Tiekėjas

Subtiekėjas:

PROJECT DOCUMENTATION DEVELOPMENT SERVICE CONTRACT FOR RECONSTRUCTION OF IGNALINA NPP BITUMINISED RADIOACTIVE WASTE STORAGE FACILITY AND CONVERTING IT INTO NEAR SURFACE REPOSITORY
No Pst-136 (13.67), as of 23/07/2018

REPOSITORY SITE EVALUATION REPORT
Nr. S/19/670

Revision 2

LIETUVOS RESPUBLIKA UAB „SVERTAS GROUP" VISAGINAS

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Visaginas, 2019

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ISO 9001
ISO 14001

S/14-1889.19.23/SER/R:2

NUCLEAR ENGINEERING LABORATORY

ENVIRONMENTAL IMPACT AND SAFETY ASESSMENT FOR RECONSTRUCTION AND TRANSFORMATION OF IGNALINA NPP STORAGE FACILITY OF BITUMINISED RADIOACTIVE WASTE INTO REPOSITORY

REPOSITORY SITE EVALUATION REPORT

Revision 2

Habil. dr. P. Poškas

20 December, 2019

<table>
<tr><td colspan="2">Report title:
Repository site evaluation report.
Report status and title:
Revision 2</td><td>Issue date:
20-12-2019</td></tr>
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98 / 0</td></tr>
<tr><td>Customer:
JSC “Svertas Group”</td><td>Contract signing date:
01-02-2019</td><td>Report reference:
S/14-1889.19.23/SER/R:2</td></tr>
<tr><td colspan="2">Contract title:
Environmental impact and safety assessment for reconstruction and transformation of Ignalina NPP storage facility of bituminised radioactive waste into repository.</td><td>Contract No.:
S/14-1889.19.23</td></tr>
<tr><td colspan="3">Summary:
A safety analysis and justification of the site where reconstruction and transformation of INPP bituminised waste storage facility (building 158) into repository is planned are presented in the report. The report identifies possible environmental changes (natural processes and human activities) that could influence the safety of the planned repository and the factors that determine the environmental impact and human radiological safety. The analysis is concluded with a summary of the findings and conclusions which justify the site’s suitability for the reconstruction of the storage facility (Building 158) into a repository, and with a summary of preliminary radiological radioactive waste acceptance criteria.</td></tr>
<tr><td colspan="3">Keywords:
Radioactive waste, bituminised RAW storage facility, RAW repository, site characteristics, external natural processes, human activity, radionuclide migration, radiation safety, repository safety assessment, waste acceptance criteria</td></tr>
<tr><td>Distribution:
JSC “Svertas Group”,
Nuclear Engineering Laboratory archive</td><td colspan="2">Storage place and file No.:
\\Server\Biblioteka\Sutartiniai_darbai\
B20_(Bitumuotu RAS pavertimas i atliekyna)\Ataskaitos\01 Aikštelės vertinimo\EN\B20_SER_Rev2_En_2019-12-20.pdf</td></tr>
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Revision	Issue date	Comment
1	December 6, 2019	For Client review
2	December 20, 2019	For VATESI review

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ABBREVIATIONS

Bld.	Building
EGG	Engineering Geological and Geotechnical (investigations)
EPP	Emergency Preparedness Plan
ERO	Emergency Response Organization
IAEA	International Atomic Energy Agency
INPP	Ignalina Nuclear Power Plant
LGS	Lithuanian Geological Service
NPP	Nuclear Power Plant
RAW	Radioactive waste
SE	State Enterprise
SPZ	Sanitary protection zone
VATESI	State Nuclear Power Safety Inspectorate (Lithuanian abbreviation)
WAC	Waste Acceptance Criteria

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1 INTRODUCTION

The report presents a safety analysis and justification of the site where the reconstruction of the existing Ignalina NPP bituminised radioactive waste storage facility (building 158) into a repository is planned. The document has been prepared in accordance with the provisions of Chapter VIII of the VATESI requirements [1].

The report contains a description of the site characteristics including features of the geological structure, seismology and tectonics, hydrological, hydro-geological, meteorological, etc. conditions and their evaluation. Demographic and socio-economic backgrounds of the region are also described. The report identifies possible environmental changes (natural processes and human activities) that could influence the safety of the planned repository and the factors that determine the environmental impact and human radiological safety. The report also presents an impact assessment on population in a long-time perspective and other aspects of the site safety assessment. The analysis is concluded with a summary of the findings and conclusions which justify the site's suitability for the reconstruction of the storage facility (Building 158) into a repository, and with a summary of preliminary radiological radioactive waste acceptance criteria.

2 SITE DESCRIPTION

Bituminised radioactive waste storage facility (building 158) is located at north-west part of Ignalina NPP industrial site (see Fig. 2.1): about 200 m west from the first reactor unit and about 600 m from the south shore of the Lake Druksiai.

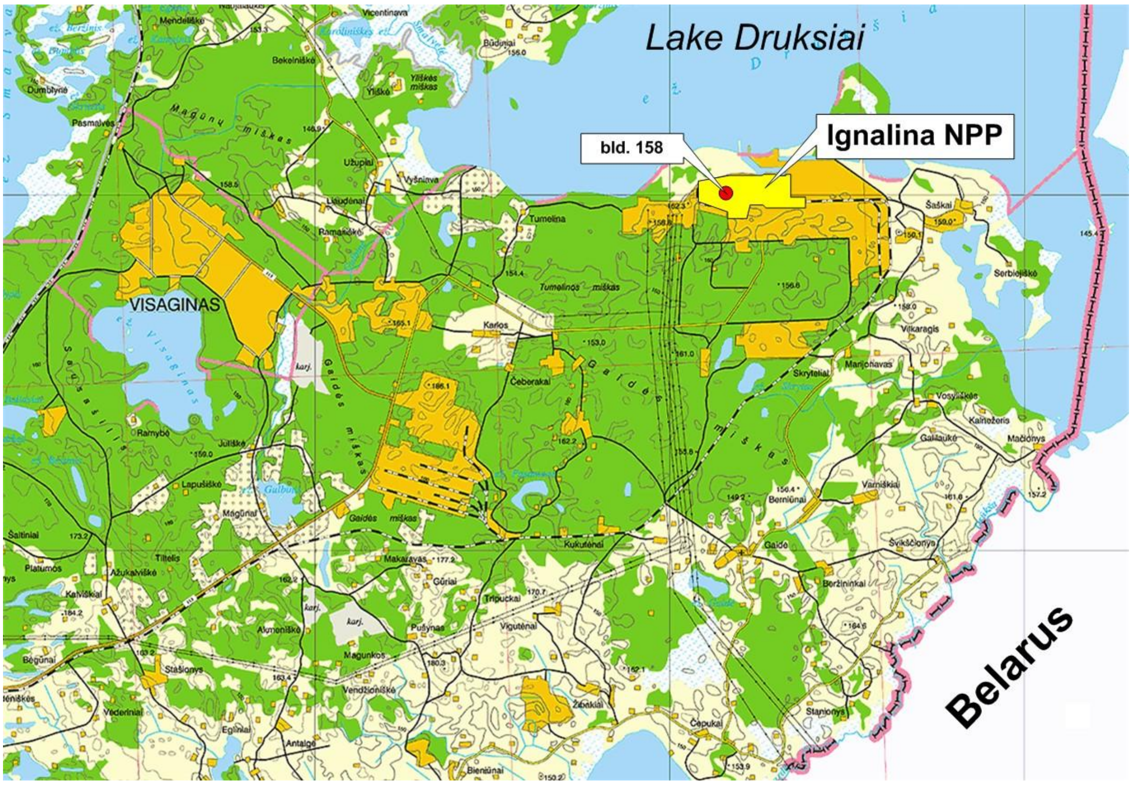


Fig. 2.1. Location of Bld.158 at the Ignalina NPP area

Storage facility (building 158) is connected to building 150 (building for processing, bituminisation, and cementing of liquid RAW) by pedestrian and technology galleries from the east side and to building 158/2 (interim storage facility for LRW) from the west side (Fig. 2.2) [12]. Minimum distance between the storage facility and the aforementioned buildings is about 9 m.

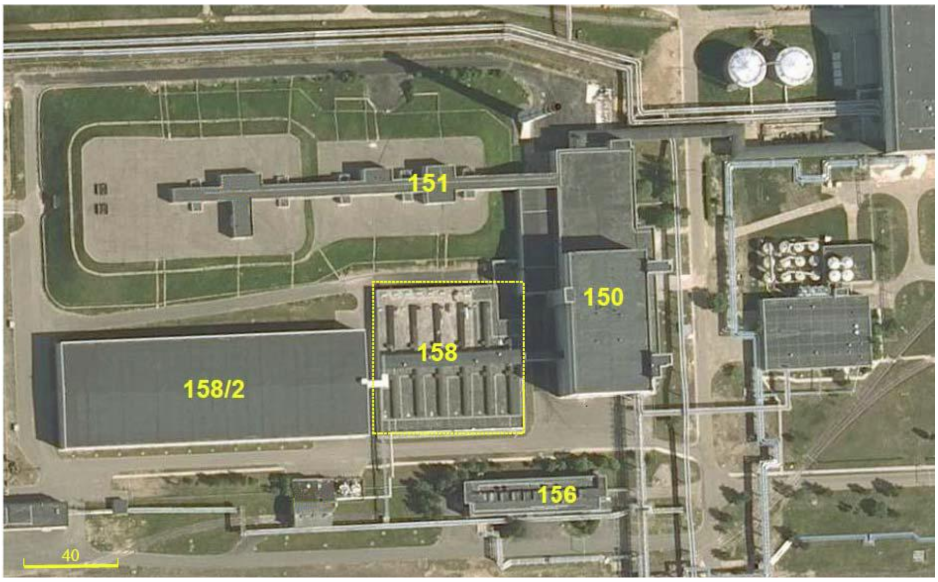


Fig. 2.2. Location of bld. 158 at the Ignalina NPP industrial site [12]

3 SITE CHARACTERISTICS

3.1 Geological features

3.1.1 Pre-Quaternary formations

The geological cross-section of the Ignalina NPP region comprises rocks of a crystalline basement and a sedimentary cover. The crystalline basement is 703–756.7 m beneath the ground surface. It consists of lower proterozoic rocks: usually gneiss, granite, migmatite, etc., which consist of biotite and amphibole [4].

The sedimentary succession consists of Pre-Quaternary and Quaternary rocks. Its thickness is 703–756.7 m. Upper Proterozoic, Vendian complex, and Paleozoic rocks spread in the Pre-Quaternary succession. The Vendian compex is composed of gravelite, feldspathic quartz sandstone of various coarseness, aleurolite and argillite. The geologic cross-section of the Paleozoic erathema consists of Lower, Middle Cambrian, Ordovician, Lower Silurian, and Middle and Upper Devonian rocks. The Lower Cambrian consists of usually fine-grained and very fine-grained quartz sandstone (with small amounts of glauconite), siltstone and clay which are of various coarseness; the Lower-Middle Cambrian of fine-grained and very fine-grained quartz sandstone; the Ordovician of limestone and marlstone layers; the Lower Silurian of domerite and dolomite; the Middle Devonian of gypsum breccia, domerite, dolimite, also fine-grained and very fine-grained sandstone, siltstone and clay layers; the Upper Devonian of fine-grained and very fine-grained sand, sandstone, siltstone and clay layers. The thickness of Vendian complex is 139–159 m, the overall thickness of the Lower and Middle Cambrian rocks is 93–114 m; 144–153 m thickness of the Ordovician rocks; 28–75 m thickness of the Lower Silurian; and the thickness of the Devonian rocks is less than 250 m [4].

The possible existence of natural resources is determined by local geological structure, which in turn is determined by geological processes have formed the sedimentary subsoil of the INPP region. As the region was mainly formed during last glacial epoch the sand and gravel resources for industrial use are a typical feature of the region [5].

3.1.2 Quaternary formations

Quaternary deposits occur on the undulatory sub-Quaternary surface with palaeoincisions. The thickness of the deposits varies from 62.0 to 260.0 m; most common thickness is 85.0–105.0 m, and in palaeoincisions it is 160.0–240.0 m.

The Quaternary succession consists of Pleistocene and Holocene sediments. The Pleistocene succession consists of layered glacial fine-grained, fluvioglacial coarse-grained and limnoglacial fine-grained as well as coarse-grained sediments of Dzukija, Dainava, Zemaitija, Medininkai and Upper Nemunas Formation, Gruda and Baltija sub-formations and locally spread interglacial alluvial, limnic and bog sediments (sand of different coarseness, silt, peat, and sapropel). Holocene sediments consist of alluvial (sand of different coarseness), lacustrine (clay, silt, sand, and sapropel), deluvial (clayey sand) sediments and bog (peat) sediments.

3.2 Seismology and tectonics

Two types of faults were distinguished in the Ignalina NPP area, i.e. the oldest pre-platform (not dissecting the sedimentary cover) and younger platform (penetrating into the sedimentary cover) features. The faults detected in the sedimentary cover are oriented to northwest and northeast, see Fig. 3.1. The faults of the Druksiai Depression (Graben) and Anisimovitshi Graben are the most distinct tectonic features recognized in the area [1].

The faults striking northeast and north-west are recorded in the all tectonic structures (blocks) of the Ignalina area. Their length varies from 3-5 km to 15-18 km; the offset is of 15-20 m [2].

Based on the data of the morphometric and morphostructural analysis and decoding of satellite snapshots an intricate network of the neotectonic lineaments was defined in the area of the Ignalina NPP (Fig. 3.1). In most cases the lineaments are confined to the faults and their zones identified by geophysical and drilling data. Similarly to the fault system, the neotectonic lineaments are oriented to northeast, northwest. Still, they show some offset with respect to the tectonic faults. The deep sub-Quaternary palaeoincisions (some are as deep as 200 m) are often confined to the neotectonic lineaments. One of neotectonically active linear zones breaks its way across the Ignalina site. The depth of associating palaeoincision exceeds 70 m (with respect to the top of the pre-Quaternary rocks) [2].

Surface sediment if INPP region is not homogenous. Clayey and integrated sand clay grounds prevail in the region. Moreover, man-caused impact on upper ground layers during INPP construction and operation is obvious [2].

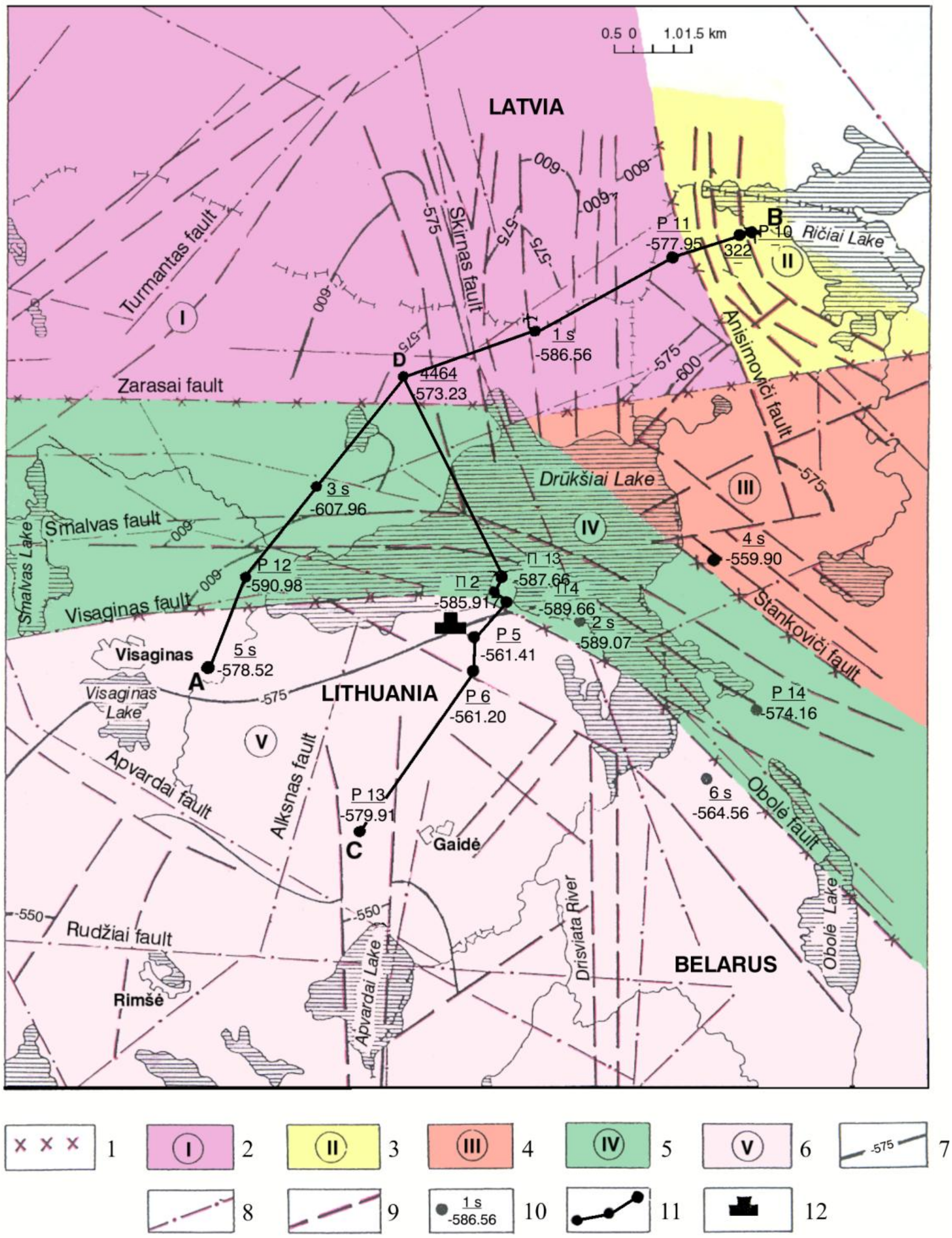


Fig. 3.1. Structural scheme of the surface of crystalline basement of Ignalina NPP area [2]:

1 – Border of the main structural elements (blocks) of the crystalline basement; Structural elements (blocks): 2 – North Zarasai bench; 3 – Anisimovitshi graben; 4 – East Druksiai uplift; 5 – Druksiai trough (graben); 6 – South Druksiai uplift; 7 – Isohypses (m) of the surface of the crystalline basement; 8 – Faults established by aeromagnetic and gravity data; 9 – Faults established by seismic data; 10 – Borehole: in numerator – number of borehole, in denominator– the absolute depth of the surface of the crystalline basement (m); 11 – Line of geological-tectonical section; 12 – Ignalina NPP

Fig. 3.2. Seismicity of Baltic States:

Circles – historical events from 1616 to 1965; hexagons – instrumental data from 1965 to 2004; triangles – operative seismic stations

Lithuanian territory is traditionally considered as non-seismic or low seismic zone. It depends on geological structure of the territory and long distance from tectonically active regions. Historical and recent instrumental data testify that seismic events of low or medium intensity have happened in territories of Baltic States (Fig. 3.2) [2].

The most recent seismic events with magnitude of 4.4 and 5.0 after Richter scale took place in Kaliningrad region of Russia in September 21, 2004. They were registered by seismological networks worldwide as well as by the seismological station of INPP [2].

Nineteen historical earthquakes took place within the radius of 250 km around the INPP from 1616. In the INPP region 4 seismological observation stations were installed in 1999. From then the Geological Survey of Lithuania according to agreement with INPP processes and analyses the data gathered in these stations [2].

At the present time, fault activity is monitored by carrying out measurements of vertical ground surface movements at a geodynamic polygone situated around Lake Druksiai. Results of the measurements performed in 1989–1994 (the last measurement in Lithuania's territory was performed in 1998) show that vertical ground surface movements at the Ignalina NPP district are connected to the movements of separate earth's crust blocks that are restrained by crystalline basement faults and sedimentary cover faults. The relative amplitude of the vertical movements of earth's crust blocks in this district is up to 2–3 mm per year, and up to 14 mm per year for horizontal movements [2].

According to available date the Geological Survey of Lithuania estimates that a design basis earthquake for the INPP area is the intensity of 6 grades on the MSK-64 scale with frequency 1 per 100 years (maximum ground acceleration a_{max} = 0.5 m/s^2 = 0.05 g). A beyond design basis earthquake for the INPP area is the intensity of 7 grades on the MSK-64 with frequency 1 per 10 000 years (a_{max} = 1 m/s^2 = 0.1 g). The main periods are from 0.15 to 0.4 s [2].

3.3 Hydrology and hydrogeology

Building 158 is located at the distance about 600 m south from the Lake Druksiai. The Lake Druksiai is the biggest lake in Lithuania; its hydrographical watershed scheme is shown in Fig. 3.3. Currently total area of the lake is about 45 km^2. 37 km^2 of this area is located in the territory of Lithuania. Maximum depth of the lake reaches 33.3 m, average depth – 8.2 m [2].

There are 11 tributaries to the Lake Druksiai and 1 river that outflows it (the Prorva). Main rivers that flow into Lake Druksiai are Ricianka, Smalva, Apyvarde and Gulbine [2].

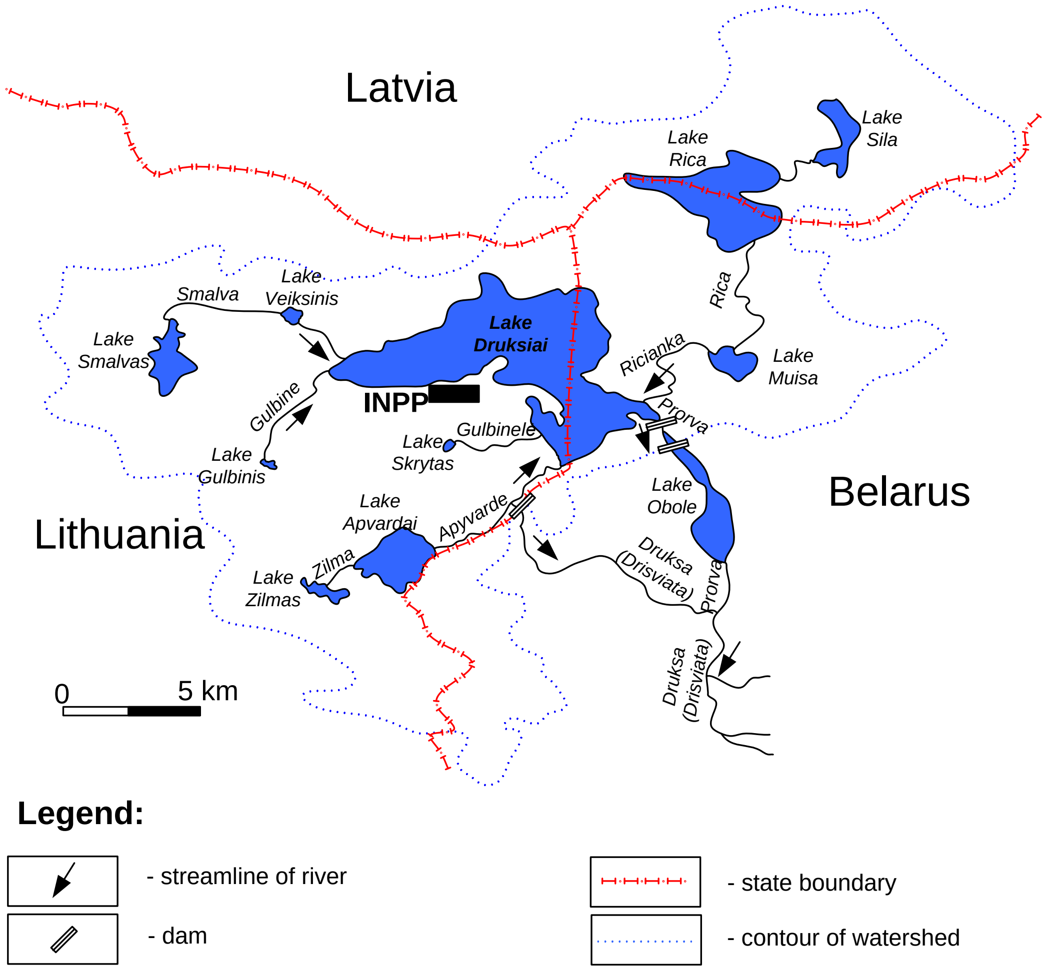


Fig. 3.3. Hydrographical scheme of Lake Druksiai watershed [2]

Nearly all surface discharge (74 %) flows to the south part of Lake Druksiai by way of the rivers Ricianka and Druksa. The rest of the surface discharge goes to the west ridge from the tributaries of the rivers Smalva and Gulbine. Discharge from the Lake Druksiai goes by way of the river Prorva through the south ridge of the lake. The summary of the main characteristics of Lake Druksiai is presented in Table 3.1 [2].

Table 3.1. Main characteristics of Lake Druksiai [2]

Parameter, units	Value
Area, ha	4480 / 3700*
Average depth, m	8.2
Maximum depth, m	33.3
Water volume, ths. m^3	367 650
Watershed area, km^2	620
Water turnover, % per year	29

* Total / Within Lithuania.

Average level of the lake is about 141.6 m above sea level, and during spring floods, maximum water level value may reach up to 142.35 m. The water regime of Lake Druksiai is formed by a combination of natural and anthropogenic factors. The main factor of natural origin is climatic conditions, i.e. atmospheric rainfall, getting into the lake and evaporation from the lake surface and its watershed. Operation of power plant hydro-engineering facility and circulation of lake water due to its necessity for cooling of the power plant installations are classified as factors of anthropogenic origin. In 1953 the hydro-engineering complex (dam) has been constructed under River Prorva before it's inflow into Lake Obole. It raised water level of Lake Druksiai approx. 0.3 m to the current level of 141.6 m [2].

The probability of the water level rise to 143.5 m is below 2.12E-08 [2].

The area of the Lake Druksiai watershed, see Fig. 3.3, is relatively small – approx. 620 km^2. Maximum length (from south-west to north-east) of watershed equals to 40 km. Maximum width equals to 30 km, average width – 15 km. The water turnover of the Lake Druksiai is slow. Outflow is mainly through the River Prorva (99 %). Further the effluents from the Lake Druksiai through the long and rather complicated way of 550 km length reach Riga‘s bay in the Baltic sea [2].

