LITHUANIAN ENERGY INSTITUTE

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NUCLEAR ENGINEERING LABORATORY

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

ENVIRONMENT IMPACT ASSESSMENT REPORT

Revision 1

Habil. dr. P. Poškas

Kaunas, 2023

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Environmental impact assessment for reconstruction and transformation of Ignalina NPP storage facility of bituminised radioactive waste into repository. EIA Report.
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The report provides an assessment of the potential impact on the environmental components of the proposed economic activity – transformation of a bituminized radioactive waste storage facility into a repository. The report was prepared according to the environmental impact assessment program approved by the competent authority. The technological solutions for the reconstruction and transformation of the bituminized radioactive waste storage facility of the Ignalina NPP into a repository are presented in the report. The environmental components in the neighbouring environment are described and assessed how they can potentially be affected by the proposed economic activity, and measures to reduce the potential impact are provided. Possible alternatives of the proposed economic activity were also evaluated and emergency situations (risks) that may occur during the implementation of the proposed economic activity were analyzed and their impacts on the environment were assessed.</td></tr>
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TABLE OF REVISIONS

Revision	Issue Date	Description
0	August 31, 2023	Submitted for Ignalina NPP review
1	October 27, 2023	Renewed according to Ignalina NPP comments; submitted to public and foreign countries review

CONTENT

LIST OF ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
Bld.	Building
CJSC	Closed joint-stock company
EIA	Environment Impact Assessment
IAEA	International Atomic Energy Agency
INPP	Ignalina Nuclear Power Plant
ISAM	Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (title of methodology recommended by IAEA for safety assessment of near surface radioactive waste repository)
ISFSF	Interim Spent Fuel Storage Facility
LEI	Lithuanian Energy Institute
NF	Nuclear Facility
NPP	Nuclear Power Plant
PEA	Proposed Economic Activity
RAW	Radioactive Waste
SE	State Enterprise
SPZ	Sanitary Protection Zone
SNF	Spent Nuclear Fuel
SWRF	Solid Waste Retrieval Facility
SWTSF	Solid Waste Treatment and Storage Facility
VATESI	State Atomic Energy Safety Inspectorate (Lithuanian abbreviation)

INTRODUCTION

Proposed economic activity – transformation of Ignalina NPP bituminized radioactive waste storage (building 158) into near surface repository.

Since proposed economic activity by its nature and scope may have a significant impact on environment, environment impact assessment (EIA) is required (see document [1], appendix 1, articles 3.5 and 3.7). This EIA report has been prepared in accordance with the regulation on preparation of the EIA program and report [2] and the EIA program [3] of the proposed economic activity approved by the competent authority.

Bituminized radioactive waste (RAW) storage (building 158) is located at the north-west part of INPP industrial site. The storage is intended for storing of bituminized waste, generated from operational and decommissioning liquid RAW.

According to RAW treatment requirements [4], when loading of bituminized waste into the storage will be finished, in order to ensure long-term storage, waste must be disposed of. After assessment of disposal approaches [5] it was assumed that taking into consideration a state of the art of RAW disposal technologies as well as accumulated experience, installation of surface engineered barriers above the existing storage in long-term perspective would at best provide its safety. A few solutions, that are related with installation of engineered barriers, have been proposed for transformation of building 158 into a repository.

According to law [1] article 4, the objectives are set for EIA under development as follows:

1) to determine, describe and assess the potential direct and indirect effects of the proposed economic activity on the following elements of the environment: soil, land surface and subsurface, air, water, climate, landscape and biodiversity, focusing in particular on species and natural habitats of Community interest, also on other species protected by the Law of the Republic of Lithuania on the Protected Species of Fauna, Flora and Fungi, material assets, immovable cultural properties and the interrelationship between these elements;
2) to identify, describe and assess the potential direct and indirect effects of biological, chemical and physical factors caused by the proposed economic activity on public health, also on the interrelationship between elements of the environment and public health;
3) to determine the potential impact of the proposed economic activity on the elements of the environment referred to in point 1 of this Article and on public health by virtue of the risk of vulnerability of the proposed economic activity due to emergency events and/or potential emergencies;

4) to determine the measures to be taken in order to prevent envisaged significant adverse impact on the environment and public health, to reduce it or, if possible, to offset it;
5) to determine whether the proposed economic activity, having assessed its nature, scale, location and/or effect on the environment, meets the requirements of environmental protection, public health, immovable cultural heritage protection, fire and civil protection legislation; whether it will not have a significant negative impact on the elements of the environment referred to in point 1 of this Article, public health and their mutual interactions.

