsvik AB.

The total amount of heavy metals was determined, i.e. no filtration of the water samples was performed before the analysis. The water sample was acidified with 1 ml HNO_3 per 100 ml sample. The metal content was determined by Plasma-emission spectrometry ICP-AES, according to the EPA methods 200.7 and 200.8 (modified).

3.1.3 Stability

The stability of the depository has been evaluated by GIB and NGI based on the field work carried out in September 1993. A GIB drilling rig with trust capacity of 120 MPa (12 tons) performed PCPT (piezocone) soundings.

A complete set of self-contained piezocone equipment was brought from NGI to the site. This included the following equipment:

-Two Memocone piezocones (cone resistance capacity, 100 MPa)
-One Geoprinter and start box for data acquisition
-One depth encoder
-One 12 V battery and necessary cables

In addition, a complete set of data processing equipment (PC, plotter and printer) was installed to be able to make detailed plots of each sounding.

The Memocone is a battery operated 10 cm^2 cone (no cable to the surface) that measures the cone resistance (q_c), pore pressure (u) and sleeve friction (f_s) every second during penetration. A standard speed of penetration of 2 cm/sec was used and pore pressures were measured behind the cone. The Geoprinter measures the depth of the sounding and, after the cone is brought to the surface, the two data sets are matched.

During testing in Sillamäe, pre drilling by auger was necessary to penetrate hard soil layers when the capacity of the drill rig was reached.

The following tests were performed (total 83.74 m):

Loc. no. 1	sounding 1.0 - 3.62 m and 9.9 - 21.34 m
Loc. no. 2	sounding 1.0 - 4.60 m and 7.0 - 7.96 m and 9.9-20.32m
Loc. no. 3	sounding 1.0 - 5.54 m and 9.9 - 17.70 m
Loc. no. 4	sounding 9.0 - 14.6 m
Loc. no. 5	sounding 9.9 - 14.56 m
Loc. no. 6	sounding 9.9 - 15.58 m
Loc. no. 7	sounding 1.0 - 16.24 m
Loc. no. 8	sounding 1.0 - 13.28 m

A sample of the Cambrian clay from the seaside of the depository was tested in the laboratory. The laboratory testing comprised 1 incremental loading redometer test and 3 direct sample shear tests.

3.2 Ground water

Five ground water samples were analysed. Three of them were household water used in the town of Sillamäe and the fourth was from the factory. The fifth ground water sample was taken from a natural spring located at a distance of some 40 meters westwards from the western end of the depository (Fig. 3.1). The water flow in this area is towards the depository. Thus the spring water is not affected by the wastes in the depository, but is influenced by the neighboring abandoned alum-shale mines. Chemical content of this water is used as a "background" value, characterizing water which is naturally flowing in the sediments under the depository.

The ground water samples from the town and from the factory were sampled directly from the tap. This water used originates from deep ground water aquifers located in different geological deposits at depths of 125 - 230 meters.

Ground water samples were preserved as described earlier but they were not filtered. The analyses were carried out by low background liquid scintillation spectrometry. In addition the uranium content was also analysed radiochemically.

3.3 Radon measurements

In order to estimate the radiological impact of airborne radon originating from the depository, passive radon film detectors were placed at 9 different outdoor locations in the town of Sillamäe from October 1992 until March 1993. In addition, radon concentrations were also measured at five different places on the depository wall using a portable radon monitor[2] .

3.4 Marine

3.4.1 Chemical

The sediment samples were taken along the shore of the pond as well as at some more distant sites in the Gulf of Finland, see Figures 3.2 and 3.3. Samples from Station F45BW (0-5 cm), reference station, Site 1 (0 - 20 cm,. sliced into 5 cm intervals), Site 7 (0 - 2 cm), Site 9 (0 - 2 cm) and Site 10 (0 - 10 cm) were analysed. The treatment and analysis of the sediment samples was the same as for the pond samples, see section 3.1.2.

3.4.2. Radioactive elements

Samples of sea sediment were taken at four places in the Gulf of Finland. Two of the sampling points, 1 and 7 in Table 4.11, are the same as for the sea water samples. Sample number 1 is from the distance of about 11 kilometres from the shore line, and sample number 7 about four kilometres from the shore line. The two other sediment samples are from the distances of about 3 kilometres and 50 meters from the shore line respectively.

Concentrations of ^{238}U, ^{235}U, ^{226}Ra, ^{232}Th, ^{137}Cs and ^{134}Cs were measured with the gamma spectrometric method described in chapter 3.3.1.

In September 1992, sea water was sampled at eight locations. The sam-

---

[2] Dr E Realo, Institute of physics, Riia, EE 2400, Tartu, Estonia

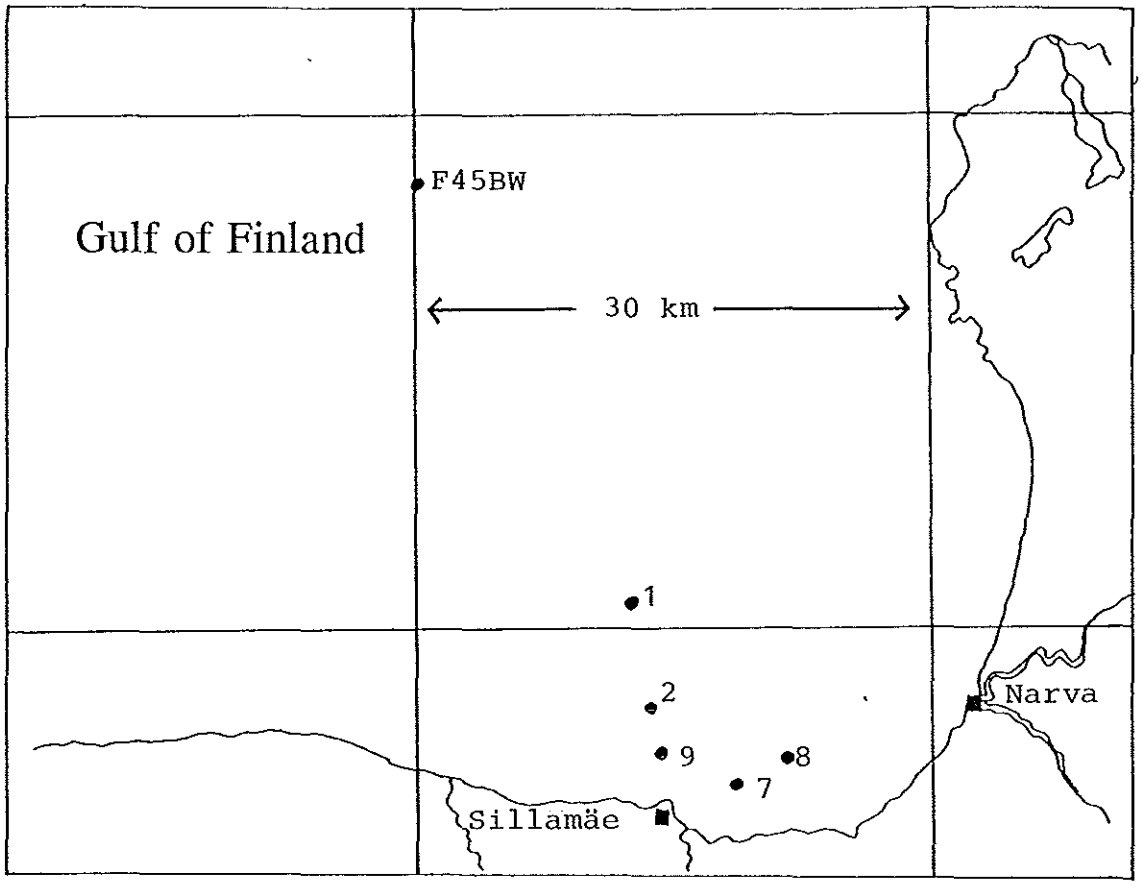
pling posisions are shown in Fig. 3.2 and 3.3. One sample was taken in the immediate shore nearest to the little pool (Fig. 3.1).