During building of Visaginas city, industrial drainage water was directed to cleaning facility constructed close to Lake Skripkai (Lake Skrytas). From there it flows to the River Gulbinele, which flows into Lake Druksiai [2].

In the site of investigation there were drilled many boreholes of different purpose and correspondingly of different depths (Fig. 3.4), information on which is placed in LGS (Lithuanian Geological Survey) information system. For more detailed description of hydrogeological conditions, 2 directions were chosen A–B and C–D. According to these directions two hydrogeological cross-sections crossing 158 site were constructed [4].

In general, the geological section of the Quaternary deposits is complex throughout the area. The succession consists of loam, clay and sandy loam with layers and lenses separated by fluvioglacial, aquaglacial and limnoglacial deposits containing groundwater. [4].

Fig. 3.4. Lines showing the hydrogeological cross sections (AB and CD) (area marked with a red rectangle is showing boreholes which data were collected, the data stored in the LGS database) [4]

It is indicated in the report [4] that According to A–B profile, the first layer from the earth's surface is till deposits (gIIInm3): loam (borehole Nr. 47857 44.4 m thick), dusty (borehole Nr. 47860 – 1.8 m thick) and clayey and sandy loam (borehole Nr. 20627 – 18.4 m thick). Due to the levelling of the relief for construction purposes, a large amount of technogenic soil is formed on natural soils, the thickness is varying from 1.8 m to 10 m (Fig. 3.5). The first aquifer is composed of fluvioglacial deposits (fIIInm3) – usually sand with coarser soil types. This aquifer is bounded by loam (gIIInm3) which is deepest at borehole No. 51795 and reaches 18 m deep. The gIIInm3 layer is mainly composed of loam, and its thickness varies from 2.6 m (No. 29544) to 20.4 m (No. 51814). The second layer is formed of fluvioglacial deposits (fIImd). These deposits are found at the depth of 20–30 m. This layer is confined from below by Medininkai aquitard deposits (gIImd). In the profile AB, the top of the gIImd layer is at the 18.4–22 depth, and bottom at the 25–54.4 m depth. [4].

According to the data provided in the report [4], Most boreholes of the C–D profile (Fig. 3.6) are about 30 meters deep, only borehole No. 44000 is deeper (65 m depth). Because most boreholes are not deep enough to provide a detailed description of hydrogeological conditions, the deeper part of the Quaternary deposits can be described very schematically according to the reported data in number of literature [4].

The hydrogeological cross section C–D (Fig. 3.6) consists of layers and lenses, where prevails till deposits – loam, clay and sandy loam (gIIInm3). The layers and lenses of water-bearing sandy fluvioglacial (fIIInm3) deposits are also common here. Lacustrine (lIV) sediments are found near Lake Druksiai. [4].

Till deposits (gIIInm3) can be found throughout all the territory of the investigation. This layer consists of loam and sandy loam, but there are also layers of sand, gravel and pebbles. The thickness of the till deposits varies from 1.8.till 9.5 m, at the wells No. 44000 and No. 44039 the deposits are at the surface, elsewhere this layer is covered by a technogenic layer (tIV), limnic (lIV) sediments (sand, silt) and fluvioglacial (fIIInm3) deposits [4].

Under till deposits the fluvioglacial water-bearing sandy deposits (fIIInm3) are found. The fluvioglacial deposits are found here at depths of 2–5.6 m, at boreholes No 29221 and No 29210 fluvioglacial deposits fIIInm3 are found at the surface and are 13-14 m thick. The second aquifer fIImd has limited spread, the layer mostly consists of sand, and is confined at the 16–21.8 m depth with layer of limnoglacial (lgIImd) deposits, which at boreholes No. 44000 and No. 43995 composed of sand, clay, loam and sandy loam layers (lgIImd). This layer is confined from below by the gIImd aquitard, which in borehole No. 44000 is found at 28 m depth and forms an 18 m thick loam and sandy loam layer. [4].

Intermorainic aquifers are separated by semi-permeable moraine fine-grained sediment layers of different (from 0.5–1.0 to 50–70 m) thickness—usually from 10–15 to 25–35 m. These sediments have interstices with sand and gravel lenses, and therefore vertical water exchange between intermorainic aquifers takes place. At the areas, where there are no moraine sediment layers (usually in palaeoincisions), adjacent intermorainic layers have a close hydraulic connection. In such a case, there is also a close hydraulic connection between the groundwater and intermorainic aquifers underneath [4].

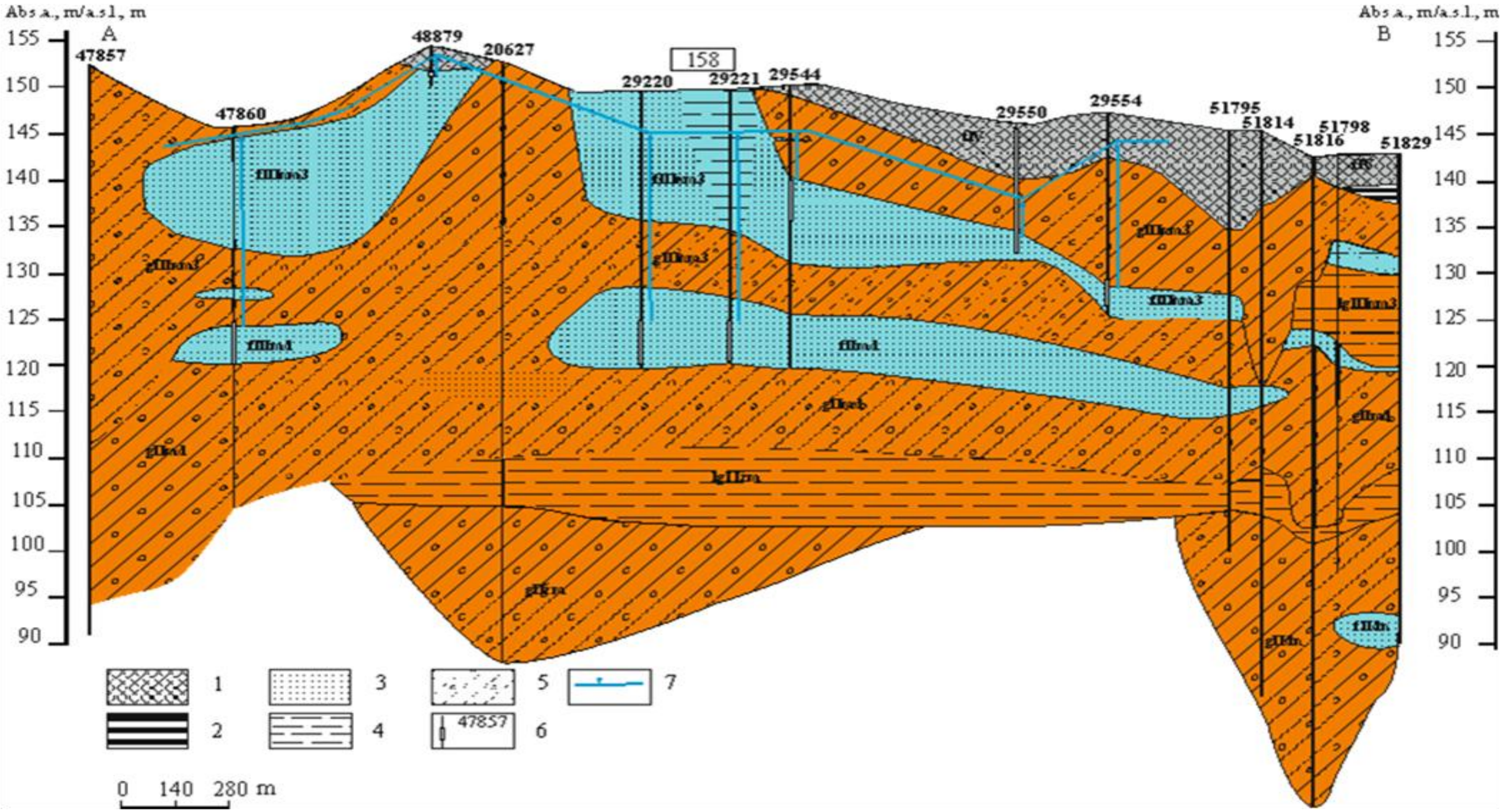


Fig. 3.5. Hydrogeological cross section (blue aquifers; brown aquitards) according to line AB (see Fig. 3.4) 1 – technogenic soil; 2 – bog sediments; 3 – various sand; 4 – clay; 5 – sandy loam, clayey loam; 6 – borehole number and filter interval; 7 – groundwater level [4]

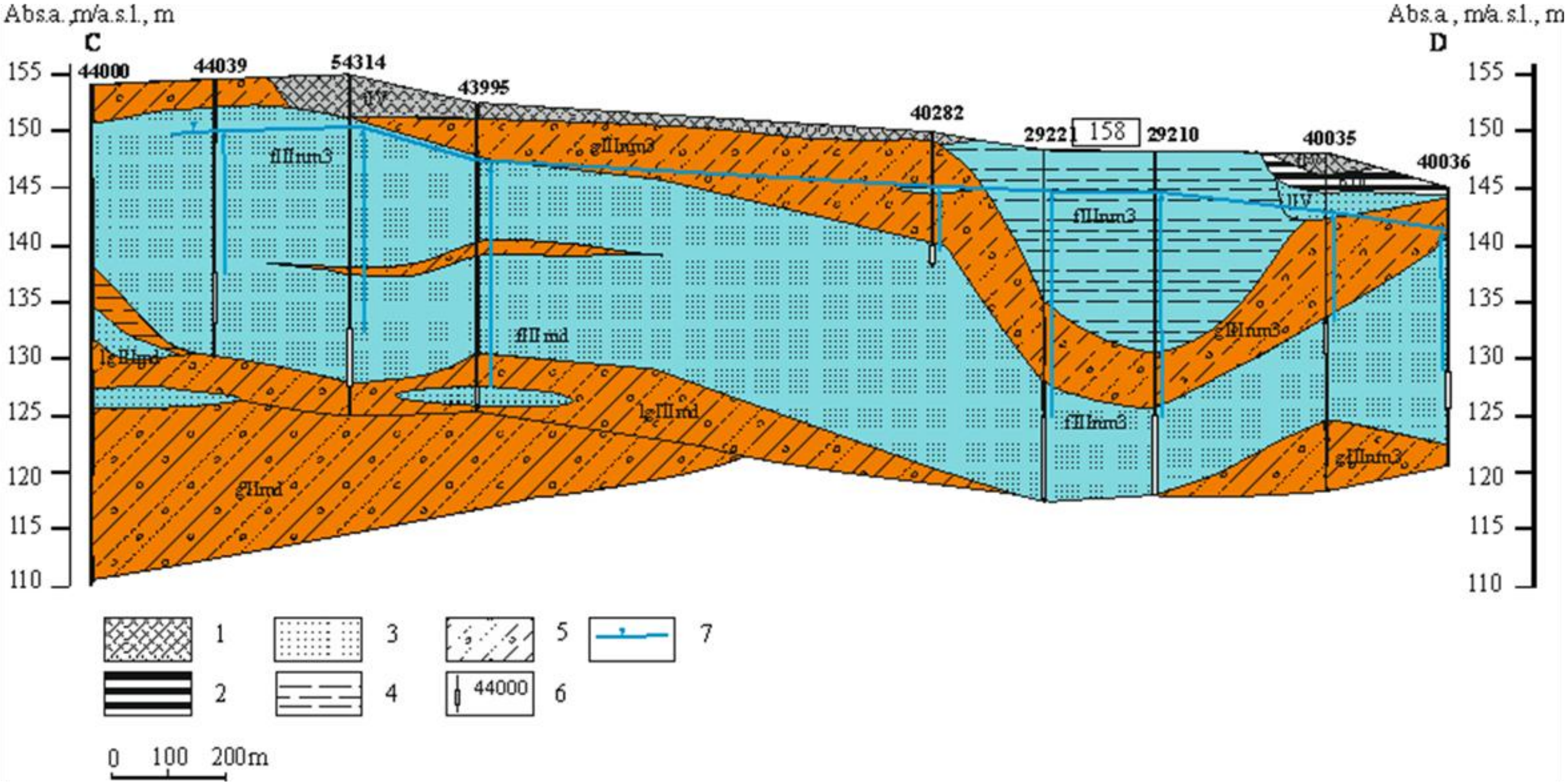


Fig. 3.6. Hydrogeological cross section (blue aquifers; brown aquitards) according to line CD (see Fig. 3.4) 1 – technogenic soil; 2 – bog sediments; 3 – various sand; 4 – clay; 5 – sandy loam, clayey loam; 6 – borehole number and filter interval; 7 – groundwater level [4]

In order to identify soil lithologies, evaluate the hydro-geological conditions, and take soil and groundwater samples, four engineering geological wells of up to 15.0 m depth and two hydro-geological wells of up to 12.0 m depth were installed near the building 158 planned for reconstruction so as to evaluate the soil filtration features in-situ by the pumping method. The data from the drilling process are presented in engineering-geological cross-sections (Fig. 3.7, Fig. 3.8).

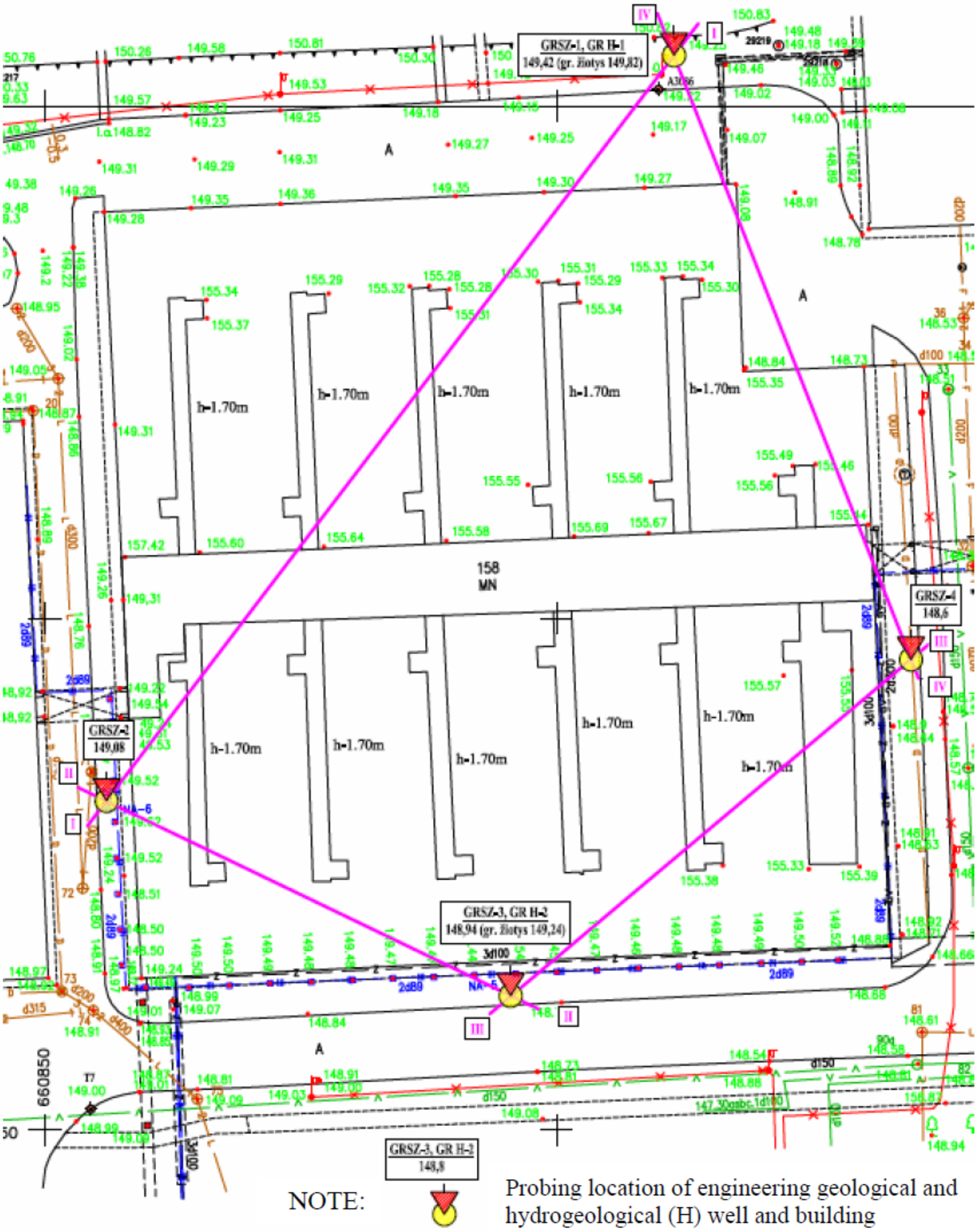
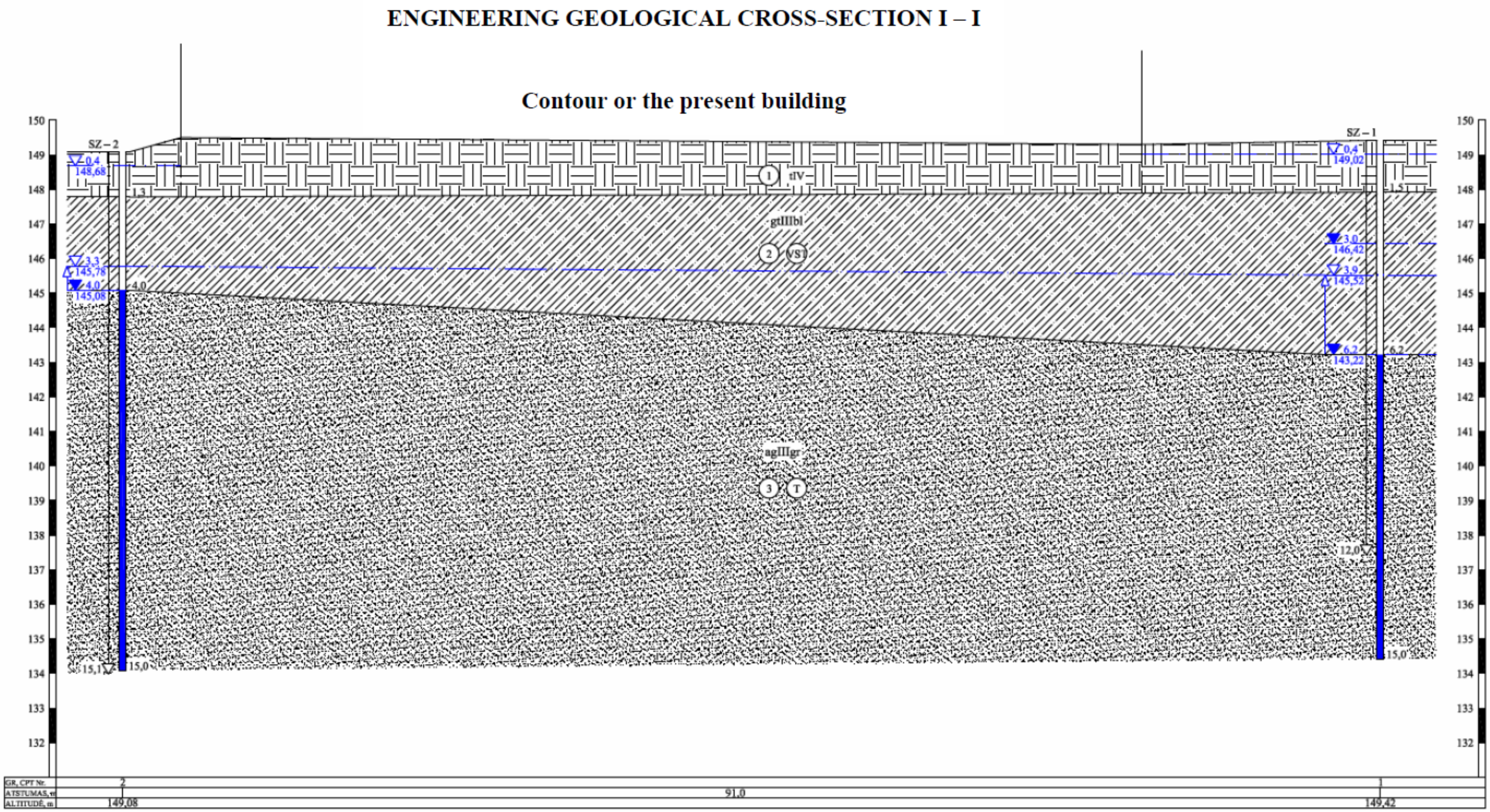
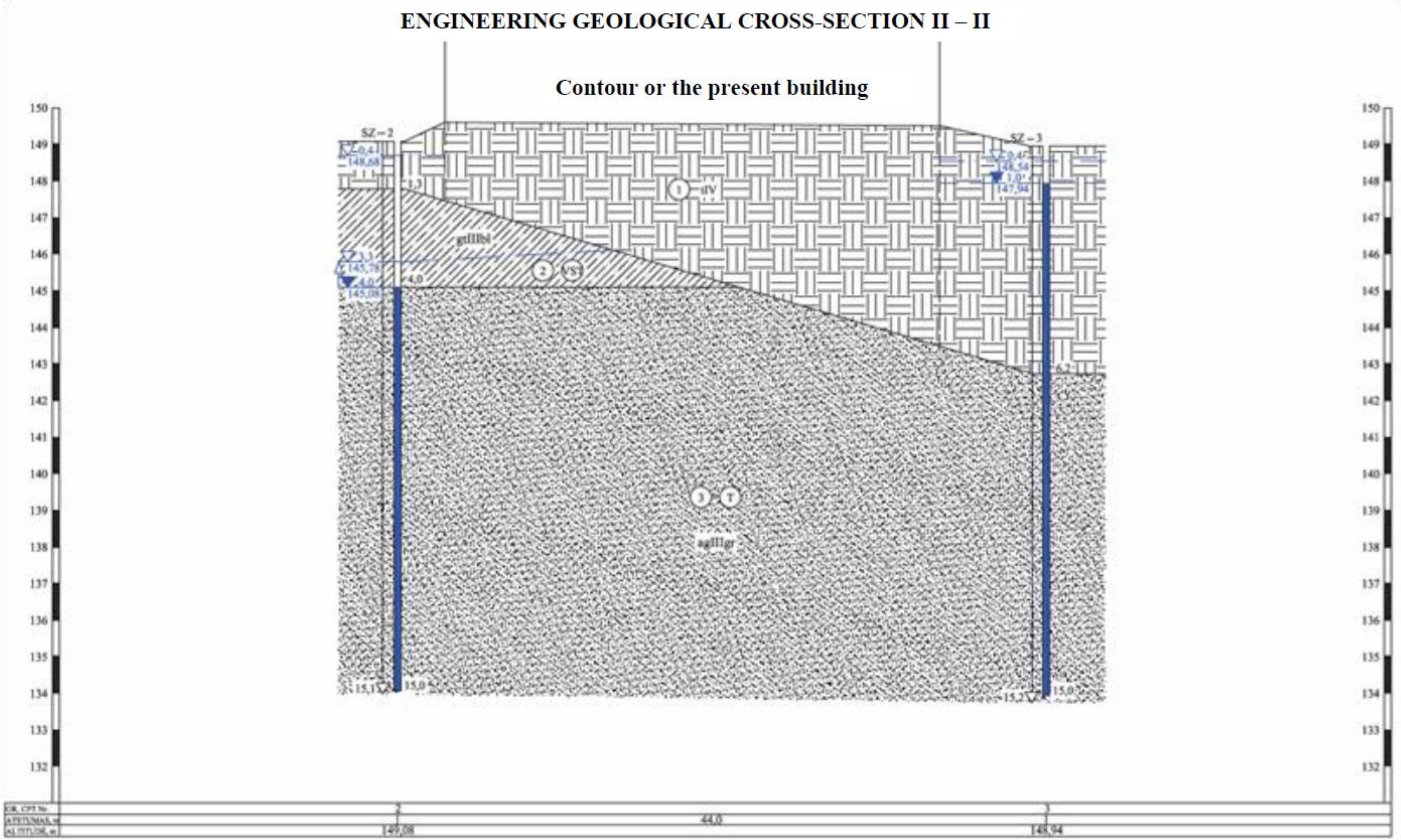
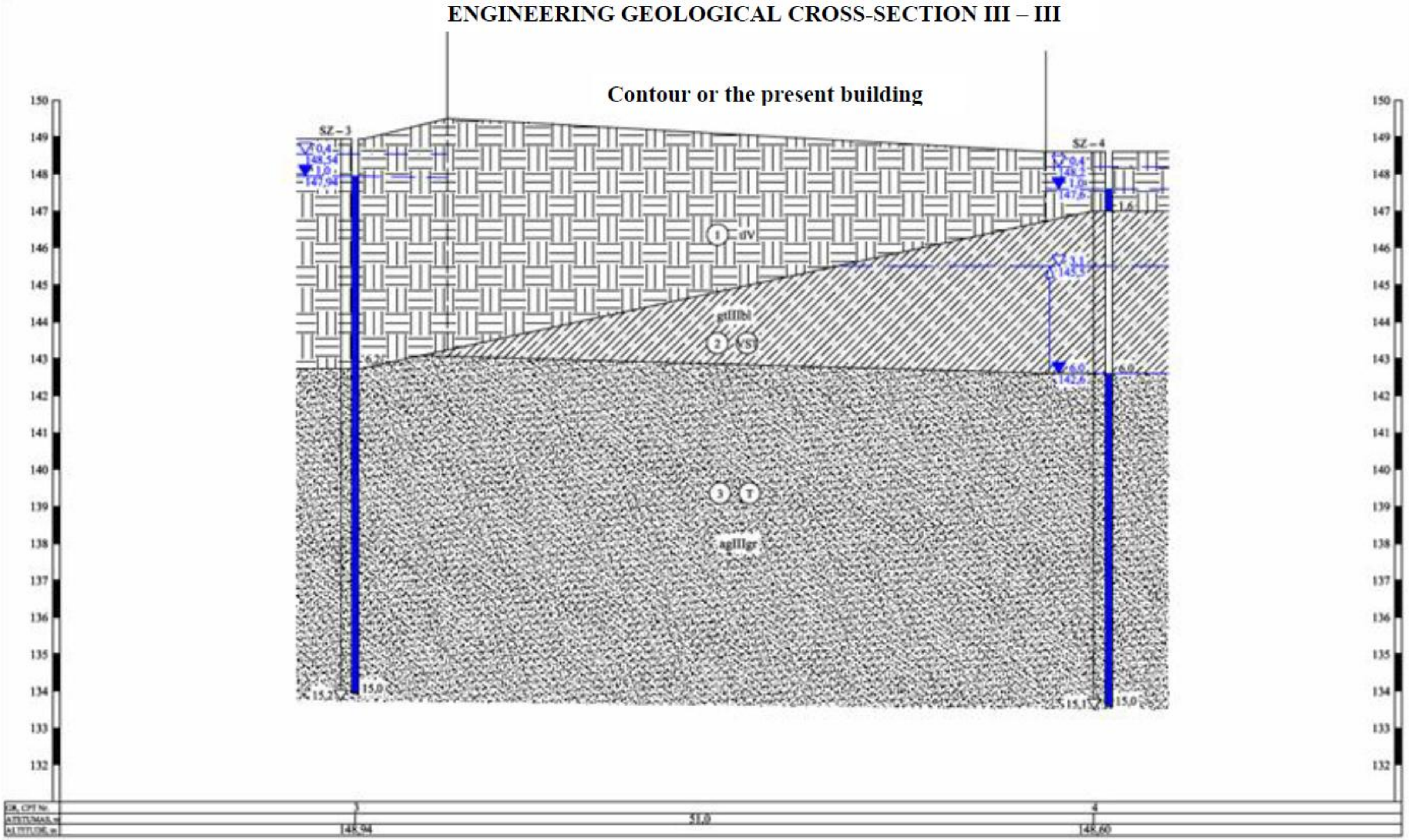