SUMMARY

During the operation of the Ignalina NPP all water discharged in the controlled area from the various technological tanks and pipelines as well as wastewater was collected in dedicated storage tanks. The collected water was evaporated in special facilities and the concentrate of the impurities present in the water was mixed with bitumen in a bituminisation facility. The resulting mixture of bitumen and evaporator concentrate (compound) was placed in the storage canyons in Building 158. During the operation of the Ignalina NPP when both Units were in operation, an average of ~250 000 m^3 of water was collected and treated per year, resulting in an average of 915 m^3 of evaporator concentrate from which 605 tons of bituminized waste was produced. Over the entire period from 1987 to 2015 (when the bituminization process was stopped) 19 415 m^3 of evaporator concentrate was generated resulting in 14 422 m^3 of bituminized radioactive waste which is stored in building 158. Bituminized radioactive waste is classified as Class B and C solid radioactive waste (short-lived, low and intermediate level activity).

Bituminized radioactive waste storage (building 158) is located at north-west part of Ignalina NPP industrial site (see Figure S1): about 200 m west from the first reactor unit and about 600 m from the south shore of the Lake Druksiai.

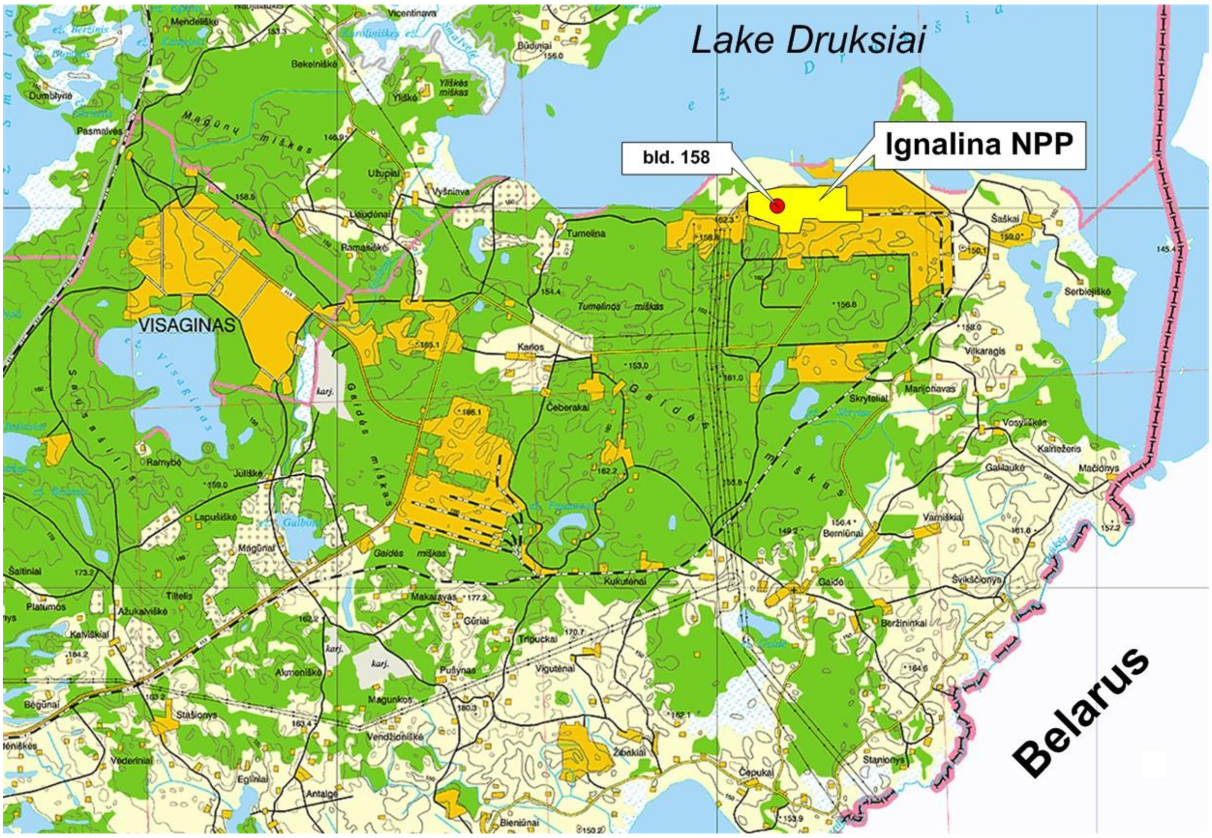

Figure S1. Location of bld.158 at the Ignalina NPP area

Retrieval of the bituminized radioactive waste from building 158 and placing it in a repository would be a complex and ambitious task – it would be necessary to develop the technology for retrieval and treatment of the bituminized radioactive waste from the storage canyons, design or find the suitable packaging, select the site for the repository, design, construct and transfer the waste to the repository. An alternative way is to transform the storage facility into a repository, such a solution would require much less financial and other resources and would be much less hazardous from the radiological impact point of view. This proposed economic activity (PEA) aims to reconstruct and transform the bituminized radioactive waste storage facility of Ignalina NPP into a repository. One of the main tasks during the transformation of the bituminized radioactive waste storage (building 158) into a repository is the installation of engineered barriers that protect the repository from ingress of water (rain, melting snow, etc.), possible external impacts caused by accidental or deliberate human activity, and limiting the ionising radiation exposure and the releases of radionuclides into the environment.