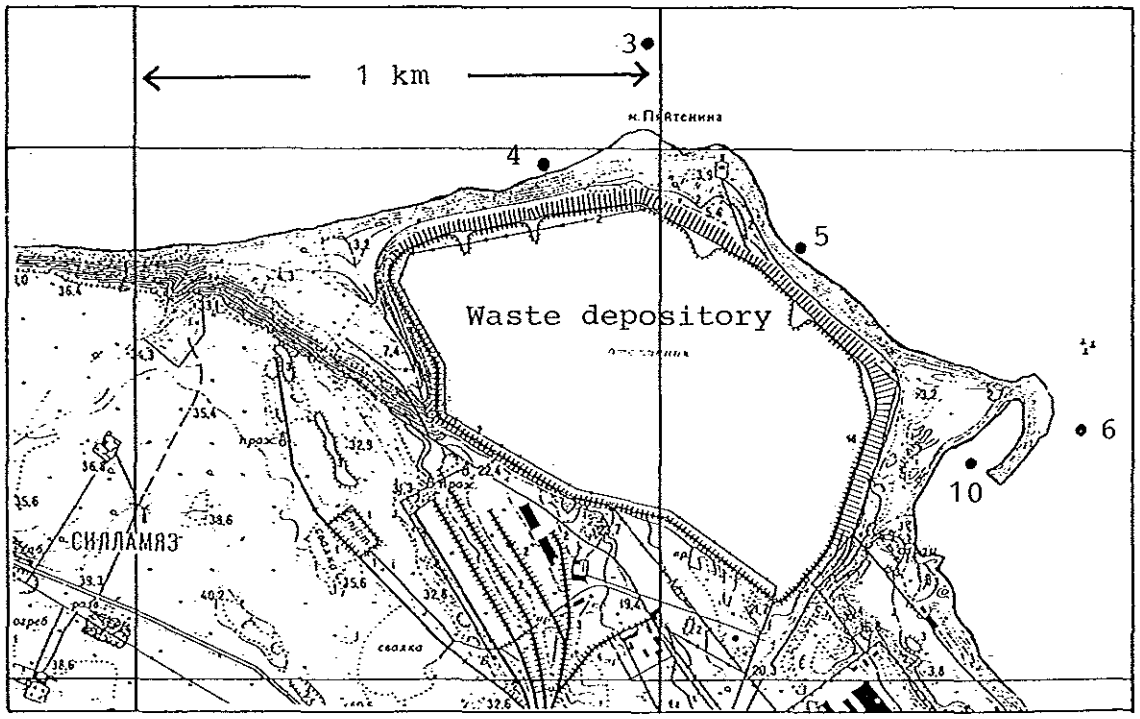
In order to compare the radioactivity levels in the near shore coastal waters of Sillamäe, with those in waters from other regions of The Baltic Sea, the results of four other sea water samples are presented here. These samples were taken by the research vessel Aranda in the summer 1991 from the Gulf of Finland and from the Bothnian Bay.

The sea water samples were acidified as described before. They were filtered through 0.45 µm membrane filter, which was wet ashed and the residue soluted and remixed with the filtrate and then analysed together by the same methods as the ground water samples.

3.4.3 Erosion of coast line

As the Sillamae waste depository is located directly on the waterfront of the Gulf of Finland, estimations of the erosion processes of the coast line is essential. Earlier investigations of erosion in the vicinity of the depository are missing. For the exploration of lithodynamical and morphodynamical processes, 13 profiles were established and measured across the beach in the vicinity of the waste depository. Repeated measurements of these profiles will, in the future, enable the quantitative estimation of the velocity and volumes of movement of the sediments.





Figures 3.2 and 3.3. Places of sea water and sediment samples from the Gulf of Finland outside the Sillamäe waste depository. The refernce site F45BW was sampled in 1991 within a radioactivity surveillance of the Baltic Sea.

4. RESULTS AND DISCUSSION

4.1. Depository

4.1.1. Radioactive elements

Radionuclide concentrations in the samples collected from the surface of the surrounding walls are presented in Table 4.1. These results, together with the external dose rates, show that the surface of the outer walls consists mainly of mill tailings from uranium enrichment.

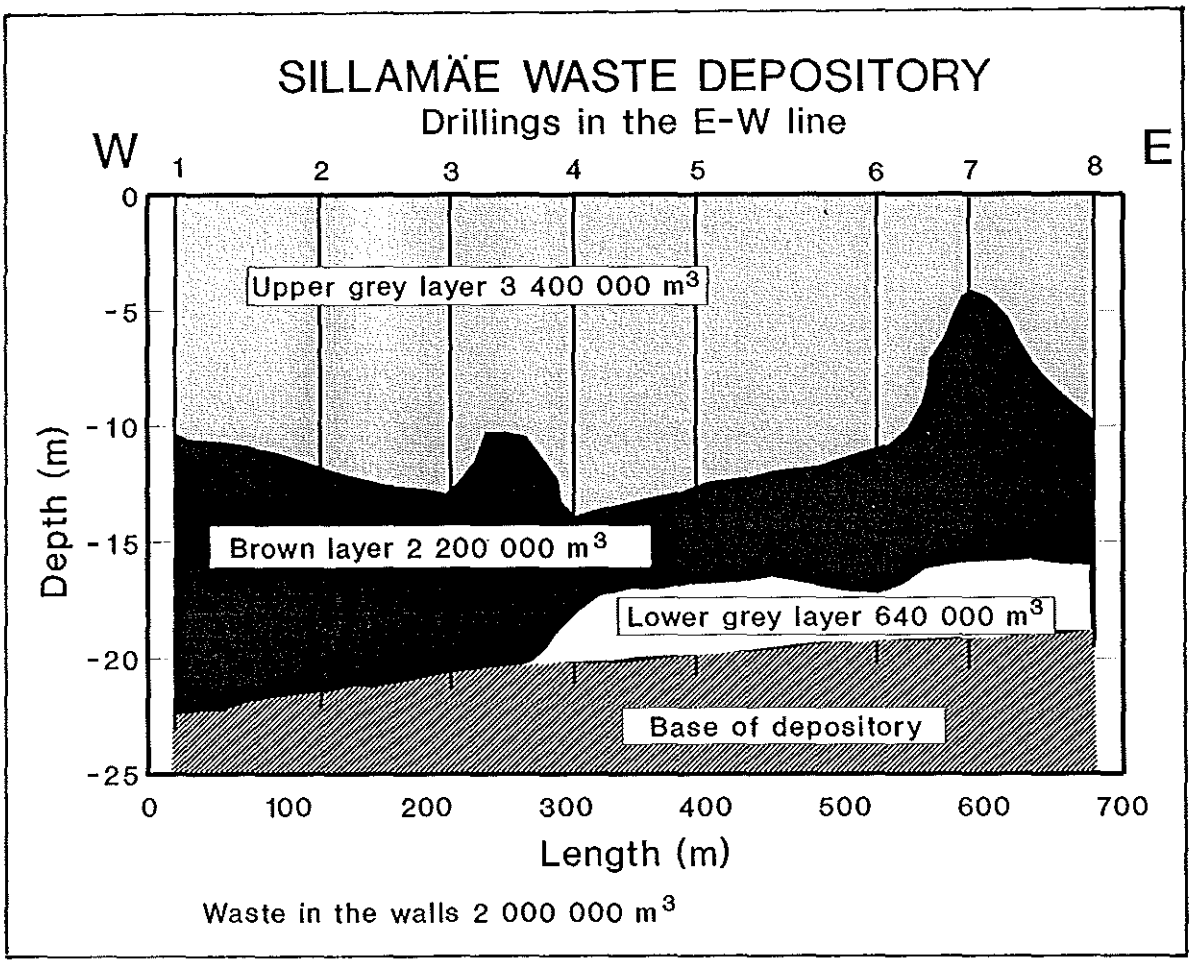


Figure 4.1. Rough presentation of different waste types on the drilling line across the Sillamäe waste depository. The upper grey layer mainly consists of waste from the present processing of loparite and from the waste ash of the local thermal power plant. The brown layer consists of uranium mill tailings and the lower grey layer of waste from the power plant.

Radionuclide compositions of the inner parts of the depository are presented in Table 4.2. On the basis of the results of the bored samples from the inner parts of the depository and on the information of the history of the deposition, the depository is subdivided into three compartments (Fig 3.1) and four waste types (Fig. 4.1). The volumes and the mean radionuclide concentrations of the different waste types are shown in Table 4.3. The uppermost

waste layer (the upper grey layer, 3.4 x 10^6 m^3) is a mixture of ash from the local power plant and waste from the loparite processing. The middle layer (the brown layer, 2.2 x 10^6 m^3) is mainly of uranium mill tailings, and the lowest layer (the lower grey layer, 0.64 x 10^6 m^3) is mainly of ash from the power plant. The fourth waste type consists of the outer walls of the depository (2.0 x 10^6 m^3) and it is a mixture of different wastes, the uranium mill tailings being the major component.

