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Radon in Estonian Buildings

ESTABLISHMENT OF A MEASUREMENT SYSTEM AND OBTAINED RESULTS

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CONTENTS.

SUMMARY

The radon project as a part of the Swedish East European co-operation programme in the field of radiation protection made possible the indoor radon monitoring in Estonia. One purpose for this project was the establishment of a radon monitoring programme inside of the state environmental monitoring programme. Another purpose was to investigate regions, expected to have high radon levels indoors.

A new method for the long-term measurement of indoor radon was established and the staff for these measurements was trained.

The results of the measurement can be used by Estonian decision-makers to work out the respective rules and standards. There is no legislative act in the field of radiation in the Republic of Estonia at this time.

To summarize the results of the measurements we can say that indoor radon concentrations vary by regions. The radon investigations must be continued to identify the radon risk areas and types of housing construction. The results of the state radon monitoring are provided to the municipalities, who advise the owners of new houses to select the right construction for the house.

A new project will follow (EST 6-05) with an investigation of radon in randomly selected dwellings, training and equipment for radon measurements in soil, and general advice with regard to radon, as well as assistance in preparing information about radon.

INTRODUCTION.

Background and objectives.

The elevated indoor radon concentration as a hazard to human health was recognised in Estonia at the end of the 1980s. Information about radon problems was mostly acquired from Western Europe, especially from publications in Sweden and Finland. Public attention was drawn to the problems of natural radioactivity and to the possible existence of high indoor radon concentrations by the "Sillamäe case" in 1989. Until then all the data concerning ionizing radiation as well as natural radioactivity had been kept secret. Since December 1989 until 1991 the radon measurements have been carried out by the Estonian Building Research Institute (EBRI) and from 1992 by the Estonian Meteorological and Hydrological Institute (EMHI). The radon concentrations have been measured in:

1) indoor air
2) soil air
3) building materials produced in Estonia
4) groundwater and tap water

Most of the earlier measurements were made by grab sampling using Pylon AB-5. Some were made by using alpha-track detectors from Finland and Sweden, which were analysed in the Finnish Radiation Protection Centre or the Swedish Radiation Protection Institute (SSI). The results of the measurements made by the Department of Building Physics of the EBRI in 1989 - 1991 [1] show that the main source of indoor radon in Estonia is the soil under the buildings.

The present project is a part of the Swedish East Europe co-operation programme in the field of radiation protection, called Project Radiation Protection East.

The objectives of the project were:

1. establishment of a system for radon measurements in buildings in Estonia and the training of the staff for these measurements;
2. overview of the radon problems in Estonia.

Estonian dwelling stock.

Multi-family houses are dominant in the Estonian dwelling stock. One million or 2/3 of the population in Estonia live in apartment houses. Single-family houses are more common in rural areas, but almost half of the rural population also live in multi-family houses. Today's dwelling stock consists of three major types of houses - brick walls, concrete panel buildings and wood constructions. The wood constructions are more dominant in rural areas and among the buildings built before 1940. The period of construction of concrete panel buildings took over from the early sixties. Most of the urban residents live in apartment houses built after 1950, 26% were built even after 1970. These flats typically have 2-3 rooms, plus a kitchen, a hall, a bathroom and a toilet. The average floor space per capita is about 20 m^2. The houses are mostly provided with district central heating, water supply, and natural chimney ventilation. The estimated average ventilation rate in the heating season is about 0.8 - 1.2 exchanges per hour. The ventilation rate of 1.0 times per hour was established in the construction rules (SNiP) for the dwellings in former Soviet Union.

The percentage of single-family houses among dwellings is about 30 and they are more common in rural areas and smaller towns. Most of them are 1-2 storey wooden or brick houses, with 3 - 4 rooms, a kitchen, a hall and a toilet. In towns there is public tap-water and drainage. They have stove heating or their own heating system and natural ventilation. Saunas are more spread in single-family houses in rural areas. Private houses built after 1950 are often "self-made" - built by the people living in them. The insulation standard of these houses is often a lot better, but the ventilation rates may be lower than in the standard houses.

EXPERIMENTAL DESIGN

Measurements

Measurements were made in randomly selected houses by the test areas. Data from selected buildings such as type, year of construction, building materials etc. were collected, the questionnaires were filled on site and the detectors were put in position by our specialists. After three months the detectors were returned for evaluation at the laboratory in EMHI. Two detectors were placed in each dwelling usually: one in a bedroom and one in the living room. In single-family houses with two stories the detectors were put one in the living room and one in a bedroom on the other floor. In schools the detectors were placed in two classrooms - usually at the ground floor and at the first floor, and in the kindergartens - in the bedroom and in the classroom.

The measurements were made with passive alpha-track detectors, a method which has been further developed at SSI [2]. CR-39 (polyallyl diglycol carbonate) alpha-track detector material from TASL Ltd of Bristol, UK, was used. The film was placed in a closed cup holder of electrically conductive plastic used by SSI originally developed at the National Radiological Protection Board (NRPB). After chemical etching in 20% NaOH solution (17 hours, etching temperature 68°C) the detectors were evaluated in an image analysis system using special software GIPSRAD developed at Image House a/s in Denmark. Sensitivity calibration of detectors was made at SSI.

Selection of test areas.

There are no special maps of radon risk areas in Estonia today. What areas may be radon risk areas in Estonia due to geological structure?

1. On the Cambrian and under the Lower Ordovician rocks in a Regional Stage of Pakerort, one of the main rock types is kerogen-bearing argillite, the analogue of Scandinavian alum shale. In north-east Estonia these argillites are rather rich in Uranium - more than 300 g/t (3.7 kBq/kg), maximum 1038 g/t (12.8 kBq/kg) [3]. In North-Estonia the Quaternary cover is thin (Fig. 1, 2, in Annex 1) and in the building process the argillites in some places may stay straightly under the buildings.

2. There are many deep-seated faults in the sedimentary rocks finished in the Precambrian basement (Fig.1 in Annex 1). Through these faults and cracks in the sedimentary rocks radon gas from granites of the basement can reach the ground.

3. In the regions using the Vendian-Cambrian groundwater in waterworks the water may contain radium and radon from granites of basement and from the argillites of the Pakerort Stage.

We decided to carry out measurements in the following places (Fig. 1) which we had reasons to believe had high levels.

Tallinn, where the 1/3 of the population of Estonia lives. Early measurements of radon in this town (mostly by using grab sampling) have given relatively high values.

Kunda, where the cement industry creates lots of problems of pollution. In this region, the Pakerort Stage is covered with a very thin blanket of Quaternary deposits and may lie straightly under the houses.