Chapters 1 and 2 of the Environmental Impact Assessment (EIA) report provide the general information of the planned surface repository and describe the main facilities and technological processes. The period of implementation of the proposed economic activity and the stages of the activity are indicated, the amount of materials required for the installation of the engineering barrier of the repository is preliminarily estimated, potential sources of pollution are named, the physical properties of bituminized radioactive waste are described, and the list of radionuclides that present in the waste and their activities are provided. The possibilities of transforming the bituminised radioactive waste storage facility at Ignalina NPP into a repository have been evaluated since 2007, when a feasibility study for transforming the storage facility into a repository was prepared [1.1]. Later, an IAEA expert mission was organised in 2015 to assess the feasibility of converting the storage facility into a repository, and in 2019-2022 the conceptual design of a repository [1.2] was prepared, the safety justification of the repository concept [1.3] and an evaluation of the repository site [1.4] were performed. Taking into account the characteristics of the bituminised radioactive waste and the features of the site, the conceptual design of a repository considers possible technical solutions for the installation of engineered barriers during the transformation of building 158 into a repository. Engineered barriers of different thicknesses and layers were also analysed taking into account the peculiarities of the constructions of the building 158, the possible loads of engineered barriers, the requirements for ensuring radiation safety, and the external impacts of the environment. It was determined that the optimal option for the transformation of building 158 into a repository would be to install steel-reinforced concrete structures on the reinforced concrete upper cover of building 158, which would support the 5.8 m thick engineering barrier (multilayer cap) installed above the building (see Figure S2).

