2. SITE CHARACTERISTICS

2.1 GEOGRAPHY AND DEMOGRAPHY

The Ignalina nuclear power plant is located in Lithuania, close to the borders of Belorus and Latvia, as shown in Fig. 2.1. The plant is built on the southern shores of lake **Drūkšiai**, 39 km from the town of Ignalina. Nearest cities to the plant are Vilnius at a distance of 130 km with over 600,000 inhabitants, and Daugavpils in Latvia 30 km away with 126,000 inhabitants. Six kilometers from the plant is the city of Visaginas, about 33,200 inhabitants, residence of the Ignalina nuclear power plant personnel.

In the vicinity of the Ignalina NPP are the following lakes and rivers:

- lake Visaginas,
- lake **Drūkšiai**,
- lake Apyvardė, located 8 km and lake Alksnas, 13 km to the south from the Ignalina NPP,
- river Daugava passes 30 km to the north of the Ignalina NPP.

Visaginas is part of the Ignalina district. The construction of the nuclear power plant has made a big impact on the demography in this district. In 1979 the total population of the Ignalina district was 37,800, then in 1989 it rose to 59,700, while the population in the country-side decreased from 21,600 to 18,200 [5].

In 1979 the natural population increase rate was 4.8 people per 1000 (the birth and the death rate were 16.1 and 11.3 per 1000, respectively) and in 1989 it was 3.8 people per 1000 (the birth and death rate was 13.5 and 9.7 per 1000, respectively) [6]. The main cause of the increase of population in the Ignalina district was migration to Visaginas. This also led to a significant shift in the nationality of the population of the Ignalina district. In 1979 the percentage of Russians and Russian speakers was about 26 % in 1989 it had increased to about 53 %. This immigration was concentrated in the city of Visaginas which consisted of about 92 % Russians and Russian speakers.