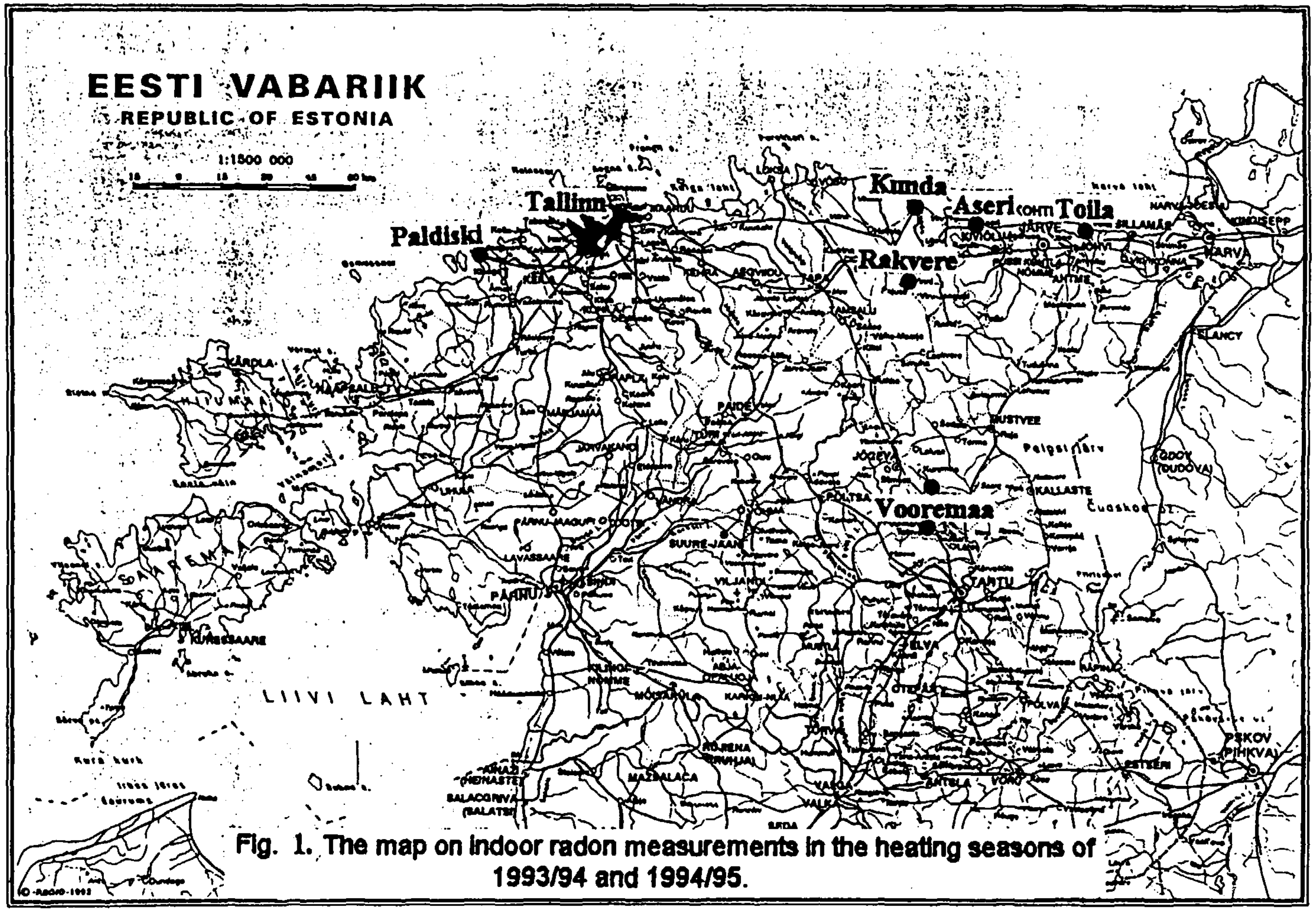

Fig. 1. The map on indoor radon measurements in the heating seasons of 1993/94 and 1994/95.

Aseri, the fault zone, the bedrock in North Estonia is covered with thin Quaternary deposits.

Rakvere, publications describe high radon concentrations in the tap water of this town [4].

Toila, Voka, the largest radon concentrations in the soil air in Estonia have been measured here [1]. According to the analyses made by Anne Vuotilainen from the Finnish Radiation Protection Centre the argillites from Toila had a concentration of

Radium-226	2400 Bq/kg (emanation percent 30)
Uranium-238	3200 Bq/kg
Uranium-235	170 Bq/kg
Thorium-232	44 Bq/kg
Potassium-40	1600 Bq/kg

Paldiski, the Regional Stage of Pakerort is covered with very thin Quaternary deposits.

Vooremaa (Palamuse, Tabivere), the area differs from northern Estonia with several tens of meters of thick Quaternary cover. There are drumlins consisting of loamy till layers. The area is a reference site for the investigations.

DATA AND ANALYSIS

The results of measurements made in the heating seasons of 1993/94 and 1994/95 are presented here. A map of the measurements is provided in Fig. 1. For the characterisation of each house where the measurements were made and to form the database of radon investigations a questionnaire was used (Annex 3). The readings of all measurements by area are added (Annex 2).

Summaries of the measurements are presented in Table 1, where the number of investigated houses (flats), the arithmetical mean (AM), geometrical mean (GM), and maximum values for the living areas are given. The distribution (%) of the indoor radon concentrations (Bq/m^3) is provided in the same table.

The results of measurements by test areas are provided below.

Tallinn. Compared with the other measurement areas Tallinn is too large, so we made the measurements by the districts of the town. We used the map of aerial gamma measurements carried out by the geophysicists of Saint Petersburg. The measurements of indoor radon were made in the parts of Tallinn where the highest levels of gamma radiation were observed. One district - Nömme, located on a huge glaciofluvial delta area with a thick Quaternary cover, was used for comparison as a location with low gamma levels.

Tallinn - Centre - the district where there are mostly multi-storey houses, some of them very old. The maximum level - 286 Bq/m^3 - was measured in a single-storey wooden house without a cellar and built in the beginning of this century.

The detectors were received from 77 flats, the arithmetical mean of the radon concentrations measured 38 Bq/m^3 and the geometrical mean 19 Bq/m^3.

Tallinn - Lasnamäe 1, the detectors were received from 44 flats, all the flats are in 5- or 9-storey panel houses built after 1980, the maximum value was 301 Bq/m^3 in the first floor of a 5-storey house with a cellar. The area stands out on the gamma measurement map due to the high values, which is explained by the geological structure of the area - the Pakerort Stage is covered with thin limestone and Quaternary cover. The arithmetical mean of indoor radon in this area is 47 Bq/m^3 and the geometrical mean is 30 Bq/m^3.

Table 1 Indoor radon concentrations

Area	No. of flats	Indoor ^{222}Rn, Bq/m^3			The distribution of indoor ^{222}Rn concentrations, %				
		AM	GM	Max	<100	101-200	201-400	401-800	>800
Tallinn, centre	77	38	19	286	90,7	7,3	2,0	-	-
Tallinn, Lasnamäe-1	44	47	30	301	92,9	3,6	3,5	-	-
Tallinn, Lasnamäe-2	16	37	26	133	87,5	12,5	-	-	-
Tallinn, Pirita-Kose	13	157	86	631	61,5	15,4	7,7	15,4	-
Tallinn, Nõmme	10	23	14	65	100.0	-	-	-	-
Kunda - 94	50	151	91	1223	54,0	28,0	8,0	8,0	2.0
Kunda - 95	28	234	142	1392	42,9	21,4	14,3	17,8	3,6
Aseri	41	91	57	526	61,9	30,9	2,4	4,8	-
Rakvere	77	86	47	499	68,8	20,8	9,1	1,3	-
Toila	46	361	260	878	10,9	17,4	34,8	34,7	2.2
Paldiski	14	163	85	769	42,9	28,6	14,3	14,2	-
Vooremaa	28	97	80	263	56,8	40,6	2,6	-	-

Tallinn - Lasnamäe 2, the detectors were received from 16 houses. All the houses are of the multi-storey type, built in the period of 1960 - 1980, the maximum measured value is 133 Bq/m^3, the arithmetical mean is 37 Bq/m^3 and the geometrical mean is 26 Bq/m^3.

Tallinn, Pirita-Kose. In this area the single-family houses built after 1960 dominate, most of them with their own heating system and sauna in the cellar. The area stands out on the gamma maps because of its higher values, near the Lasnamäe-1. The detectors were received from 13 houses, the maximum value measured in a house without a cellar is 631 Bq/m^3. The arithmetical mean in this area is 157 Bq/m^3 and the geometrical mean is 86 Bq/m^3, all the values are highest in Tallinn.

Tallinn, Nömme as was mentioned above was the region selected as a location with low gamma levels in the radiometric maps. The private houses predominate in the area. The maximum value measured is 65 Bq/m^3, the arithmetical mean in this area is 23 Bq/m^3 and the geometrical mean is 14 Bq/m^3. The lowest values measured in Tallinn were found in this district.