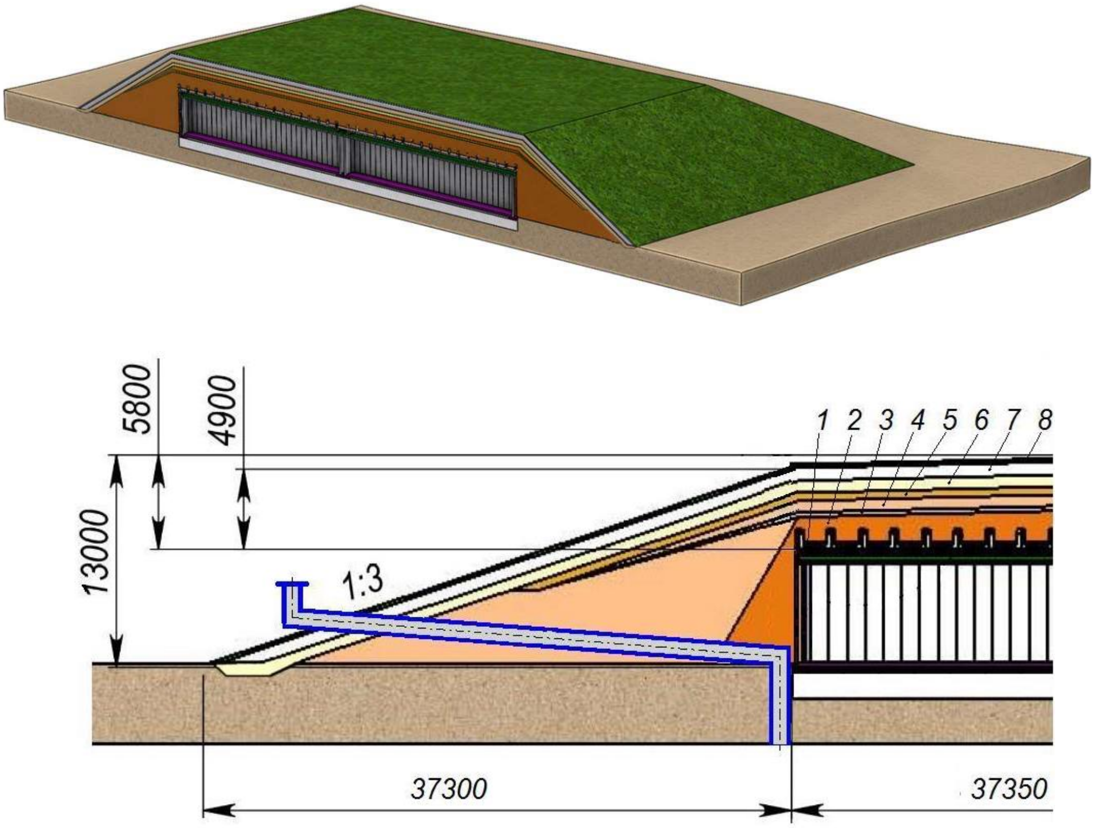

Figure S2. Image and composition (cross-section) of the 5.8 m thick engineered barrier after transformation of the storage facility (bld. 158) into the repository:
1 – drainage layer (0.2 m of sand); 2 – insulating clay layer (1.5 – 2.4 m); 3 – drainage layer (0.3 m of gravelly sand); 4 – protective 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

Chapter 3 of the EIA report describes the waste that may be generated during the proposed economic activity, their estimated amounts and management. During the proposed economic activity, waste will be generated during the dismantling of the construction and communication structures of the 2nd floor of building 158 and the removal of unnecessary roof layers. The generated construction waste will be sorted, characterized and, depending on its activity, managed according to waste management requirements [1.5]. The organizer of this proposed economic activity (Ignalina NPP) strives to convert the waste generated during any decommissioning project into secondary raw materials as much as possible. This PEA is not an exception, the generated waste as much as possible will be to convert into secondary raw materials or reusable materials.

Chapter 4 of the EIA report describes the current status of the various environmental components and examines the possible impacts on these components. It should be noted that the PEA will be implemented within the closed industrial site of Ignalina NPP, locally around building 158 (see Figure S3). A sanitary protection zone (SPZ) has been established around the Ignalina NPP within a radius of 3 km, where economic activities not related to the operation and decommissioning of the Ignalina NPP are restricted and there are no permanent residents within the SPZ. Therefore, the impact on most environmental components will be negligible or absent. The main potential impact, which is examined in detail in the EIA report, is the radiological impact on the water component and public health. Non-radiological air pollution may be expected during reconstruction activities of the storage facility and construction of engineered barriers for future repository. Due to these activities, NO_x, SO_2, CO, CO_2, solid particles will be released into the ambient air, however the pollution will be local, the zone of reconstruction or installation of an engineering barrier and its surroundings within a radius of ~50 m will be impacted only. Ignalina NPP is performing chemical and radiological monitoring of the ambient air since the start of operation, according to the monitoring results the decommissioning activities at Ignalina NPP site have not had a significant negative impact on the ambient air so far.