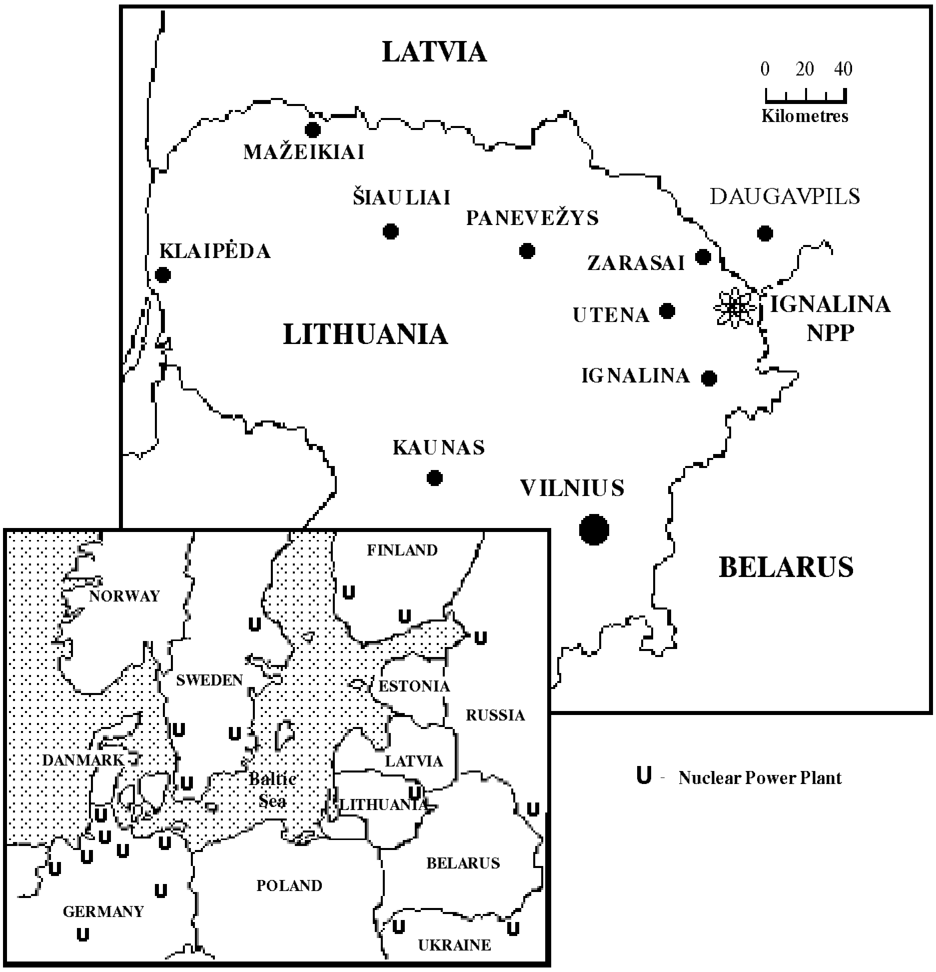

Fig.2.1 Location of the Ignalina NPP

2.2 POPULATION DISTRIBUTION

The population distribution in the region of concern on the basis of location is presented in Table 2.1.

The total population within a 30 km radius excluding the population of Daugavpils is about 85,000. Within a 15 km radius the population density is 16.1 people/km^2 without taking the Visaginas inhabitants into account, and 63.1 people/ km^2 including the Visaginas inhabitants. Within the 25 km radius the density of population is 18.7 and 35.6 people/km^2, respectively. This does not exceed the nominal density of population of 56.7 people/km^2 in Lithuania.

2.3 NEARBY INDUSTRIAL REGIONS

The nearest highway passes 12 km to the west of the Ignalina NPP. This highway joins the city of Ignalina with those of Zarasai, **Dūkštas** and has an exit to the highway connecting Kaunas - St. Petersburg. The entrance of the main road from the Ignalina NPP to the highway is near the town of **Dūkštas**. The extension of the road from Ignalina NPP to **Dūkštas** is about 20 km.

The main railroad line Vilnius - St. Petersburg passes nine km to the west of the Ignalina NPP. A single track extends from Visaginas to **Dūkštas**, the rest of the main line connecting Vilnius - St. Petersburg is double-track. The weight limit of the train is 3500 tons. The railway station **Dūkštas** is used for the cargo traffic as well as for passenger transportation.

An installation for the treatment of sewerage is located one km to the south from the Ignalina NPP. This is a repository of chlorine, the capacity of which is 16,000kg.

As a note, no chemical or oil process industries exist in the vicinity of the Ignalina NPP.

2.4 METEOROLOGY

The Ignalina NPP is situated in the temperate climate zone. The region concerned, as well as all Lithuanian territory, is located along the path dominated by western wind currents, therefore in the global sense its climate can be considered as homogeneous. However, on the regional scale it is rather variable, because of the prevalent intrusion of air flows from the adjacent geographical zones [8].

The territory of the Lithuanian Republic is divided into four climatic regions, depending on their proximity to the Baltic see, the orography of relief and the diversity of the underlying surface. The territory of concern belongs to the East climatic subarea [9]. In comparison with other Lithuanian areas, this area is marked by a big variation of air temperature over the year, the colder and longer winters with abundant snow cover, and warmer, but shorter summers.

On the whole the local climate depends on the circulation of air mass from the Atlantic, but the influence of air mass from the continents of Europe and Asia continent are perceptible as well [10].

Wind Regime

About 60 cyclones and 50 anticyclones are expected yearly due to the weather conditions of the territory concerned. Cyclones are influenced by the weather about 170 days and anticyclones about 130 days a year, because they are moving faster. During the rest of the time baric formation are observed [8].

The entire territory of Lithuania has practically no influence on the formation of new air masses or their considerable transformation. During the year about 170 atmospheric fronts pass over the Ignalina territory.