The investigations on the waste depository indicate that the total amount of uranium mill tailings in the depository is about 6.3 million tons. The rest of the wastes, about 6.1 million tons, is oil-shale ash and residue from the loparite processing. The total amounts of pure uranium and thorium in the depository are estimated to 1830 tons and 850 tons, respectively. The total amount of radium is estimated to 7.8 kg, corresponding to 2.9 x 10^{14} Bq of ^{226}Ra.

The total activity amounts of ^{238}U and ^{226}Ra in the uranium mill tailings (the brown layer) indicate that the mean uranium yield in processing the ore has been about 92% (91.9 ± 6.1%). The comparison of the concentrations of the uranium isotopes, ^{238}U and ^{235}U, in the uranium mill tailings shows that isotopic enrichment of ^{235}U has not been performed at the plant. The mean ratio of the activity of ^{238}U to ^{235}U in the brown layer is 18 ± 14, compared to 21.5 in natural uranium.

No indications on dumping of other kinds of radioactive waste in the depository have been found. The small amounts of the cesium isotope, ^{137}Cs, found on the surface layers of the depository walls, are traces from the global fallout in 1960's and from the Chernobyl accident.

There is one place outside the wall on the north side of the depository where the external dose rate is higher than the rest of the area and varying between 26 and 38 μSv/h. Two soil samples collected at this place contained high amounts of ^{226}Ra, 85 000 and 139 000 Bq/kg dry weight. The ^{238}U concentrations were 5500 and 3500 Bq/kg, respectively. This waste is assumed to have been produced in the beginning of the uranium enrichment at the plant or it is the waste brought thereto from elsewhere between 1948 and 1959.

The waste from the present production at the plant contains high amounts of thorium as well as elevated amounts of uranium and radium. ^{232}Th concentration of the two samples of the present waste from the top of the depository were 26 000 and 15 000 Bq/kg dry weight. Uranium concentrations were 2200 Bq/kg and 1500 Bq/kg, and radium concentrations were 1800 Bq/kg and 1400 Bq/kg, respectively.

The results of water samples are shown in Table 4.4. Concentrations of uranium in the well waters vary in a large range, between 4 - 400 Bq/l (170 - 16 000 μg/l). Most of uranium was soluted, in the filtrate, except two samples (from well 4 and 5) for which uranium was mainly in suspended matter. These two samples had also the lowest uranium contents. Due to the inhomogenity of the waste material in the depository as well as to different permeability and retention properties of the wall, large differences in activity concentrations could be expected.

Concentrations of ^{226}Ra and ^{232}Th seem to be below 1 Bq/l except in the sample from well 7c (^{226}Ra content was 7.9 Bq/l). This well is located in the point of the inner wall between the

middle and the western compartment of the pond. The high uranium and ^{226}Ra activities in this well are evidently due to the higher radioactivity of the waste material used for the construction of the inner wall.

The radionuclide concentrations in the depository water were quite equal to those measured in waters from the wells 1 and 2, which are located in the soil outside the wall. This indicates that the radionuclides soluted in depository water are not retained much by the wall materials or the soil.

The uranium content in the water from the little pool, located between the depository and the sea, is much lower than in the depository water. This might indicate that the pool water originates mainly from the ground waters from deeper soil layers and to a lesser extent from the depository. However its radioactivity comes from the depository (the uranium isotope ratio is 1).

The results from the water analyses show that uranium is much more soluble and mobile than radium or thorium. The results also indicate that the radioactive wastes in the depository have originated from the processing of uranium ore (the uranium isotope ratio is 1 within the error limits).

4.1.2 Chemical compounds

The content of 31 elements of the solid material from sites 1, 4, 6, 9, 12, 15, 19, 21, 27 and 29 were analysed[3] (See Figure 3.1). The wall samples represent a mixture of old waste. The observed values are presented in Table 4.5.

[3] See Sundblad B, 1992

The content of the samples from the wall, representing old waste is usually higher for most of the elements compared to the present waste . However, the concentration of La, Nb, Sr and Th in the present waste is much higher due to the different raw material used within the processing plant.

In the report from IFE (1994), four different waste types were identified. Three layers, upper grey, brown and lower grey, represent the material inside the wall. The fourth material is the wall itself. The content of B, Cd, Co, Cu, Fe, Mg, Ni, P, Pb and radionuclides are presented in the report. These values are within the ranges given in Table 4.5.

Water samples from nine wells surrounding the pond, pond water and water from a small pool north of the pond were analysed for the composition of 28 various elements. Background values of groundwater were also analysed. The composition of well, pond and "background" water is presented in Table 4.6.

Metals in the water such as Cu, Mo, Nb, Pb and Zn show very high concentration. These are considered to be the most important elements from hazardous point of view. Thus, they have been used in the risk assessment, see Section 5.

4.1.3 Stability

The stability of the deposit and the dam have been calculated making use of available data. The calculated factor of safety, F, varies from close to 0 (unrealistic) to far above 1.0 (stable). This large variation is mainly due to uncertainties related to the soil parameters selected for various soil types. However, from the model calculations and evaluations made on site one can estimate the factor of safety to

be low, close to 1.0. The dam and the deposit are stable under the present *in situ* conditions and stress distributions, but do clearly not meet international requirements for stability. It is therefore recommended that any changes made to the depository must be made so that the stability of the construction is increased. This can in principle be obtained by reducing the inclination of the upper part of the dam, and/or adding material at the foot of the slope. However, any future development of the dam will require an exact determination of the stability of the dam.

4.2 Ground water

The results from the ground water analyses are in Table 4.7. They show that the radioactivity of the tap waters in Sillamäe area is extremely low. The concentrations of uranium are lower than 0.01 Bq/l (1 µg/l) and the maximum ^{226}Ra concentration is 0.1 Bq/l. The ratio of uranium isotopes ^{238}U/^{234}U in the tap waters varies between 1.6 and 2.5. This indicates that the various tap waters utilised in Sillamäe come from different ground water aquifers. The thick soil deposits, especially the impermeable clay, have protected the underlaying ground waters from contamination of the radionuclides in the depository.

The concentrations of ^{226}Ra reported here might be too high. This is due to the low activity levels, which should be analyzed by a radiochemical method. The results, presented in Table 4.7, were calculated from the alpha spectra from the liquid scintillation spectrometer. Its spectra indicates that minor amounts of radioactivity from the thorium series are also present. ^{228}Ra is visible in the beta spectra and correspondingly some alpha nuclides in alpha spectra. This might explain the overestimation of the ^{226}Ra activity.

The radioactivity levels in ground waters in the Sillamäe area are low compared e.g. to those in ground waters from many areas in Finland. Hydrogeological conditions vary much in Finland and they differ from those in the Sillamäe area.

The spring ("background") water, westwards from the depository, has considerably higher uranium content (80 µg/l, ^{234}U/^{238}U activety ration is 1.2) than the tap waters from the deep ground water aquifers. This can be explained by the intensive weathering and leaching processes of uranium rich alum-shale in the abandoned mining area a few hundred meters in south from the out-flow of the spring.

4.3 Radon measurements

The results of the radon measurements show that airborne radioactivity in the form of radon and its daughter products is the major contribution to the radiation exposures to the population in the town of Sillamäe. Outdoor radon concentrations in the town, during winter time, is measured to be in the range of 14 to 130 Bq/m^3 (Fig.4.2) which could be compared to 5 to 10 Bq/m^3 which is considered to be the "normal" radon concentration. However, other sources of radon are also present and these sources make a significant contribution to the total radon concentration in the town. Most likely the origin of this radon is caused by the presens of uranium-containing oil shale layers in the soil.