Fig. 3.7. Lines of engineering geological cross-sections [4]


ENGINEERING GEOLOGICAL CROSS-SECTION I – I
Contour or the present building
SZ – 2
SZ – 1
tIV
gtIIIbl
agIIIgr
91,0
149,08
149,42
GR, CPT Nr.
ATSTUMAS, m
ALTITUDĖ, m


ENGINEERING GEOLOGICAL CROSS-SECTION II – II
Contour or the present building
SZ-2
SZ-3
dIV
gtIIIbl
agIIIgr
44,0
149,08
148,94


ENGINEERING GEOLOGICAL CROSS-SECTION III – III
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SZ – 4
dV
gtIIIbl
agIIIgr
51,0
148,94
148,60

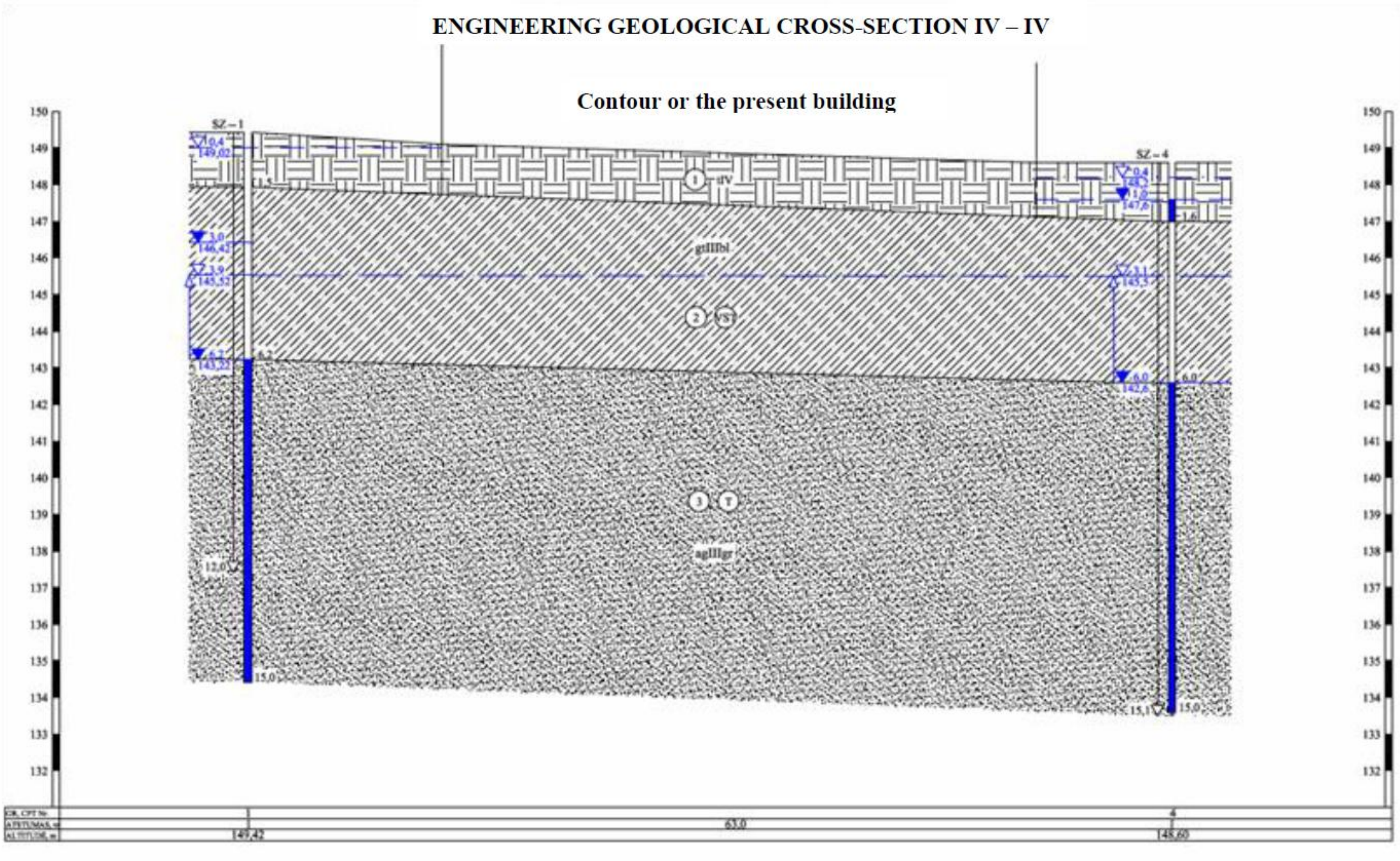


Fig. 3.8. Engineering-geological cross-sections I-I, II-II, III-III and IV-IV developed from data obtained during EGG investigations [4]

After design engineering-geological and geotechnical investigation of the site, the following Quaternary layers have been identified: technogenic soil (tIV), fine-grained sediments of the Upper Pleistocene, Nemunas glacial period, marginal moraine formations of the Baltic stage (gtIIIbl), and a layer of coarse-grained sediments of intermorainic aqua-glacial formations (agIIIgr) [4].

The technogenic soil (tIV) has been detected in all wells at the depth of up to 1.3–6.2 m. The thickest layer (6.2 m) of the technogenic soil has been detected in the southern part of the building (well No. 3). Based on archival data, the technogenic soil layer at the western part of the building is at the depth of 0.3–1.3 m [4].

Fine-grained sediments of the Upper Pleistocene, Nemunas glacial period, marginal moraine formations of the Baltic stage (gtIIIbl) have been detected in wells No. 1, 2 and 4 underneath the technogenic soil at the depth of 4.0–6.2 m [4].

The layer of coarse-grained sediments of intermorainic aqua-glacial formations (agIIIgr) is underneath the moraine and the technogenic soil (well No. 3) reaching the depth of the investigation (15.0 m). The bed of the layer has not been reached in the investigation. Based on archival data, the bed of these sediments is lower than 25.0 m [4].

It is stated in the EGG investigation report [4], that engineering geological as well as hydro-geological conditions of investigation site (i. e. site of bld. 158) allows to implement the intended project.

According to data provided in the EGG investigation report [4] the generalized values of the underground water parameters have been estimated as follows:

- *Vadose zone (in the close vicinity of bld. 158)*: clayey/loam filled-up layer (1 m thick) with hydraulic conductivity (filtration coefficient) of 4.62E-05 m/s (average value), 2,12E-04 m/s (maximal value). The direction of water flow is vertically down to the groundwater and aquifer;
- *Groundwater and 1st aquifer* (8 m thick): the distance to the discharge point (Lake Druksiai) – 600 m, the longitudinal dispersion (maximal) – 60 m (10 % of distance to the lake), the hydraulic gradient – 0.005, generalized value of the hydraulic conductivity – 1.31E-04 m/s.

According to data provided in the EGG investigation report [4] A balance of water flow in the INPP region is schematically presented in Fig. 3.9.

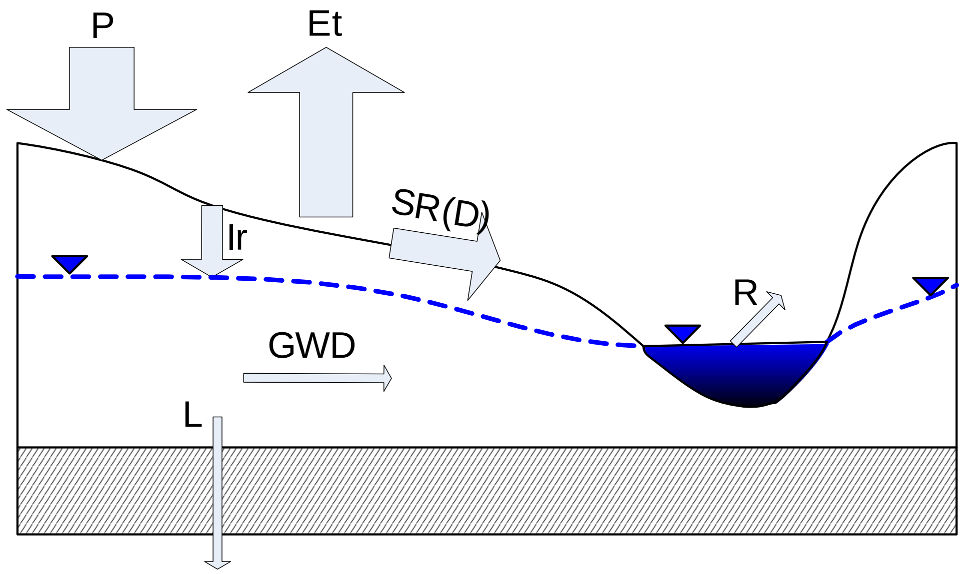


Fig. 3.9. Generalized scheme of annual water flow balance:
P – precipitation, approx. 767 mm, Et – total evaporation – 480 mm, SR(D) – surface run-off (drain) – 247 mm, Ir – infiltration – 40 mm, containing two components: i) GWD – flow to the local hydrographical system and, ii) L – flow to aquifer

According to meteorological data (see subsection 3.5.3) long-term average precipitation amount for INPP region is estimated to 767 mm per year. As total evaporation for the region is estimated to 480 mm the remaining 287 mm from the total water flow is for surface run-off (247 mm) and infiltration (40 mm) to deeper layers of the ground.

Active artesian wells in the INPP region presented in Fig. 3.10, do not fall into direction of underground water flow from bld. 158 towards Lake Druksiai [2].

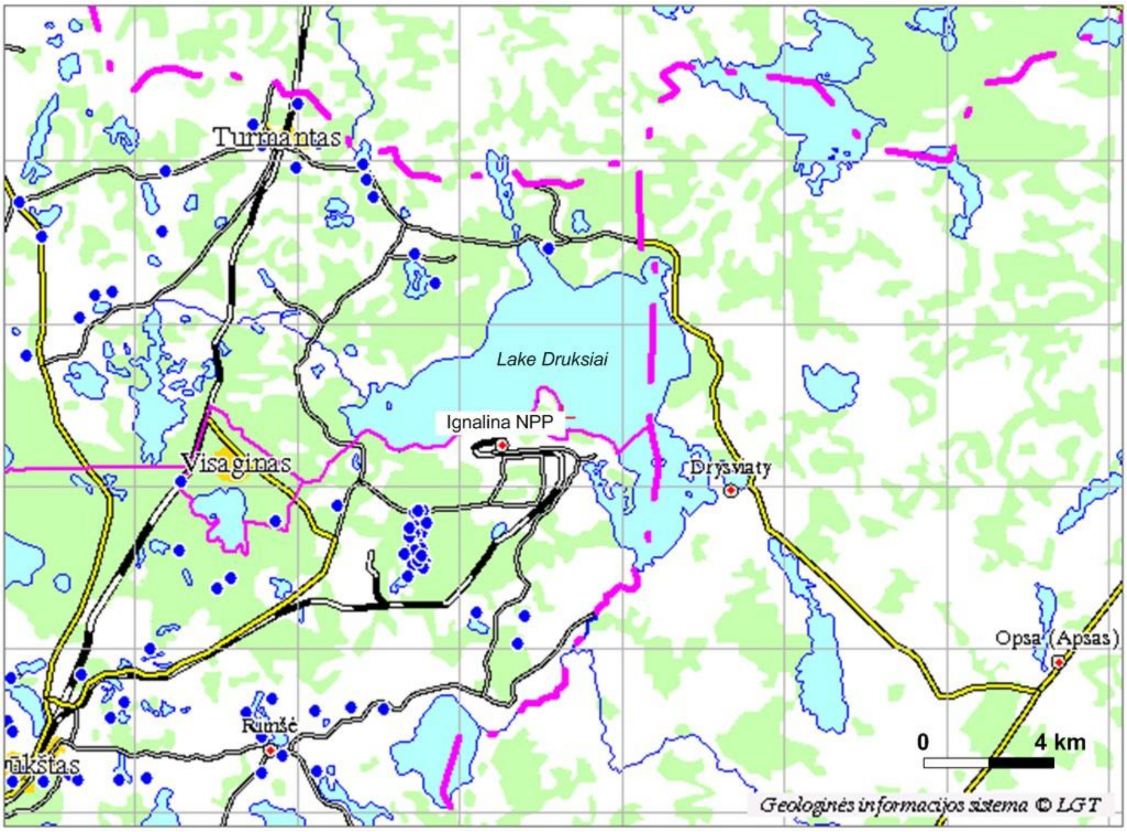


Fig. 3.10. Active artesian wells (marked as blue circles) [2]

3.4 Geochemistry and hydrochemistry

According to the results of geochemical analysis [4] the groundwater is low aggressive towards concrete containing Portland cement. The *pH* value of groundwater equals to approx. 7.1 – 7.2.

According to the lithological character of soil (prevalence of clayey soil) and groundwater chemistry, the impact of colloids and organic materials on the migration of radionuclides is rather expected. The presence of *Fe* and *Al* in the geological environment increases the influence of colloids on radionuclide migration. There are amounts of components forming the colloids in the groundwater of INPP region: *Fe* and *Mn* – 0.3-3.0 mg/l, C_{org} – 10-40 mg/l [8]. Therefore, an application of conservative K_d (sorption coefficient) values is recommended for the analysis of radionuclide migrations through the components of the disposal system.

3.5 Meteorological and Climatic conditions at the Site

3.5.1 Temperature

Data on monthly as well as yearly average temperatures in the INPP region for time period 2009 – 2018 are given in Table 3.2.

Average yearly temperature within period of year 2009 – 2018 varies from 6.3 °C in 2010, 2012 to 7.6 °C in 2015. Average temperature -11.9 °C in January 2010 is the lowest one recorded during reported period. Average temperature +22.5 °C in July 2010 is the highest one [5].

Estimated average air temperatures of the coldest five-day period are –27 ºC. Absolute maximum of recorded temperature is 36 ºC and absolute minimum is –40 ºC. Absolute maximum of calculated temperature with a frequency of 1 in 10000 years is 40.5 ºC and absolute minimum of calculated temperature with a frequency of 1 in 10000 years is –44.4 ºC [2].

Table 3.2. Monthly and annual average temperatures, ºC**,** in the INPP region [5, 6]

Month / **Year**	1	2	3	4	5	6	7	8	9	10	11	12	**Yearly average**
2009	-3.2	-4.2	0.2	8.3	12.4	15.1	18.1	16.1	13.6	4.9	3.5	-3.6	**6.8**
2010	-11.9	-4.8	-0.5	7.6	14.1	17.0	22.5	19.8	11.5	4.5	3.3	-7.4	**6.3**
2011	-3.7	-9.6	-0.4	8.3	13.1	18.4	20.6	17.4	13.3	7.0	3.1	1.3	**7.4**
2012	-4.7	-10.5	0.8	7.4	13.8	15.0	19.4	16.0	12.9	6.5	3.9	-5.4	**6.3**
2013	-7.9	-3.0	-6.3	4.8	15.8	18.3	18.0	16.7	11.2	7.7	4.1	0.9	**6.7**
2014	-7.4	-0.2	4.1	7.7	13.1	14.3	19.5	17.3	12.1	5.8	1.3	-2.3	**7.1**
2015	-1.3	-0.9	3.3	6.6	11.1	15.3	16.8	18.0	12.7	4.4	3.7	2.0	**7.6**
2016	-8.6	0.7	0.6	6.9	14.1	16.9	18.2	16.7	12.6	4.4	-0.4	-0.8	**6.8**
2017	-4.8	-3.2	2.2	4.6	11.4	14.5	15.9	16.6	12.7	6.1	2.7	0.3	**6.6**
2018	-2.4	-7.8	-2.8	9.0	15.2	16.1	19.1	18.1	13.8	7.0	1.5	-2.1	**7.1**
Minimal	**-11.9**	**-10.5**	**-6.3**	**4.1**	**11.1**	**14.3**	**15.9**	**16.0**	**11.2**	**4.4**	**-0.4**	**-7.4**	**6.3**
Average	**-5.6**	**-4.4**	**0.1**	**7.1**	**13.4**	**16.1**	**18.8**	**17.3**	**12.6**	**5.8**	**2.7**	**-1.7**	**6.9**
Maximal	**0.1**	**1.2**	**5.0**	**10.9**	**16.5**	**18.4**	**22.5**	**19.8**	**13.8**	**7.7**	**4.1**	**2.0**	**7.6**

3.5.2 Humidity

In the course of time period of year 2009 – 2018 [5, 6]:

- Minimum value of relative humidity of air 46.2 % is recorded in April, 2009;
- Maximum value of relative humidity of air 92.5 % is recorded in November, 2012;
- Average yearly relative humidity of air equals to 76.9 % and varies from 66.7 % in year 2011 to 82.8 % in year 2017.

3.5.3 Precipitation

Data on average values of monthly and yearly amounts of precipitation in the INPP region within period 2009 – 2018 are provided in Table 3.3.

Long term (year 1987 – 2018) average yearly amount of precipitation equals to 688.2 mm. 47 % of precipitation occurs during summer time (April – October) and 53 % within period from November to March. Minimum amount of precipitation recorded in January 2006 (10 mm), maximum (227.8 mm) in July 2010. Maximum yearly amount of precipitation (1054 mm) is recorded in year 2017, minimum (529.4 mm) is recorded in year 2008 [5, 6].

Table 3.3. Monthly and yearly average precipitation, mm**,** in the INPP region [5, 6]

Month / Year	1	2	3	4	5	6	7	8	9	10	11	12	Yearly sum
2009	43.8	48	32.2	7.4	25.7	126	132.1	49.7	103.9	104.3	68.7	78.9	**820.7**
2010	22.7	44.5	53.3	47.2	90.8	105.9	227.8	110.8	94	43.7	55.8	105.8	**1002.3**
2011	64.9	39.8	18.9	15.2	74.8	58.9	108.8	82.6	68.3	29.3	24.4	59	**644.9**
2012	64.7	47.6	44.3	63.5	49.7	137.3	56.8	69.6	36.2	83.5	93.5	58.2	**804.9**
2013	42.7	59.9	42.8	27.9	41.9	51.2	102.2	60.9	50.3	32	63.4	26.3	**601.5**
2014	44.3	41	38.4	36.7	102.9	90.1	50.7	113.4	29.8	52.7	16.2	55.2	**671.4**
2015	84.6	20.4	24.1	50.9	72.8	15.9	99.4	14.2	117.4	29.5	76.8	40	**646.0**
2016	41.8	66.6	49.7	61.9	32.2	69.8	162.1	53.2	11.1	112.3	67.1	57.6	**785.4**
2017	41.1	49.2	89.7	70.8	23.4	87.2	219.7	147.1	113.3	91.9	55.7	64.9	**1054**
2018	51.7	24.8	24.8	44.7	52.4	58.9	102.3	77.9	52.0	67.4	23.5	61.7	**642.1**
Minimal	**22.7**	**20.4**	**18.9**	**7.4**	**23.7**	**15.9**	**50.7**	**14.2**	**11.1**	**29.3**	**16.2**	**26.3**	**601.5**
Average	**50.2**	**44.2**	**41.8**	**42.6**	**56.7**	**80.1**	**126.2**	**77.9**	**67.6**	**64.7**	**54.5**	**60.8**	**767.3**
Maximal	**84.6**	**66.6**	**89.7**	**70.8**	**102.9**	**137.3**	**227.8**	**113.4**	**117.4**	**112.3**	**93.5**	**105.8**	**1054**

3.5.4 Snow cover

The snow cover in the region is about 70–105 days per year. Average height of snow cover is 16 cm, and maximum is 64 cm. Density of snow cover gradually increases from 0.2 to 0.5 g/cm^3 in the middle of March. During observation period since year 1966 to year 1989 the absolute maximum of recorded weight of snow cover is 1.2 kN/m^2. This value is also accepted for INPP industrial site [2].

According to STR 2.05.04 2003 “Impacts and Loads” INPP is attributed to category II region in relation to snowfall. In this case, specific value of snow load is up to 1.6 kN/ m^2 [2].

3.5.5 Winds

Winds with speeds below 7 m/s dominate – recorded events constitute more than 90 % of the total number of observations.

Recorded events with wind speeds above 10 m/s are not frequent – less than 10 events per year [2].

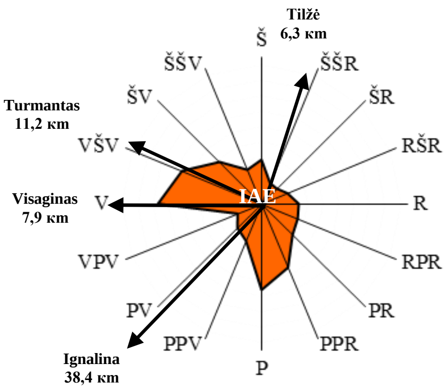
Western and western-southern winds predominate according to local wind measurements performed during year2009 – 2018, see Table 3.4, Fig. 3.11. Prevailing wind direction is not varying significantly within reported period. In general atmospheric conditions are favourable for dispersion of INPP releases to atmosphere [2].