Table 2.1 Population distribution

Populated area	Distance from Ignalina NPP, km	Direction with respect to Ignalina NPP	Number of inhabitants
Villages and farmsteads	within 15 radius	-	11,400
Villages and farmsteads	within 25 radius	-	30,400
Visaginas	6	west	33,200
Turmantas	12	north-west	0,400
Dūkštas	17	south-west	1,200
Zarasai	22	north-west	8,900
Daugavpils	30	north	126,000
Ignalina	39	south-west	6,800
Vilnius	130	south-west	600,000

During the cold season the warm fronts predominate over the cold ones, while during the warm seasons they are distributed equally. Colds fronts move faster than the warm ones. Western and southern winds predominate. The strongest winds have western and south - east directions. The average annual wind speed is 3.5 m/s, and maximal (gust) speeds can reach 28 m/s. No-wind conditions are observed on the average of 6 % of the time and last no more than one day (24 hours) in the summer, and no more than two days in the winter [8].

The predominant wind direction changes depending on the distance above the ground. Beginning from the 200 m distance above ground the predominate direction is as follows: in January from south to south-west, in April from south-south-east to south-east, in October from west-north-west to north. Only during July is the predominate direction west at elevated altitudes.

The wind velocity changes depending on the distance from the ground surface. At a distance of 100 m from the ground the average wind velocity doubles in comparison with wind velocities at the height of the wind vane. They continue to grow within the half km layer. Then the increase of the wind velocity as a function of height decrease. On the whole the area atmospheric conditions are favorable for scattering substances from the plant ventilating stacks.

Hurricanes and Spouts [12,13]

Spouts in the vicinity of the Ignalina NPP do not exceed class F-2 according to Fujita classification [11]. The probability of a class F-2 spout for the plant platform with one km^2 area is one time in more than 61667 years. For a class F-1 spout such a probability is one time per 43023 years. As a calculated characteristic of a spout for the Ignalina NPP platform with one km^2 area is assumed to be the characteristic of a class F-0 spout, the probability of which is one time per more than 10000 years.

The season of spouts begins at the end of April and ends in the first half of September. The directions of spout motion is from south-west to north-east in 73 % of the cases. The average length of spout shift trajectory is 20 km and the length varies from 1 to 50 km. Average width of the spouts is 50 m, and it varies mostly from 10 to 300 m. Calculated maximal spout velocity with frequency one time per 10000 years is about 39 m/s.

Data about the most destructive spouts are incomplete. However, the following data in normally used for calculations:

- maximal rotation speed of the spout wall is 105 m/s,
- pressure differential between center of the funnel and the fringe region of the spout is 135 kPa.

Sunshine and Cloudiness

Average annual duration of sunshine in the region is about 1710 hours (42 % of the maximum possible duration of the earth's surface irradiation by the sun). June is the most sunny month: the amount of sunshine in June is about 280 hours (58 % of the possible duration). The shortest period of sunshine because of cloudy weather is observed in December, which is about 20 hours (12 % of possible duration) [14].

Average annual cloudiness in region is about a force 7, and in December it increase to a force 8.5 and in May it decrease to a force 6.5. The average annual amount of cloudy days (175) is considerably larger than the clear ones.

Air Temperature

Average annual air temperature in the region is 5.5 ^oC. January is the coldest month with an average monthly temperature of - 6.5 ^oC, and June is the warmest one with 17.8 ^oC. Annual amplitude of average monthly temperatures is 24.1 degrees. Absolute maximum of recorded temperature is 36 ^oC, and absolute minimum is - 40 ^oC. The greatest oscillations of twenty-four-hour amplitude of temperature are usually in May-June, and the lowest - in December. The lowest temperature is usually observed in winter during the northern and north-east winds. In the summer the hot weather brings about the east and south-east winds [8].

Atmospheric Precipitations and Snow

The atmospheric conditions are formed by circulation of air mass on the whole. Average annual amount of precipitation with correction for the moistening of the draught gauge is 638 mm. During the warm period of the year (April-October) about 70 % of all precipitation takes place, and during the cold period (November-March) - about 30 %. The coefficient of variation of multi-year annual precipitation is 0.15. Minimum of precipitation occurs in March, and the maximum - in July-August. There are about 170-180 days with precipitation (0.1 m and more) per year [8]. The snow cover in the region is about 100-110 days per year. Average height of snow cover is 30-40 cm [8].

Evaporation and Humidity

Multi-year amount of annual evaporation from the dry land is about 500 mm, evaporation from the water surface during the warm period (April-November) is about 600 mm with the coefficient of variation 0.15 [8].