Close to the waste deposit the radon concentration was 310 Bq/m^3. In order to estimate the radiation dose received from radon and its daughter products originating from the depository it is assumed that the outdoor radon concentration is increased with 10 Bq/m^3. That

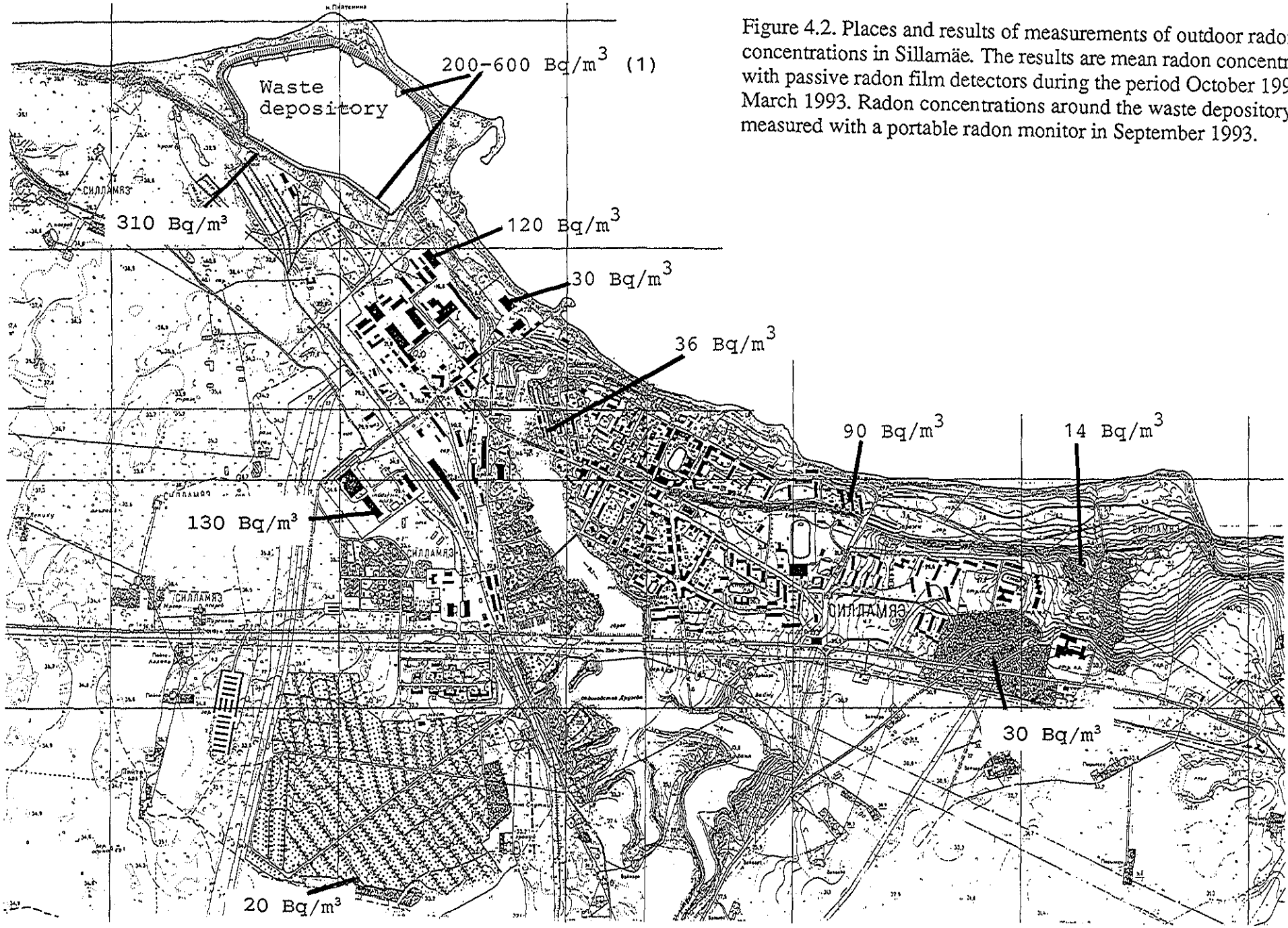


Figure 4.2. Places and results of measurements of outdoor radon concentrations in Sillamäe. The results are mean radon concentrations with passive radon film detectors during the period October 1992 - March 1993. Radon concentrations around the waste depository were measured with a portable radon monitor in September 1993.

would increase the annual individual dose with about 200 µSv.

Although this dose estimate includes many uncertainties it is however obvious that the radon emanating from the depository is the greatest source of radiation exposure.

4.4 Marine

4.4.1 Chemical

Results from the sediment sampling from the five sites are presented in Table 4.8. Comparisons with the reference site F45BW (Fig. 3.2) show no contamination from the Sites 1, 7 and 9. However, enhanced concentrations of As, Cu, La, Nb, Pb, Th, U and Zn are observed in the sediment at Site 10. This site is situated east of the pond in an area where accumulation can be expected due to the prevailing sea water currents.

4.4.2. Radioactive elements

Radionuclide concentrations in bottom sediment are presented in Table 4.9. Elevated concentrations of uranium and radium were detected in a shallow cove alongside the depository, where the sediment was typical organic "gyttja-clay". The highest concentrations of ^{238}U and ^{226}Ra were 450 and 470 Bq/kg dry weight. At all other sampling places the concentrations were at the level characteristic for the whole Gulf of Finland (see table 4.10). The concentrations of artificial cesium isotopes, ^{137}Cs and ^{134}Cs, were in all samples at the same level as in the Gulf of Finland in general.

The results of the bottom sediment and the sea water indicate that the actual consequences of the Sillamäe depository to the marine environment can be found only in a narrow coastal area. This can be explained by relatively small releases through the embankment and by the exposed character of the sea area. The coast is open without any archipelago. Thus the water currents and the effective water exchange with the open Gulf of Finland are promoting dispersion of radioactive and chemical substances in large water masses. Furthermore, the bottoms in the Narva Bay are mostly hard sand bottoms (erosion bottoms), where sedimentation does not occur, and the particulate matter is transported farther to the open sea.
Uranium, ^{226}Ra and ^{40}K in sea water samples from the environs of Sillamäe and uranium in sea water in the reference site F45WB of the Gulf of Finland are shown in Table 4.11.

The radioactivity in sea water was highest (U= 190 µg/l) in the immediate shore (place 9) in the shallow water. In two other places the uranium content in sea water was also clearly increased (27.7 and 43.0 µg/l). In all of these samples the uranium isotope ratio was about 1, which reveals that their uranium originates from the depository. In the other places, where the uranium contents were increased only slightly (uranium= 2 µg/l), the uranium isotope ratio was about 1.1. In these places only a part of the uranium originates from the depository while the rest is uranium normally present in sea water. (0.6 - 0.7 µg/l).

The concentrations of uranium in the sea water samples taken from the Gulf of Finland and the Bothnian Bay, in 1991, varied between 0.59 and 0.66 µg/l. These values are low and could be expected for the brackish water of the Baltic Sea compared to the big oceans, for which the values range from 1 - 5 µg/l. In nearshore coastal waters and estuaries the concentrations are more variable and usually lower than open-ocean values and

often vary with chlorinity. The uranium concentrations in the Baltic Sea seem to be very equal. Also their uranium isotope ratios varied in quite a short range, between 1.17 -1.39. The ratio for ocean waters has been reported to be 1.15, which is quite the same as obtained here for the Baltic Sea waters.

The results of the sea water samples show that the radioactivity of sea water is increased only in five sampling places in the nearby shore of the depository, not more than 300 meters away from the shore-line. In other sampling places the radioactivity was at the level typical to the Baltic Sea. This means that waste waters from the depository leak to the sea but they are mixed and diluted rapidly with the sea water.

4.4.3 Erosion of coast line

The preliminary exploration of the costal area in the vicinity of the Sillamäe waste depository indicates that the shore in front of the depository is affected by the active erosion process. During the recent years the shore has been strongly eroded in particular in north and north-west from the depository, in Figure 4.3.

The direction of the natural movement of beach sediments at the northern coast of Estonia is from west to east. Normal movement of sediments in the vicinity of the depository takes place from western parts of the shore-line and these areas are at present under active erosion (sections C and D in Figure 4.3).

The shore in front of the north-east (section B) and east (section A) slopes of the depository is not currently at risk from the erosion point of view. The beach in north-east from the depository is protected against heavy sea by chaotically piled up boulders and concrete blocks at the foot of the bluff, but in the western part of this coast-segment this kind of protection has proved insufficient. At present the eastern beach is growing as an accumulative spit, the material (pebbles and sand) accumulated there have been transferred from the western segments.