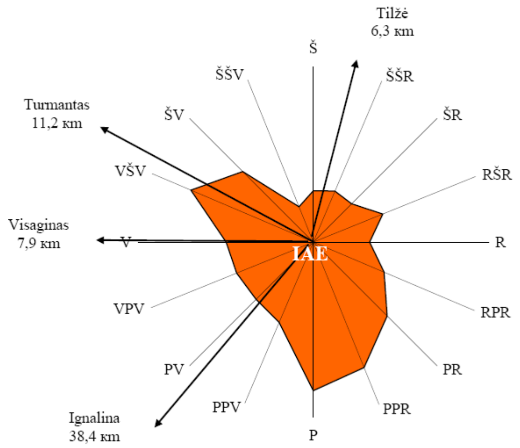
Table 3.4. Average and maximal winds, m/s**,** in the INPP region [2, 5, 6]

Year 2009												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	4.1	3.9	4.1	4.2	4.3	4.2	2.8	2.7	2.9	3.2	3.4	3.4
Maximal	10.1	8.6	9.4	10.0	10.6	**11.0**	7.0	6.4	6.9	7.7	7.1	7.8
Year 2010												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	3.0	2.9	3.6	2.9	3.0	3.1	2.5	2.6	3.2	3.3	3.2	2.8
Maximal	6.4	6.1	**8.1**	6.9	7.0	7.3	6.1	6.6	7.3	7.3	7.3	6.6
Year 2011												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	3.3	3.4	3.9	3.1	2.9	2.9	2.8	2.7	3.2	3.0	3.1	4.0
Maximal	7.5	7.6	**8.9**	7.2	7.2	7.2	6.7	6.5	7.6	7.0	7.3	9.3
Year 2012												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	3.2	2.9	3.7	3.2	2.9	3.0	2.6	2.8	3.1	3.0	3.4	3.8
Maximal	22.9	16.4	23.3	20.5	19.3	16.0	23.0	22.8	15.7	**35.9**	15.6	17.9
Year 2013												

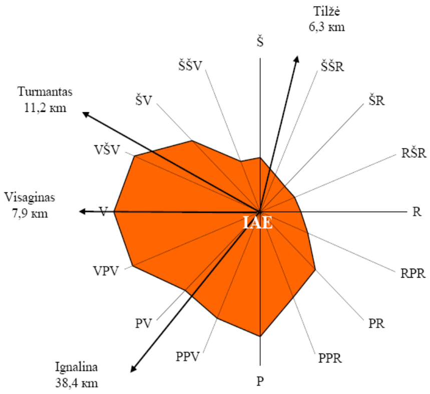
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	3.8	3.2	4.1	3.6	3.0	2.8	3.0	2.9	3.3	3.2	3.7	4.3
Maximal	22.8	20.9	18.3	21.5	18.3	21.8	16.7	22.8	18.0	16.3	**23.5**	21.1
Year 2014												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	4.1	3.6	3.9	3.1	3.5	3.3	2.9	3.3	2.8	3.4	3.3	3.5
Maximal	16.3	21.4	**25.5**	21.9	16.2	15.6	14.6	16.7	15.8	14.4	12.5	20.7
Year 2015												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	4.3	3.1	3.9	4.0	3.3	3.1	3.3	2.8	2.9	3.0	3.5	4.2
Maximal	**31.1**	15.7	14.9	21.8	16.2	14.1	23.4	18.1	17.5	15.8	17.8	23.3
Year 2016												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	3.2	4.2	3.1	3.4	2.9	3.4	3.1	3.1	2.7	4.1	3.9	3.8
Maximal	21.5	23.3	23.6	16.3	15	16.5	18.5	15.8	17.6	**25.1**	21.5	19.9
Year 2017												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	3.5	3.5	3.3	3.4	2.8	3.7	4.8	3.0	3.4	3.7	3.5	3.6
Maximal	22.2	16.9	25.9	22.1	16.8	19.1	18.5	15.7	17.8	**34.6**	16.4	27.4
Year 2018												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed, m/s												
Average	3.7	2.7	3.6	4.1	3	3.2	3	2.7	3.2	3.4	3.2	3.2
Maximal	20.3	19.8	14.1	18.8	14.8	18.2	**23.8**	16.6	19.8	20	15.4	23.4

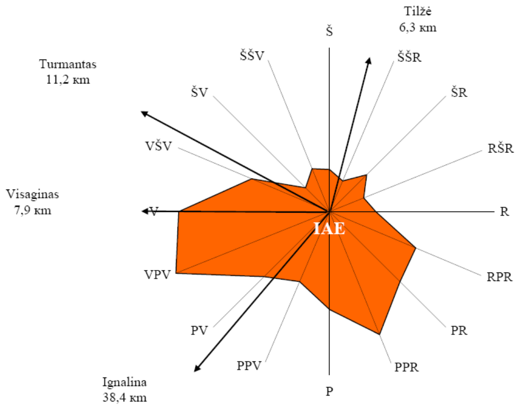
2009 **2010**



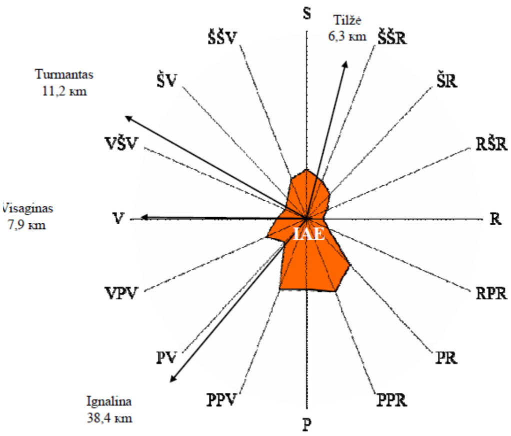


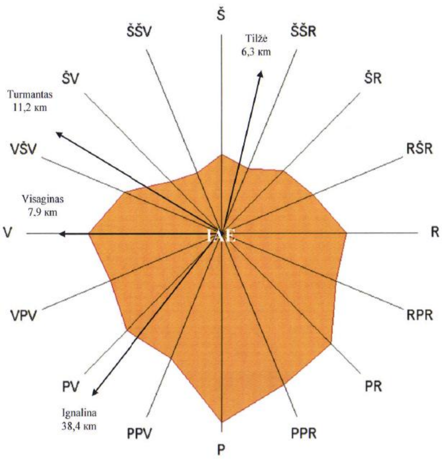
2011 **2012**





2013 **2014**





2015 **2016**

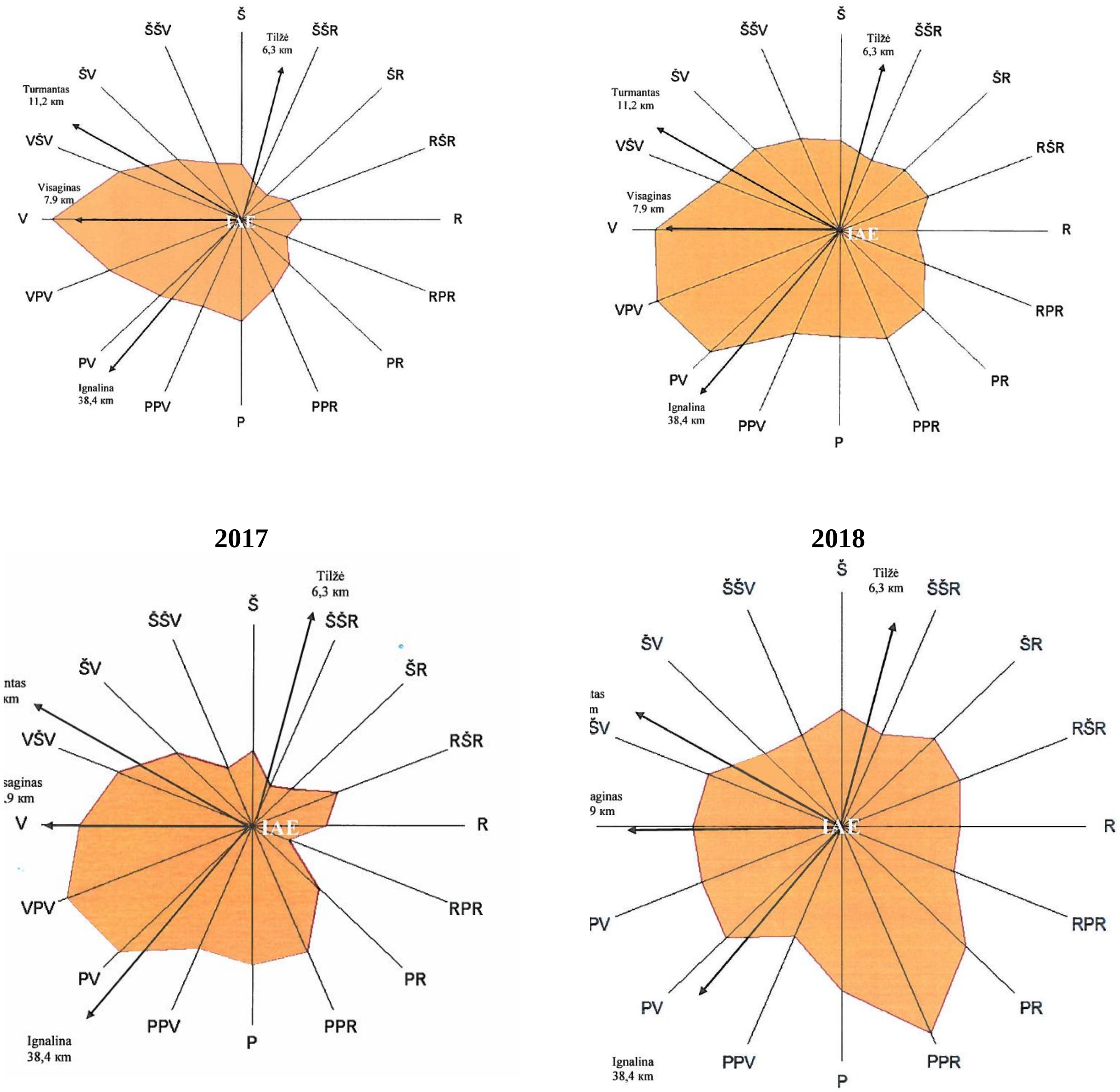


Fig. 3.11. Prevailing wind directions at the INPP region (wind direction – off INPP) [1, 5, 6]

3.5.6 Extreme Events (Hurricanes and Spouts)

In the control zone of INPP during reported period of year 2009 – 2018 strong wind was recorded as follows [2, 5, 6]:

- Three events with wind speed above 30 m/s: October 2012 – 35.9 m/s, January 2015 – 31.1 m/s October 2017 – 34.6 m/s;
- Four events with wind speed above 25 m/s: March 2014 – 25.5 m/s, October 2016 – 25.1 m/s, March 2017 – 25.9 m/s, December 2017 – 27.4 m/s.

Recorded average wind speed is from 2.5 to 4.8 m/s in the control zone of INPP during period 2009 – 2018. Strong winds with speed above 30 m/s constitutes 1.5 %, above 25 m/s - 3%, above 20 m/s – 20 % [2, 5, 6].

Spouts in the vicinity of INPP site do not exceed class F-2 according to Fujita classification. The probability of spout class F-2 in the area of 1 km^2 equals to 1 event during period of 61 667 years. The probability of spout class F-1 constitutes 1 event during period of 43 023 years. The probability of spout class F-0 constitutes 1 event during period of 10 000 years [2].

The season of spouts begins at the end of April and ends in the first half of September. The direction of spout motion is from south-west to north-east in 75 % 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 with variations from 10 to 300 m. Calculated maximum spout velocity with a frequency of 1 in 10 000 years is 39 m/s [2].

3.5.7 Climatic conditions

The region is located in the continental East Europe climate area. One of the main features of the climate in the region is the fact that no air masses are formed over this area. Cyclones are mostly connected with the polar front and determine continuous movement of air masses. The cyclones formed over the medium latitudes of the Atlantic Ocean move from the west towards the east through Western Europe and the INPP region is often located at the intersection of the paths of the cyclones bringing humid maritime air. The variation of maritime and continental air masses is frequent, therefore the climate of the region can be considered as a transient climate from the maritime climate of Western Europe to the continental climate of Eurasia [3].

On a regional scale, climatic conditions depend on the distance from the Baltic Sea. Due to airflow invasion from neighbouring geographic zones, eastern regions of Lithuania (i.e. INPP region), in comparison to western parts, are characterized by greater annual temperature range, colder and longer winters with a greater snowfall and warmer but shorter summers. Average precipitation is also higher [2].

The analysis of the meteorological conditions of the INPP region has been recently made within the scope of the periodic safety review of INPP Unit 1. The conclusion is that no changes in meteorological conditions are observed [3].

The main meteorological parameters describing the climate of Lithuania in the second part of the 20th century (average values from observation period 1961-1990) are presented in Table 3.5.

Table 3.5. Main meteorological parameters of Lithuania climate [2]

Parameter, units	Value
Solar radiation, MJ/m^2	3 690
Weather temperature, °C:	
Monthly average (within period 1961-1990)	5.5–7.0
January	-6.5– -2.8
April	4.5–6.2
July	16.1–17.5
October	6.3–9.0
Cloud amount (annual average within period 1961-1990), class	6.7–7.2
Precipitation, mm:	
Annual average (within period 1961-1990)	550–900
Summer season (April–October)	375–525
Winter season (November–March)	175–350
Duration of snow blanket, days	70–105

4 DEMOGRAPHIC DATA AND SOCIAL ECONOMIC ENVIRONMENT IN THE REGION

According to portals of official statistics for year 2018 the total population of the INPP region (including the municipality of Visaginas (58 km^2), Ignalina district (1 447 km^2) and the Zarasai district (1 334 km^2) was 49 548 (in Visaginas 18 514 people and in Ignalina and Zarasai districts 15 366 and 15 668 people, respectively). This makes about 4.3 % of the total territory of Lithuania and 1.8 % of the total population.

Approximately 38 thousand inhabitants living in the Daugavpils town (Latvia) should be also included into the 30 km radius zone as about 30% of Daugavpils‘ territory is distant 27 – 30 km from INPP (Fig. 4.1). Within the 30 km radius, the density of population is about 48 human/km^2. This is lower than the nominal density of population of 56.7 human/km^2 in Lithuania. In fact, population density in the INPP region is one of the lowest in Lithuania. Within the sanitary protected zone of INPP (within radius 3 km) there are neither farmsteads nor inhabitants. The nearest Visaginas town is about 8 km from the INPP. The main information about the population distribution in the region of 30 km is presented in Table 4.1 and Fig. 4.1

Table 4.1. Population distribution (thousands) in the INPP region within the 30 km zone (for year 2007) [2]

Direction of segment / Radius of circle	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**	**Amount of inhabitants**	
									in the ring	**in the circle**
30 km	27.9	0.6	6.3	1.0	1.2	1.7	1.7	0.7	39.9	99.3
25 km	0.9	0.7	1.8	1.8	3.3	1.1	1.0	6.1	16.9	58.4
20 km	0.3	0.2	1.0	0.9	0.9	2.0	0.6	0.5	6.4	41.7
15 km	0.4	0.6	0.6	0.6	0.7	0.9	0.2	0.7	4.7	35.3
10 km	0.3	0.4	0.5	0.3	0.7	0.3	27.7	0.2	30.4	30.6
5 km	–	–	–	–	0.1	–	–	0.1	0.2	0,2
3 km	–	–	–	–	–	–	–	–	–	–
Total in the segment	**29.6**	**2.5**	**10.2**	**4.6**	**6.9**	**6.0**	**31.2**	**8.3**	**Total 99.3**	

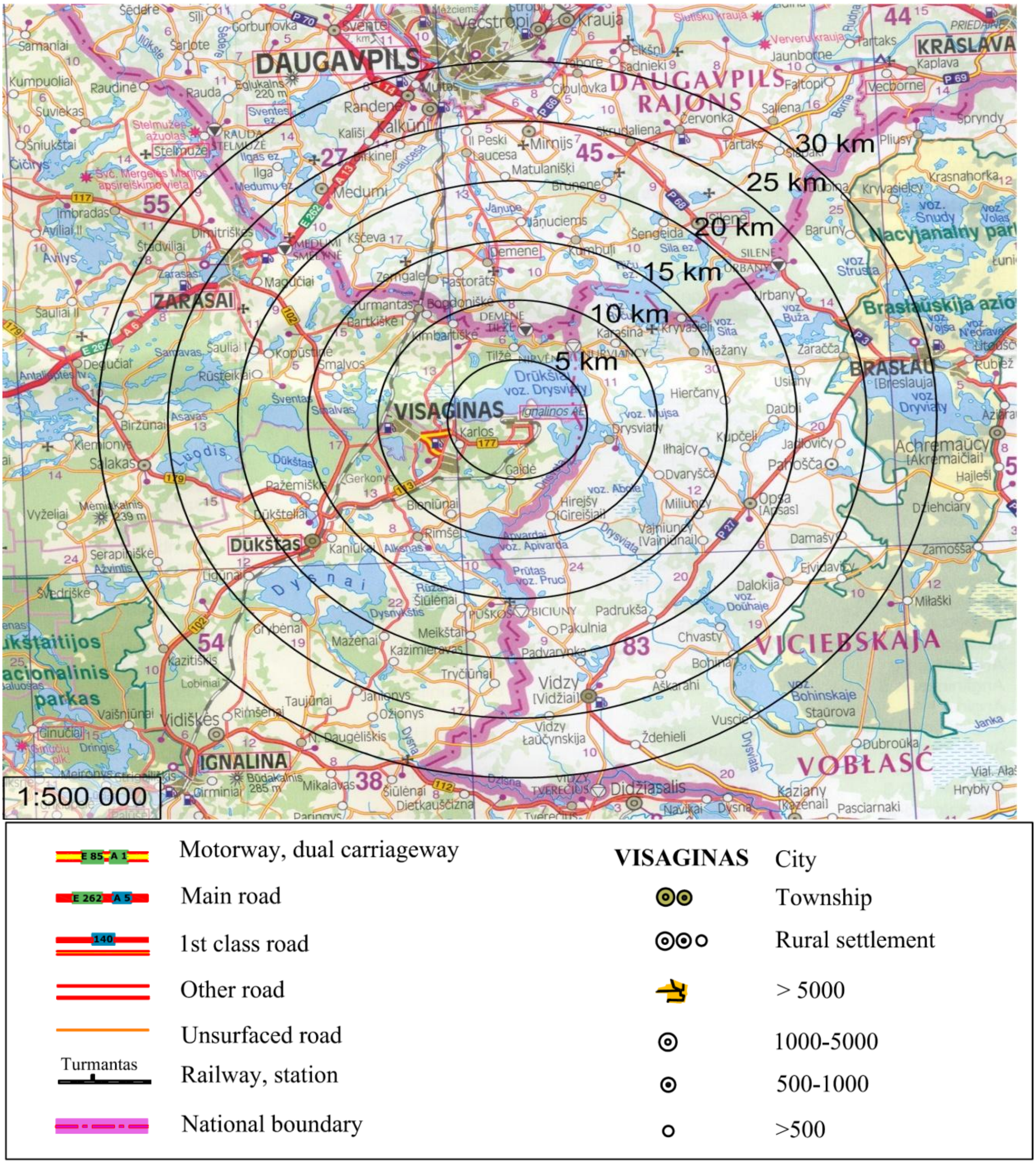


Fig. 4.1. Population distribution in 5, 10, 15, 20, 25 and 30 km zones [2]

The main demographic indicators at INPP region for year 2018 are presented in Table 4.2.

Table 4.2. The main demographic indicators at INPP region for year 2018

Indicator	**Ignalina region**	**Zarasai region**	**Visaginas town**	**INPP region (average)**
Population younger than 15 years, %	11.1	12.3	15.0	12.8

Indicator	Ignalina region	Zarasai region	Visaginas town	INPP region (average)
Population of age 15-44 years, %	29.9	30.3	26.0	28.7
Population of age 45-64 years, %	31.6	32.3	40.9	34.9
Population of age 65-74 years, %	12.7	11.9	11.0	11.9
Population older than 75 years, %	14.9	13.3	7.2	11.8
Migration (internal and external) for year2018, human	-258	-193	-176	-209
Change of number of inhabitants due to natural conditions for year 2017	-157	-110	-28	-89

5 FACTORS THAT COULD HAVE IMPACT ON REPOSITORY SAFETY

5.1 Economic activity at the surroundings

As reported in [2] from the economic point of view the INPP region, except for the town of Visaginas, is a less developed region in Lithuania. Agriculture and forestry of low intensity dominate in the region. For example, the intensity of cattle breeding is about 1.4 times lower than on the average in Lithuania. Only small farmsteads and agriculture societies are on lands in the vicinity of the INPP. They mainly are occupied with cattle-breeding and market-gardening [3]. No important minerals with the exception of quartz sand are found in the region. The turnover of the retail trade in the region is 1.5, and the volume of services is more than 2.5 times lower than on the average in the country. In addition to INPP, there are a number of large and medium scale enterprises and organizations in Visaginas town, see Table 5.1 [2].

Table 5.1. Enterprises and organizations established in Visaginas town

No	Name	Number of personnel (insured)	Category
1.	JSC “Visagino linija“	791	Large
2.	JSC “Visatex”	549	Large
3.	Hospital of Visaginas town	327	Large
4.	Municipality of Visaginas town	210	Medium
5.	JSC “Visagino energija”	192	Medium
6.	JSC “Visagino būstas”	136	Medium
7.	JSC “Kogus”	142	Medium
8.	Policlinic of Visaginas town	90	Medium

Visaginas town has an urban type labour force including educated people and great variety of professional training. Ignalina and Zarasai districts have a rural type labour force, which means an older age structure, lower education and a small variety of professional training.

Quantities of the able to work population as well as of pensioners in the INPP region is presented in Table 5.2 According to data of Department of Statistics under the Government of Republic of Lithuania

Table 5.2. Quantities of the able to work population as well as of pensioners in the INPP region [2]

Region	Able to work population (age 18 – 64 years)	Pensioners (age ≥ 65 years)
Ignalina region	8 964	4 226
Zarasai region	9 321	3 935
Visaginas region	11 939	3 366

There are no large commercial pursuits in the vicinity of INPP. At the approximately 5 km distance to the south-west direction with respect to INPP there are former military base, motor transport departments, heating plant and at the approximately 6 km distance there are town motor transport department, construction base, furniture factory (“Visagino linija”) and garment factory (“Visatex”). Visaginas town is distant about 8 km to the west with respect to INPP, see Fig. 5.1 [2].

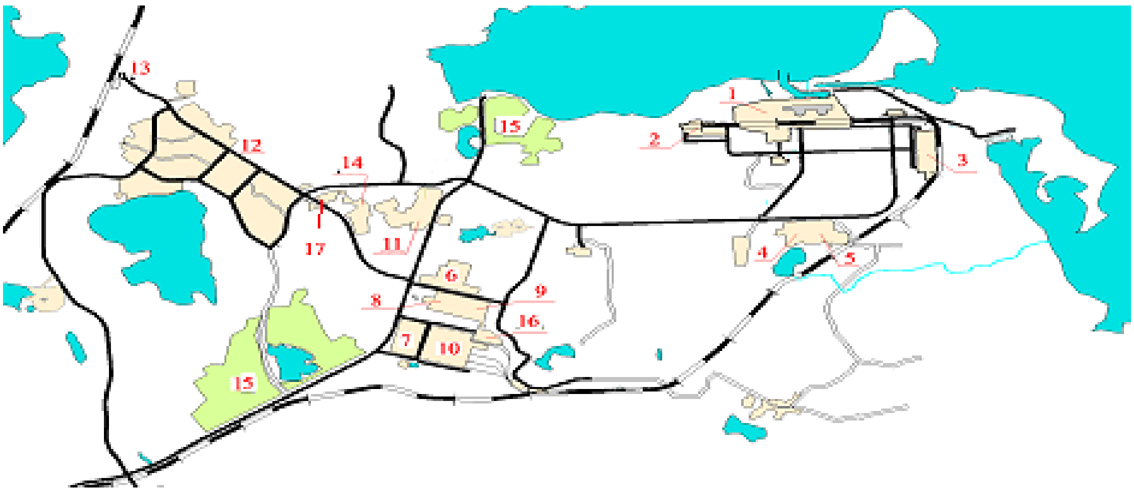


Fig. 5.1. Panorama of residential and commercial pursuits [2]:

1 – NPP site, 2 – open distributive system, 3 – storehouses, 4 – treatment plant for sewage water, 5 – Visaginas transport service, 6 – town supply base, 7 – town motor transport department, 8, 9 – motor transport departments, 10 – construction base, 11 – health clinic, 12 – Visaginas town, 13 – railway station, 14 – the town transformer, 15 – recreational area; 16 – heating plant; 17 – garment factory VISATEX

The planned economic activity will be performed inside industrial site of INPP. There are no residents within sanitary protection zone of INPP, economical activity is limited.

The impact on social and economic environment or its evident changes are not foreseen.

5.2 Overground and air transport

5.2.1 Roads

The nearest motorway passes 12 km to the west of the SWMSF. This motorway joins the city of Ignalina with those of Zarasai, Dukstas and has an exit to the highway connecting Kaunas–St. Petersburg. The entrance of the main road from the INPP to the motorway is near the town of Dukstas (Fig. 5.2). The extension of the road from INPP to Dukstas is about 20 km [2].

There are two entrances to the main road Dukstas – Zarasai from Visaginas town. The first one is passing by recreation service centre – distance 6 km; another one is closer to Dukstas – distance 14 km. The exit from territory of INPP site is also available by local network of roads to the south direction towards places Gaide and Rimse [2].

Fig. 5.2. Road and railway network [2]

5.2.2 Railway

The main railroad Vilnius – Turmantas passes 9 km to the west from INPP site. A single railway branch is also from INPP to Dukstas (Fig. 5.2).

5.2.3 Air Corridors

More than 20 international air tracks cross the Lithuanian air space (Fig. 5.3). 30 airports of civil, military and mixed purpose are located in the country. Nearest airports are located in Daugavpils (50 km to the south direction from the INPP site) and in Vilnius (130 km to the south-west direction from INPP site) [2].

There are 3 zones where flights are prohibited in Lithuania: territory 5.4 miles (10 km) around INPP, 3 miles around "Achema" factory in Jonava and Mazeikiai oil refinery. In addition, there are 8 zones, linked in to 5 areas with some restrictions for flights (mostly due to the military purposes). Seven dangerous zones are defined due to the terrain military activities (military polygons). The highest concentration of such territories is in the Northern and South-Western (Jonava–Marijampole–Alytus) part of Lithuania (Fig. 5.4) [2].

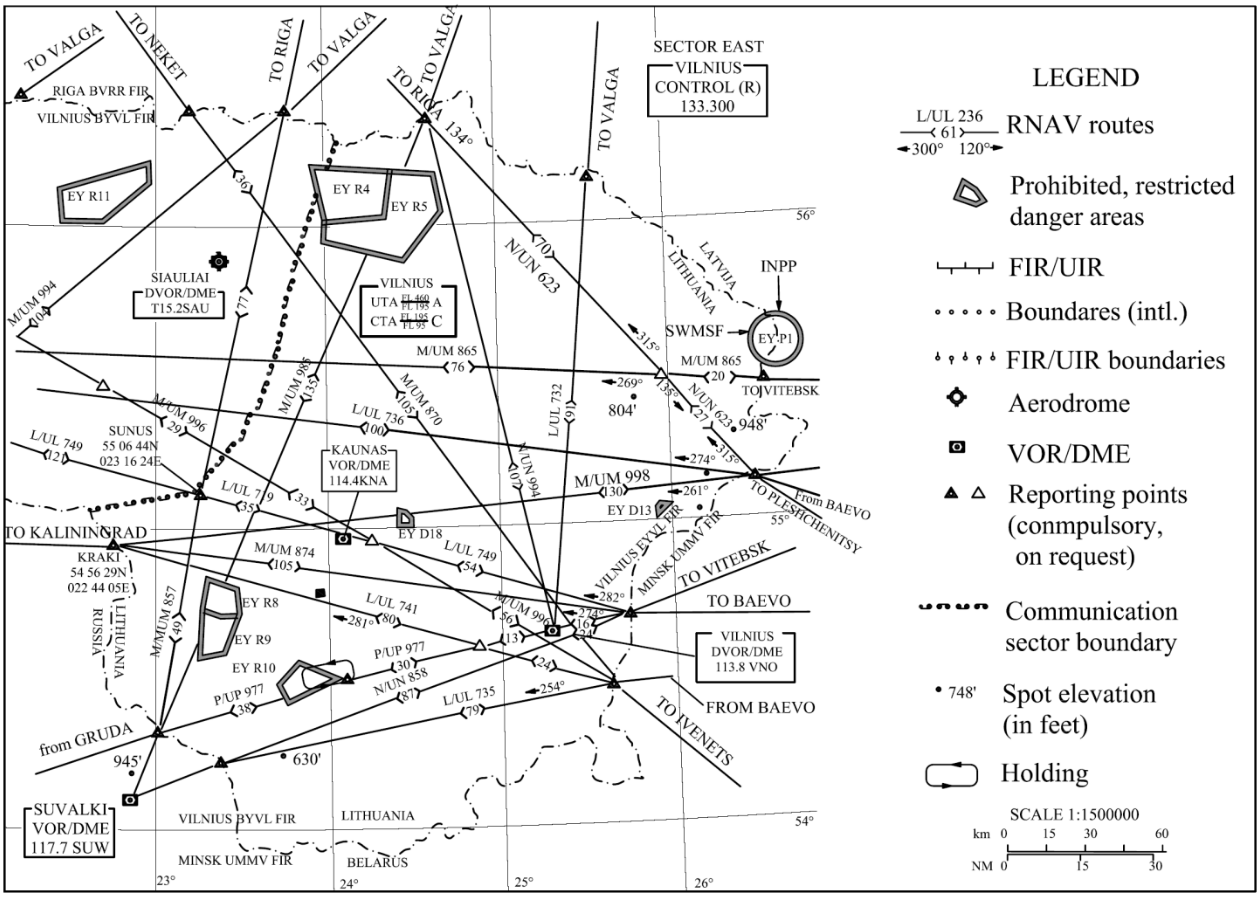


Fig. 5.3. Air tracks of the Republic of Lithuania [1]

As can be seen from Fig. 5.3 the network of lowest density is in the North-Western and North-Eastern parts of Lithuania. The highest concentration of airports is in Vilnius–Kaunas–Marijampole area and in Panevezys–Palanga area [2].