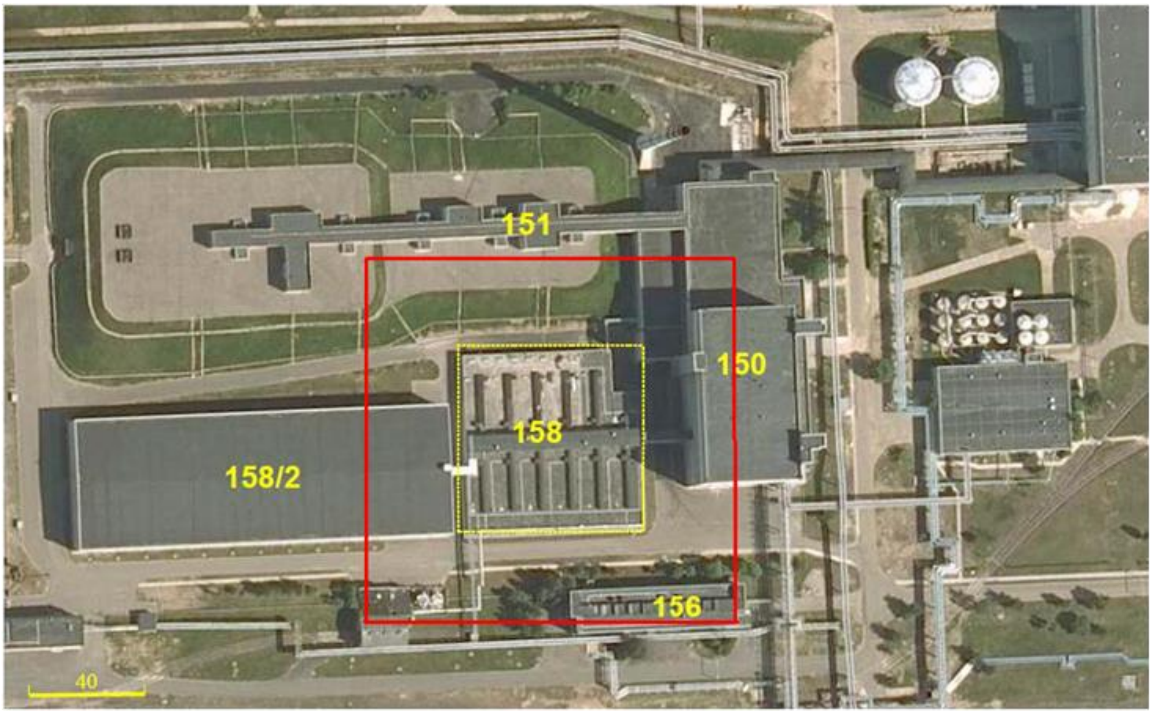

Figure S3. Reconstruction of bituminised radioactive waste storage facility (building 158) into the repository. The red line marks the 36 m wide area around the building, which will be used for the engineered barrier (multilayer cap)

bld. 150 – liquid radioactive waste treatment and bituminization facility; **bld. 151** – drainage water collection tanks; **bld. 156** – special washhouse; **bld. 158** – bituminized radioactive waste storage; **bld. 158/2** – interim storage facility for cemented RAW.

The potential impact on water depends on the scenarios of the repository development (evolution of engineered barriers), which are developed according to ISAM methodology [1.6]. According to this methodology the disposal system is subdivided into components (the waste zone, the geosphere and the biosphere), and then possible states of the components are defined. Finally, scenarios are developed after the estimation of the possible states and their interrelation. Computer programs AMBER and COMSOL were used to model radionuclide transport through engineered barriers of the repository, ground water and in geosphere.

Two discharge points of radionuclides are investigated, exactly a well installed in the aquifer at the distance of 50 m from the repository (at the border of the supposed SPZ of the repository) and the lake Druksiai located at the distance of 600 m from the repository. The water taken from the well or the water taken from the lake can be used by the humans (members of reference group of population) for their everyday needs and, thus it can become a source of exposure. The following internal exposure pathways have been taken into account:

- 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).