Average relative humidity of air reached 80 %, and about 90 % in winter. A minimum relative humidity (53-63 %) is observed in June, and a maximum - in January [8].

Fog and Oscillation of Atmospheric Pollutants

In the Ignalina NPP area, fog is observed during the entire year. Average number of foggy days is 45 and a maximum - 62 days. Fog absorbs different impurity (noxious gases, smoke, dust) and, combined with high humidity, increases corrosion intensity, aggravating visibility and impeding transportation. Average duration of fog in the course of a month is from 4 to 29 hours and in the course of year is about 173 hours. During the cold period total duration of fog oscillates between 92 to 106 hours, and during the warm period it is about twice lower which is 49-68 hours.

Maximum dust intensity is observed in May, and minimum-in December. Oscillations of total content of sulphurous gas has the following annual distribution: lower values are observed in the summer and autumn, and highest ones-during the cold period of the year.

Ground Freezing

The ground usually begins to freeze in the first part of December and lasts to the middle of April. Average depth of the frost line reaches about 50 cm, with a maximum extending to 110 cm depending on the composition of the ground and its humidity.

2.5 HYDROLOGIC ENGINEERING

The lake **Drūkšiai** serves as a natural water reservoir and supplies the plant with cooling water. Lake **Drūkšiai** is the biggest lake in Lithuania. The catchment basin of the lake is located near the foot of the east slope of the Baltic ridge, which is bordered by the **Švenčionys** upland from the south and by the Latgal upland from the north. Such a watershed location with predominating north and south winds influences its hydrologic regime [10].

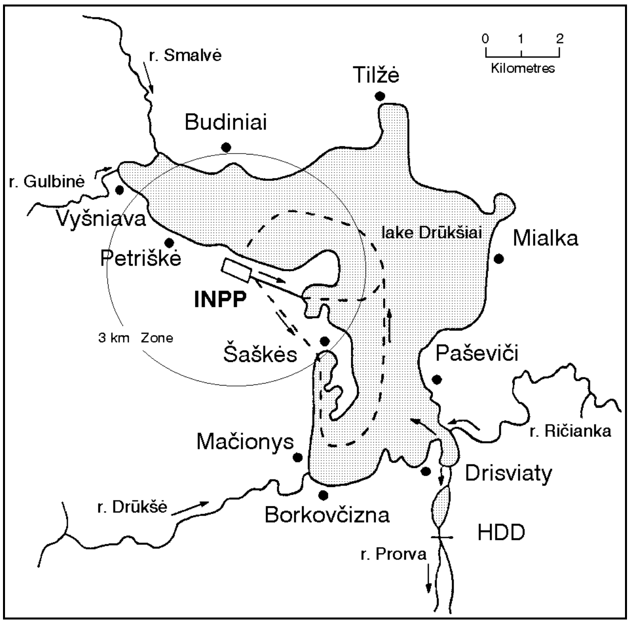

Fig. 2.2 Configuration of lake Drūkšiai, location of the Ignalina NPP and permanent testing stations (1-6) [15]

Total area of the lake, including nine islands, is 49.32 km^2. The area of the biggest island is 0.23 km^2, and the areas of other islands are smaller than 0.05 km^2. The surface of the islands varies from one to twelve meters above the water level. All islands, except one, are located in the south part of the lake.

The biggest depth of the lake is 33.3 m, and average is 7.6 m, while the predominate depth is 12 m. The channel of the lake was formed during the movement of the glaciers by two perpendicular runways, which were extended from the north to the south and from the west to the east. Maximum depth of the first runway was 29 m, and second one - 33.3 m [8]. The largest depths are located in the middle of the lake. The most shallow water is on the south ridge of the lake, the depth of which does not exceed 3-7 m.

The length of the lake is 14.3 km, the maximum width is 5.3 km, and the perimeter is 60.5 km. Drainage area of the lake is small, only 613 km^2 [15].