On average there are 1 or 2 civil aeroplanes (Airbus A319, Airbus A320, ATR 72-210, Avro RJ100, Boeing 737–300, Boeing 737–500, Boeing 737–800, Bombardier CRJ200, Bombardier CRJ900, Bombardier Dash 8 Q400, Embraer E-170, Embraer E-175, Embraer E-190, Fokker 100, Fokker 70, Saab 2000) flying in air track M865 per day. The minimum distance between the track and INPP is 10–15 km. The minimum distance of the track from INPP is 10–15 km. On average 6 civil aeroplanes fly per day at a speed of 900 km/h above the territory of Republic of Belarus (the minimum distance from INPP is 15 – 20 km) [2].

According to the data of Administration of civil aviation, there were around 40 accidents of aircraft in Lithuania during last decade. Mostly accidents have taken place in the surroundings of airdromes of air clubs. The big airplanes, which crossed Lithuanian air space or landed here, have not experienced any accident [2].

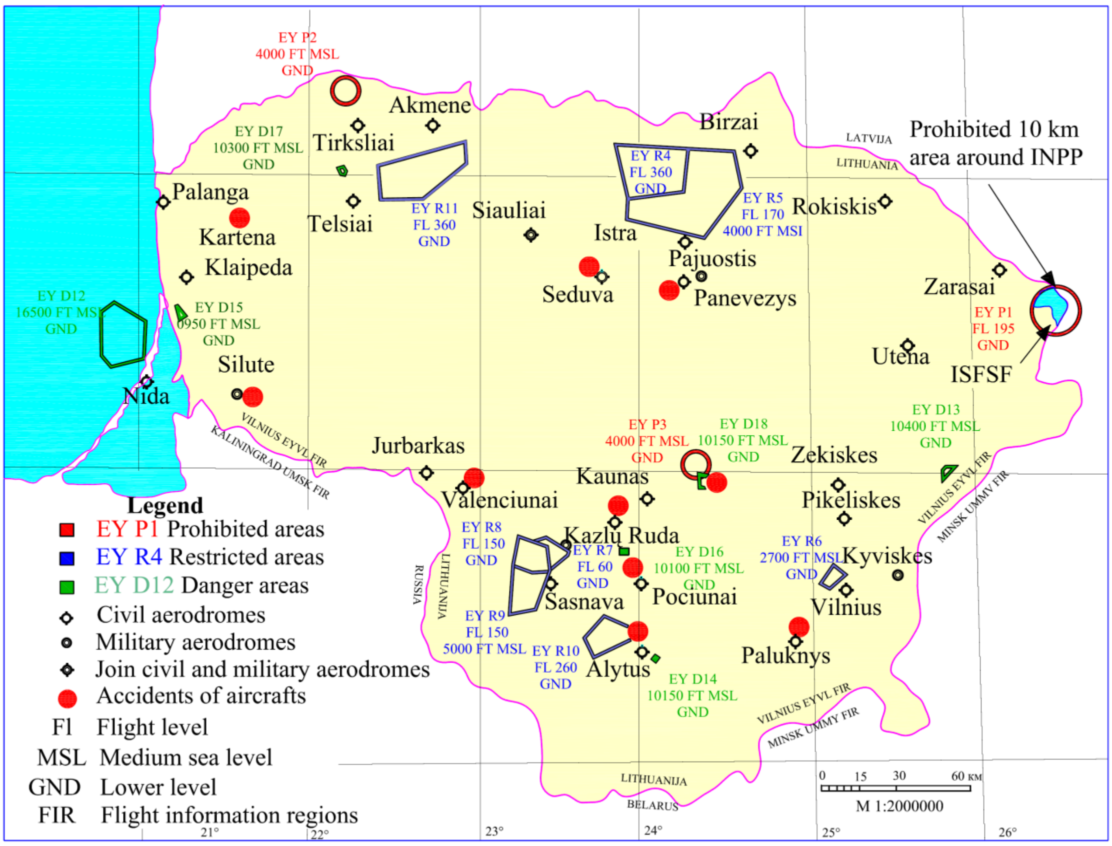


Fig. 5.4. Airports, forbidden, restricted and dangerous areas in Lithuania [2]

5.2.4 Pipelines

A gas pipeline connects gas discharge station located at Visaginas town and Steam Boiler Plant located at INPP site. Length of pipeline is about 12 km. Minimum distance between the gas pipeline and Bld. 158 is about 150 m. Gas flow in the pipeline is 4000 m^3/h, diameter of pipeline is 180 mm, and pressure in the pipeline is 6 bars [2].

The gas pipeline branch between the new Steam Boiler Plant and gas discharge station is equipped with emergency valves. Distance between these valves is 8.5–9 km. Shut down time of the valves on emergency (pressure drop) is 1 min [2].

A main pipeline of heat supply connects the INPP with Visaginas town. Minimum distance between the heat supply pipeline and bld. 150 is approx. 50 m and to bld. 158 is approx. 110 m.

Diameter of pipeline is 800 mm, pressure in the pipeline is 16 kg/cm^2, and maximum temperature of the heat carrier is 128 °C [2].

6 PREDICTED ENVIRONMENTAL CHANGES

According to the provisions of VATESI requirements [1], in order to assess the potential impact on the planned repository due to possible environmental changes the forecast of natural surface processes at the site as well as identification of site specific external factors and processes induced due to human activity are presented in the chapter.

6.1 Natural surface processes

In accordance to IAEA developed methodology on systematic analysis of features, events and processes (FEPs) [9] (the analysis will be performed in detail during developing preliminary safety analysis report) external natural factors that potentially could affect the planned repository are relevant to geological processes and effects as well as climatic processes and events.

At this stage of the project bypassing detailed FEPs analysis only processes which presumably could stipulate severe consequences related to the safety of the planned nuclear facility are considered in the report, namely earthquake, ground settlement as well as extreme precipitation and the flooding.

Based on report [10] seismic hazard is not excessive, due to distance to possible seismic sources. However, hypothetically it is assumed that earthquake might affect the integrity of the facility and thus accelerate water uptake by bituminised RAW (bitumen compound) and consequently radionuclide releases into environment. The case is considered in the impact assessment chapter of the report. Identical consequences, i.e. damage of the repository‘s engineered barriers, should occur if more intensive (in comparison to the present measurements) ground movements under the foundation of the facility should take place (though it is stated in the report [12] that settlement of the storage facility is stabilized and is no more than 1 mm per year) . However, it is very likely that an earthquake is a conservative case implying a sudden incident causing destructions of higher degree.

Considering climate change of regional and local scale it is concluded after detailed analysis [11] that in the short/intermediate time scale a conservative position should be assuming present conditions for the short/intermediate time period, as the increasing evapotranspiration (resulted from higher temperature) and decreasing amount of precipitation consequently causing the average amount of infiltrating water to decrease. Comparing precipitation data from the last decades with the available data from period of previous century, an increase in the number of extreme events has been observed. As the increase of amount of atmospheric precipitation is directly related to the increase of water infiltration rate through the vadose zone the case of hypothetical extreme precipitation is considered in the impact assessment chapter of the report.

Geomorphological changes due to glacial retreat are out of consideration as the time scale of interest is shorter. The start of the next glacier is estimated in 60 000 to 100 000 years from present with a maximum about 180 000 years from present. By that time the flux of radionuclides from the repository would be negligible.

6.2 Impact due to human activity

The site is well characterized during site investigation studies. No valuable natural resources are found in the surroundings. Boreholes drilling in the vicinity of the planned repository will only remove small amounts of material, and involve limited disruption of the geological environment. Therefore, it can be omitted from further consideration.

Surface excavations are related to any type of human activities that may be carried out in the surface environment that can potentially affect the performance of the engineered barriers. Examples of surface activities that may need to be considered are excavation for residential, industrial, transport and road construction. The typical activities which can be assumed after institutional control period of the site usually consider road construction and residence at the site area The activities cause extraction of the contaminated material to the surface therefore the intruder can be exposed from contaminated ground and this situation is evaluated in the impact assessment chapter of the report.

There are no explosive materials in the inventory. Accumulation of gases is prevented by design. Therefore, only external sources of explosions and crashes need to be considered. These include accidents (e.g. aircraft crash). Aircraft crash as the most severe accident is analysed in the impact assessment chapter of the report.

Present hydrological and hydro-geological processes and conditions in geosphere are presented in the site characterization chapter of the report. During period of storage building transformation into repository (including demolition of the nearby buildings as well as relevant systems) certain changes in the water balance at the site are going to be performed, including site drainage system. Flooding can be expected after failure of drainage at the site. Therefore an extremely unfavourable case of flooding is considered in the impact assessment chapter of the report.

7 FACTORS STIPULATING IMPACT ON ENVIRONMENT AND HUMAN FROM RADIATION SAFETY POINT OF VIEW

7.1 Description of the radioactive waste for disposal in the repository

According to the solutions proposed in the Sketch Design [13] it is intended that the bituminised RAW (i.e. the waste already loaded in the nine canyons) will be disposed off in the planned repository, and the sand-gravel RAW from the reactor zone R3 should be disposed off in the remaining three empty canyons. A description of the properties of indicated RAW is below.

7.1.1 Bituminised RAW

7.1.1.1 Waste origin

Drainage waters from the buildings 101 (reactor building), 130, 150 (liquid waste evaporator and bituminisation building), 156 (laundry) and 159 are collected in the storage tanks in the building complex 151, 154 and 154A/B. The tank farm consists of twelve tanks made of concrete and lined with stainless steel. The six 1500 m^3 tanks will receive:

- drainage water from the reactor maintenance areas;
- water from the special laundry;
- condensate from the evaporator units;
- spent ion-exchange resins and perlite pulp.

The six 5000 m^3 volume tanks contain mainly treated water that is recycled to the reactor.

The water in the receiving tanks in building 151 is fed to one of two interconnected batch-evaporation units located in building 150. This building also contains the bituminisation unit. In the evaporator the drainage water is driven off until the salt concentration reaches 130 g/l. The concentrate is then further concentrated in a re-evaporation unit until a salt concentration of 360-390 g/l is reached. After settling the evaporator concentrate is fed to one of two bituminisation units of the extruder type. The bitumen compound having a salt concentration about 40% (in mass) is transferred to the bitumen storage building 158.

7.1.1.2 Waste class

In compliance with the new waste classification system [22] bituminised radioactive waste is attributed to solid radioactive waste of classes B and C, cf. [23], i. e. to short-lived low and intermediate level radioactive waste. In accordance to requirements on radioactive waste management [22] RAW of classes B and C should be disposed in the near surface repository. It is conservatively assumed that radioactive waste from decommissioning will be class C waste.

7.1.1.3 Physical properties

In the last years pure bitumen of type BDUS 70/100 was used in bituminization process. Earlier bitumen of type BND 60/90 and BND 90/130 was used. Physical characteristics of pure bitumen are presented in Table 7.1. Physical characteristics of bituminised RAW are provided in Table 7.2.

Table 7.1. Physical properties of pure bitumen [25, 26, 27]

Parameter, units	**Value for bitumen type**		
	BND 90/130	**BND 60/90**	**BDUS 70/100**
0.1 mm diameter needle penetration depth at 25 °C, mm	90 – 130	61 – 90	71 – 100
0.1 mm diameter needle penetration depth at 0 °C, mm, not below	28	20	23
Softening point, °C, not below	43	47	43 – 51
Extensibility, at 25 °C, cm, not below	65	50	110
Extensibility, at 0 °C, cm, not below	4	3.5	3.7
Temperature of brittle’s, °C	-17	-15	-15
Temperature of flash, °C	230	230	240
Temperature of ignition, °C, not below	300	300	300
Temperature of self ignition, °C, not below	380	380	380
Moisture, %	0.1 – 0.2	0.1 – 0.2	0.1 – 0.2
Density, kg/m^3	940	940	940
Working temperature, °C	100 – 125	100 – 125	100 – 125

Parameter, units	Value for bitumen type		
	BND 90/130	**BND 60/90**	**BDUS 70/100**
Working pressure, kg/cm^2	3 – 7	3 – 7	3 – 7

Table 7.2. Physical properties of bituminised RAW [24]

Parameter, units	Value
Salt fraction (mass proportion) in waste, %	35 – 45
Moisture content, %	0,5 – 2
Density, kg/m^3	1 155 – 1 215
Working (transportation) temperature, °C	100 – 129
Working pressure, kg/cm^2	1 – 2

Average density value of bituminised RAW is assumed 1 200 kg/m^3 [24].

7.1.1.4 Long-term properties

7.1.1.4.1 Radiolysis effect

The production of radiolitic gases depends upon the type of bitumen, the dose rate and the absorbed dose [26]. Radiation can cause generation of radiolysis gases in bitumen waste containing high activities. About 95 % of the produced gas is hydrogen [26]. Based on experimental results the following judgement has been made of the effect of radiolysis[26]:

- For absorbed doses of less than 0.1 MGy negligible effects on gas generation, swelling, hardening, heating and decrease in leach resistance are found.
- The amount of generated gases for absorbed doses between 0.1 and 2 MGy must be considered in packaging the bituminised product, for instance by assuring that the gas can escape from the packaging and that there is enough volume for swelling. The changes in leachability and mechanical properties of the product are insignificant.
- For even higher absorbed doses, 2-10 MGy, a substantial swelling can take place.

The radiation doses corresponding to the nuclide inventory in building 158 has been estimated to be several orders of magnitude lower than the limits indicated above, therefore concluded that swelling will not be of importance [28].

In addition under conservative assumption it is estimated [29] that hydrogen production caused by radiolysis in the bituminised is negligible. Based on calculations it has been determined that it is unlikely that the concentration of the hydrogen in the canyons that should cause the explosion should be reached. In spite of that the measures of hydrogen quantities are carried out periodically (once per three month).

Based on the data provided by INPP [30], hydrogen is not detected in the air of the canyons (according to measurements it amounts 0.00 % as the limit is 0.4 %).

However, assuming that the possibility of gas generation in the bituminised waste cannot be excluded, the drainage layer for the removal of the generated gas is foreseen in the conceptual design of the planned repository, see Table 7.6.

7.1.1.4.2 Biodegradation

The rate of biodegradation of bitumen is generally low [26]. This is especially true for anaerobic conditions (foreseen to prevail in the planned repository). The influence of biodegradation on release rate of radionuclides from bitumen matrix will therefore most likely be small [26]. This is supported by studies on long term stability of natural bitumen and natural bitumen analogues indicating that bitumen is stable over periods for more than 10^4 up to 10^7 years [26]. It is concluded that the effect of micro-organisms on the long-term properties of the bituminised waste can be negligible [26].

7.1.1.4.3 Ageing

The main effect of ageing is that the bitumen becomes harder and more brittle, which can lead to fracturing [26]. The most important ageing process in the short-term seems to be oxidation [26]. The conditions at repository are, however, not favourable (darkness and anaerobic). Oxygen may penetrate into a thin region close to the matrix surface only. The volume of the bitumen matrix that is affected by oxidation is small in comparison to that affected by water uptake. In contrast to oxidation, the hardening of bitumen caused by a redistribution of molecules or evaporation of hydrocarbons affects the whole bitumen volume [26]. The water uptake rate is not influenced by the hardening process at first, but as the bitumen hardens a reduced ability to deform when the waste swell can be obtained [26]. Small cracks may be formed in the material instead [26]. This in turn increases the rate of water uptake, swelling and release of radionuclides. The effect of this ageing process on the long-term performance of a bitumen barrier is unknown [26].

7.1.1.4.4 Water uptake

In spite of that bitumen is a hydrophobic material, water can be transported into the bitumen matrix [26]. This process is usually described as diffusion of water vapour. Water uptake does not only take place in water saturated systems but also in humid air [26]. In pure bitumen the water uptake is negligible However, since the waste being bituminised often is hygroscopic (e.g. salts), there is a driving force for water vapour in the bitumen matrix [26]. The waste is dispersed in the form of particles in a continuous phase of bitumen. Water vapour can diffuse through the surrounding layer of bitumen to the waste particles. When the waste particles absorb water they begin to swell [26].

A possible swelling will be closely related to the used waste process [26]. It is normally not possible to estimate the swelling without making tests on the actual wastes [26].

The swelling of the particles could have several consequences [26]:

- internal stresses will be generated within the matrix;
- the bitumen matrix may increase in size;
- the distance between the particles and thus the thickness of the bitumen layer between them could decrease.

When enough water has been taken up, an open communicating porosity will be generated [26]. This can be caused in two ways [26]:

- internal stresses cause cracks and fissures;
- and possibly the waste particles increase in size until the touch each other.

The process of water uptake depends mainly on the amount of waste in the matrix, the waste composition and the type of bitumen. Other factors affecting water uptake is the repository conditions for instance temperature, material surrounding the matrix and available volume for swelling. Fractures and open pores lead to an increased transport of water into the matrix [26]. The amount of water uptake in bituminised waste has in general been found to be proportional to the square root of time [26]. The data analysed in the report [26] indicates that water uptake rate should be a very slow process why it should take a very long time before the waste matrix is severely affected by penetrating water.

7.1.1.4.5 Leaching

The term “leaching” is mostly used to refer to the release of radioactive components embedded in the bitumen matrix [26]. Leached radionuclides may be kept dissolved or may sorb, precipitate or form complexes [26]. The diffusivity of radionuclides in undisturbed bitumen is negligible. Thus, a network of pores or fractures in the matrix is a necessity for release of nuclides [26]. As discussed in the previous sections there are several mechanisms by which such an open porosity can be formed. Once a communicating porosity is established, the radionuclides dissolve and are released from the bitumen matrix by diffusion [26]. Highly soluble radionuclides in evaporator concentrate can be assumed to be released at the same rate as highly soluble salts [26]. Sparingly soluble radionuclides and nuclides in sparingly soluble salts can remain in the pore system for a long time. In a simplified model two different cases can be defined [26]:

- the release of highly soluble radionuclides is governed by the rate by which open pores are formed.
- the release of sparingly soluble radionuclides and nuclides in sparingly soluble salts governed by the nuclide dissolution rate.

The release rate is dependent upon type of bitumen, type of waste, waste loading, concentration of nuclides in solution and also all factors influencing the diffusivity of radionuclides (e.g. temperature). Complex formation may increase the release rate. On the contrary, sorption of radionuclides on bitumen or insoluble salts will reduce it [26]. The leachability of a radionuclide can be characterised by its leach rate. The lower the leach rate the more difficult is it to release the nuclide from the matrix. The leach rate is in general higher for bitumen matrices consisting of a hard bitumen than for those consisting of a soft bitumen [26]. The leach rate increases with increasing salt loading. This is probably due to a thinner layer of bitumen surrounding the salt crystals when the salt content increases [26]. Based on data from experiments it is evaluated that a 200 litres drum with bituminised concentrate will be depleted in Na+ and NO_3^- in less than 13 000 and 20 000 years, respectively [26]. For nuclides with a low solubility the depletion rate will be even lower [26].

7.1.1.4.6 Gas evolution

There is general consensus about the mechanisms that may give rise to the generation of significant quantities of gases in repositories and that need to be considered in safety cases [31]:

a) corrosion of metals (steels);

b) microbial degradation of organic materials; and

c) radiolysis.

Hydrogen evolving corrosion can occur only in the absence of dissolved oxygen, where in the reaction between iron and water magnetite and hydrogen are produced (the overall reaction: $3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2$ (g)). This reaction will start when aerobic corrosion or another oxygen consuming reaction, such as microbial activity has consumed the oxygen initially present. Initially, the anaerobic corrosion rate is quite high but falls off rapidly to very low rates as the surface film of magnetite develops. Anaerobic corrosion rate of steel is about 0.1 μm/year after a few thousand hours, even in the most aggressive water [32]. The rate of hydrogen production at the highest measured long-term corrosion rate is about 0.5 $dm^3/(m^2 \bullet year)$ [32]. Strongly anaerobic conditions are not expected in the canyon, due to oxygen dissolved in the surface water penetrated into the repository. Reinforcement in concrete is protected from corrosion by the chemical reactions of cements on the steel surface leading to the formation of protective film on the steel and its passivity as a result of the high alkalinity (high pH) as well as the environmental barrier provided by the concrete cover. Therefore, there are very low possibilities for the anaerobic corrosion to occur and for hydrogen gas to compose.

Hydrogen is an excellent source of energy for many microbes [33] and can be reacted by microbes with an array of different compounds (e.g. sulphide, nitrogen, nitrite, methane, acetate and various other organic compounds). Many of the hydrogen utilizers use carbon dioxide as carbon source for their production of organic compounds. In general it could be expected some gas (hydrogen and carbon dioxide) formation, while there are suggested in [34] that the microbial degradation of bitumen will be a very slow or insignificant process.

Gas evolution relevant to radiolysis process in bituminised waste is considered in subsection 0.1 above.

In the case of the gas formation the sand layer is intended for removal of gas (see [13]).

7.1.1.5 Quantities

Waste quantities in canyons with respected to loading periods are presented in Table 7.3.

Table 7.3. Canyon filling process flow and quantities of waste [14]

Canyon No.	Filling period	Amount, m^3
UF44B01	1987 – February 1989	1 963
UF44B02	February 1989 – August 1990	2 054
UF59B01	May 1991– December 1991	844
UF44B03	January 1992 – June 1994	1 964

Canyon No.	Filling period	Amount, m^3
UF44B04	June 1994– July 1996	1 745
UF45B01	September 1996– April 2001	2 002
UF45B02	May 2001 – December 2006	1 862
UF59B03	January 2007 – May 2014	1 950
UF59B02	2015 – June 2017	38
	Total:	**~14 422** 1)

1) Bitumen volume of top and bottom protective layers is included.

In the period of 1987 – 2017 approximately 14 422 m^3 bituminised RAW were loaded in the storage facility.

7.1.1.6 Activities

Data on radionuclide content and activity of bituminised radioactive waste is presented in Table 7.4. The radionuclide activities are estimated for date 31 of December 2015 as no loading of canyons by radioactive waste was performed after this date.

It is shown in the table that total activity of wastes is mostly determined by the activity of ^{137}Cs and equals to 2.48E+14 Bq.

Table 7.4. Activities of the declared radionuclides in the loaded canyons of the building 158 estimated for date 31 of December 2015 [14]

Radio nuclide	Total activity (Bq) in canyons									
	UF44B01	**UF44B02**	**UF59B01**	**UF44B03**	**UF44B04**	**UF45B01**	**UF45B02**	**UF59B03**	**UF59B02**	**Sum**
^{14}C	1.17E+10	1.63E+10	6.14E+09	1.49E+10	1.38E+10	1.71E+10	1.80E+10	2.11E+10	3.57E+08	**1.19E+11**
^{60}Co 1)	3.10E+09	5.64E+09	2.85E+09	9.28E+09	1.21E+10	2.66E+10	6.75E+10	2.18E+11	8.77E+09	**3.53E+11**
^{59}Ni	2.78E+08	3.88E+08	1.46E+08	3.54E+08	3.29E+08	4.07E+08	4.29E+08	5.03E+08	8.49E+06	**2.84E+09**
^{63}Ni	3.13E+10	4.35E+10	1.64E+10	3.97E+10	3.70E+10	4.57E+10	4.82E+10	5.65E+10	9.53E+08	**3.19E+11**
^{90}Sr	1.05E+10	1.46E+10	5.52E+09	1.34E+10	1.24E+10	1.54E+10	1.62E+10	1.90E+10	3.21E+08	**1.07E+11**
^{94}Nb	6.10E+09	8.49E+09	3.20E+09	7.75E+09	7.21E+09	8.92E+09	9.40E+09	1.10E+10	1.86E+08	**6.23E+10**
^{99}Tc	8.85E+09	1.23E+10	4.64E+09	1.12E+10	1.05E+10	1.29E+10	1.36E+10	1.60E+10	2.70E+08	**9.03E+10**
^{129}I	1.44E+07	2.01E+07	7.57E+06	1.83E+07	1.71E+07	2.11E+07	2.22E+07	2.61E+07	4.40E+05	**1.47E+08**
^{134}Cs 1)	1.88E+07	5.47E+07	4.58E+07	2.55E+08	6.13E+08	4.03E+09	5.16E+10	1.17E+12	1.55E+11	**1.38E+12**
^{137}Cs 1)	2.41E+13	3.35E+13	1.26E+13	3.06E+13	2.85E+13	3.52E+13	3.71E+13	4.35E+13	7.34E+11	**2.46E+14**
^{234}U	7.96E+04	1.11E+05	4.18E+04	1.01E+05	9.41E+04	1.16E+05	1.23E+05	1.44E+05	2.43E+03	**8.13E+05**
^{235}U	5.22E+03	7.26E+03	2.74E+03	6.63E+03	6.17E+03	7.63E+03	8.04E+03	9.43E+03	1.59E+02	**5.33E+04**
^{238}U	2.33E+04	3.25E+04	1.22E+04	2.96E+04	2.76E+04	3.41E+04	3.60E+04	4.22E+04	7.11E+02	**2.38E+05**
^{237}Np	4.50E+05	6.26E+05	2.36E+05	5.71E+05	5.32E+05	6.58E+05	6.93E+05	8.13E+05	1.37E+04	**4.59E+06**
^{238}Pu	1.27E+07	1.76E+07	6.64E+06	1.61E+07	1.50E+07	1.85E+07	1.95E+07	2.29E+07	3.86E+05	**1.29E+08**
^{239}Pu	1.12E+07	1.56E+07	5.87E+06	1.42E+07	1.32E+07	1.64E+07	1.73E+07	2.02E+07	3.41E+05	**1.14E+08**

Radio nuclide	Total activity (Bq) in canyons									
	UF44B01	UF44B02	UF59B01	UF44B03	UF44B04	UF45B01	UF45B02	UF59B03	UF59B02	Sum
^{240}Pu	1.41E+07	1.96E+07	7.40E+06	1.79E+07	1.67E+07	2.06E+07	2.17E+07	2.55E+07	4.30E+05	**1.44E+08**
^{241}Pu	1.04E+09	1.44E+09	5.44E+08	1.32E+09	1.23E+09	1.52E+09	1.60E+09	1.88E+09	3.16E+07	**1.06E+10**
^{241}Am	6.83E+08	9.50E+08	3.58E+08	8.67E+08	8.07E+08	9.98E+08	1.05E+09	1.23E+09	2.08E+07	**6.97E+09**
Total:	2.42E+13	3.36E+13	1.26E+13	3.07E+13	2.86E+13	3.53E+13	3.73E+13	4.50E+13	9.00E+11	**2.48E+14**

1) Radionuclide (key radionuclide) is measured directly

7.1.2 Sand-gravel RAW

7.1.2.1 Origin and amount of waste

The reactor shaft (cross-section 21.6 × 21.6 m) is filled with a mixture of sand and gravel between the big and small water tanks (outer diameter 19.0 m) and the shaft's walls (height 11.6 m) [12].