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 irradiation of uncovered bituminized radioactive waste would be a member of the reference group in case of inadvertent intrusion into the repository after completion of the institutional control period.

The analysis of the scenarios of the repository evolution and the dispersion of radionuclides (14 scenarios in total were analysed) has shown that the calculated annual doses to the member of the reference group are below the permissible limits. Maximum values of the exposure dose were compared with the design criterion of 0.1 mSv per year, which is less than effective dose constraint, 0.2 mSv/year, defined in Lithuanian hygiene norm requirements HN 73:2018 for operation and decommissioning of nuclear facilities [1.7]. The value of the design criterion was defined taking into account the fact that, in addition to the planned bituminized radioactive waste repository, other nuclear facilities are (or will be) in operation at the site of Ignalina NPP. Therefore, the exposure of the member of reference group must be distributed in such a way that the total annual dose caused by all nuclear facilities at the site cannot exceed the dose constraint. 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 [1.8].

Chapter 5 of the EIA report presents an analysis of PEA alternatives. "Zero", location and technological alternatives were considered. In the case of the "zero" alternative, it was concluded that the indefinite storage of bituminized radioactive waste in building 158 is not feasible because previous assessments have shown that in the long term the structures of building 158 will start to degrade and would not provide a reliable containment of the waste. When considering the location alternative, i.e., the repository is constructed in another site, the bituminized radioactive waste from bld. 158 should be retrieved, placed in appropriate packages and transported to the disposal site. This alternative would lead to additional socio-economic challenges in the selection of the repository site, it would be necessary to develop the technology for waste retrieval, treatment and transport of the waste would lead to increased exposure of personnel and the members of population. As technological alternatives different technical solutions of the engineered barrier were considered, preliminary assessment of the advantages and disadvantages of these solutions was performed and optimal solution was selected [1.2].

Chapter 6 of the EIA report specifies the monitoring objectives and the conceptual description of environmental radiological monitoring. It shall be noted, that from 1987 to the present day the building 158 operates as storage facility for bituminous radioactive waste, which is monitored according to the currently valid Ignalina NPP environmental radiological monitoring [1.9]. In accordance with this program, groundwater samples are taken from boreholes in the vicinity of the building, dose rate values on the roof and walls of the building are measured at defined points, etc. This section of the EIA Report provides a conceptual description of environmental radiological monitoring when building 158 will be transformed into a repository, i.e., engineering barrier will be installed, a multilayer cap will be formed. Environmental monitoring of a repository includes measurements of dose rate, external absorbed dose and radionuclide activities in various environmental components. The selection of environmental objects is determined by the exposure significance of representative member due to the radionuclides they may contain. Automatic electronic devices are usually for dose rates measurements and dose-accumulating devices (thermoluminescent dosimeter) are used for measuring external absorbed dose. Environmental objects shall be sampled for radioisotopic analysis in the vicinity of drainage water and other effluent discharges and in areas of highest probable contamination. The radionuclide composition of the samples shall be determined to assess the contamination of the environment by measuring the specific activities of gamma-emitters. Contamination with beta (^{90}Sr, ^{3}H, ^{14}C, etc.) and alpha (^{239,240}Pu, ^{241}Am, etc.) emitting radionuclides shall be assessed by analysing a selection of representative samples.

Chapter 7 of the EIA report considers possible accidental situations (risks) that may arise during the implementation of proposed economic activity and assesses the potential radiological impact due to the accidents. The following initiating events that potentially can cause the damages of engineered barriers of the repository and radionuclide releases into environment:

- External natural, namely earthquake, ground settlement, increase of atmospheric precipitation;
- External man-induced, namely airplane crash onto the repository;
- Internal man-induced, such as a fire;
- Failure of the equipment and its components, namely malfunctioning of drainage system.