Total volume of water is about $369 \cdot 10^6$ m^3. It should be noted, that all data are given at the Normal Affluent Level (NAL) of water reservoir 141.6 m for the Baltic System (BS) elevation. During the exploitation of the water reservoir by multi-year regulation of discharge, the water level of the lake can decrease to an elevation of 140.7 m, that is by 0.90 m from nominal. As a result, the surface area of the lake decreases to 42 km^2, and the volume of water - to $326 \cdot 10^6$ m^3. At the present the water regime of the lake is regulated by a hydro-engineering complex of a former hydroelectric power plant [10].

The hydrographic schematic of lake **Drūkšiai** is presented in Fig. 2.2, and the bathygraphic curves of the lake in Fig. 2.3. Main data of the water-cooling reservoir of the Ignalina NPP are presented in Table 2.2.

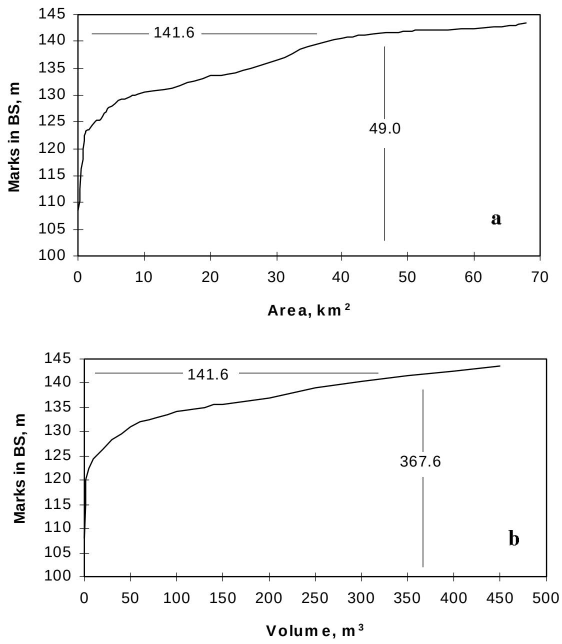

Fig. 2.3 Bathygraphic curves of lake Drūkšiai [15]
a - area, b - water volume

Table 2.2 Main data of hydrologic and hydrothermic regime of water cooling reservoir of the Ignalina NPP

Drūkšiai lake drainage area, km^2	613
Water area of lake at NAL, km^2	49
Multiyear flow rate of water from lake, m^3/s	3.19
Multiyear discharge from lake, m^3/year	$100.5 \cdot 10^6$
Multiyear quantity of atmospheric precipitation, mm/year	638
Multiyear value of evaporation from water surface, mm/year	600
Normal affluent level of lake, m	141.6
Minimum permissible lake level, m	140.7
Regulating volume of lake, m^3	$43 \cdot 10^6$
Permissible drop of lake level, m	0.90

A number of lakes are present in the area of the Ignalina NPP. Their total water surface area is 48.4 km^2 (without lake **Drūkšiai**). Lakes occupy 15 %, swamps - 15 %, farming land - 40 % and forests - about 30 % of the surrounding area. Net density of rivers is 0.3 km/km^2.

Nearly all surface discharge (74 %) flows to the south part of lake **Drūkšiai** by way of two rivers Ričianka and **Drūkšė**, the rest of the surface discharge goes to the west ridge from the tributaries of the rivers Smalvė and Gulbinė. Discharge from the lake goes by way of the river Prorva through the south ridge of the water reservoir. Warm coolant water of the NPP is discharged into the same place. So, the most intensive water exchange take place in the south part of the lake.

The water regime of lake **Drūkšiai** is formed by correlation of natural and anthropogenic factors. The main natural factors are the climatic conditions of the region: precipitation onto the surface of the water reservoir and natural evaporation from lake surface and watershed. Anthropogenic factors, which have an influence on the NPP operation, are the control of discharge by the hydro-engineering complex and water circulation in the lake because of the needs for cooling of the NPP equipment.

The Ignalina NPP operation has no perceptible influence on the amount of atmospheric precipitation and on the water inflow into the lake. The NPP power has an influence on the evaporation from the water surface. Evaporation processes from the water surface of lake **Drūkšiai** is very important.