Kunda. In the course of the state environmental monitoring programme the indoor radon measurements were made in the heating season of 1993/94 (Kunda-94) in 50 houses. In this town the cement industry causes a lot of environmental pollution problems. The radon investigations carried out by the Estonian Building Research Institute show that there are houses with elevated indoor radon concentrations in Kunda [1]. There are some data of elevated radon concentrations in the water from the drilled wells of Kunda [3], which may affect the indoor radon levels. In most of the houses there is tap water where water from Cambrian-Vendian waterbearing complex is used. 50 houses investigated in the heating season 1993/94 were randomly selected. The maximum value measured was 1223 Bq/m^3 in a building, that was used as a hospital. The building was constructed in the fifties, without a cellar. The arithmetical mean of all measurements was 151 Bq/m^3 and the geometrical mean was 91 Bq/m^3.

Analyzing the results of measurements made in 1993/94 it was possible to localise the houses with higher indoor radon levels. In the heating season of 1994/95 the municipality of Kunda was ordered to carry out the investigations in these "hot spots" - in the areas with higher indoor radon levels. The radon detectors were distributed in 30 houses. The radon concentrations of 2 houses were above the range of our radon reading system. We can only say that the indoor radon concentration in these houses was more than 2000 Bq/m^3. Next year we shall repeat the measurements with a shorter exposure time in these houses. In the other 28 houses investigated in Kunda the maximum value was 1392 Bq/m^3. The arithmetical mean in these selected houses was 234 Bq/m^3 and the geometrical mean was 142 Bq/m^3. All of the houses with higher radon levels had similar construction and they were built in the fifties. Elevated indoor radon levels caused by tap water were not observed.

Aseri. The Aseri fault zone is in the bedrock, but the zone is covered with clay, which obstructs the radon gas. The maximum values were measured in a brick house without a cellar - 526 Bq/m^3. In most of the houses (93%) the radon levels are below 200 Bq/m^3, the arithmetical mean of measurements is 91 Bq/m^3 and the geometrical mean is 57 Bq/m^3.

Rakvere. The population of Rakvere is 20 000. There are many houses built in the beginning of this century. These are wooden houses without cellar. In most of the investigated houses there was tap-water. The water supply system in Rakvere uses the Cambrian-Vendian groundwater. The maximum value was 499 Bq/m^3, measured in a single-family house without a cellar. All of the houses where indoor radon levels above 200 Bq/m^3 were measured, were single-family houses, described as "self-made" in the introduction. The arithmetical mean of measurements was 86 Bq/m^3 and the geometrical mean 47 Bq/m^3. Elevated levels caused by tap-water were not observed.

Toila. In Toila 46 randomly selected houses (flats) were investigated, most of them are single-family houses built at different times, many of them are "self-made". The maximum measured value was 878 Bq/m^3, but only in less than 30% of the houses was the radon concentration lower than 200 Bq/m^3. Even in multi-storey houses, where the lower radon levels are measured in the other regions, there were concentrations higher than 200 Bq/m^3. The influence of the cellar was observed in two multi-storey houses, where on one section there was a cellar and under the other one there was none. In the flats of the same house without a cellar the radon concentrations were 526 Bq/m^3 and 710 Bq/m^3 and in the flats with a cellar 120 Bq/m^3 and 240 Bq/m^3. The arithmetical mean of measurements is 361 Bq/m^3 and the geometrical mean is 260 Bq/m^3.

Paldiski. In Paldiski we distributed detectors for 20 houses, but received the results from 14. Paldiski was formerly a closed soviet army town with a training-nuclear-reactor and a base for submarines, and now with many social problems. The maximum measured value is 769 Bq/m^3, measured in the house without a cellar. The arithmetical mean of measurements is 163 Bq/m^3 and the geometrical mean 85 Bq/m^3.

Vooremaa. Vooremaa is a region with thick glacial sediments, it is called drumlinland in Estonia. This is a rural area with some large settlements (Tabivere, Palamuse). Single-family houses are predominant there, some built in the beginning of the century. We investigated 28 houses. The maximum value of 263 Bq/m^3 was measured in a single-family house built in the seventies. The house was without a cellar. All of the values measured in the other houses of the region have radon levels below 200 Bq/m^3, the arithmetical mean of the measurements is 97 Bq/m^3, and the geometrical mean is 80 Bq/m^3.

CONCLUSIONS

During the Swedish-Estonian co-operation project, about 500 houses were investigated and this comprises the database of measurements. The measurements were made in randomly selected houses within each region (not randomly selected), except for the measurements in Kunda in 1994/95. From the results of the investigations the main conclusions that can be drawn are:

- there are two regions - Kunda and Toila - that are potentially high radon risk areas. The municipalities of these towns have to understand the problem and take measures for reducing the risk from indoor radon;
- elevated levels of indoor radon caused by the Cambrian-Vendian groundwater used in the waterworks in Kunda and in Rakvere were not observed;
- cellars in the houses may reduce the indoor radon levels on the first floor by a factor of two;
- the radon levels in single-family houses are higher than in apartment houses, except for one type of multi-storey apartment houses built in the fifties. Dwellings with this construction type had the highest indoor radon levels in Kunda. The

basements of these houses are without ventilation outlets, the houses have no cellars and in the floors of the first storey there are ventilation outlets for the underground space, which created very good conditions for radon gas inflow.

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ANNEX 1

GEOLOGICAL STRUCTURE OF ESTONIA

GEOLOGICAL STRUCTURE OF ESTONIA

Estonia is located in the north-western part of the East-European platform. In Estonia two structural stages can be distinguished - the folded crystalline basement and sedimentary cover.

The crystalline basement consists of Early Proterozoic rocks of metamorphic and igneous origin. Metamorphic rocks are represented mainly by gneisses and migmatites, and igneous rocks by gabbros and especially potassium granites of porphyritic texture belonging to rapakivi granites. The surface of the crystalline basement has a gentle south-ward inclination (10 - 15') dipping 2 - 4 m per km. On the Juminda peninsula in Northern Estonia the basement lies at a depth of 100 m while on Ruhnu Island it is at a depth of 800 m (Fig. 1 and 2). In Southern Estonia near Mäniste the basement rises abruptly reaching a depth of less than 300 m from the surface.

The Precambrian basement is overlain by a cover of sedimentary rocks of less than 1 km (Fig. 2): Vendian and Cambrian sandstone, siltstone and clay; Ordovician and Silurian mostly carbonate rocks (limestone, marl, dolomite); and Devonian mostly terrigenous rocks (sandstone, siltstone). In Estonia there are no bedrock strata younger than Devonian.

The bedrock is covered by Quaternary deposits of which the thickness is rather variable. On the Ordovician and Silurian carbonate rocks in the north of the country it is usually less than 5 m, on South Estonian plains less than 10 m while in Haanja and Otepää uplands the Quaternary cover may reach 100 - 150 m and in buried valleys of Southern Estonia even more than 200 m.

In the Vendian-Cambrian sand- and siltstones between the crystalline basement and Ordovician and Silurian limestones and marls the most significant groundwater resources of Northern Estonia occur.

The most important structure of cratonic type is the Estonian homocline [5] stretching from the Gulf of Finland to northern Latvia. In the southeast this homocline borders on the Valmiera-Lokno uplift, 20 - 30 km wide and 200 km long. On the crest of the anticline the basement lies at a level of -230 m. It descends northward to -500 m and southward to -1000 m. There are deep-seated faults in the northern and southern flanks of the uplift (Fig. 1).

The Estonian homocline is complicated by many narrow, some 1 to 4 km, anticlinal belts trending mainly north-east to south-west, and their steep-dipping flanks largely to the north-west. The folds are usually very gentle and no more than 50 m high. Anticlinal belts are ascribed mostly to fault movements in the basement because their shape is very asymmetrical. Some narrow linear structures are due to clay diapirs.

Dome-like plains-type folds, some 1 to 6 km in diameter and 30 to 130 m in height, have so far only been found in North Estonia. The folds become more pronounced in depth, and there is a thinning out of the lowermost strata on the flanks of the folds.

The Quaternary cover of the Estonian territory consists mainly of Pleistocene deposits (Fig. 3) of different thickness (Fig. 4). In Lower Estonia (0 - 50 m a.sl.) the Pleistocene deposits are mostly covered by the marine, all over the republic mainly by alluvial, lacustrine or bog
deposits of the Holocene age [6].