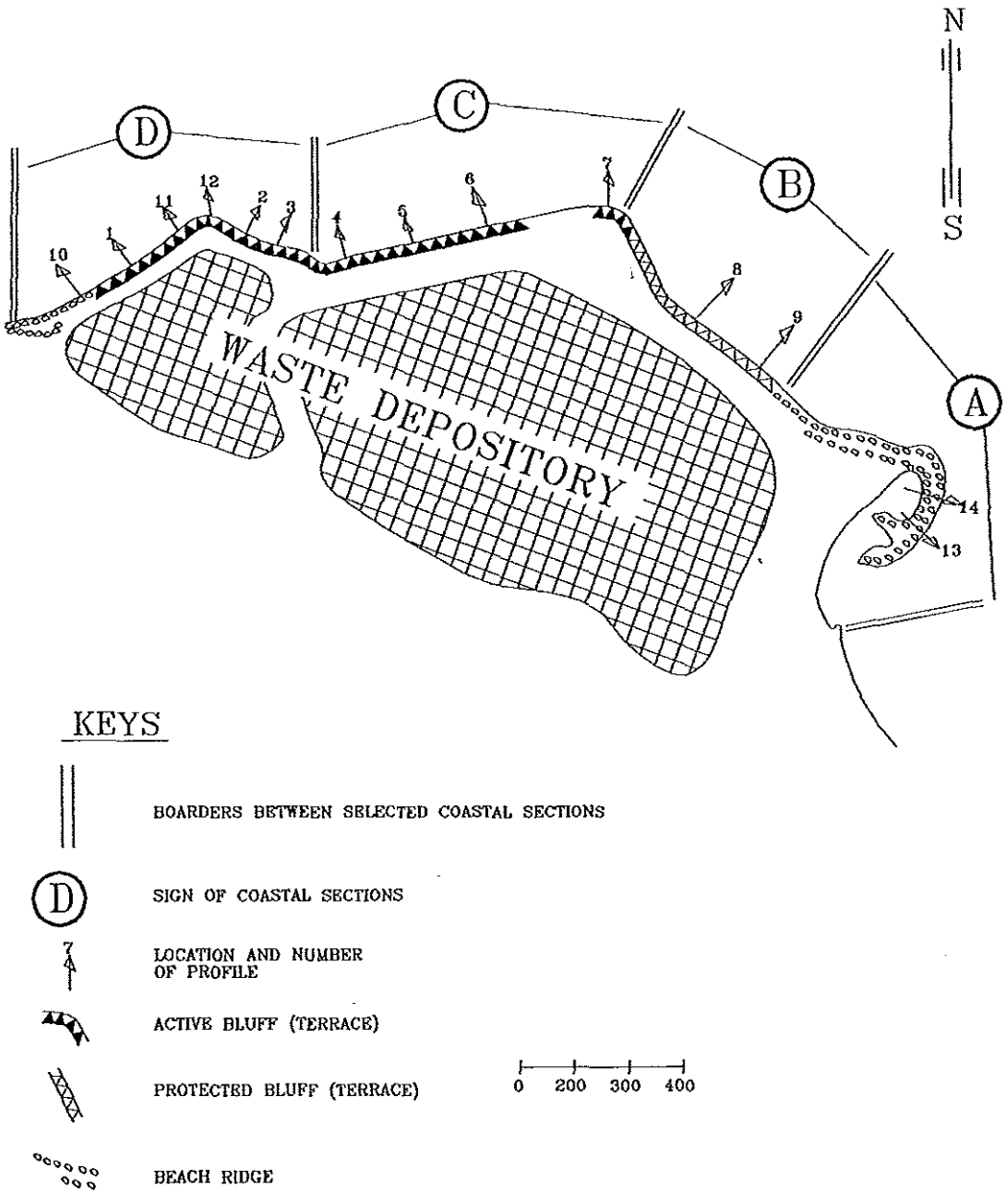


Figure 4.3. Classification of the shore-line in front of Sillamäe waste depository according to the strength of erosion. The segment A is an accumulation area and segment B is protected by the belt of boulders. Segments C and D are at present under active erosion.

5 Risk assessment - modelling

The information about the pond, the content of radioactive and chemical elements in the pond, leakage of these elements to the Gulf of Finland etc form the base for modelling the environmental consequences of the depository.

A risk assessment has been performed (Bergström et al, 1994) for the present situation, so called **normal situation**, and for **an extreme case** as a breakthrough, where the total amount of the liquid waste and up to 20 % of the solid waste is expected to enter the near shore area. The remaining waste is supposed to leak out with the same rate as the current situation. Leakage from the near-shore deposited elements to the overlying water is depending on their chemical solubility.

The model system used for the risk assessment is presented in Figure 5.1.

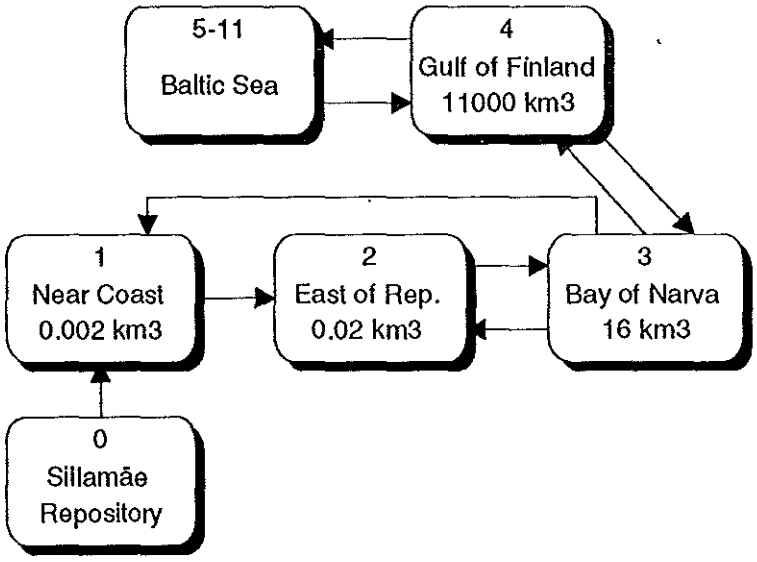


Figure 5.1. Compartment system used for the Sillamäe risk assessment

5.1 Normal situation

Individual doses are calculated for ^{238}U, ^{234}U, ^{232}Th, ^{226}Ra and ^{210}Pb. The consumption of fish, milk and meat is included in the calculations. However, the consumption of fish is the dominating exposure pathway. The results of the calculated committed effective doses during 50 years from the Bay of Narva are presented in Table 5.1.

5.2 Extreme case

5.2.1 Radionuclides

Consumption of fish is the dominant exposure pathway, and therefore sufficient for the dose calculation. The integrated individual doses after one and 50 years are presented in Table 5.2. The collective doses are presented in Table 5.3.

5.2.2 Chemicals

The elements, copper, zink, niobium, and molybdenium were chosen for the risk assessment of the chemical releases. These elements are expected to be the most important to study due to the high content and toxicity.

The total intake of metals via consumption of fish from the Bay of Narva has been calculated for different times up to 50 years. The calculated integrated intakes have been compared to limits of intake, where such limits are available, see Table 5.4.

5.3 Summary

Two scenarios have been studied, firstly the environmental impact at present conditions and secondly, the impact from a sudden dam collapse. Calculations show that the highest individual committed dose for the *present leakage* is less than 1 µSv. Furthermore, the individual committed dose for the *dam collapse* scenario will become about 2 µSv. The collective committed dose is about 1 manSv for both cases.

The impact from a sudden release of zinc, niobium, copper and molybdenum was also studied. The additional contribution to the content of zinc and niobium in the Bay of Narva will become negligible. On the other hand the concentration of copper and molybdenum will initially rise to considerable levels. The additional load from the depository will still after 50 years be in the same order as observed concentrations in the sea.

The intake of zinc and molybdenum via fish caught in the Bay of Narva will be well below the limits of intake, while the copper intake will be in the same order as the recommended. There are no limits for the niobium available.

6 Recommendations

6.1 Waste management project

Before any remedial actions can be started, the use of the present waste deposit must end. In order to ensure that the ongoing production of rare earthmetals can continue, a new high quality waste deposit must be constructed. This new waste deposit should meet requirements in accordence with what is usually accepted internationally and within the Estonian legal framework.