Net losses of water from the lake depend on the amount of evaporation. In conditions of limited water resources this amount can limit the power of the NPP. For this reason the natural and additional evaporation from the water surface are monitored carefully. During the years 1973-1976 a total annual evaporation from the water surface of lake **Drūkšiai** was determined to be 585 mm.

The twenty-four-hour average evaporation during all this period was 3 mm. During the hottest months-June and July-the evaporation was the largest - about 115 mm per month. In general, during the May-October period the evaporation was 535 mm [8].

The slope of subsoil waters in the lake is sufficiently small: a depth of 5 m in about 150-200 m from the bank. The flow is directed to the area of drainage of lake **Drūkšiai**. Subsoil discharge is about 3 % from all the multiyear water balance of lake **Drūkšiai**.

Ignalina NPP began operation in 1984. At the start only the first turbine of the first unit was put in operation. At the end of the same summer the second turbine was introduced, which reached full power in summer of 1985. Then the power of Ignalina NPP reached 1200 MW (e). During the years 1985-1987 Ignalina NPP operated at power of 1300-1500 MW on the whole with preventive maintenance during summer months. The first turbine of the second unit reached full power in August, 1987. During the year of 1988 the two units with a total power not exceeding 2500 MW (e) operated with interruptions.

During the operation of one unit the heat load to the lake is more than 0.06 kW/m^3 (i. e. the amount of heat transmitted to the lake per month is $8.7 \cdot 10^{15}$ J), and during the operation of two units - 0.11 kW/m^3.

Since the time when the first turbine started operating, the NPP coolant water began adding heat to the lake, this intensified the evaporation from the water surface. With the increase of power of the Ignalina NPP and gradually rising water temperature of the lake, there were additional losses of water by evaporation [10]. During the operation of Ignalina NPP the intensity of evaporation from the surface of lake **Drūkšiai** is sufficiently high and reaches a monthly average of 5 mm/day. This corresponds to a total evaporation of 158 mm/month during the operation of one unit, and 198 mm/month during the operation of two units.

From May to October in the 1984, the evaporation from the lake surface was 627 mm, in 1985 - 720 mm, in 1986 - 712 mm, in 1987 - 684 mm and in 1988 - 788 mm. During the May-October period, the evaporation norm is 540 mm, and during all the evaporation season (end of April-November) - 600 mm. From May to October in 1984 the evaporation norm was exceed by 16 %, in 1985 - by 33 %, in 1986 - by 32 %, in 1987 - by 27 %, and in 1988 - by 46 %, which shows the influence of the operation of the NPP [10].

The other side of the effect of Ignalina NPP to the amount of evaporation from the surface of lake **Drūkšiai** is the lengthening of the active evaporation time because of the extended period during which no ice forms on lake **Drūkšiai**. During the cold period the evaporation process persists in the zone which is adjacent to the mouth of discharge channel.

During the entire season of the year 1984 evaporation was $36 \cdot 10^6$ m^3, in 1985 - $48 \cdot 10^6$ m^3, in 1986 - $45.7 \cdot 10^6$ m^3, in 1987 - $50.8 \cdot 10^6$ m^3, and in 1988 - $52.2 \cdot 10^6$ m^3. These values exceeded the multi-year average values of evaporation (600 mm) by 14 % in the year 1984 during the operation of one turbine of Ignalina NPP with power of 750 MW, and by 72 % when the power was increased to 2500 MW [10].

Predictive calculations of the former Research and Development Institute for Energy Technology, St.Petersburg, Russia, together with LEI (at that time the Institute for Physical and Engineering Problems of Energy Research, Kaunas, Lithuania), the additional evaporation was found to be $16.2 \cdot 10^6$ m^3 or 55 % from the multi-year average value of the Ignalina NPP operation at 1500 MW (e), and $32.4 \cdot 10^6$ m^3 at 3000 MW (e). During the years of 1985-1987 the measured evaporation corresponds to computed predictions.

Employing the calculated estimates of water loss by evaporation from the lake's surface - a cooling discharge equal to about 5.5 l/s km^2 is obtained. This is equivalent to a discharge of the Ignalina NPP operating at 3000 MW (e) [10].