By generalizing the data obtained on Estonian territory, one may conclude that the vast majority of the Pleistocene cover consists of till (about 60 - 70%). The rest of the strata is mainly composed of aqueo-glacial (coarse-grained glaciofluvial and fine-grained glaciolacustrine) deposits. Predominantly in South Estonia five till layers, often of great thickness, are to be noticed more or less distinctly.

The granulometric composition of tills is determined by glacial ploughing of bed, crushing and abrasion of drift load and by the mixture of the material during its transport and deposition. Tills contain various-sized components, from colloidal particles to gigantic blocks.

The engineering-geological properties of tills are greatly dependent on the mode of occurrence, first of all on the hydrological regime, conditioning hydration or dehydration of deposits.

The paragenetic group of glaciofluvial deposits (Fig. 3) is divided into englacial and periglacial genetical types with possible frequent transitions between them. Glaciofluvial deposits form wide delta plains, hummocky kame fields, radial and marginal esker chains, are in their main part characterized by great variety in granulometrical composition and structure. As a rule, they are coarse-grained well drained by water. As the aqueo-glacial deposition followed the formation of basal till, the glaciofluvial deposits are usually located on the till. There are exceptions in North Estonia, where the coarse-grained deposits of the radial eskers are sometimes situated on the bedrock surface.

Fine-grained glaciolacustrine (Fig. 3) deposits (clay, silt and loam) mainly occupy the depressions of the till surface, and their thickness varies from several metres to 27 m (West Estonia).

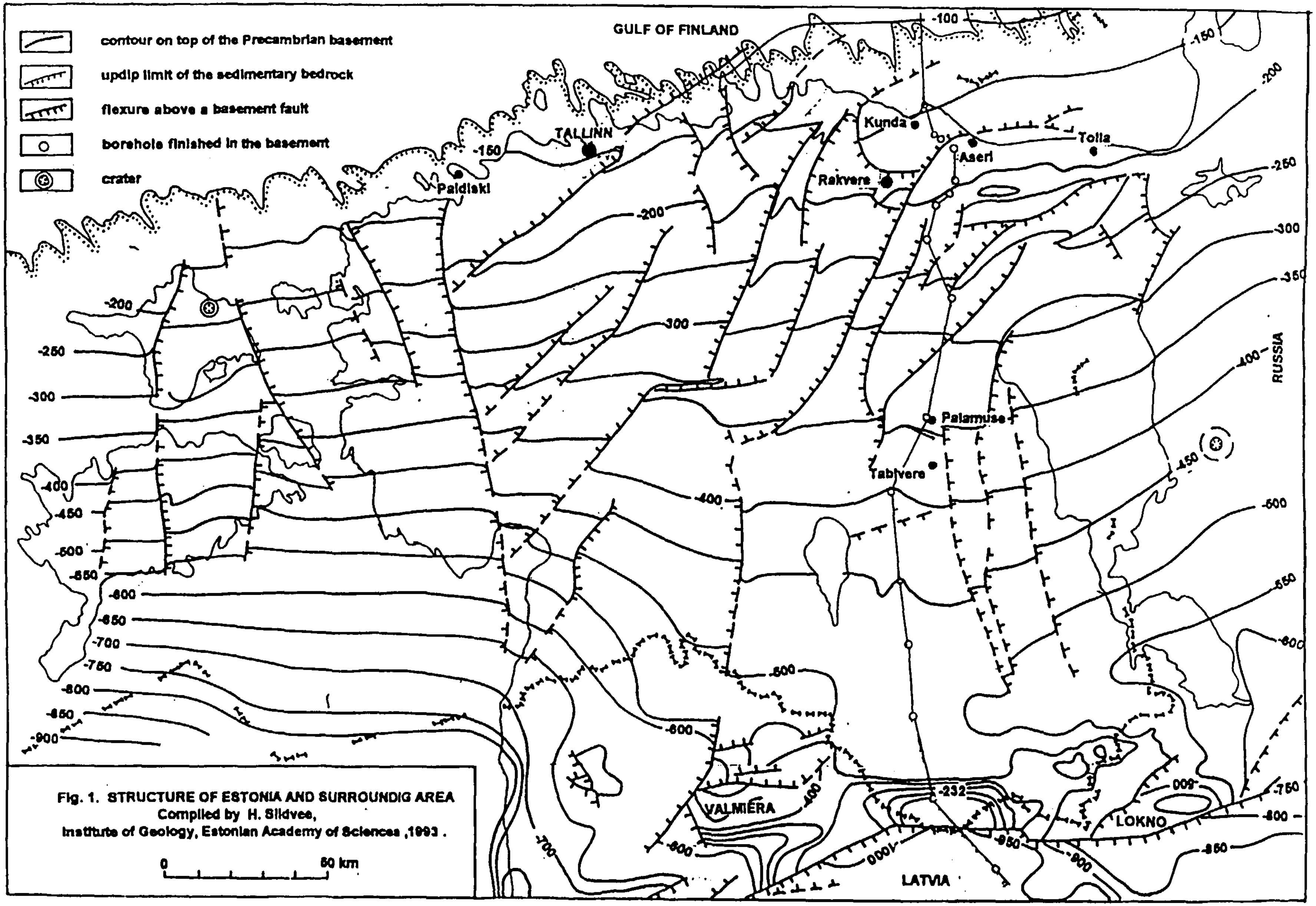


Fig. 1. STRUCTURE OF ESTONIA AND SURROUNDIG AREA
Compiled by H. Siidvee,
Institute of Geology, Estonian Academy of Sciences ,1993 .