Based on the data the volume of the sand and gravel mixture from both units is approx. 5 000 m^3. Assuming that the design sand density is 1 300 kg/m^3, it would make 6 500 tonnes. [12].

7.1.2.2 Physical characteristics of waste

The density of the sand and gravel obtained during experiments is higher (because of higher humidity, coarser sand and gravel fractions), and therefore the mass should be approx. 8 300 tonnes. In this case, the actual estimated density of the sand and gravel is approx. 1 650 kg/m^3 [12].

7.1.2.3 Radiological data of waste

The radiological investigation on the waste (concrete, sand, serpentine) from Unit 1 was conducted already in 2012. According to the data presented in an INPP report, the radiological assessment of sand-gravel samples showed that [12]:

- Sand filling is nonuniform at heights 0.4–1.5 m, and radiological parameters increase at the surface layer of 0.5 m.
- The overall gamma radiation equivalent dose rate (EDR) does not exceed 0.16 μSv/h. However, locally the maximum values increase to 2.8 μSv/h and 0.24 μSv/h.
- Sand samples contain natural radionuclides with the following activities: K-40 – 706.13 Bq/kg, Ra-226 – 15.74 Bq/kg, Th-232 – 19.35 Bq/kg.
- Main technogenic radionuclides are the following: Cs-137 and Co-60.
- Activities of most samples of main technogenic radionuclides are the following: Co-60 – 12.71 Bq/kg and Cs-137 – 32.03 Bq/kg.

- Co-60 activity at the surface layer of sand (0.5 m) is 28 060 Bq/kg and Cs-137 1 043 Bq/kg.

The radiological investigation on the waste (concrete, sand, serpentinite) from Unit 2 was conducted in 2018. According to the data presented in an INPP report, the radiological assessment of sand-gravel samples showed that [12]:

- The gamma radiation equivalent dose rate does not exceed 0.16 μSv/h;
- Sand samples contain natural main radionuclides with the following activities: K-40 – 540.04 Bq/kg, Ra-226 – 29.4 Bq/kg, Th-232 – 24.56 Bq/kg;
- Main technogenic radionuclides are the following: Cs-137 and Co-60;
- At higher EDR, activities of main technogenic radionuclides are the following: Co-60 – 12.25 Bq/kg and Cs-137 –10.68 Bq/kg.

7.1.2.4 Waste class

Based on performed radiological assessment of Units 1 and 2 the sand-gravel waste is classified as follows according to the new waste classification system [12]:

- At Unit 1 as conditionally nonradioactive waste (90 %) which stands for Class 0, and the remaining 10 % of waste are classified as Class A;
- At Unit 2 all sand and gravel waste is classified as Class 0.

Treatment and disposal of exempt waste (Class 0) are performed in compliance with the provisions of BSR-1.9.2-2018 [12].

Very low-level radioactive waste (Class A) is disposed of in a near-surface repository for very low-level radioactive waste.

7.1.2.5 Nuclide vector of waste

Based on radiological assessment of the structures and systems of Unit A1 the following list of radionuclides characterizes structures of non- activated sand: ^{14}C, ^{36}Cl, ^{54}Mn, ^{55}Fe, ^{59}Ni, ^{60}Co ^{63}Ni, ^{65}Zn, ^{90}Sr, ^{93m}Nb, ^{94}Nb, ^{93}Zr, ^{99}Tc, ^{110m}Ag, ^{129}I, ^{134}Cs, ^{135}Cs, ^{137}Cs, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{244}Cm. The following radionuclides are not declared for structures of non- activated sand: ^{3}H, ^{91}Nb, ^{92}Nb, ^{93}Mo, ^{108m}Ag, ^{133}Ba, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{158}Tb, ^{166m}Ho, ^{232}U, ^{233}U, ^{236}U, ^{242m}Am, ^{243}Am, ^{246}Cm [12].

The table below presents the identified nuclide vector and scaling factors dated for 01-01-2018 for the sand backfill of Unit A1.

Table 7.5. Nuclide vectors for the sand backfill of Unit A1 determined for date 01-01-2018 [12]

Radionuclide	Scaling factor
^{14}C	9.80E-03
^{36}Cl	1.00E-03
^{54}Mn	3.50E-02
^{55}Fe	7.20E+00
^{59}Ni	1.10E-01
^{60}Co	**1.00E+00**
^{63}Ni	1.20E+01
^{65}Zn	5.70E-09
^{90}Sr	3.50E-02
^{93}mNb	2.80E-01
^{94}Nb	1.10E-02
^{93}Zr	1.10E-02
^{99}Tc	1.60E-04
^{110m}Ag	2.20E-08
^{129}I	2.40E-06
^{134}Cs	1.70E-03
^{135}Cs	3.80E-06
^{137}Cs	8.60E-01
^{234}U	5.10E-07
^{235}U	1.30E-08
^{238}U	1.50E-07
^{237}Np	2.30E-08
^{238}Pu	1.20E-04
^{239}Pu	6.50E-05
^{240}Pu	8.40E-05
^{241}Pu	7.60E-03
^{241}Am	4.90E-04
^{244}Cm	2.80E-04

7.2 Description of repository

7.2.1 Reconstruction and transformation of the storage facility (bld. 158) into the repository

Reconstruction of Ignalina NPP bituminised radioactive waste storage facility (building 158) into the repository shall include [12]:

1. Repair of the storage facility and maintenance of the required technical state (preliminary term 2020 – 2040).
2. Adjustment of loads on foundation slabs of the storage facility (preliminary term 2025 – 2026).

3. Filling in all the canyons of the storage facility (preliminary term 2026 – 2027).
4. Dismantling of the second floor of the Storage Facility (preliminary term 2026 – 2027) (Fig. 7.1).
5. Covering of all flooring and exterior walls of the Storage Facility with waterproofing material (preliminary term 2026 – 2027).
6. Conservation and maintenance of the Storage Facility (preliminary term 2027 – 2039).
7. Dismantling of nearby buildings 150, 151 , 156 and 158/2 (preliminary term 2035 – 2039).
8. Installation of engineered barrier supports of future repository on the flooring of building 158 (preliminary term 2039 – 2040).
9. Installation of engineering barrier (multilayer cap) of the repository (preliminary term 2039 – 2040) (Fig. 7.2).

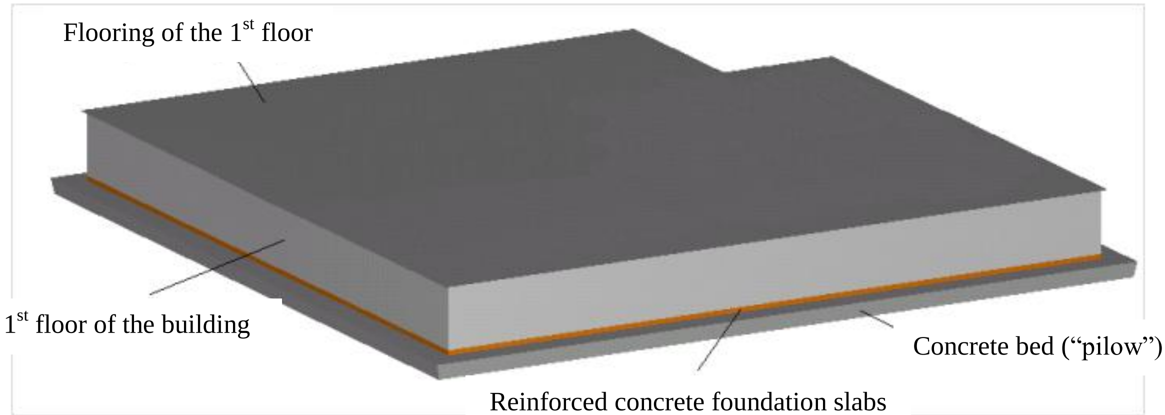


Fig. 7.1. Reconstruction of building 158 (bituminised radioactive waste storage facility) into the repository. General view of bld. 158 after the dismantling of rooms located on the second floor (simplified scheme) [12]

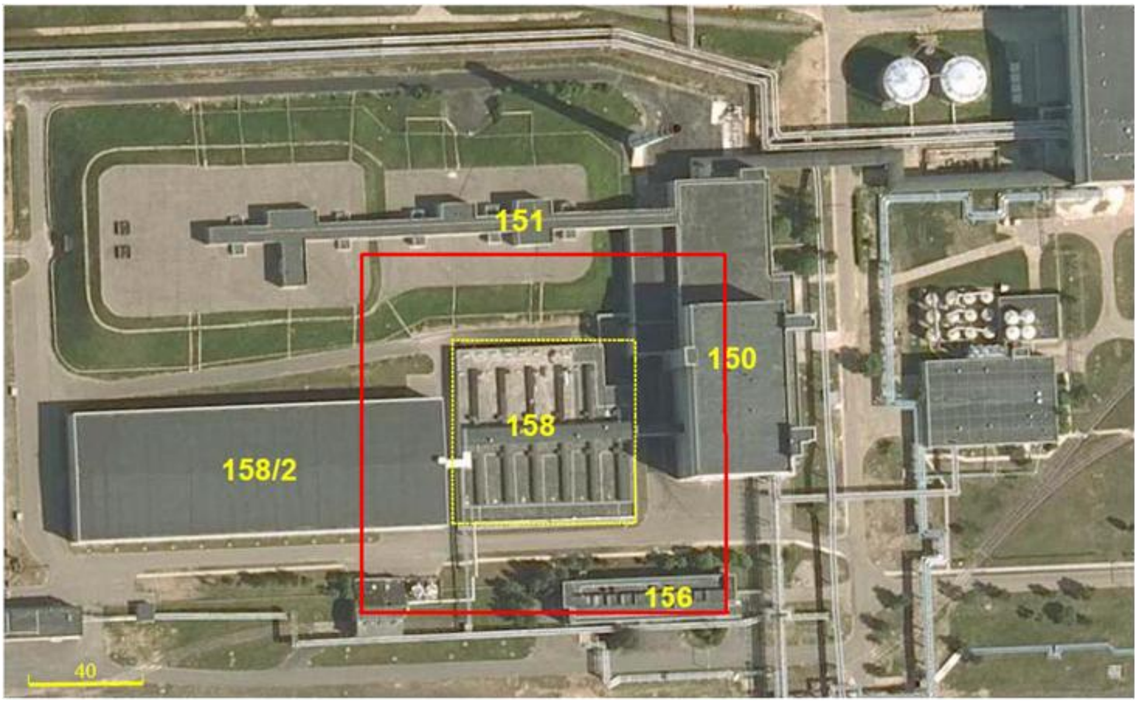


Fig. 7.2. Reconstruction of building 158 (bituminised radioactive waste storage facility) into the repository. The red line marks the 36 m wide area around the building, which will be used for the engineering barrier (multilayer cap) maintaining a slope of 3:1 [12]

A detailed description of the activities of reconstruction of INPP bituminised waste storage facility into repository is presented in the report [12].

7.2.2 Engineering and technical solutions as well as proposed measures for loading of 7-9 and 11 canyons of the storage facility with radioactive waste other that the bituminised waste

The more evenly filled the canyons of building 158 (bituminised RAW Storage Facility) are, the more evenly its structures are loaded, so it is advisable to fill the remaining empty canyons (7-9 and 11) with some material when transforming the storage facility into the repository or when preserving it [12]. The type of materials (waste) to be used for filling in the storage facility depends on the following main factors: mechanical resistance of the existing structures of the Storage Facility, technical opportunities for placing the waste and potential radiological and radiological as well as toxic impact of RAW. Another important feature of filling in the canyons of the storage facility is the low hygroscopicity, i.e., ability to attract water molecules from the environment by absorption or adsorption, as after the sealing of the storage facility due to moisture inside it can intensify the aging of structures, corrosion of reinforcement and other processes [12].

In accordance with the requirements of the Technical Specification [14], placement of the materials present at INPP to the empty canyons of the storage facility has been considered: sand, serpentine and concrete waste.

Sand, as a structural material for the reactor zone, is a RAW with surface contamination. According to ^{60}Co measurements, the specific activity of sand RAW is lower than that of bituminised waste. According to preliminary data, the volume from both reactors would be about 5000 m3, so it could fill slightly more than 2 empty canyons out of the existing three without considering the partially filled canyon No. 11. Placement of sand RAW into the canyons through openings in the flooring of the storage facility should not be technically complicated, unless problems occur only at the final stage, when sand dripping through relatively small openings needs to be spread thinly over the entire canyon area [12].

Concrete waste, as a structural material for the reactor zone, also belongs to the waste with surface contamination, which has a specific activity lower than bituminised waste. The amount of this waste and the possible size of the concrete waste rubble are unknown. Placement of concrete waste to canyons can be problematic due to the size of the concrete waste rubble which must fit through a relatively small, 0.7×0.7 m opening, and it will be difficult to distribute such debris evenly across the canyon and the larger the debris, the larger the air gaps will be (it also may include wet concrete). Widening of the opening can cause additional problems with the structural strength of the canyon, so in this case it is only possible to suggest that concrete waste be shredded as much as possible [12].

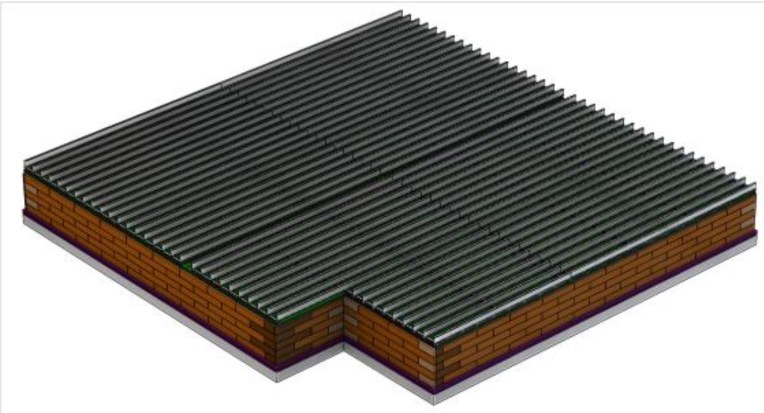
Placement of serpentinite RAW in the planned repository would be the most complicated case because, firstly, some of them are activated RAW and secondly, the serpentinite is a toxic substance containing asbestos. Placement of serpentinite RAW into the canyons would cause additional problems due to increased dusting and airborne asbestos fibres, which would pose increased radiological and toxic risks to the environment and humans during the placement of the waste into the repository. In addition, partial disintegration of serpentinite particles is expected, leading to additional formation of asbestos particles [12].

A safety of the repository for the option when sand-gravel radioactive waste from the reactor zone is disposed of in the empty canyons of the repository has been analysed in this report.

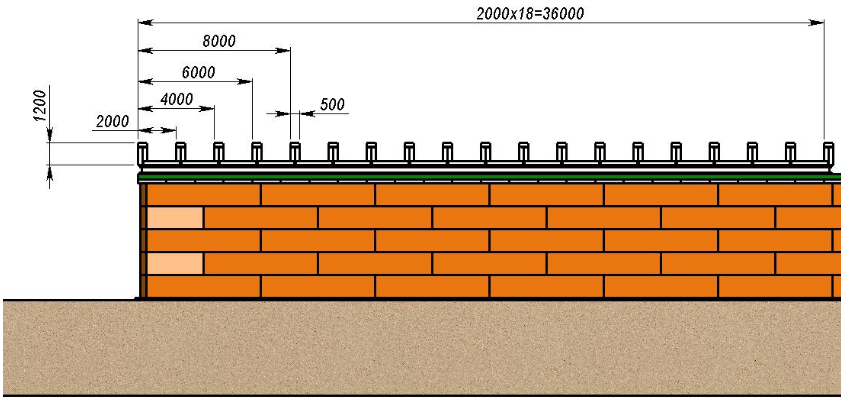
7.2.3 Description of the planned repository

During transformation of Ignalina NPP bituminised radioactive waste storage facility into the repository it is proposed to install steel and reinforced concrete bearing structures (see general view in Fig. 7.3 *a)*), to support the engineering barrier (multilayer cap) of 5.8 m thickness upon the building 158 [12]. The bearing frame standing on all the walls (including intersections between canyons) of the bld. 158 is made of H-beams (HD310x310x500), and the beams ensuring rigidity (H-beam HE1000B profiles). Metallic structures are not directly covered with soil forming the engineering barrier (multilayer cap), but are concreted longwise at 500 x 986 mm cross-section (Fig. 7.3 *b)*). Concreting in this case both increases the bearing capacity of the beams (prevents them from tripping) and protects them from corrosion.

During the reconstruction and transformation of the storage facility into the repository, building 158 will be waterproofed. Metal structures of the future repository shall be covered with an appropriate anti-corrosion coating, the steel elements of the engineered barrier (main supporting H-beams) shall be concreted with cold-cycle concrete (e.g., F1000 class). Installation of the engineering barrier (multilayer cap) of 5.8 m thickness ensures protection of the structure from environmental (atmospheric) impact (temperature humidity, mechanical impact, etc.). The protection measures listed above ensure the permanence of all features of the construction elements of building 158 and their stability for at least for 100 year period [12].



a)



b)

Fig. 7.3. Reconstruction of the storage facility (bld. 158) into the repository: metallic structures supporting the engineered barrier of 5.8 m thickness *a)* – general view, *b)* – cross-section [12]

Bearing structures are covered with soil layers of different purpose (thus, and of different properties) layer by layer and compacted to form the engineering barrier (composition of the multilayer cap is provided in Fig. 7.4), which is additionally covered with a top vegetation layer formed by a forestation of the repository and hiding (protecting from external impacts) the embankment with region-specific vegetation [12].

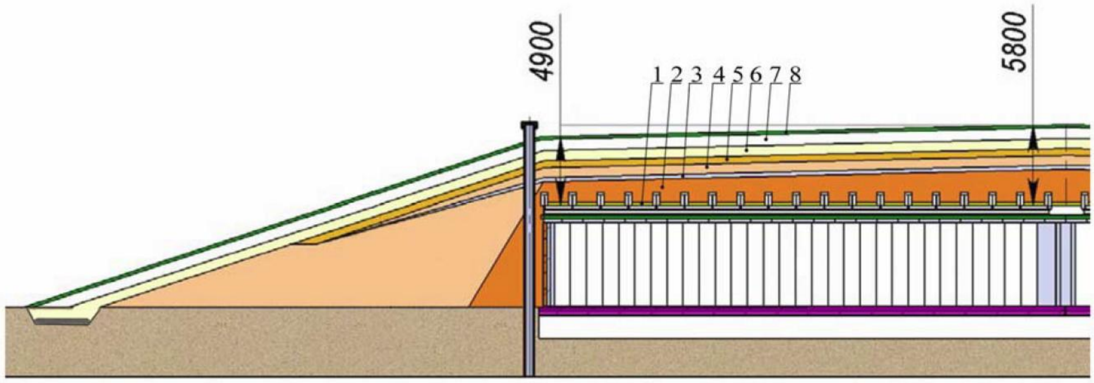


Fig. 7.4. Composition (cross-section) of the 5.8 m thick engineered barrier after transformation of the storage facility (bld. 158) into the repository:
1 – drainage layer (0.2 m of sand); 2 – insulating clay layer (1.5 – 2.4 m); 3 – drainage layer (0.3 m of gravelly sand); 4 – protective clay layer (0.7 m); 5-7 – drainage layers (0.6 m of sand, 0.6 m gravel and 0.8 m of crushed stone); 8 – vegetation layer of 0.2 m thickness [12]

Detailed description of the engineered barrier (multilayer cap) and of the constitutive materials is presented in the report [12].

Moreover the report [12] provides preliminary calculation analysis of the functionality of the engineering barrier (ability to withstand operating loads (loads caused by the own weight and snow coating) and the ability of structural elements of the storage facility on which the engineered barrier shall be installed, to withstand own weight and loads caused by bituminised waste as well as additional loads of engineering barrier weight in case of the selected option of the repository concept. A preliminary computational analysis of the structure revealed that reconstruction and transformation of the storage facility into the repository for the option of 5.8 m thick engineered barrier (multilayer cap) with supporting metallic structure standing on all the walls on the building (including intersections between canyons) after the uniform distribution of bottom slab loads by fillig the canyons up to the ceiling level with an inert material technically can be implemented.

7.2.4 Repository parameters

A summary of the parameters of engineered barriers that are considered in the analysis, is presented in Table 7.6.

Table 7.6. Parameters of the layers of the planned repository taken into account for the analysis of the radionuclide migration [13]

Title	**Material**	**Thickness, m**	**Bulk density, kg/m^3**	**Effective porosity**		**Filtration coefficient, m/s**			**Effective diffusion coefficient, m^2/s**		
				Barrier not degraded	**After barrier degradation**	**Barrier not degraded**	**After barrier degradation** Phase 1 (100 y after repository closure)	**After barrier degradation** Phase 2 (500 y after repository closure)	**Barrier not degraded**	**After barrier degradation** Phase 1 (100 y after repository closure)	**After barrier degradation** Phase 2 (500 y after repository closure)
Drainage layer (a mixture of sand and gravel)	Sand	0.5				5.0E-05					
Protective layer against impact of external conditions	Moraine clay	0.7	2 250	0.35		1.0E-06					
Drainage layer	Gravel sand	0.3	2 000	0.55		1.7E-04					
Insulating barrier	Clay	1.5 – 2.4	1 920	0.7		1.0E-09	≥ 1.0E-08				
Layer for gas withdrawal	Sand	0.20	1 800	0.6		1.2E-04					
Layer of reinforced concrete	Concrete	0.20	2 295	0.15	0.25	1.0E-09	1.0E-08	5.0E-05	3.0E-11	1.0E-10	5.0E-10
Supporting metal constructions	Steel	-									
Reinforced concrete top slab	Concrete	0.6	2 295	0.15	0.25	1.0E-09	1.0E-08	5.0E-05	3.0E-11	1.0E-10	5.0E-10

Title	Material	Thickness, m	Bulk density, kg/m^3	Effective porosity		Filtration coefficient, m/s			Effective diffusion coefficient, m^2/s		
				Barrier not degraded	**After barrier degradation**	**Barrier not degraded**	**After barrier degradation**		**Barrier not degraded**	**After barrier degradation**	
							Phase 1 (100 y after repository closure)	Phase 2 (500 y after repository closure)		Phase 1 (100 y after repository closure)	Phase 2 (500 y after repository closure)
Backfill (only in case of bituminised RAW)	-	0.9									
Layer of clean bitumen (only in case of bituminised RAW)	Bitumen	~0.1									
Bituminise RAW / Sand-gravel RAW	Bitumen compound / Sand-gravel	5.0 / 6.0	1 200 / 1 650 kg	0.40 / 0.40		- / 5.0E-05			- / 1.0E-10		
Concrete side walls of the canyons	Concrete	0.80	2 295	0.15	0.25	1.0E-09	1.0E-08	5.0E-05	3.0E-11	1.0E-10	5.0E-10
Reinforced concrete bottom slab	Concrete	0.62	2 295	0.15	0.25	1.0E-09	1.0E-08	5.0E-05	3.0E-11	1.0E-10	5.0E-10
Concrete backfill of the building 158 foundation (“pillow”)	Concrete	1.60	-	-	-	-	-	-	-	-	-

Remarks:

a) Dark background colour marks barriers and layers that are planned to be installed during transformation of the storage facility into a repository.

b) Due to present state as well as future state of the “pillow” is not determined it is not take into account in the analysis of the radionuclide migration (conservative assumption).

8 EVALUATION OF EXTERNAL NATURAL HAZARDS

Regarding IAEA recommendations presented in the documents [15, 16] and on the basis of the performed analysis [24] the following external natural hazards which could result the damage of the repository and the release of the radionuclides are included into the analysis:

- earthquake/ground settlement;
- increase of atmospheric precipitation (extreme precipitation).