2.6 GEOLOGICAL AND SEISMOLOGICAL EFFECTS [8]

The Ignalina NPP is located in the area of the East-European platform, at the junction of two large structure elements: the Baltic sineclize and the Mazur-Belorus antiklize. Therefore, the crystal foundation and sediment case are separated by a series of tectonic breaks. Some of these were discovered by geophysical methods and determined by data from drilling samples. Data of seismic prospecting and test drilling 10 km to the north-west from the Ignalina NPP show, that dimensions of tectonic blocks can not be large, in the neighborhood of 2 x 2 km. From the evidence of such tectonic disintegration of this area, the probability of availability of tectonic disintegration zones near the Ignalina NPP is sufficiently high.

The surface in the Ignalina NPP area is rough. Their absolute elevation-marks change from 150 m to 180 m and more. Glacial Quaternary sediments exist near the surface within a depth from 60 to 200 m, they are supported from below by Before-Quaternary, Devonian, Silurian, Ordovician, Kembrician and Upper-Protozoan sediment variety. At a depth of 700-750 m imbedded methomorphic and Crystal sediments of Upper Proterozoic and Archei are present.

Table 2.3 Filtration properties of glacial accretions of the ground-cover in the Ignalina NPP area [10]

Type of accretion	Geological index	Distribution, %	Power, m	Filtration coefficient, m/day	Depth of water bed level, m	Water yield coefficient
Swampy	b**IV**	5	2 - 6	0.04 - 6	0.2 - 0.4	0.001 - 0.05
Alluvial	a**IV+III**	5	1 - 20	1 - 190	0.2 - 5	0.01 - 0.25
Limno-glacial	lg**III**nm$_3$	5	4 - 6	0.2 - 8	0.5 - 2.5	0.0002 - 0.15
Fluvi-glacial	fg**III**nm$_3$	5	10 - 15	5 - 20	2.5 - 5	0.05 - 0.35
Water-glacial	ag^t**III**nm$_3$					
	ag^t**III**nm$_1$	30	5 - 10	10 - 20	2.5 - 5	0.05 - 0.35
Glucagon	g^t**III**nm$_3$					
	g^t**III**nm$_1$	50	5 - 50	0.01 - 2	0.5 - 1.5	0.001 - 0.1

Table 2.4 Engineering-geological properties of glacial accretions of the ground-cover in the Ignalina NPP area [10]

Type of accretion	Particle density, g/cm^2	Soil density, g/cm^2	Humidity	Porosity coefficient	Fluidity limit	Plasticity limit	Angle of friction, ^{0}	Adhesion, MPa	Young's modules, MPa
Swampy	1.57	0.89	6.76	13.3	-	-	-	-	0.5
Alluvial	2.71	1.97	0.29	0.77	0.33	0.11	22	0.034	7
Limno-glacial	2.71	1.94	0.21	0.82	-	-	14	0.011	5
Fluvi-glacial	2.64	1.69	0.09	0.72	0.33	0.22	33	0.001	27
Water-glacial	2.65	1.67	0.09	0.71	-	-	32	0.001	6
Glucagon	2.70	2.24	0.13	0.34	0.19	0.14	23	0.028	30

Surface sediments in the area of Ignalina NPP are very inhomogeneous. They were formed during the retreat of the last glacier as a result of different glacial and water-glacial processes. Later on, alluvial, marsh and lake-sediments were formed.

The lithologycal structure, the filtration and engineering-geological properties of separate genetic types of surface sediments are not equal (Tables 2.3 and 2.4). Most prevalent are the permeable water-glacial sediments, which are located in direct proximity of lake **Drūkšiai** and the Ignalina NPP, Fig. 2.4. All surface sediments contain subsoil water, which range in depths from 0.2 to 7 m. Heterogenous supporting weight, the marsh, lake-marsh, lake-glacial and water-glacial sediments are located near the surface and at the level of the building foundations and other constructions. According to lithologycal classification this is peat, sand, gravel, sandy soil, sandy loam and clay.