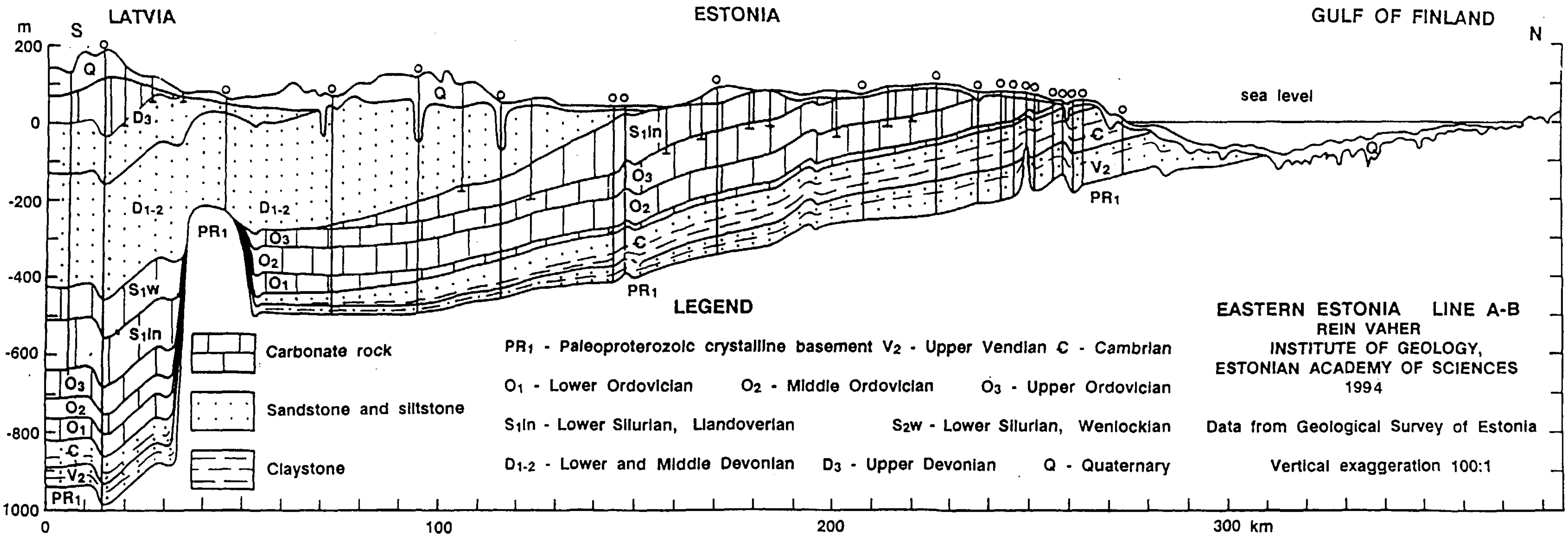
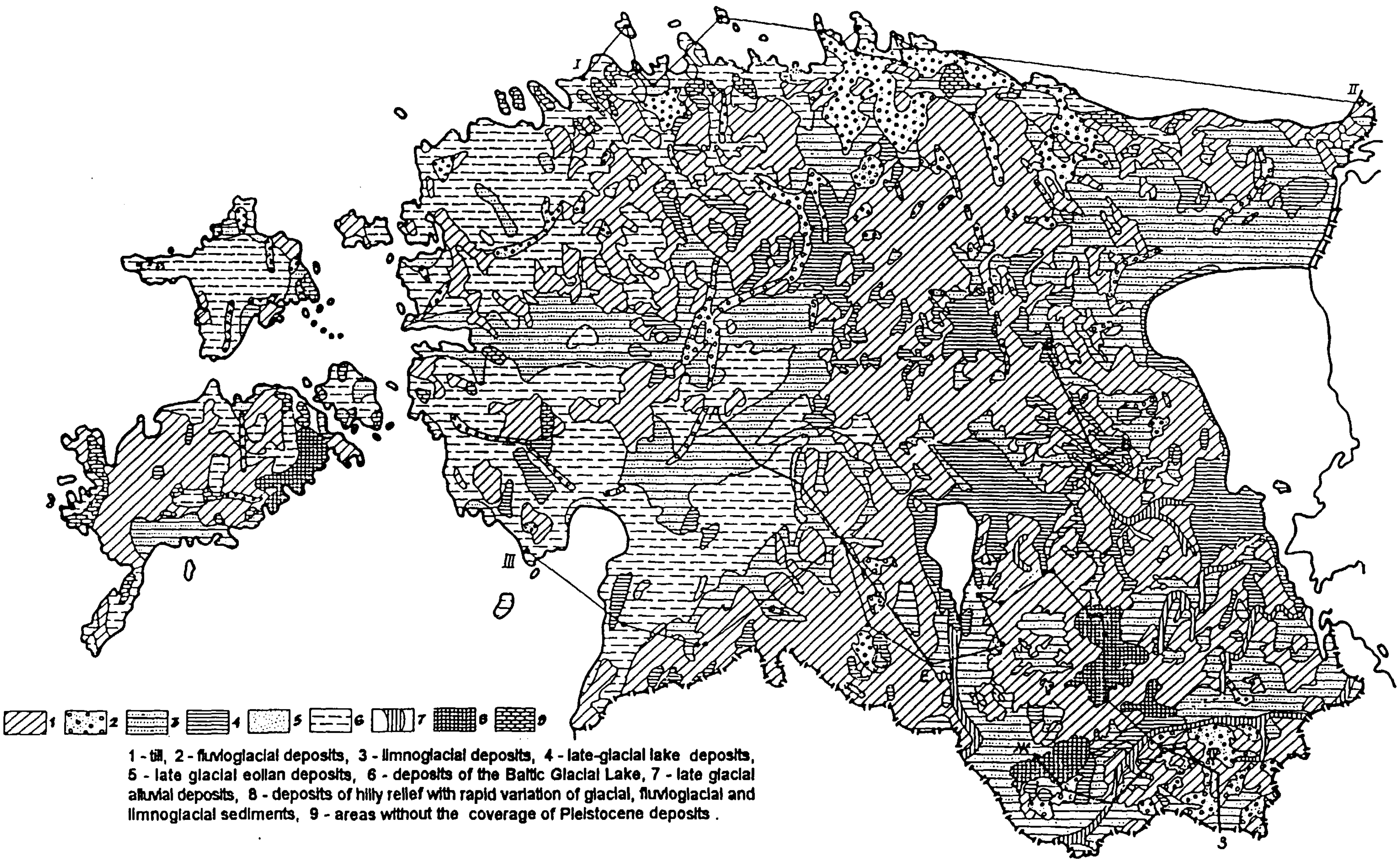
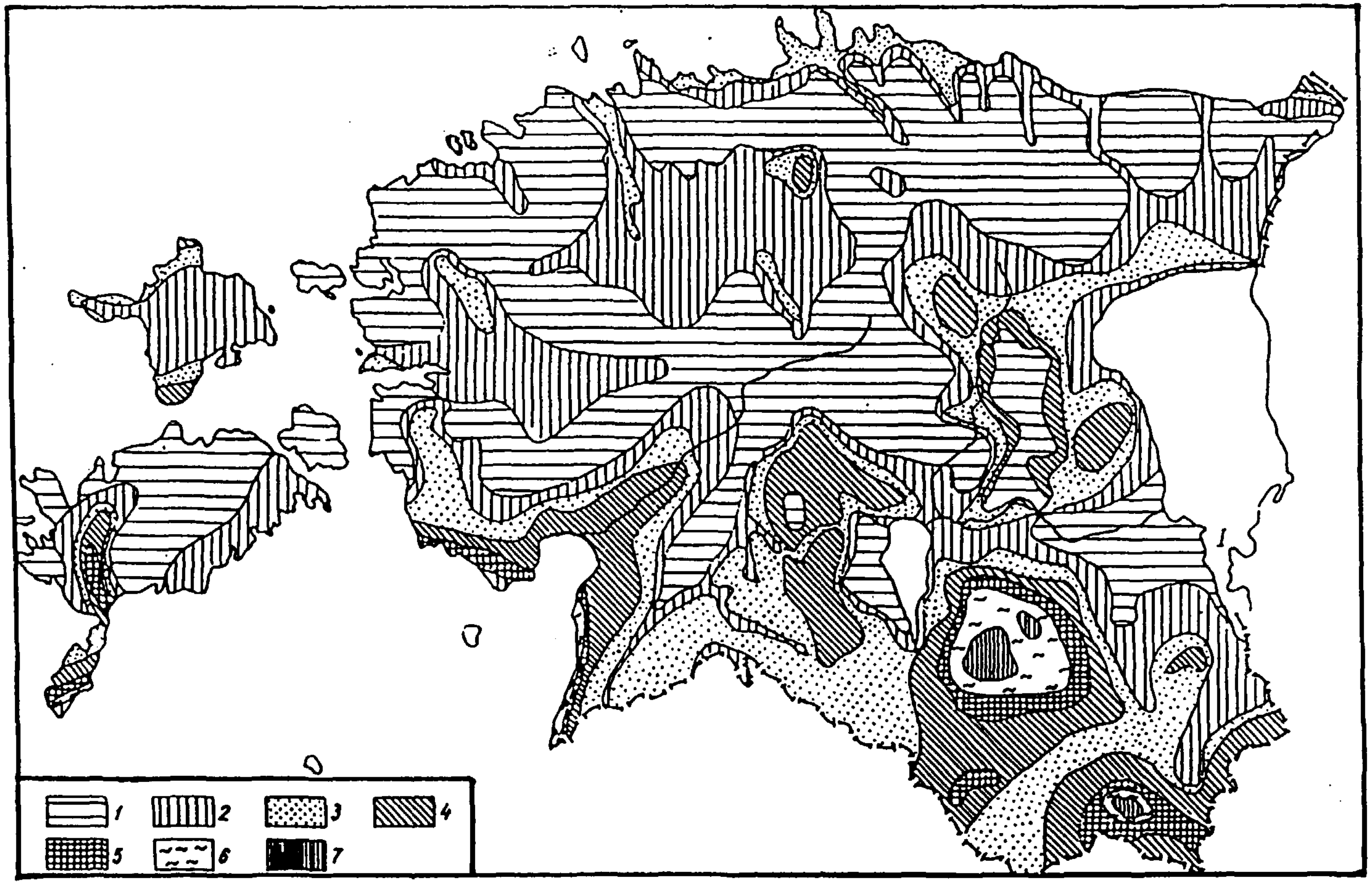


Fig. 2. Schematic cover structure of eastern Estonia.