8.1 Earthquake

An earthquake can be expected both in the period of institutional control and after it as design basis earthquakes for the Ignalina NPP area it is assumed to be earthquakes of the intensity of 6 grades on the MSK-64 scale with frequency 1 per 100 years and the beyond design basis earthquakes it is assumed to be the ones of the intensity of 7 grades on the MSK-64 scale with frequency 1 per 10 000 years [24]. The formation of cracks in the engineered barriers of the repository could occur. It is assumed that due to an earthquake the side walls and the top slab of the repository should be completely destroyed and all the surface of the bituminised RAW would appear available to the water uptake, except the bottom area of the waste contacting the bottom slab of the repository. Neither the side walls nor the top slab of the repository are isolating the RAW after the earthquake. The engineered barriers should be recovered within active institutional control; however, it is impossible after the period. Therefore, a case of earthquake incident after 100 years after repository closure (just after active institutional control period) is considered. As a result of water getting into the open RAW the radionuclides are released directly into the vadose zone.

Identical consequences, i.e. damage of the repository‘s engineered barriers, should occur if more intensive (in comparison to the present measurements) ground movements under the foundation of the building should take place. However, it is assumed that an earthquake is a conservative case to mean a sudden incident causing destructions of higher degree.

The mathematical models of radionuclide release from the bitumen matrix and leaching from the sand-gravel waste as well as a mathematical model of radionuclide transport through the vadose zone and the input data for modelling are presented in the report [13].

The values of exposure doses received by a member of the reference group of the population consuming well water in the case of the earthquake accident are presented Table 8.1.

Table 8.1. Exposure doses, received by a member of the reference group of the population due to consumption of well water in case of the earthquake accident

Radionuclide	**Resulted from bituminised RAW**		**Resulted from sand-gravel RAW**		**Total dose, mSv/year**
	Maximum dose, mSv/year	**Maximum time after repository closure, years**	**Maximum dose, mSv/year**	**Maximum time after repository closure, years**	
^{14}C	4.28E-04	110	8.31E-06	79	4.28E-04
^{36}Cl	-	-	3.78E-06	4	3.78E-06
^{90}Sr	5.05E-04	120	-	-	5.05E-04
^{94}Nb	2.40E-05	13 200	-	-	2.40E-05
^{99}Tc	4.88E-05	690	-	-	4.88E-05
^{129}I	8.62E-05	110	-	-	8.62E-05
^{137}Cs	2.02E-02	120	-	-	2.02E-02
^{239}Pu	1.15E-05	840	-	-	1.15E-05
^{240}Pu	1.34E-05	690	-	-	1.34E-05
^{241}Am	2.06E-04	250	-	-	2.06E-04
Sum:	**2.15E-02**		**1.21E-05**		**2.15E-02**

It is seen from table above that in case of the earthquake accident an exposure dose to a member of the reference group of the population mostly is caused by radionuclides ^{137}Cs. The dose equals to 2.15E-02 mSv and few times less in comparison to design criterion value 0.1 mSv per year and by two orders of magnitude below the limiting dose value 5 mSv per year established for population in case of beyond design basis accidents [1]. The maximum value of the total dose is expected in 120 years after repository closure (or 20 years after the earthquake event).

8.2 Extreme precipitation

In the analysis of radionuclide migration through the components of the disposal system it is assumed that the increase of amount of atmospheric precipitation is directly related to the increase of water infiltration rate through the vadose zone. The average rate of the water flow through the vadose zone equals to 4.62E-05 m/s, and maximum value is 2.12E-04 m/s (see section 3.3). Thus the increase of the water flow rate by factor 4.5 is assumed in this case.

All assessment conditions as well as input data are presented in the report [13].

Exposure doses received by member of reference group of population consuming well water due to maximum flow rate through the vadose zone in case of extreme precipitation are presented in Table 8.2.

Table 8.2. Exposure doses received by member of reference group of population consuming well water due to maximum flow rate through the vadose zone in case of extreme precipitation

Radionuclide	Resulted from bituminised RAW		Resulted from sand-gravel RAW		Total dose, mSv/year
	Maximum dose, mSv/year	Maximum time after repository closure, years	Maximum dose, mSv/year	Maximum time after repository closure, years	
^{14}C	7.09E-05	1 200	3.91E-06	636	7.48E-05
^{36}Cl	-	-	3.58E-06	16	3.58E-06
^{59}Ni	-	-	1.16E-06	642	1.16E-06
^{63}Ni	-	-	7.79E-06	414	7.79E-06
^{90}Sr	7.35E-05	170	3.34E-04	71	4.08E-04
^{94}Nb	2.16E-05	16 200	-	-	2.16E-05
^{99}Tc	1.20E-04	1 030	-	-	1.20E-04
^{129}I	6.61E-05	520	-	-	6.61E-05
^{137}Cs	3.33E-03	170	-	-	3.33E-03
Sum:	**3.68E-03**		**3.50E-04**		**4,03E-03**

As it is presented in Table 8.2, the increase of the total dose in the considered case remains below the design criterion, 0.1 mSv per year, by factor of one order of magnitude.

9 EVALUATION OF HAZARDS DUE TO HUMAN ACTIVITY

Regarding IAEA recommendations presented in the documents [15, 16] and on the basis of the performed analysis [24] the following hazards due to human activity which could result the damage of the repository and the release of the radionuclides are included into the analysis:

- aircraft crash in the repository site;
- fire;
- failure of the equipment and its components, namely malfunctioning of drainage system.

9.1 Aircraft crash

The engineered barriers should be destroyed after the aircraft crash in the repository site. The probability of the aircraft crash depends on number of the parameters, namely the intensity of flights in the region, effective area of the facility, etc. The assessment probability of the aircraft crash and hit a repository is presented in the report [13].

The results of the calculated aircraft crash probabilities onto the repository of bituminised RAW are presented in Table 9.1. It is conservatively assumed that the site radius equals to 100 m, the effective area of the repository (canyons) equals to 6 400 m^2 (80 m × 80 m).

Table 9.1. Probabilities of aircraft crash onto the planned repository

Probability type	**Value**
Aircraft crash probability related to the airports located beyond 8 km (Equation 5.2)	**2.26E-10**
Aircraft crash probability when the air traffic corridor pass at the distance *s=10 km* from object (Equation 5.3)	**3.24R-10**
Aircraft crash probability when airplanes pass the 50 km zone on the straight line touching the 10 km zone around the INPP (Equation 5.5)	**2.11E-08**

Aircraft crash probability calculations have showed that in all cases the probability is less than the screening probability level (1E-07 per year for nuclear objects). The initiating events with a probability of occurrence lower than the screening probability level should not be given further consideration in spite of their consequences [21].

9.2 Fire

According to the solutions proposed in the sketch design [12] empty canyons will be loaded with sand-gravel RAW which is not combustible. Engineered barriers installed over the building as well as building structures will restrain oxygen access to the waste. As shown in the RAW description section of the document [12] the temperature of bitumen self-ignition is 400 °C. However, investigations have shown that even with 45% of evaporator concentrates incorporated into bitumen the possibility of ignition is excluded [20]. Taking into account the factors mention above a fire as a result of self-ignition is not further considered.

9.3 4.8.1.6 Failure of the drainage system (flooding)

Flooding is not expected even under conservative assumptions (see [4]). Therefore it is assumed hypothetically that potential radionuclide flux released from the repository will be transported by the surface water into the Lake Druksiai bypassing vadose zone as well as aquifer. In the case of failure of the drainage system during active institutional control period the respective recovery works should be performed therefore the start point of the flooding after 100 years past the repository closure, i.e. just after completion of the active institutional control period, is assumed.

All assessment conditions as well as input data are presented in the report [13].

The exposure doses received by a member of the reference group of the population due to consumption of lake water in case of flooding are presented in Table 9.2.

Table 9.2. Exposure doses received by a member of the reference group of the population resulted from the consumption of lake water in case of the flooding incident

Radionuclide	**Resulted from bituminised RAW**		**Resulted from sand-gravel RAW**		**Total dose, mSv/year**
	Maximum dose, mSv/year	**Maximum time after repository closure, years**	**Maximum dose, mSv/year**	**Maximum time after repository closure, years**	
^{14}C	4.75E-06	1 150	1.28E-07	1 030	4.88E-06
^{90}Sr	-	-	1.83E-08	53	1.83E-08
^{129}I	2.98E-08	520			2.98E-08
^{137}Cs	-	-	7.43E-08	50	
Sum:	**4.81E-06**		**2.21E-07**		**4.93E-06**

The table presented above demonstrates that the total exposure dose is below the design criterion of 0.1 mSv/year by several orders of magnitude in case of flooding. The value of the total exposure dose is mostly determined by ^{14}C. The contribution of other radionuclides is negligible.

10 ASSESSMENT OF IMPACT TO POPULATION

10.1 Composition and activities of radionuclide releases

10.1.1 Source term for bituminised RAW

Total activities of declared radionuclides in bituminised RAW assessed according to INPP data are presented in Table 10.1 [13]. The radionuclide activity is also estimated for date 01-01-2025 when the beginning of reconstruction of the storage facility is planned.

Approximately 14 422 m^3 of bituminised RAW there are loaded in the nine canyons of bld. 158 [13].

Table 10.1. Activities of bituminised waste in the planned repository [13]

Radionuclide	**Total activity, Bq**	
	estimated for 31-12-2015	**estimated for 01-01-2025** (start of reconstruction)
^{14}C	1.19E+11	1.19E+11
^{60}Co	3.53E+11	1.08E+11
^{59}Ni	2.84E+09	2.84E+09
^{63}Ni	3.19E+11	2.99E+11
^{90}Sr	1.07E+11	8.64E+10
^{94}Nb	6.23E+10	6.23E+10
^{99}Tc	9.03E+10	9.03E+10
^{129}I	1.47E+08	1.47E+08
^{134}Cs	1.38E+12	6.68E+10
^{137}Cs	2.46E+14	2.00E+14
^{234}U	8.13E+05	8.13E+05
^{235}U	5.33E+04	5.33E+04
^{238}U	2.38E+05	2.38E+05
^{237}Np	4.59E+06	4.59E+06
^{238}Pu	1.29E+08	1.20E+08
^{239}Pu	1.14E+08	1.14E+08
^{240}Pu	1.44E+08	1.44E+08
^{241}Pu	1.06E+10	6.87E+09
^{241}Am	6.97E+09	6.87E+09
Suma:	**2.48E+14**	**2.01E+14**

The same radionuclide activity for post close period of the repository as in the start date of the reconstruction is conservatively assumed in spite of radioactive decay which would be more important for some short-lived radionuclides.

Waste density equals to 1 200 kg/m^3 and porosity 0.4 is assumed following [13].

10.1.2 Source term for sand-gravel RAW

Total activities of declared radionuclides in sand-gravel RAW estimated to date 01-01-2025 are presented in Table 10.2.

Table 10.2. Activities of sand-gravel waste assumed for the analysis or radionuclide migration from the planned repository [13]

Radionuclide	**Total activity, estimated for 01-01-2025** (start of reconstruction)**, Bq**
^{14}C	2.15E+07
^{36}Cl	2.19E+06
^{54}Mn	2.62E+05
^{55}Fe	2.61E+09
^{60}Co	8.72E+08
^{59}Ni	2.41E+08
^{63}Ni	2.50E+10
^{65}Zn	8.75E-03
^{90}Sr	6.49E+07
^{93m}Nb	4.29E+08
^{94}Nb	2.41E+07
^{93}Zr	2.41E+07
^{99}Tc	3.51E+05
^{110m}Ag	4.02E-02
^{129}I	5.26E+03
^{134}Cs	3.53E+05
^{135}Cs	8.32E+03
^{137}Cs	1.60E+09
^{234}U	1.12E+03
^{235}U	2.85E+01
^{238}U	3.29E+02
^{237}Np	5.04E+01
^{238}Pu	2.49E+05
^{239}Pu	1.42E+05
^{240}Pu	1.84E+05
^{241}Pu	1.19E+07
^{241}Am	1.06E+06
^{244}Cm	4.69E+05
Suma:	**3.09E+10**

Sand-gravel RAW density equals to 1 650 kg/m^3 and porosity 0.4 is assumed [13].

10.2 Assessment of radionuclide transport

The long-term safety analysis is carried out in accordance to ISAM methodology [9], developed and recommended by IAEA for a safety assessment of near surface repositories for radioactive waste. Basic steps of the methodology are described in detail in the report [13] – namely 1) *Assessment context;* 2) *Description of waste disposal system;* 3) *Development of scenarios and conceptual models of radionuclide migration;* 4) *Development of mathematical models and calculations; and* 5) *Analysis of the results*.

10.2.1 Assessment context

The purpose of the analysis presented in this report is to assess a potential radiological impact on the environment as well as to the population resulted from radionuclide release from the planned bituminised waste repository, installed in accordance to engineering and technical solutions accepted in the sketch design as well as proposed measures, considering a long-term safety.

Both physical and chemical properties of radioactive waste, present bituminised RAW and intended sand-gravel RAW, as well as a sketch design of the repository and the peculiarities of the repository site are taken into account during analysis.

Maximum values of the exposure dose to a member of the reference group of the population obtained after the assessments of the repository safety are compared to the design criterion 0.1 mSv per year (more details see in document [13]), t. y. mažesnis nei gyventojų apribotosios metinės efektinės dozės vertė, 0,2 mSv, set for the planned repository and which is less then effective dose constraint, 0.2 mSv/year, defined in Lithuanian hygiene norm requirements HN 73:2001 for operation and decommissioning of nuclear facilities.

For analysis of scenarios of inadvertent intrusion into the repository the limiting dose value of 10 mSv per year is established in the VATESI document BSR-3.2.2-2016.

According to Lithuanian hygiene norm HN 73:2001 requirements, when estimating impact it is necessary to take into account both the existing as well as planned nuclear facilities in the vicinity of the repository that could contribute to the value of the annual effective dose received by a member of the analyzed reference group (more details see in document [13]).

The analyzed period covers a time period of institutional control (100 years of the active control and 200 years of the passive control of the repository) and the time period following the period of institutional control while the maximum impact on a member of the reference group of the population is possible..

The potential radionuclide migration is analyzed in the characteristic points of the disposal system in order to show how the containment as well as safety functions are performed by specific components of the disposal system (engineered barriers, vadose zone, aquifer), exactly:

- At the outside of the canyon concrete walls and bottom slab at the point of structure contact with the ground;
- At the discharge points of the activities in the aquifer: well installed at the distance of 50 m from the repository (boundary of the assumed SPZ of the site), as well as the Lake Druksiai located at the distance of 600 m from the repository.

10.2.2 Description of the disposal system

A description of the source term used in the analysis is presented in section 10.1. A summary of physical and chemical parameters of radionuclides considered in safety analysis are provided in Table 10.3. It is conservatively assumed that process of sorption in the bitumen matrix does not make any influence (K_d values for all radionuclides equal to 0 for bitumen).

Table 10.3. Physical and chemical parameters of the considered radionuclides (more details see in [13])

Radio nuclide	Half-life, years	Sorption coefficient (K_d) in the material (or zone), m^3/kg							
		Bituminised RAW	Sand-gravel RAW	Concrete (bottom slab and walls of the building)		Loam (vadose zone)	Sand (aquifer)	Soil	Suspended matter
				Non-degraded	Degraded				
^{14}C	5.73E+03	0	0.0005	0.2	0.02	0	0	0.1	0.1
^{36}Cl	3.01E+05	0	0	0.001	0.0001	0*	0	0.001	1
^{54}Mn	8.54E-01	0	0.049	0.1	0.01	0.18	0.049	0.18	1
^{55}Fe	2.70E+00	0	0.018	0.1	0.01	0.8	0.005	0.16	5
^{60}Co	5.27E+00	0	0.01	0.04	0.004	0.5	0.015	0.54	5
^{59}Ni	7.50E+04	0	0.01	0.04	0.004	1.411	0.335	0.67	10
^{63}Ni	9.60E+01	0	0.01	0.04	0.004	1.411	0.335	0.67	10
^{65}Zn	6.68E-01	0	0.016	0.001	0.0001	7.6	0.34	2.4	0.5
^{90}Sr	2.91E+01	0	0.0001	0.001	0.001	0.1	0.015	0.11	1
^{93m}Nb	1.36E+01	0	0.5	0.5	0.05	6.9	6.9	0.9	10
^{94}Nb	2.03E+04	0	0.5	0.5	0.05	6.9	6.9	0.9	10

Radio nuclide	Half-life, years	Sorption coefficient (K_d) in the material (or zone), m^3/kg							
		Bituminised RAW	Sand-gravel RAW	Concrete (bottom slab and walls of the building)		Loam (vadose zone)	Sand (aquifer)	Soil	Suspended matter
				Non-degraded	Degraded				
^{93}Zr	1.53E+06	0	0.5	0.5	0.1*	0.8	0.005	3.3	1
^{99}Tc	2.13E+05	0	0.3	0.5	0	0.038	0.217	0.0012	0.005
^{110m}Ag	6.84E-01	0	0.01	0.001	0.001	0	0	0.18	2
^{129}I	1.57E+07	0	0	0.003	0.0003	0.0091	0	0.18	0.01
^{134}Cs	2.06E+00	0	0.01	0.001	0.001	2	0.3	1.8	1
^{135}Cs	2.30E+06	0	0.01	0.001	0.001	2	0.3	1.8	1
^{137}Cs	3.00E+01	0	0.01	0.001	0.001	2	0.3	1.8	1
^{234}U	2.44E+05	0	1	5	0.1	0.046	0.56	1.5	0.05
^{235}U	7.04E+08	0	1	5	0.1	0.046	0.56	1.5	0.05
^{238}U	4.47E+09	0	1	5	0.1	0.046	0.56	1.5	0.05
^{237}Np	2.14E+06	0	1	5	0.1	7.6	0.34	0.055	0.01
^{238}Pu	8.77E+01	0	1	5	1	7.6	0.34	4.9	100
^{239}Pu	2.41E+04	0	1	5	1	7.6	0.34	4.9	100
^{240}Pu	6.54E+03	0	1	5	1	7.6	0.34	4.9	100
^{241}Pu	1.44E+01	0	1	5	1	7.6	0.34	4.9	100
^{241}Am	4.32E+02	0	1	1	0.2	7.6	0.34	8.1	5
^{244}Cm	1.81E+01	0	1	1	0.2	1	1	10	5

The parameter values for engineered barriers of the planned repository are provided in subsection 7.2.4.

Based on data presented in the Chapter 3 a conceptual geological model developed for the analysis of the radionuclide migration is presented below.

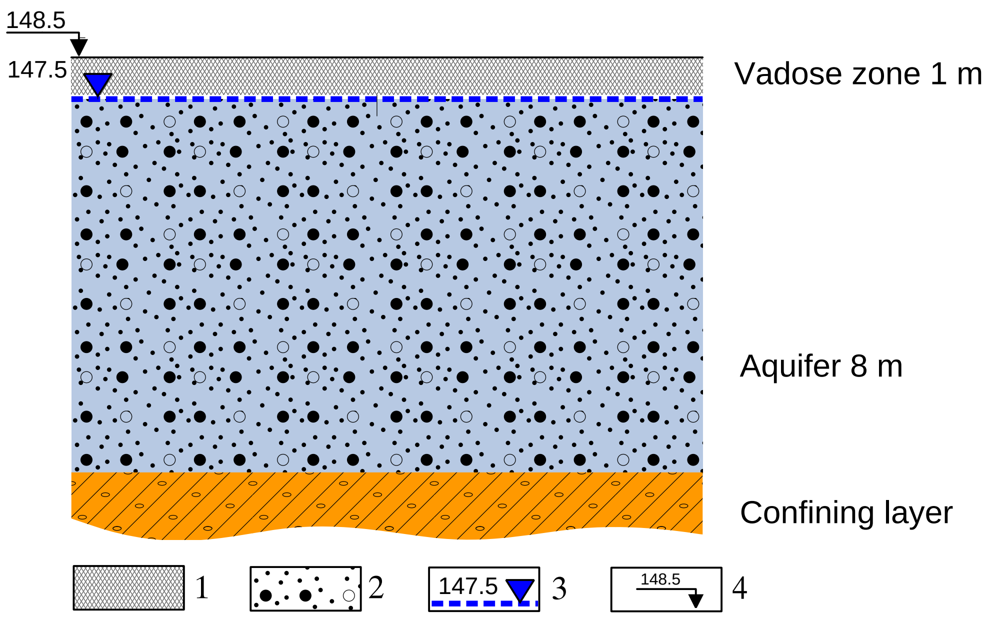


Fig. 10.1. Conceptual geological model used in the analysis:

1 – filled up ground; 2 – sandy loam; 3 – piezometric underground water level and its abs.s.l.(m); 4 – abs.s.l (m) of the bottom slab of bld. 158

Based on data presented in the Chapter 3 a summary of the parameters of the vadose zone necessary for the analysis of potential radionuclide migration is provided in Table 10.4. The process of diffusion does not prevail in radionuclide transport through the geosphere therefore the value of effective diffusion coefficient for the vadose zone is set to 1.0E-10 m^2/s.

Table 10.4. Summarized values of the vadose zone characteristics

Prevailing material in the layer	**Thickness, m**	**Bulk density, kg/m^3**	**Effective porosity**	**Hydraulic conductivity, m/s**	
				Average	**Maximum**
Clayey/sandy filled up layer	1.0	1 500	0.2	4.62E-05	2.12E-04

Based on data presented in the Chapter 3 the characteristics of the aquifer necessary to the radionuclide migration analysis are presented in Table 10.5.

Table 10.5. Summarized values of the aquifer characteristics

Prevailing material in the layer	Thickness, m	Bulk density, kg/m^3	Effective porosity	Hydraulic conductivity, m/s	Hydraulic gradient
Sand of various coarseness	8	1 750	0.15	1.31E-04	0.005

The biosphere parameter values considering the local environmental conditions are provided in. Table 10.6. The pathways of both external and internal exposure are considered in case of consumption of contaminated water from the well or the lake (scenarios of radionuclide migration by water pathway). The path of external exposure is the garden soil, after irrigation with contaminated water. A member of the reference group of the population has been considered in regard to pathways of internal exposure as follows:

- inhalation of air contaminated with the dust suspended from soil during works in the garden;
- ingestion of contaminated water during drinking;
- ingestion of vegetables irrigated with contaminated water;
- ingestion of meat and milk from the cattle watered with contaminated water;
- ingestion of fish, caught in the contaminated lake;
- inadvertent ingestion of soil (e.g., particles of soil residual on vegetables).

Table 10.6. Main biosphere parameters [13]

Parameter, units	Value
Square of Lake Druksiai, m^2	4.9E+09
Volume of Lake Druksiai, m^3	3.69E+08
Turnover of Lake Druksiai, years	3.5
Yield of green vegetables, kg/m^2	0.7
Yield of root vegetables, kg/m^2	1
Consumption of meat and meat products, kg/year	70
Consumption of milk and milk products, l/year	300
Consumption of fish, kg/year	20
Consumption of green vegetables, kg/year	36.5
Consumption of root vegetables, kg/year	130
Water drinking, l/year	600

A site dweller (in case of on-site residence scenario) consuming vegetables grown in the garden or a worker constructing a road (in case of road construction scenario) receiving a dose due to uncovered RAW irradiation would be a member of the reference group in case of unintended intrusion into the repository after completion of the institutional control period.

10.2.3 Pathways and scenarios of radionuclide migration

10.2.3.1 4.4.1 Water pathway scenarios

Water pathway scenarios (natural evolution of the repository and barrier degradation) are developed following the ISAM methodology, which is described in more detail in the report [13]. Conceptual models of the radionuclide migration from the waste zone (exactly from the bitumen matrix and sand-gravel waste through the engineered barriers of the repository)) to the geosphere are presented in Fig. 10.2 and Fig. 10.3 in case of bituminised and sand-gravel waste respectively.

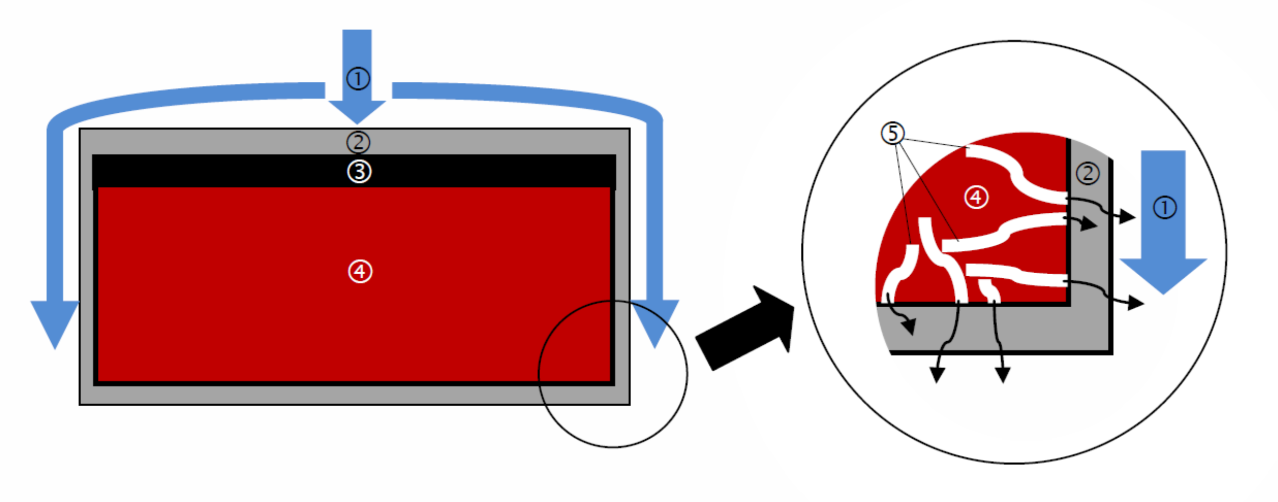


Fig. 10.2. Conceptual model of the radionuclide migration (diffusion) from the bitumen compound through the reinforced concrete structures (walls and bottom) of bld. 158: 1 – water flow; 2 – reinforced concrete structures of bld. 158 ; 3 – layer of inert material; 4 – bituminised RAW (bitumen matrix); 5 – formed pores

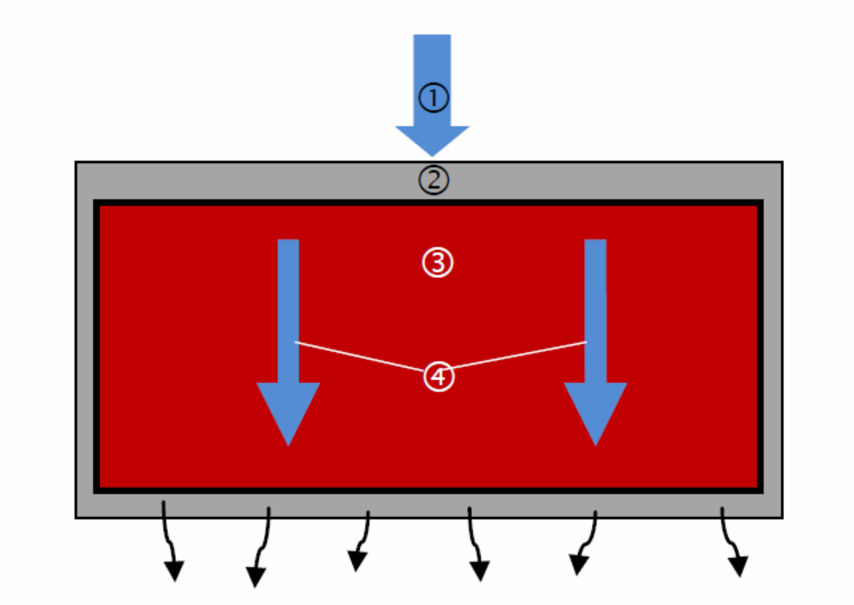


Fig. 10.3. Conceptual model of the radionuclide migration (leaching) from the sand-gravel waste through teh bottom slab of bld.158: 1 – water flow; 2 – reinforced concrete structures of bld. 158 ; 3 – sand-gravel radioactive waste; 4 – diffusive-advective flow

A summary of the scenarios of the radionuclide migration by the water pathway with the corresponding states of the disposal system components and their changes during the period under consideration is presented in Table 10.7. The processes prevailing in the radionuclide transport through the disposal system components taken into account during the assessment are also included into the table.