In view of the present production and its radiological and chemical hazards, occupational and environmental, the whole waste management must be considered. The project group therefore proposes that a new project, "Waste management in RAS-Silmet" should be initiated.

6.2 Investigation of stability

As shown by the initial investigation of the stability of the area close to the deposit, the possibility for a land slide could not be neglected. This must be taken into account when the choice of remedial actions is made. In order to have a complete basis for that kind of decision the project group proposes that the stability of the deposit and its surrounding area is investigated in more detail.

6.3 Decreasing Rn emanation, gamma exposure and leakage of radioactive and other substances into the Gulf of Finland.

As the major radiological impact to the inhabitants of the town of Sillamäe is from inhaled radon daughter products originating from the waste deposit, the emanation of radon should be decreased. This can be acheived by covering the deposit with layers of different materials. This method has been used in many locations all over the world already and may well be applicable here. In some places, just outside the deposit, gamma exposures are higher than normal. The origins of these enhanced levels could either be covered by protective material or removed to another location, perhaps inside the present deposit. The project group proposes that the Sillamäe project will continue with a second phase. The task of this phase should be to investigate and propose a plan for remedial actions to be taken in order to decrease the environmental impact from the deposit. The plan should also include to what level present impact should be reduced as well as the future use of the restored area.

6.4 Warning against constructions outside the deposit.

The environmental impact from the deposit today is not calling for immediate measures. However, if the erosion of the coast line continues or in some way is increased due to external constructions outside the shore line or if measures that might influence the stability of the area are performed, the integrety of the deposit might be jeopardised. The project group therefore proposes that constructions outside the deposit is restricted until it can be proven that such constructions will not jeopardise the present situation.

6.5 Information and documentation

The project group also proposes that all material, existing and what will be produced in the future, concerning the waste deposit, is collected and documented in a professional manner. This will simplify for desicion makers and public informers to get useful information of the Sillamäe life story.

7 Conclusions

The significant environmental impact from the waste deposit in Sillamäe to the Gulf of Finland is at present limited to a few hundred meters outside the shore line. Leakage from the depository is occurring but radiological and other hazards are today not as serious as belived in the beginning of the project. The major radiological exposures to the population in the town of Sillamäe due to the radon leaking from the depository is in the order of 200 µSv per year which corresponds to around 20% of the individual doses recieved in so called "clean areas" due to natural radiation. Collective committed dose during the fifty years to the population around the Gulf of Finland and the Baltic Sea is estimated to be in the order of 1 manSv.

Before restoration can be performed, additional work has to be done. Firstly there is the question of new waste managment plans for the factory, RAS Silmet, and secondly, investigation of the stability in order to take measures to keep the integrety of the deposit at least at the same level as it is today.

REFERENCES

(1) Ehdwall, Mustonen, Putnik, Salonen, Illus, Qvale, Sunblad and Nosov: Studies on the Waste Depository of the Sillamäe Plant, Swedish Radiation Protection Institute, Sweden 1993, (SSI 93-06)

(2) Munz I A and Qvale H: The Sillamäe Depository, Estonia - Site Investigations, Sampling and Analyses: Institutt for Energiteknikk, Kjeller, Norway 1994 (IFE/KR/F -94/034)

(3) Sundblad B: The Content of Metals and Radioactive Substances at the Sillamäe Depository. Studsvik AB, Sweden 1992 (Studsvik /NS -92/75)

(4) Mokkelbost K H and Kolstad P: Sillamäe -Estland. Soil investigations 1993. Norwegian Geotechnical Institute, Norway 1993 (NGI/932522-1)

(5) Bergström U, Nordlinder S and Aggeryd I: Leakage and accidental releases from Sillamäe waste depository and environmental risk assessment. Studsvik EcoSafe, Sweden 1994 (Studsvik/ES -94/26)

(6) Lutt J and Orviku K: Present State of the the Coastal Area around the Sillamäe Waste Depository. Results of the preliminary investigations. Institute of Geology, Estonian Acedemy of Science, Estonia 1993

(7) Mets M and Torn H: Review of investigations works in radioactive waste depository in Sillamäe. Report 223. Geotechnical Engineering Bureau in Estonia, 1993.

8 Tables

Table 4.1. Radionuclide concentrations in the samples collected from the surface of the walls of the Sillamäe depository and the measured external dose rates inside the sample pits.

Sample #	^{238}U	^{235}U	^{226}Ra Bq/kg dry weight	^{232}Th	^{137}Cs	Dose rate μSv/h
1	2800	150	12100	21	-	7.0
2	1800	100	20000	12	8.9	11.0
3	1960	90	14600	24	7.3	8.5
4	1850	90	11200	24	-	6.6
5	3000	140	20000	120	-	12.0
6	3000	150	16900	19	15	7.2
7	2470	100	24600	65	-	14.0
8	1870	80	17000	-	-	6.5
9	2300	100	24200	140	25	14.0
10	7600	310	72900	190	-	14.0
11	2200	100	14900	34	12	8.9
12	2840	150	36800	-	17	17.0
13	3100	130	12400	49	-	7.5
14	-	-	-	-	-	8.5
15	1800	80	10400	-	-	6.0
16	1540	70	14100	120	26	7.6
17	1700	75	11500	49	-	5.3
18	2100	90	9100	250	-	5.5
19	1230	50	980	570	220	2.7
20	1800	90	1300	800	50	3.1
21	9800	430	12300	250	210	9.2
22	2640	120	20600	29	-	7.2
23	2350	120	11100	40	-	7.0
24	1550	70	8900	39	-	5.7
25	2360	110	10000	16	-	4.8

(-) Not measured or the result below the detection limit

Table 4.2 Sillamäe core samples, results of the gammaspectrometic analyses

Cores: DH	Sample	Depth m	Material type	Ra-226 Bq/kg	U-238 Bq/kg	U-235 Bq/kg	Th-232 Bq/kg
1	A	11.4	b 1*	222000	3800	180	1900
1	C	13.5	b	85400	7000	330	53
1	E	16.0	b	129000	5800	490	25
1	F	17.0	b	135000	3800	480	30
1	G	19.0	b	143000	11000	560	40
1	H	20.5	b	123000	3200	450	30
1	I (Bag s.)	10.0-10.5	ug 2*	930	540	26	300
1	J (Bag s.)	21.6-22.0	b	100000	4000	250	150
2	A	15.6	b	77600	6500	310	110
2	B	18.0	b	76500	7700	300	330
2	C	19.1	b	203000	7100	400	30
2	D	19.7	b	56000	4000	310	86
3	B	3.5	ug	128	180	9	480
3	G	13.9	b	100000	6300	480	30
3	J	17.0	b	55500	5400	360	20
3	K	18.8	b	101000	5900	490	94
3	L	19.2	u.sand 3*	2270	1100	55	16
4	A	3.9	ug	168	250	11	194
4	C	12.4	ug	333	730	30	308
4	D	13.5	b	83000	3000	290	30
4	E	15.1	b	95900	8300	390	30
4	F (Bag s.)	17.0-17.4	lg 4*	2350	120	10	25
5	A	4.2	ug	296	410	20	733
5	B	7.7	ug	1040	2000	120	2490
5	D	12.4	b	42900	3500	250	74
5	E	13.8	b	102000	8100	480	30
6	B	4.3	ug	810	2100	89	1830
6	C	6.6	ug	760	3100	150	1480
6	E	8.2	ug	190	2900	150	490
6	F	10.4	ug	2300	3600	170	3010
6	G	11.7	b	35900	2300	400	40
6	I	14.8	b	103000	5200	350	30

table 4.2 cont´d

Cores: DH	Sample	Depth m	Material type	Ra-226 Bq/kg	U-238 Bq/kg	U-235 Bq/kg	Th-232 Bq/kg
7	B	5.0	b	50200	14000	730	110
7	D	8.5	b	84700	2300	290	30
7	F	11.6	b	22200	1400	160	25
7	H	14.1	b	9750	1600	260	17
7	I	14.8	lg	642	300	17	15
8	A	4.5	ug	2040	3200	170	4000
8	C	10.3	b	30000	3300	390	210
8	D	11.5	b	28100	1700	300	30
8	E	12.7	b	50400	2700	240	20
8	F	14.5	b	12800	1500	32	20
9	B	6.2	ug	810	1100	62	1030
9	D	12.9	b	181900	8500	410	1400
9	E	13.6	b	177000	9000	460	1200
9	F	14.6	lg	6770	2500	140	24
9	G (Bag s.)	8.0-8.3	ug	610	4200	200	240
S-2	(Bag s.)		s.sand 5*	68	81	3	12
S-3	(Bag s.)		n.dep 6*	32	34	2	15

1* b=brown
2* ug=upper gray
3* u.sand= underlaying sand
4* lg=lower gray
5* s.sand=shore sand
6* n.dep=new deposit

Table 4.3. Volumes and mean radionuclide concentrations of the different waste types in the waste depository of Sillamäe.