1 - till, 2 - fluvioglacial deposits, 3 - limnoglacial deposits, 4 - late-glacial lake deposits, 5 - late glacial eolian deposits, 6 - deposits of the Baltic Glacial Lake, 7 - late glacial alluvial deposits, 8 - deposits of hilly relief with rapid variation of glacial, fluvioglacial and limnoglacial sediments, 9 - areas without the coverage of Pleistocene deposits .

Fig. 3. Map of the Pleistocene deposits on Estonian territory (the Holocene coverage is removed). Compiled by R. Karukäpp.



1 - below 5m, 2 - from 5 to 10 m, 3 - from 10 to 20 m, 4 - from 20 to 40 m 5 - from 40 to 60 m, 6 - from 60 to 80 m, 7 - over 80 m.

Fig. 4. Thickness of Quaternary deposits in Estonia by K.Kajak

ANNEX 2

The readings of the all measurements by areas.

TALLINN CENTRE - 1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Dwellings with cellar		
1.	Flat no. 1	40	-
2.	Flat no. 2	31	1
3.	Flat no. 4	11	11
4.	Flat no. 7	10	32
5.	Flat no. 8	1	15
6.	Flat no. 9	11	1
7.	Flat no. 10	1	13
8.	Flat no. 11	13	1
9.	Flat no. 12	26	26
10.	Flat no. 13	10	13
11.	Flat no. 14	40	27
12.	Flat no. 15	13	40
13.	Flat no. 17	51	103
14.	Flat no. 18	53	80
15.	Flat no. 20	13	13
16.	Flat no. 21	1	1
17.	Flat no. 22	31	15
18.	Flat no. 23	15	12
19.	Flat no. 24	65	25
20.	Flat no. 26	47	23
21.	Flat no. 27	30	14
22.	Flat no. 28	60	30
23.	Flat no. 30	43	14
24.	Flat no. 31	29	29
25.	Flat no. 33	51	12
26.	Flat no. 34	25	64
27.	Flat no. 36	27	54
28.	Flat no. 37	15	48
29.	Flat no. 39	27	1
30.	Flat no. 40	23	23
31.	Flat no. 41	11	11
32.	Flat no. 42	1	12
33.	Flat no. 43	26	93
34.	Flat no. 44	-	25
35.	Flat no. 45	15	1
36.	Flat no. 47	38	38
37.	Flat no. 48	25	25
38.	Flat no. 49	13	10
39.	Flat no. 50	118	65
40.	Flat no. 51	142	116
41.	Flat no. 53	47	10
42.	Flat no. 54	25	38

43.	Flat no. 55	27	13
44.	Flat no. 56	14	21
45.	Flat no. 57	79	45
46.	Flat no. 58	231	174
47.	Flat no. 59	13	1
48.	Flat no. 60	14	11
49.	Flat no. 61	10	1
50.	Flat no. 62	10	12
51.	Flat no. 63	22	-
52.	Flat no. 64	39	12
53.	Flat no. 65	41	-
54.	Flat no. 66	13	13
55.	Flat no. 67	38	12
56.	Flat no. 70	15	15
57.	Flat no. 71	15	38
58.	Flat no. 72	1	1
59.	Flat no. 73	15	31
60.	Flat no. 75	1	1
61.	Flat no. 76	48	1
	Dwellings without cellar		
63.	Flat no. 19	40	-
64.	Flat no. 25	131	184
65.	Flat no. 35	81	122
66.	Flat no. 46	45	31
67.	Flat no. 69	39	39
68.	Flat no. 74	10	31
69.	Flat no. 77	115	10
	Single house without cellar		
70.	House no. 5	249	286
71.	House no. 38	159	31
72.	House no. 68	12	25
	Schools and kindergartens		
73.	School no. 3 (with cellar)	51	116
74.	School no. 32 (without cellar)	12	12
75.	Kindergarten no. 6 (with cellar)	1	12
76.	Kindergarten no. 16 (with cellar)	27	10
77.	Kindergarten no. 29 (with cellar)	13	81

LASNAMÄE-1 - 1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Dwellings with cellar		
1.	Flat no. 1	10	15
2.	Flat no. 2	82	123
3.	Flat no. 3	27	13
4.	Flat no. 4	54	60
5.	Flat no. 5	54	68
6.	Flat no. 6	54	54
7.	Flat no. 7	301	295
8.	Flat no. 8	1	13
9.	Flat no. 9	12	38
10.	Flat no. 10	44	62
11.	Flat no. 11	25	12
12.	Flat no. 12	38	38
13.	Flat no. 13	25	38
14.	Flat no. 14	95	102
15.	Flat no. 15	13	13
16.	Flat no. 16	27	27
17.	Flat no. 17	31	-
18.	Flat no. 19	33	22
19.	Flat no. 20	22	22
20.	Flat no. 21	46	36
21.	Flat no. 22	85	63
22.	Flat no. 23	48	48
23.	Flat no. 24	36	24
24.	Flat no. 25	12	10
25.	Flat no. 26	63	76
26.	Flat no. 28	58	68
27.	Flat no. 29	34	45
28.	Flat no. 30	-	45
29.	Flat no. 31	63	42
30.	Flat no. 32	21	21
31.	Flat no. 33	21	10
32.	Flat no. 34	36	24
33.	Flat no. 35	36	24
34.	Flat no. 36	61	61
35.	Flat no. 37	-	24
36.	Flat no. 38	-	24
37.	Flat no. 39	16	20
38.	Flat no. 40	11	11
39.	Flat no. 41	206	193
40.	Flat no. 42	25	25
41.	Flat no. 43	13	1
42.	Flat no. 44	13	1

Kindergartens with cellar

43.	Kindergarten no. 18	13	12
44.	Kindergarten no. 27	68	58

LASNAMÄE-2 -1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Dwellings with cellar		
1 .	Flat no. 1	11	11
2 .	Flat no. 4	107	-
3 .	Flat no. 6	21	21
4 .	Flat no. 7	42	63
5 .	Flat no. 9	22	22
6 .	Flat no. 10	1	11
7 .	Flat no. 11	82	133
8.	Flat no. 12	30	-
9.	Flat no. 13	-	40
10.	Flat no. 14	10	10
11.	Flat no. 15	32	32
	Single house with cellar		
12.	House no. 5	22	30
	Single house without cellar		
13.	House no. 3	22	-
	Schools and kindergartens with cellar		
14.	School no. 2	34	77
15.	Kindergarten no. 8	45	24
16.	Kindergarten no. 16	60	20

PIRITA-KOSE -1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Single house with cellar		
1 .	House no. 3	45	13
2 .	House no. 4	100	90
3 .	House no. 5	63	15
4 .	House no. 7	64	64
5 .	House no. 9	42	-
6 .	House no. 10	49	264
7 .	House no. 11	24	131
8.	House no. 12	57	57
9.	House no. 13	10	29
	Single house without cellar		
10.	House no. 1	194	115
11.	House no. 2	631	566
12.	House no. 6	279	194
13.	House no. 8	307	512

TALLINN-NÕMME - 1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Dwellings with cellar		
1.	Flat no. 1	20	20
2.	Flat no. 2	26	26
	Single house with cellar		
3.	House no. 7	60	30
4.	House no. 10	20	11
5.	House no. 8	30	14
	Single house without cellar		
6.	House no. 3	65	40
	Schools, kindergartens and hospitals		
7.	Kindergarten no. 4 (without cellar)	13	10
8.	School no. 5 (with cellar)	14	1
9.	School no. 6 (with cellar)	1	1
10.	Hospital no. 9 (with cellar)	30	14