Table 10.7. A summary of the scenarios of the radionuclide migration by the water pathway

Scenario	Period (duration)	State of the bitumen compound	State of engineered barriers (side walls and bottom slab)	State of geosphere	State of biosphere	Key processes
Natural evolution	*Active control* (100 years)	**Disturbed.** Because of water uptake through the side walls as well as bottom slab the pores are formed	**Intact**	Without changes.	Without changes	Radioactive decay, radionuclide diffusion through the side walls and the bottom slab in case of bituminised RAW, leaching and
	Passive control (200 years)		**Degraded.** The features of the top cover layers as			

Scenario	Period (duration)	State of the bitumen compound	State of engineered barriers (side walls and bottom slab)	State of geosphere	State of biosphere	Key processes
	After institutional control	throughout the whole volume of the waste. The bitumen matrix does not perform the function of RAW containment.	well as of the concrete structures change as indicated in Table 7.6.			diffusion-advection in the RAW zone in case of sand-gravel RAW. Advection–dispersion in the geosphere.
Engineered barrier degradation	Active control (100 years)	**Disturbed.** Because of water uptake through the side walls as well as bottom slab the pores are formed throughout the whole volume of the waste. The bitumen matrix does not perform the function of RAW containment.	**Intact**	Without changes.	Without changes	Radioactive decay, radionuclide diffusion through the side walls and the bottom slab in case of bituminised RAW, leaching and diffusion-advection in the RAW zone in case of sand-gravel RAW. Advection–dispersion in the geosphere.
	Passive control (200 years)		**Degraded.** The state of the top cover layers (clay layer of low permeability) as well as of concrete structures suddenly changes into the degraded concrete phase 2			
	After institutional control					

Detailed description of the conceptual and mathematical models of the radionuclide migration is presented in the report [13].

10.2.3.2 Unintended intrusion scenarios

It is expected that an unintended intrusion into the repository can occur after the institutional control period when the restrictions on the land use as well as on activity in the repository site have already been withdrawn. Usually it is represented by two scenarios, i.e. the on-site residence scenario and the road construction scenario (typical scenarios recommended in IAEA documents [9, 42]. The other ones such as drilling or large-scale excavation scenarios are unlikely because drilling for water from top of the cover (cap) is not expected as well as mining and other underground activities are not expected because there are no valuable resources in the area.

On-site residence scenario

According to the proposed design solutions of the repository installation the thickness of the top engineered barriers makes about more than 5 m. According to the IAEA documents [9, 42], for the construction of the house foundation the required excavation depth is about 2.5 – 3 m. Therefore, the penetration depth for the house construction is not sufficient to reach the waste and assessment for such scenario is not required. This approach is consistent with the above mentioned IAEA document [42]. No further assessment.

Road construction scenario

Taking into account the dimensions of the repository (approx. 120×120 m^2) the length of the road segment across the repository should be equal to 120 m. The excavated radioactive waste will be mixed with the materials of the top barriers of the repository as well as construction materials. The workers should be exposed due to external exposure to excavated radioactive waste mixed with the soil and construction materials as well as due to internal exposure through inhalation of dust and inadvertent ingestion of soil particles.

Detailed description of the conceptual and mathematical models of the radionuclide migration in case of inadvertent intrusion is presented in the report [13].

The modelling of radionuclide migration in the waste zone, geosphere as well as biosphere is performed using the computer program *AMBER* [19].

10.3 Radiological impact assessment to population

10.3.1 4.7.1 Water pathway scenarios

Table 10.8 presents the maximum dose values to a member of the reference group of population due to consumption of contaminated well water or lake water for daily needs in the case scenario of the natural evolution of the repository.

Table 10.8. Exposure dose values obtained by a member of the reference group due to consumption of contaminated water in the case of scenario of the natural evolution of the repository

Radionuclide	Due to well water consumption			Due to lake water consumption		
	Maximum dose value resulted from bituminised RAW, mSv/year	Maximum dose value resulted from sand-gravel RAW, mSv/year	Total, mSv/year	Maximum dose value resulted from bituminised RAW, mSv/year	Maximum dose value, resulted from sand-gravel RAW, mSv/year	Total, mSv/year
^{14}C	7.09E-05	2.62E-06	7.25E-05	4.81E-06	1.97E-07	5.01E-06
^{36}Cl	-	3.46E-06	3.46E-06	-	-	-
^{55}Fe	-	6.95E-06	6.95E-06	-	-	-

Radionuclide	Due to well water consumption			Due to lake water consumption		
	Maximum dose value resulted from bituminised RAW, mSv/year	Maximum dose value resulted from sand-gravel RAW, mSv/year	Total, mSv/year	Maximum dose value resulted from bituminised RAW, mSv/year	Maximum dose value, resulted from sand-gravel RAW, mSv/year	Total, mSv/year
^{90}Sr	7.34E-05	3.14E-04	3.87E-04	-	-	-
^{94}Nb	2.16E-05	-	2.16E-05	-	-	-
^{99}Tc	1.20E-04	-	1.20E-04	-	-	-
^{129}I	6.61E-05	-	6.61E-05	2.96E-08	-	2.96E-08
^{137}Cs	3.20E-03	4.65E-06	3.20E-03	-	-	-
Sum:	**3.56E-03**	**3.32E-04**	**3.89E-03**	**4.84E-06**	**1.97E-07**	**5.04E-06**

As Table 10.8 shows, the total maximum dose value obtained due to consumption of the contaminated water from a well is higher by three orders of magnitude compared to the total maximum dose value obtained from the contaminated lake water and lower by two orders of magnitude compared to the design criterion – 0.1 mSv per year. The maximum dose is determined by ^{137}Cs, and is expected to appear 170 years at the earliest past the repository closure (more details see in the report [13]). Dose resulted from sand-gravel RAW would be factor by 10 less than Dose resulted from bituminised RAW.

Table 10.9 presents the maximum dose values for the engineered barrier degradation scenario.

Table 10.9. Values of exposure doses received by a member of the reference group of population due to consumption of contaminated water in case of engineered barrier degradation scenario

Radionuclide	Due to well water consumption			Due to lake water consumption		
	Maximum dose value determined by bituminised RAW, mSv/year	Maximum dose value determined by sand-gravel RAW. mSv/year	Total. mSv/year	Maximum dose value determined by bituminised RAW, mSv/year	Maximum dose value determined by sand-gravel RAW, mSv/year	Total. mSv/year
^{14}C	7.05E-05	2.68E-06	7.32E-05	4.77E-06	1.79E-07	4.95E-06
^{36}Cl	-	3.46E-06	3.46E-06	-	-	-
^{55}Fe	-	6.95E-06	6.95E-06	-	-	-

Radionuclide	Due to well water consumption			Due to lake water consumption		
	Maximum dose value determined by bituminised RAW, mSv/year	Maximum dose value determined by sand-gravel RAW. mSv/year	Total. mSv/year	Maximum dose value determined by bituminised RAW, mSv/year	Maximum dose value determined by sand-gravel RAW, mSv/year	Total. mSv/year
^{90}Sr	3.35E-04	3.14E-04	6.49E-04	-	-	-
^{94}Nb	2.16E-05	-	-	-	-	-
^{99}Tc	1.19E-04	-	-	-	-	-
^{129}I	3.97E-05	-	-	1.79E-08	-	1.79E-08
^{137}Cs	1.39E-02	4.65E-06	1.39E-02	-	-	-
Sum:	**1.45E-02**	**3.32E-04**	**1.45E-02**	**4.79E-06**	**1.79E-07**	**4.97E-07**

As Table 10.9 shows, the assessed maximum total dose value received due to consumption of the contaminated water from a well in the case of the engineered barrier degradation scenario is three times higher compared to the case of the scenario of the natural evolution of the repository; however, it remains much lower (approx. by one order of magnitude) compared to the design criterion – 0.1 mSv per year. For consumption of the contaminated lake water, the dose remains lower than the design criterion, 0.1 mSv per year, by several orders of magnitude. The dose resulted from sand-gravel RAW would be 10 times lower compared to the dose resulted from bituminised RAW. The maximum dose values, which are determined by ^{137}Cs, are expected to appear 140 years past the repository closure (more details see in the report [13]).

10.3.2 Inadvertent intrusion scenarios

Table 10.10 presents the assessment results in the case of scenario of the road construction in the repository site. The table shows only the doses of those radionuclides that have values higher than 1.0E-20 mSv/year.

Table 10.10. Estimated maximum doses to a worker in the case of the road construction scenario

Radionuclide	External exposure dose, mSv/year	Inhalation dose, mSv/ year	Ingestion dose, mSv/ year	Total dose, mSv/ year
^{14}C	2.12E-12	3.50E-11	9.91E-11	1.36E-10
^{36}Cl	4.47E-11	4.66E-12	1.68E-11	6.62E-11
^{59}Ni	-	3.08E-11	1.25E-10	1.56E-10

Radionuclide	External exposure dose, mSv/year	Inhalation dose, mSv/ year	Ingestion dose, mSv/ year	Total dose, mSv/ year
^{63}Ni	-	1.09E-09	3.55E-09	4.63E-09
^{90}Sr	2.80E-13	2.38E-12	1.18E-11	1.45E-11
^{93m}Nb	8.38E-17	5.15E-17	9.74E-17	2.33E-16
^{94}Nb	1.75E-06	3.41E-10	3.35E-10	1.75E-06
^{93}Zr	-	1.76E-10	2.19E-10	3.94E-10
^{99}Tc	3.39E-13	1.35E-12	1.88E-12	3.56E-12
^{129}I	5.21E-13	5.52E-14	4.78E-12	5.36E-12
^{135}Cs	2.42E-15	2.09E-14	1.37E-13	1.61E-13
^{137}Cs	1.09E-11	1.79E-11	1.69E-10	1.98E-10
^{234}U	3.45E-15	3.06E-12	4.52E-13	3.51E-12
^{235}U	1.56E-13	7.05E-14	1.11E-14	2.37E-13
^{238}U	1.63E-15	7.66E-13	1.22E-13	8.90E-13
^{237}Np	3.59E-14	7.38E-13	4.60E-14	8.20E-13
^{238}Pu	2.80E-14	7.44E-10	4.41E-11	7.89E-10
^{239}Pu	3.19E-13	4.94E-09	2.91E-10	5.23E-09
^{240}Pu	2.08E-13	6.23E-09	3.68E-10	6.60E-09
^{241}Pu	2.85E-19	4.26E-15	2.52E-16	4.52E-15
^{241}Am	2.18E-10	1.84E-08	1.08E-09	1.97E-08
^{244}Cm	4.86E-18	7.98E-14	4.76E-15	8.46E-14
Iš viso:	**1.75E-06**	**3.20E-08**	**6.32E-09**	**1.79E-06**

As Table 10.10 demonstrates, the total exposure dose to a worker working in road construction in the repository site is 1.79E-06 mSv/year, and it is lower than the dose limit 10 mSv/year by several orders of magnitude. The biggest impact on the total exposure dose value is from *^{94}Nb*. Impact from other analysed radionuclides is insignificant. For the identified radionuclides, the biggest contribution to the total dose would be because of external exposure from the mixture of soil and waste.

11 OTHER ASPECTS OF THE SITE SAFETY ASSESSMENT

11.1 Feasibility to apply measures required for physical protection

The goals for physical protection of nuclear facility, nuclear material and nuclear cycle material are defined by the law on Nuclear Energy [35] and are as follows:

- To protect a nuclear facility, nuclear materials and (or) nuclear fuel cycle materials against unauthorized possession or seizure;
- To prevent unauthorized access to protected areas of a nuclear facility;
- To protect a nuclear facility, nuclear materials and (or) nuclear fuel cycle materials against actions which might directly or indirectly endanger human health and security as a result of ionizing irradiation as well as to prevent disruption of the normal operation of a nuclear facilities;
- To implement preventive measures against unauthorized possession or seizure of a nuclear facility, nuclear materials and (or) nuclear fuel cycle materials, against unauthorized access to protected areas of a nuclear facility, against actions which might directly or indirectly endanger human health and security as a result of ionizing irradiation as well as to prevent disruption of the normal operation of a nuclear facilities.

Implementation of provisions of the law is specified by the VATESI nuclear safety regulation BSR-1.6.1-2012 [36]. In accordance with the regulation, the physical protection must be based on the following main principles:

- Physical protection should give due priority to the security culture, to its development and maintenance necessary to ensure effective implementation of the physical protection goals;
- Physical protection requirements should be based on a graded approach, taking into account the potential threat, the class of the nuclear material and potential consequences associated with the unauthorized possession or seizure of nuclear material and (or) nuclear fuel cycle material and with the sabotage against the nuclear facility, nuclear material and (or) nuclear fuel cycle material;
- Organization and assurance of physical protection of a nuclear facility, nuclear materials and (or) nuclear fuel cycle materials must be based on a principle of defence in depth, i.e. on implementation of several layers of physical protection.

A planned reconstruction and transformation of the storage facility of bituminised radioactive waste into repository is performed exceptionally inside the INPP industrial site.

Physical protection of the INPP site is organized in accordance with the prepared and the regulatory approved physical security plan. The plan has been prepared and approved following requirements of the VATESI nuclear safety regulation BSR-1.6.1-2012 [36] and nuclear safety rules BST-1.6.1-2012 [37]. The plan is based on the analysis of division of INPP site into protection areas. The plan itself and it supporting documents are classified and analysis of these documents are not in the scope of this report. Additional physical protection measures associated with planned activities, if needed, will be foreseen in INPP site physical security plan. After closure of the repository during active institutional control period an application of required measures of physical protection will be foreseen regarding certain changes of the site and its environment features and in accordance to the requirements of normative documents in force.

11.2 Feasibility to apply measures required for emergency preparedness

The purpose of emergency preparedness in a nuclear facility [38] is prevention of occurrence of accidents and incidents, and, in the case of accident, to be prepared to:

- Implement actions for returning nuclear facility to the normal operation conditions;
- Protect the people present in nuclear facility;
- Mitigate consequences of the accident;
- Define the class of accident;
- Inform VATESI and other state regulating and supervising institutions that participate in the emergency response;
- Invoke support from external emergency response organizations and services;
- Perform radiological monitoring in nuclear facility and it's sanitary protected zone;
- Support the state regulating and supervising organizations in the public informing.

A planned reconstruction and transformation of the storage facility of bituminised radioactive waste into repository are performed exceptionally inside the INPP industrial site. In accordance with INPP procedure on management of emergency preparedness [39], emergency preparedness of the planned activity will be integrated into the existing INPP emergency preparedness structure. Emergency preparedness at the INPP is described in Chapter 11.2.1.

Identified emergency situations in the long-term perspective are estimated in Chapter 8 and Chapter 9 of this report. Expected doses remain a few times or even orders of magnitude below design criterion value 0.1 mSv per year, or event probability is lower than screening probability level. Therefore according to the performed estimations no specific measures of the emergency preparedness are required.

Decommissioning of the INPP (expected in 2030 or later) will bring the INPP site to the so named “brown field conditions” with operational spent nuclear fuel and long-lived radioactive waste storage facilities. After decommissioning of the INPP emergency preparedness of bld. 158 will be integrated into the emergency preparedness system of the INPP site.

11.2.1 Emergency preparedness in the INPP

Emergency preparedness in the INPP is organized and guided by the Emergency response plan (ERP). The ERP is the main leading document establishing organizational, technical and other requirements, directed on performance of emergency mitigation, medical, evacuation and other actions necessary for protection of the personnel and the population from technogenic and natural phenomena induced accidents in the INPP. The ERP is developed in compliance with the established requirements and is coordinated with authorities in accordance with the established procedure [38]. After closure of the repository during active institutional control period ERP will be reviewed and corrected regarding certain changes of the site and its environment features and in accordance to the requirements of normative documents in force.

11.2.2 Emergency response plan

The current revision of the ERP considers situation after shutdown of the INPP including specific of on-going decommissioning activities, management of SNF and construction of new nuclear facilities which are planned to become operational in 2014-2020.

The ERP consists of two parts:

- General part with appendices;
- Operational part (collection of instructions).

The general part of the ERP [40] contains:

- General provisions including description of purpose, tasks and content of the ERP, description of ERO structure and definition of responsibilities of the ERO officials;
- General provisions for classification of accidents;
- Order on organization of management of beyond design basis accidents and elimination their consequences including orders on initial assessment of accidents, notification and collection of the ERO officials and personnel, actions of the ERO officials on the

accident management, notification of state institutions and authorities, interaction with support organizations and termination of emergency preparedness status;

- Description of technical means, resources, premises and communication systems required for performance of the tasks assigned to the ERO;
- Description of general protective actions, limitation of accidental exposure and personal protective means;
- Appendices: list of the ERO officials; diagram of the ERO structure; diagram tree for the decision making; plan-schedule for the initial actions on management of accidents; criteria for application of protective actions; definition of responsibilities of ERO officials; plan-schedule for main actions on management of accident consequences; list of storage locations for personal protective means etc.

The ERP is revised each three years.

12 RESULTS OF THE SITE SAFETY ANALYSIS AND JUSTIFICATION AND CONCLUSIONS

Based on the geologic, seismic/tectonic and hydrologic/hydrogeologic characteristics of the site as well as characterization of the geochemical/hydrochemical and meterological conditions at the site obtained after EGG investigations of the site as well as from the analysis of the previous investigations [4] and available data on predicted environmental changes and factors stipulating impact on the safety of the planned repository no factors contradicting the suitability of the site to reconstruction and transformation of the existing storage facility of bituminised waste (bld, 158) to the repository have been identified. No site disadvantages requiring the application of the compensatory measures under present engineering geological and geotechnical conditions have been determined during EGG investigations [12].

The long-term safety assessment for the period after repository closure presented in the report, including the scenarios of the potential radionuclide migration by water pathway as well as inadvertend human intrusion into repository as well as emergency situations resulted from the hazards due to external natural factors as well as human activity, revealed that the impact of the ionized radiation to the population would remains below the specified design criterion value of 0.1 mSv per year by factor from a few times to few orders of magnitude for all cases under investigation.

The feasibility to apply measures required for physical protection as well as for emergency preparedness are described and assessed in the report. Due to negligible impact of the foreseen emergency situations no other (additional) measures are required than indicated in the INPP present emergency preparedness plan.

Preliminary radiological waste acceptance criteria for disposal of bituminised RAW as well as sand-gravel RAW from reactor zone are presented in the report.

After the site analysis no site disadvantages requiring the compensation applying design technical solutions or organizational measures have been determined.

In the scope of the performed analysis it can be concluded that the site is suitable for the reconstruction and transformation of the present storage facility of bituminised waste (bld. 158) into the repository.

13 PRELIMINARY RADIOACTIVE WASTE ACCEPTANCE CRITERIA

Radiological WAC for the radioactive waste disposal in the planned repository of Bituminised radioactive waste are defined following VATESI requirements established in the document [41] and taking into account IAEA recommendations [42], as well as peculiarities of the waste disposal in situ by transforming present storage facility into the final repository. A detailed description of methodology and derivation of radiological WAC is presented in the report [13].

Table 13.1 presents specific activity limits and total activity limits derived for the planned repository.

Table 13.1. Radiological WAC derived for radioactive waste planned to be disposed of in the future repository

Radionuclide	**Half-life, years**	**Specific activity limits, Bq/kg**				**Total activity limits, Bq**	
		$A_{i,max}$, Natural evolution (leaching) scenario		**$C_{i,max}$, Inadvertent intrusion into repository scenario**			
		Bituminised RAW	**Sand-gravel RAW**	**Bituminised RAW**	**Sand-gravel RAW**	**Bituminised RAW**	**Sand-gravel RAW**
^{14}C	5.73E+03	9.34E+06	3.52E+03	3.41E+14	6.17E+10	1.62E+14	2.92E+10
^{36}Cl	3.01E+05	-	7.62E+03	-	1.29E+10	-	6.33E+10
^{54}Mn	8.54E-01	-	**	-	**	-	***
^{55}Fe	2.70E+00	-	4.52E+06	-	**	-	3.76E+13
^{59}Ni	7.50E+04	2.34E+07	4.14E+06	7.12E+12	6.04E+11	4.05E+14	3.43E+13

Radionuclide	Half-life, years	Specific activity limits, Bq/kg				Total activity limits, Bq	
		$A_{i,max}$, Natural evolution (leaching) scenario		$C_{i,max}$, Inadvertent intrusion into repository scenario			
		Bituminised RAW	Sand-gravel RAW	Bituminised RAW	Sand-gravel RAW	Bituminised RAW	Sand-gravel RAW
^{63}Ni	9.60E+01	8.36E+09	1.46E+09	2.52E+13	2.11E+12	1.45E+17	1.21E+16
^{60}Co	5.27E+00	1.50E+16	2.88E+14	**	**	***	***
^{65}Zn	6.68E-01	-	2.02E+06	-	**	-	1.68E+13
^{90}Sr	2.91E+01	1.55E+06	2.49E+03	2.27E+15	1.75E+12	2.68E+13	2.06E+10
^{93}Zr	1.53E+06	-	1.54E+08	-	4.25E+11	-	1.28E+15
^{93m}Nb	1.36E+01	-	7.99E+06	-	4.04E+16	-	6.63E+13
^{94}Nb	2.03E+04	1.67E+07	1.34E+04	1.39E+10	5.38E+06	2.88E+14	1.11E+11
^{99}Tc	2.13E+05	4.36E+06	3.54E+01	9.90E+15	3.85E+10	7.55E+13	2.93E+08
^{110m}Ag	6.84E-01	-	4.17E+06	-	**	-	3.46E+13
^{129}I	1.57E+07	1.27E+04	9.50E-01	1.07E+13	3.83E+08	2.20E+11	7.88E+06
^{134}Cs	2.06E+00	1.99E+15	3.07E+10	**	**	***	2.55E+17
^{135}Cs	2.30E+06	-	1.15E+05	-	2.02E+10	-	9.59E+11
^{137}Cs	3.00E+01	2.43E+11	4.15E+06	3.85E+17	3.16E+12	4.20E+18	3.44E+13
^{234}U	2.44E+05	8.11E+04	2.33E+02	9.04E+10	1.25E+08	1.40E+12	1.93E+09
^{235}U	7.04E+08	5.62E+04	6.26E+01	8.78E+10	4.69E+07	9.72E+11	5.20E+08
^{238}U	4.47E+09	2.75E+05	7.91E+02	1.04E+11	1.44E+08	4.75E+12	6.57E+09
^{237}Np	2.14E+06	2.02E+05	4.63E+00	2.19E+12	2.40E+07	3.50E+12	3.84E+07
^{238}Pu	8.77E+01	3.11E+08	1.36E+06	5.90E+10	1.23E+08	5.39E+15	1.13E+13
^{239}Pu	2.41E+04	1.04E+06	2.71E+03	8.51E+09	1.06E+07	1.81E+13	2.25E+10
^{240}Pu	6.54E+03	7.03E+06	1.87E+04	8.52E+09	1.09E+07	1.22E+14	1.56E+11
^{241}Pu	1.44E+01	4.47E+10	1.69E+08	5.66E+17	1.03E+15	7.73E+17	1.40E+15
^{241}Am	4.32E+02	6.41E+08	2.07E+05	1.36E+11	2.11E+07	1.11E+16	1.72E+12
^{244}Cm	1.81E+01	-	3.15E+05	-	2.16E+12	-	2.62E+12

** Values above 1E+20 Bq/kg
*** Values above 1E+20 Bq
For derivation of specific activity limits for bituminised RAW it is assumed that the mass of the bituminised waste is 17 306 400 kg.
For derivation of specific activity limits for sand-gravel RAW it is assumed that the mass of the sand-gravel waste is 8 300 000 kg.
Waste accepted in the repository if the following criteria are met: $\sum_i \frac{Q_i}{A_{i,\max}} \le 1$; $\sum_i \frac{Q_i}{C_{i,\max}} \le 1$,

here: Values of specific activity limits $A_{i,max}$ are calculated according to the scenario of the repository's natural evolution; $C_{i,max}$ – according to the scenario of inadvertent intrusion into the repository; Q_i is the actual specific activity of the i^{-th} radionuclide in a canyon.

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