The complexity of engineering-geological conditions of the platform in question is:

1. Heterogeneity of grounds,
2. Availability of weak grounds, especially, peat,
3. Availability of numerous cradles, lenses and interbeds in the sand - gravel sediments,
4. Availability of swamps.

All these factors have an influence to the settlement of buildings and constructions. The deformation of the split slabs can be considerable - from 50 to 1000 mm - and can be highly irregular.

The Ignalina NPP territory is located in the area of a Before - Kembrician platform. In spite of this, the earth's crust is pulsating, even experiencing perceptible shocks. The predicted intensity of neotectonic motion in the area of Ignalina NPP is 3.5 mm per year. The district was affected by the Karpat earthquake, which had a predicted intensity of 5 on the Richter scale.

Construction and operation of the Ignalina NPP essentially widens the spectrum of technogenic influence on the geologic environment. The character and scales of the consequences depends on the geological situation such as power of the aeration zone and filtration, as well as from drainage conditions of the subsoil aquifer. From this point of view the territory of Ignalina NPP is located in unfavorable conditions. The depth of the aeration zone is from 1-2 m to 5-8 m and is insufficient to protect subsoil waters. It is composed of fine sands, the filtration coefficient of which is 5-20 m/day, the water-yield coefficient is 0.05-0.35, and for sandy loam, the filtration coefficient of which is 0.01-2 m/day, the water-yield coefficient is 0.001-0.1. Soils of the Ignalina NPP area can not guarantee a reliable localization of radionuclides during an accidental leak, and can not be a barrier, which prevents the migration of such radionuclides as ^{90}Sr and ^{137}Cs to the biosphere.

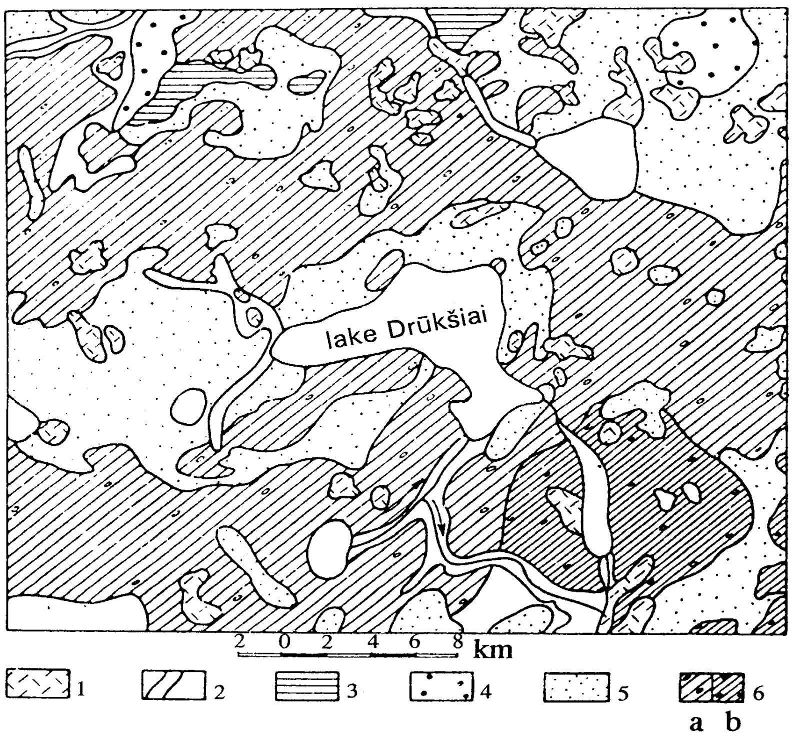

Fig. 2.4 Glacial accretions of the ground-cover in the Ignalina NPP area [10]
1 - swampy accretions (peat, slimy sand), 2 - alluvial accretions (sand, gravel, pebble, sandy soil), 3 - limno-glacial accretions (clay, alevrit, sand), 4 - fluvi-glacial accretions (sand, gravel, pebble), 5 - water - glacial accretions of local formations (sand, gravel, pebble, sandy soil), 6 - glucagon accretions of local formations (sandy soil, sandy loam) of late (a) and early (b) stage of last glacier