Material type	Volume (m^3)	Bq/kg (dry weight)			
		^{239}U	^{235}U	^{226}Ra	^{232}Th
Upper gray	3.4×10^6	2000	90	500	1200
Brown	2.2×10^6	500	300	80 000	100
Lower gray	0.64×10^6	300	15	2000	20
Outer walls	2.0×10^6	3000	200	50 000	100

Table 4.4. Radionuclide concentration (Bq/l) in water samples collected in September 1992 from wells drilled into the walls of the depository or into the soil outside the wall and from the depository itself and a pool. Samples from the walls were filtrated through 0,45 μ membrane filter and filtrate and suspended solids were analyzed separately.

Samling place	Well location	Concentration[1] in filtrate (Bq/l)					Concentration[2] in suspended matter on filter (Bq/l)				
		^{238}U	^{234}U	U μg/l	^{226}Ra[3]	^{234}U:^{238}U	^{238}U	^{235}U	U μg/l	^{226}Ra	^{232}Th
Well 1	In soil outside the wall	30.0	30.2	2450	0.60	1.01	2.9	0.083	240	0.04	0.042
Well 2	-"-	35.6	36.2	2900	0.04	1.02	3.3	0.12	270	0.02	0.059
Well 3	In lower edge of the wall	76.2	76.4	6200	0.12	1.00	2.7	0.11	220	<0.02	<0.04
Well 4	In outer edge of the wall	0.21	0.21	17	0.15	1.01	2.5	0.094	200	0.47	0.071
Well 5	In soil outside the wall	0.18	0.18	15	0.10	1.02	1.9	0.092	160	0.08	0.040
Well 6 a	In outer edge of the wall	10.8	11.1	880	0.04	1.02	2.3	0.051	180	0.08	0.077
Well 7 a	-"-	110	110	8980	0.13	1.00	2.5	0.10	6	0.06	0.024
Well 7 c	In inner edge of the wall	173	167	14100	0.87	0.97	13	0.21	1070	7.9	0.037
Well 8 a	In outer edge of the wall	192	190	15700	0.37	0.99	5.1	0.17	410	0.07	<0.07
Pond	no filtration	33.4	34.7	2700	0.05	1.04					
-"-	-"-	34.1	34.4	2780	0.11	1.01					
Little pool	-"-	2.98	2.95	240	0.07	0.99	0.06	0.002	5	<0.02	0.002
Little pool.[4)]		1.15	1.13	94	0.09	1.02					

[1] Determined by radiochemical and alphaspectrometric method.
[2] Determined by gammaspectrometric method. Results have been corrected to correspond the concentration in the filtrate.
[3] Calculated from alpha spectrum measured with a liquid scintillation spectrometer.
[4] Sampling date 16th June 1992.

Table 4.5 The content of solid material.

Element	Unit	Wall	Old	Present
Al	%	2.3 - 5.6	5.4	0.4
Ca	%	4.2 - 21.9	9.6	21.2
Fe	%	2.2 - 3.6	4.0	0.4
K	%	1.0 - 2.3	2.1	0.1
Mg	%	1.2 - 0.7	0.8	0.2
Na	%	0.2 - 1.3	0.5	0.7
P	%	0.09 - 0.59	0.20	0.09
Ti	%	0.2 - 0.7	0.2	4.9
Mn	%	0.20 - 0.95	0.05	0.01
Ba	%	0.02 - 0.27	0.03	0.03
As	ppm	73 - 659	858	<8
Ag	ppm	2.0 - 16.1	17.8	<2
Be	ppm	<2.0 - 3.2	4.9	<2
Co	ppm	3.0 - 37.2	7.6	<25
Cr	ppm	39 - 64	95	28
Cu	ppm	50 - 323	268	65
La	ppm	12 - 333	30	10 800
Mo	ppm	<12 - 40	15	15
Nb	ppm	22 - 345	58	8 880
Ni	ppm	30 - 54	42	57
Pb	ppm	76 - 497	1 050	279
Sc	ppm	3.9 - 7.4	8.6	32.1
Sn	ppm	<12	<12	37
Sr	ppm	141 - 627	275	7 240
Zn	ppm	167 - 564	331	46
Zr	ppm	51 - 153	111	579
V	ppm	52 - 221	374	<25
W	ppm	<12 - 14	23	<12
Y	ppm	8.8 - 23.5	28.1	42.3
Th	ppm	1.2 - 78.1	11.3	3 750
U	ppm	35 - 299	290	42

Table 4.6 The composition of water.

Element	Unit	Well	Pond	Background
Na	mg/l	775 - 1 190	1 030	21
K	mg/l	177 - 768	87	28
Ca	mg/l	119 - 582	701	308
Mg	mg/l	37 - 436	123	114
Fe	mg/l	0.04 - 1.9	125	0.45
Mn	mg/l	0.01 - 6.9	7.0	2.4
B	mg/l	0.13 - 1.8	0.42	0.06
Al	mg/l	<0.3	30	<0.1
Si	mg/l	0.1 - 1.3	0.3	4.6
P	mg/l	0.4 - 3.6	25	0.1
S	mg/l	1 770 - 10 700	17 400	460
As	µg/l	<150	<300	<30
Ba	µg/l	5 - 67	95	88
Cd	µg/l	<25	111	<5
Co	µg/l	35 - 61	1 520	<7
Cr	µg/l	35 - 70	2 810	<7
Cu	µg/l	25 - 13 100	2 830	<5
Hg	µg/l	<0.8 - 12	<4	<2
La	µg/l	35 - 52	1 930	<7
Li	µg/l	74 - 260	135	39
Mo	µg/l	1 270 - 6 760	<40	6
Ni	µg/l	100 - 411	3 250	<20
Pb	µg/l	<250 - 334	<500	<50
Sr	µg/l	2 230 - 12 300	73 900	293
U	µg/l	6 - 37 200	2 800	60
V	µg/l	<25	<25	<5
Zn	µg/l	<20 - 4 410	10 400	5

Table 4.7. Uranium and ^{226}Ra concentrations in ground water samples in the Sillamäe area.

Sampling place	Water	^{234}U Bq/l	^{238}U Bq/l	U µg/l	$^{234}U/^{238}U$	^{226}Ra[1]
40 m westwards from depository	Spring water	1.18	0.99	80.8	1.2	0.01
Factory, laboratory	Tap water	0.0031	0.0016	0.13	1.9	0.02
Main factory	"	0.0035	0.0014	0.11	2.5	0.13
Hospital	"	0.0051	0.0032	0.26	1.6	0.04
Hotel	"	0.0015	0.0008	0.06	1.9	0.15

[1] Calculated from alpha spectrum measured with a liquid scintillation spectrometer

Table 4.8 The composition of sediment in the Finnish Gulf.