KUNDA - 1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Dwellings with cellar		
1.	Flat no. 1	43	43
2.	Flat no. 8	57	57
3.	Flat no. 10	376	463
4.	Flat no. 26	43	84
5.	Flat no. 28	10	28
6.	Flat no. 29	29	14
7.	Flat no. 30	41	13
8.	Flat no. 33	57	43
9.	Flat no. 34	159	202
10.	Flat no. 35	43	28
11.	Flat no. 36	15	57
12.	Flat no. 37	72	72
13.	Flat no. 39	129	100
14.	Flat no. 40	202	159
15.	Flat no. 46	55	41
16.	Flat no. 47	119	89
17.	Flat no. 48	73	43
	Dwellings without cellar		
18.	Flat no. 4	826	1223
19.	Flat no. 6	290	-
20.	Flat no. 11	43	57
21.	Flat no. 45	274	129
22.	Flat no. 49	550	647
	Single house with cellar		
23.	House no. 2	28	13
24.	House no. 3	419	463
25.	House no. 7	83	55
26.	House no. 9	10	144
27.	House no. 16	83	125
28.	House no. 21	13	13
29.	House no. 32	16	46
30.	House no. 38	72	57
31.	House no. 41	59	59
32.	House no. 43	144	129
33.	House no. 44	159	144

Single house without cellar

34.	House no. 5	168	196
35.	House no. 12	166	221
36.	House no. 14	173	86
37.	House no. 15	89	89
38.	House no. 17	42	56
39.	House no. 18	134	149
40.	House no. 19	104	74
41.	House no. 20	86	86
42.	House no. 22	134	119
43.	House no. 23	119	224
44.	House no. 24	181	154
45.	House no. 25	78	104
46.	House no. 27	303	216
47.	House no. 31	216	491
48.	House no. 42	28	34
49.	House no. 50	658	254
50.	House no. 13	168	122

KUNDA - 1995

No.	Place	Indoor Rn, Bq/m³ bedroom	living room
	Dwellings with cellar		
1.	Flat no. 2	689	570
2.	Flat no. 5	44	47
3.	Flat no. 6	523	456
4.	Flat no. 7	184	137
5.	Flat no. 8	118	104
6.	Flat no. 9	226	135
7.	Flat no. 10	49	148
8.	Flat no. 11	95	81
9.	Flat no. 15	236	176
10.	Flat no. 16	191	358
11.	Flat no. 18	56	65
12.	Flat no. 19	73	70
13.	Flat no. 21	10	20
14.	Flat no. 24	92	179
15.	Flat no. 27	72	97
16.	Flat no. 28	16	40
	Dwellings without cellar		
17.	Flat no. 4	734	660
18.	Flat no. 12	1392	621
19.	Flat no. 13	113	125
20.	Flat no. 14	269	254
21.	Flat no. 20	525	451
22.	Flat no. 22	193	647
23.	Flat no. 23	226	153
24.	Flat no. 25	190	20
	Single house without cellar		
25.	House no. 17	435	227
26.	House no. 26	124	49
	Schools without cellar		
27.	School no. 29	109	76
28.	School no. 30	38	138

ASERI - 1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Dwellings with cellar		
1.	Flat no. 1	66	-
2.	Flat no. 3	43	66
3.	Flat no. 4	82	53
4.	Flat no. 5	27	46
5.	Flat no. 6	40	30
6.	Flat no. 7	21	21
7.	Flat no. 8	15	37
8.	Flat no. 10	-	2
9.	Flat no. 11	46	77
10.	Flat no. 12	33	110
11.	Flat no. 15	40	15
12.	Flat no. 22	12	15
13.	Flat no. 23	133	128
14.	Flat no. 24	40	24
15.	Flat no. 25	2	5
16.	Flat no. 34	67	50
17.	Flat no. 36	25	15
18.	Flat no. 37	24	18
	Dwellings without cellar		
19.	Flat no. 14	110	291
20.	Flat no. 29	277	56
21.	Flat no. 38	77	37
	Single house with cellar		
22.	House no. 17	65	62
23.	House no. 26	145	139
24.	House no. 33	110	43
25.	House no. 40	40	30
26.	House no. 41	176	37
	Single house without cellar		
27.	House no. 13	335	237
28.	House no. 16	62	53
29.	House no. 30	494	526
30.	House no. 18	63	82
31.	House no. 19	189	161
32.	House no. 20	151	132
33.	House no. 21	126	113
34.	House no. 27	108	130
35.	House no. 28	68	135
36.	House no. 31	33	21

37.	House no. 32	122	122
38.	House no. 35	110	110
39.	House no. 39	33	46
	Schools		
40.	School no. 2 (without cellar)	117	181
41.	School no. 9 (with cellar)	94	11

RAKVERE - 1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Dwellings with cellar		
1.	Flat no. 4	54	43
2.	Flat no. 12	36	36
3.	Flat no. 20	96	80
4.	Flat no. 28	149	192
5.	Flat no. 31	1	1
6.	Flat no. 39	203	142
7.	Flat no. 42	9	15
8.	Flat no. 46	70	65
9.	Flat no. 55	58	58
10.	Flat no. 56	10	2
11.	Flat no. 72	86	90
	Dwellings without cellar		
12.	Flat no. 15	19	479
13.	Flat no. 16	53	15
14.	Flat no. 17	43	29
15.	Flat no. 18	60	57
16.	Flat no. 19	168	53
17.	Flat no. 22	82	133
18.	Flat no. 27	1	56
	Single house with cellar		
19.	House no. 5	38	29
20.	House no. 11	1	1
21.	House no. 13	145	77
22.	House no. 25	12	26
23.	House no. 26	70	100
24.	House no. 35	70	103
25.	House no. 36	103	116
26.	House no. 37	32	49
27.	House no. 40	32	29
28.	House no. 41	44	3
29.	House no. 43	36	63
30.	House no. 44	32	25
31.	House no. 47	237	267
32.	House no. 48	86	66
33.	House no. 49	166	126
34.	House no. 52	237	199
35.	House no. 54	42	45
36.	House no. 57	49	46
37.	House no. 58	267	310
38.	House no. 59	1	1
39.	House no. 60	-	492

40.	House no. 61	89	163
41.	House no. 63	19	15
42.	House no. 64	161	134
43.	House no. 65	117	107
44.	House no. 66	99	153
45.	House no. 67	149	79
	Single house without cellar		
46.	House no. 1	188	184
47.	House no. 2	56	39
48.	House no. 3	36	32
49.	House no. 6	72	76
50.	House no. 7	96	49
51.	House no. 8	137	129
52.	House no. 9	12	19
53.	House no. 10	49	19
54.	House no. 14	228	499
55.	House no. 21	73	39
56.	House no. 23	92	59
57.	House no. 24	257	227
58.	House no. 29	143	113
59.	House no. 30	53	63
60.	House no. 32	76	76
61.	House no. 33	96	19
62.	House no. 34	90	62
63.	House no. 38	22	53
64.	House no. 45	56	73
65.	House no. 50	86	49
66.	House no. 51	267	176
67.	House no. 53	29	29
68.	House no. 62	109	86
	Schools , kindergartens and hospitals		
69.	School no. 69 (with cellar)	22	19
70.	School no. 70 (with cellar)	-	26
71.	Hospital no. 73 (with cellar)	1	70
72.	Hospital no. 74 (with cellar)	1	1
73.	Hospital no. 75 (without cellar)	80	127
74.	Hospital no. 76 (with cellar)	66	42
75.	Hospital no. 77 (without cellar)	25	29
76.	Hospital no. 78 (without cellar)	9	2
77.	Kindergarten no. 71 (with cellar)	56	53