Element	Unit	Site 1 0 - 5 cm	Site 1 5 - 10 cm	Site 1 10 - 15 cm	Site 1 15 - 20 cm	Site 7 0 - 2 cm	Site 9 0 - 2 cm	Site 10 0 - 10 cm	F45BW 0 - 5 cm
Al	%	6.0	6.1	6.0	6.2	4.8	2.5	3.4	5.6
Ca	%	0.85	0.84	0.73	0.67	0.82	0.83	4.0	0.83
Fe	%	3.1	3.1	2.9	2.9	2.6	1.0	2.6	3.4
K	%	2.9	2.7	2.5	2.9	2.1	1.2	1.8	2.4
Mg	%	0.93	0.90	0.83	0.87	0.77	0.21	1.2	0.93
Na	%	1.16	1.12	1.12	1.12	0.91	0.69	0.46	1.41
P	%	0.12	0.13	0.09	0.08	0.13	0.25	0.15	0.17
Ti	%	0.33	0.33	0.32	0.35	0.27	0.15	0.24	0.24
Mn	ppm	460	385	357	352	415	216	888	6 310
As	ppm	9.4	12.5	11.4	<2.9	<3.0	6.5	33.8	11.8
Ag	ppm	7.4	7.0	6.8	6.6	6.2	4.1	8.7	7.1
Ba	ppm	484	498	511	509	553	645	433	1 540
Be	ppm	2.07	2.06	2.02	2.15	1.88	1.08	1.61	1.76
Co	ppm	11.9	13.2	12.0	11.8	9.40	3.66	10.3	15.5
Cr	ppm	55.7	56.8	47.1	50.3	38.0	14.9	32.1	48.8
Cu	ppm	33.9	32.4	25.9	21.5	22.8	10.8	68.1	25.6
La	ppm	34.5	34.9	35.1	35.2	34.7	29.0	136	32.8
Mo	ppm	<5.1	<4.9	<5.0	<4.9	<5.0	<4.9	<5.0	6.1
Nb	ppm	15.6	15.2	14.5	18.0	15.5	9.3	158	13.8
Ni	ppm	26.9	25.9	23.4	23.3	19.8	7.1	33.0	30.6
Pb	ppm	32.9	36.9	32.6	25.6	20.9	17.4	60.0	24.1
Sc	ppm	7.8	7.8	7.3	7.8	5.3	<0.9	4.3	6.9
Sn	ppm	<5.1	<4.9	<5.0	<4.9	<5.0	<4.9	<5.0	<5.0
Sr	ppm	123	126	126	123	116	124	108	189
Zn	ppm	104	118	94	82	60.0	25	224	81
Zr	ppm	177	180	186	189	183	190	144	131
V	ppm	68.0	67.7	65.0	67.6	48.8	17.7	76.0	60.7
W	ppm	<5.1	<4.9	<5.0	<4.9	<5.0	<4.9	<5.0	<5.0
Y	ppm	24.9	25.6	25.4	25.9	24.2	22.5	24.1	19.2
U	ppm	5.1	5.1	5.0	4.9	5.0	3.6	40.7	3.9
Th	ppm	9.0	10.0	9.4	10.8	11.5	9.5	22.3	10.6

Table 4.9. Radionuclide concentrations in bottom sediment samples from the Gulf of Finland ouside the Sillamäe town.

Sample #, depth	^{238}U	^{235}U	^{226}Ra	^{232}Th	^{137}Cs	^{134}Cs	^{212}Pb
	Bq/kg dry weight						
7(I), 0-2 cm	66	3.0	59	52	40	2.4	-
7(II), 0-2 cm	78	5.3	63	84	36	3.6	-
9(I), 0-2 cm	48	2.4	73	43	46	3.1	-
9(II), 0-2 cm	56	3.2	76	41	26	1.3	-
10(I), 0-7 cm	250	22	470	33	66	7.0	2140
10(II), 0-10 cm	450	36	380	63	100	8.8	-

Table 4.10. Depth distribution of the radionuclide concentrations in two samples of bottom sediment from the Gulf of Finland about 11 kilometers from the Sillamäe town.

Sample	^{238}U	^{235}U	^{226}Ra	^{232}Th	^{137}Cs	^{134}Cs	^{212}Pb
	Bq/kg dry weight						
1(I),							
0-5 cm	64	6.5	68	51	760	60	840
5-10 cm	65	4.0	73	52	760	60	960
10-15 cm	94	4.1	108	46	170	9.1	980
15-20 cm	70	2.5	127	53	51	-	1050
1(II),							
0-5 cm	60	3.7	70	46	680	54	-
5-10 cm	90	7.0	115	51	170	11	-
10-15 cm	74	6.8	105	51	17	-	-
15-20 cm	67	3.5	71	52	2.7	-	-

Table 4.11. Radionuclide concentrations in sea water samples collected in the nearly shore of depository and Sillamäe in September 1992 (Fig. 2 and 3).

Sampling place	^{234}UBq/l	^{238}U Bq/l	U µg/l	^{234}U:^{238}U	^{226}Ra[1] Bq/l	^{40}K Bq/l
1	0.0132	0.0113	0.92	1.17	<0.01	1.50
2	0.0106	0.0084	0.69	1.26	<0.01	1.60
3	0.0273	0.0248	2.02	1.10	<0.01	1.55
4	0.328	0.340	27.7	0.96	<0.01	1.59
5	0.535	0.527	43.0	1.01	0.01	1.92
6	0.0300	0.0277	2.26	1.08	0.01	1.64
7	0.0115	0.0088	0.72	1.31	<0.01	1.48
8	0.0107	0.0090	0.73	1.20	<0.01	1.52
9[2]	2.24	2.28	190	0.98	0.03	-
F45BW[3]	0.0077	0.0094	0.63	1.22	-	-

[1] Calculated from alpha spectrum measured with a liquid scintillation spectrometer
[2] Sampling in June 1992
[3] Reference site, collected in 1991
- not analyzed

Table 5.1
Individual committed effective doses during 50 years from the Bay of Narva and collective committed effective doses during 50 years. Normal situation.

Element	Individual (Sv)	Collective (manSv)
^{238}U	5E-7	0.5
^{234}U	5E-7	0.6
^{232}Th	3E-10	2E-5
^{226}Ra	2E-9	3E-3
^{210}Pb	3E-9	3E-3

Table 5.2
Integrated individual doses (Sv) at different times as best estimate, minimum and maximum of 95 % confidence level. Dam break.

Element	Time	Best estimate	Min	Max
^{238}U	1 year	6.4E-9	1E-9	2E-8
	50 years	5E-7	7E-8	2E-6
^{234}U	1 year	6.3E-9	1E-9	2E-8
	50 years	5.0E-7	9E-8	2E-6
^{232}Th	1 year	1.5E-10	4E-12	1E-9
	50 years	9.8E-9	2E-10	6E-8
^{226}Ra	1 year	2.0E-9	2E-11	1E-8
	50 years	1.9E-7	2E-9	1E-6
^{210}Pb	1 year	3.6E-8	1E-9	2E-7
	50 years	6.4E-7	2E-8	3E-6

Table 5.3
Collective committed effective doses (manSv), 50 years after dam break as best estimate, minimum and maximum of 95 % confidence level.

Element	Best estimate	Min	Max
^{238}U	6.3E-1	1E-1	2E+0
^{234}U	6.4E-1	1E-1	2E+0
^{232}Th	6.4E-4	9E-6	5E-3
^{226}Ra	2.2E-1	3E-1	1E+0
^{210}Pb	1.8E-1	3E-3	1E+0

Table 5.4
Integrated intake of metals (mg) after dam break as best estimate, minimum and maximum of 95 % confidence interval and comparison with recommended intake.

Element	Time	Best estimate	Min	Max	Recommended intake limit
Cu	1 year	6.9E+1	1E+1	2E+2	3.7E+2
	50 years	3.5E+2	3E+1	3E+3	1.8E+4
Zn	1 year	3.8E+0	3E-1	2E+1	4.4E+3
	50 years	9.0E+0	9E-1	5E+1	2.2E+5
Nb	1 year	7.6E-2	7E-3	4E-1	
	50 years	3.0E+0	2E-1	1E+1	
Mo	1 year	1.4E-2	7E-4	9E-2	2.5E+3
	50 years	2.0E-1	1E-2	9E-1	1.3E+5

SSI-rapporter

94-01. Publikationer
SSI-Informationsenheten. *Gratis*

94-02. Magnetfält från barnkuvöser och barnvärmebäddar.
Gert Anger *50 kr*

94-03. Datorstödd patientdosimetri vid angiografiska röntgenundersökningar.
Lasse Jangland, Ragnar Neubeck *50 kr*

94-04. Persondosmätningar Årsrapport 1993
Lars Bergman *25 kr*

94-05. Kärnkraftindustrins - aktivitetsutsläpp - yrkesexponeringar 1993
Huvudenheten för kärnenergi *50 kr*

94-06. Environmental Impact Assessment of the Swedish High -Level Radioactive Waste Disposal System- examples of likelyconsid-erations.
Huvudenheten för kärnenergi *50 kr*

94-07. Radioactive Waste in theRussian Fed-eration.
Bertil Grundfelt, Björn Lindbom *50kr*

94-08. The content and environmental im-pact from the waste depository in Sillamäe.
Hans Ehdwall, et al. *50 kr*