TOILA - 1994

No.	Place	Indoor Rn, Bq/m^3 bedroom	living room
	Dwellings with cellar		
1.	Flat no. 12	624	672
2.	Flat no. 16	202	373
3.	Flat no. 23	380	277
4.	Flat no. 25	120	104
5.	Flat no. 27	310	240
6.	Flat no. 35	281	446
7.	Flat no. 36	158	183
8.	Flat no. 40	171	139
9.	Flat no. 41	75	392
10.	Flat no. 43	42	5
11.	Flat no. 44	30	41
12.	Flat no. 45	42	25
13.	Flat no. 46	594	809
	Dwellings without cellar		
14.	Flat no. 10	755	771
15.	Flat no. 22	418	161
16.	Flat no. 24	453	526
17.	Flat no. 26	710	558
18.	Flat no. 34	281	316
19.	Flat no. 33	97	481
	Single house with cellar		
20.	House no. 4	204	267
21.	House no. 7	789	789
22.	House no. 9	513	640
23.	House no. 11	97	113
24.	House no. 13	230	319
25.	House no. 21	624	726
26.	House no. 28	164	81
27.	House no. 29	192	408
	Single house without cellar		
28.	House no. 1	634	243
29.	House no. 2	100	100
30.	House no. 3	392	65
31.	House no. 5	132	113
32.	House no. 6	618	652
33.	House no. 8	748	710
34.	House no. 14	-	145

35.	House no. 15	475	555
36.	House no. 17	354	526
37.	House no. 18	732	878
38.	House no. 19	351	592
39.	House no. 20	234	323
40.	House no. 30	-	802
41.	House no. 31	250	262
42.	House no. 37	735	662
43.	House no. 38	139	298
44.	House no. 39	122	102

Schools and kindergartens without cellar

45.	School no. 32	202	138
46.	Kindergarten no. 42	250	456

PALDISKI - 1994

No.	Place	Indoor Rn, Bq/m³ bedroom	living room
	Dwellings with cellar		
1.	Flat no. 1	9	16
2.	Flat no. 5	-	119
3.	Flat no. 6	38	34
4.	Flat no. 7	100	110
5.	Flat no. 8	38	31
6.	Flat no. 11	6	6
7.	Flat no. 13	70	77
8.	Flat no. 14	67	45
	Single house with cellar		
9.	House no. 2	396	475
10.	House no. 3	180	196
11.	House no. 4	289	199
	Kindergartens and hospitals		
12.	Kindergarten no. 9 (without cellar)	192	231
13.	Kindergarten no. 10 (with cellar)	93	124
14.	Hospital no. 12 (without cellar)	485	769

VOOREMAA - PALAMUSE, TABIVERE - 1995

No.	Place	Indoor Rn, Bq/m^3	
		bedroom	living room
	Dwellings with cellar		
1.	Flat no. 7-p	65	94
2.	Flat no. 12-p	27	21
3.	Flat no. 15-p	43	43
	Dwellings without cellar		
4.	Flat no. 1-t	43	81
	Single house with cellar		
5.	House no. 3-p	75	59
6.	House no. 8-p	199	161
7.	House no. 10-p	65	65
8.	House no. 13-p	55	106
9.	House no. 4-t	33	36
10	House no. 8-t	92	87
	Single house without cellar		
11.	House no. 1-p	181	185
12.	House no. 2-p	181	175
13.	House no. 4-p	62	24
14.	House no. 5-p	115	181
15.	House no. 6-p	236	263
16.	House no. 9-p	77	115
17.	House no. 11-p	33	21
18.	House no. 14-p	147	106
19.	House no. 16-p	93	118
20.	House no. 17-p	90	93
21.	House no. 18-p	125	100
22.	House no. 19-p	30	30
23.	House no. 2-t	55	118
24.	House no. 3-t	147	103
25.	House no. 5-t	176	60
26.	House no. 6-t	122	94
27.	House no. 7-t	-	143
28.	House no 9-t	55	36

ANNEX 3 - QUESTIONNAIRE

EMHI

ADDRESS:
TELEPHONE:

DESCRIPTION OF THE EXPERIMENTAL OBJECT

1. TYPE OF HOUSE: farmhouse, one-family house, terraced house, multi-storeyed house, panel house, number of stories ... , flat on storey No ...
2. LOCATION: on the level ground, on the slope
3. YEAR OF RIPENING:..
4. YEAR OF EXTENSIVE REPAIRS:....................................
5. GROUND: limestone, sand or gravel, clay
6. GEOLOGICAL AREA:...
7. DOES THE HOUSE LIE ON THE HILL: yes, no
8. WATER SUPPLY: well, water supply with a ground water, lake or river water
9. MATERIAL OF WALL:wood, brick, beton, rubble wall, small block ....
10. HEATING SYSTEM: stove heating, own central heating, district central heating, electric heating, else......
11. FLOOR SPACE:................m^2
12. VENTILATION: natural, mechanical ventilation, else...........
13. VENTILATION works on an average .... hours in a day
14. THE EFFECTIVENESS OF THE VENTILATION by the estimation of owner:good, average, bad
15. FOUNDATION:...
16. CELLAR:..

---

17. RADON: DET. NO
    START:
    END:

SSI-rapporter

96-01. Publikationer 1995
Informationsenheten *Gratis*

96-02. Application of best Available Technique (BAT) in Swedish Nuclear Industry: Ringhals and Barsebäck Nuclear Power Plants
Report to the Oslo and Paris Commissions in accordance with PARCOM Recommendation 91/4
Division of Waste Management and Environmental Protection *50 kr*

96-03. Radionuklidinnehåll i utbränt kärnbränsle. Beräkningar med ORIGEN2.
Cilla Lyckman *50 kr*

96-04. Isotopkommittérapporter 1993
Mauricio Alvarez *40 kr*

96-05. Statens strålskyddsinstituts mätstationer för tidig varning av förhöjd gammastrålning
Per Einar Kjelle, Karl-Erik Israelsson *40kr*

96-06. Omgivningskontroll vid kärnkraftverken och Studsvik 1994 Resultat från mätningar av radionuklidhalter i miljöprover
P. Bengtson, C-M. Larsson, M. Lüning *Gratis*

96-07. Project Radiation Protection East
Swedish Cooperation Program for Radiation Protection in Eastern and Central Europe
Status Report, March 1996
J.O. Snihs, M. Johansson, SSI, S. Grapengiesser, STEGRA Consultants,
T. Bennerstedt, Tekno Telje *50 kr*

96-08. Contamination and Radiation Exposure. Evaluation and Measures in the Nordic Countries after the Chernobyl Accident
Jan Olof Snihs *60 kr*

96-09. Kalibrerings- och normalieverksamheten vid riksmätplatsen under 1995
J-E. Grindborg, O. Gullberg, J-E. Kyllönen och G. Samuelson *50 kr*

96-10. Persondosmätningar
Årsrapport 1995
Lars Bergman *40 kr*

96-11. Kvalitetssäkring av egenkontrollen vid svenska kärnkraftverk och Studsvik AB - 1994
Kemienheten *40 kr*

96-12. Säkerhets- och strålskyddsläget vid de svenska kärnkraftverken 1995-96
November 1996
Statens Kärnkraftinspektion rapp. 96:71 och Statens strålskyddsinstitut *Gratis*

96:13. Radon in Estonian Buildings
Establishment of a measurement system and obtained results
L. Pahapill, A. Rulkov, G.-A. Swedjemark *50 kr*

SSI Rapport

STATENS STRÅLSKYDDSINSTITUT, SSI, är en central tillsynsmyndighet med uppgift att skydda människor, djur och miljö mot skadlig verkan av strålning. SSI arbetar för en god avvägning mellan risk och nytta med strålning, och för att öka kunskaperna om strålning, så att individens risk begränsas.

SSI sätter gränser för stråldoser till allmänheten och till dem som arbetar med strålning, utfärdar föreskrifter och kontrollerar att de efterlevs, bland annat genom inspektioner. Myndigheten informerar, utbildar och ger råd för att öka kunskaperna om strålning. SSI bedriver också egen forskning och stöder forskning vid universitet och högskolor.

Myndigheten medverkar i det internationella strålskyddssamarbetet. Genom projekt Strålskydd Öst bidrar SSI till förbättringar av strålskyddet i främst Baltikum och Ryssland. SSI håller beredskap dygnet runt mot olyckor med strålning. En tidig varning om olyckor fås genom svenska och utländska mätstationer och genom internationella varnings- och informationssystem.

SSI har idag ca 125 anställda och är beläget i Stockholm.

Statens strålskyddsinstitut
Swedish Radiation Protection Institute

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