In the event of an earthquake, the engineering barriers of the repository may collapse, the concrete structures no longer perform the function of retaining radionuclides, and there would be dispersion of radionuclides into the environment. In the case of an increase in the amount of atmospheric precipitation, the infiltration of water into the technogenic soil increases and therefore the amount of radionuclides transported through the geosphere zone increases. In the event of a failure of the drainage system, water flooding of the repository is possible, which may result in the transfer of radionuclides by surface water directly into the Lake Drūkšiai bypassing the geological layers. Airplane crash probability calculations have showed that in all cases the probability is less than the screening probability level ($1 \cdot 10^{-7}$ per year for nuclear objects). The initiating events with a probability of occurrence lower than this level should not be given further consideration in spite of their consequences [1.10]. Despite the low probability, radiological consequences due to airplane crash onto the building 158 have been assessed and provided in the report [1.11]. Calculated doses for all accidental situations remain a few times below design criterion value 0.1 mSv per year. According to the evaluations, no special emergency preparedness measures are required for the reconstruction and transformation of the bituminized radioactive waste storage facility into a repository.

The impact assessment on neighbouring countries is presented in Chapter 8 of the EIA report. Two states, Belarus and Latvia, are relatively close to the site of proposed economic activity. Border between Lithuania and Belarus is about 5 km east and south-east from INPP industrial area. Lithuanian and Latvian state boarder is about 8 km north from INPP industrial area. Other states are at the distance of several hundred kilometres from INPP. It is estimated that the possible radiological impact of the proposed economic activity may be on the water component, i.e. for the Lake Druksiai, part of which is at the territory of the of Belarus. Lake Druksiai is located only within the territory of Lithuania and Belarus, and the Ricianka river, via which water connection with the Lake Rica partly located in Latvia is possible, flows towards the Lake Druksiai, but not out of it, therefore is no potential radiological impact for Latvian environment components and its population. The scenarios of inadvertent intrusion into the repository are not relevant for residents of neighbouring countries. The maximum annual dose due to the water pathway scenario to the representative member, which daily uses a contaminated water from a well (located 50 meters from the repository) and assuming the very conservative hypothetical case that lower layers, foundation, walls and top slab of the repository is cracked immediately after its closure, and the multilayer cap is also assumed to be degraded immediately after a closure, is about 10 times lower than the dose constrain of 0.2 mSv/year. Taking into account that the nearest neighbouring settlements are more distant (at 5 and 8 km distances) from the site of the proposed economic activity, i.e. further than the distance taken into account for the assessment of the radiological impact on the representative member of population (50 metres away), the health impact on the population of neighbouring countries would be even lower when considering the same water pathways as for the representative in the vicinity of the repository, as the dispersion coefficient shows that the increase in distance from the source of the discharge results in a decrease in the activity concentrations of radionuclides and the resulting doses of radiation exposure.

SUMMARY REFERENCES:

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1.7. HN 73:2018. Lithuanian Hygiene Standard “Basic Standards of Radiation Protection”. TAR 2018-08-21, i. k. 2018-13208 (in Lithuanian), 2018.

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1.11. Analysis of the consequences of possible nuclear and radiological accidents at the Ignalina NPP (in Lithuania). LEI Report No. 17/14-1875.19.19-G-V:03, 2019.

1 GENERAL INFORMATION

1.1 Organizer of proposed economic activity

Organizer of proposed economic activity is the **State Enterprise Ignalina Nuclear Power Plant**:

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1.2 Developer of EIA Report

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1.3 Title and Description of Proposed Economic Activity

Title of proposed economic activity: **Reconstruction and transformation of Ignalina NPP storage facility of bituminised radioactive waste into repository.**

Bituminized radioactive waste storage (building 158) is located at north-west part of Ignalina NPP industrial site (see Figure 1.1): about 200 m west from the first reactor unit and about 600 m from the south shore of the Lake Druksiai. The storage in designed for bituminized RAW storage. Bituminized RAW is derived from bitumen and salt concentrate, which is generated by vaporizing INPP operational and decommissioning liquid radioactive waste.

The construction of building 158 had started in 1981, and its loading with bituminized waste took place between 1987 and 2015. The storage is a two-stored rectangular surface construction (~74×75 m) with bearing walls and concrete blocks for biologic protection (see Figure 1.2). At the first floor 11 canyons (sections) are located, the capacity of each is 2500 m^3 (working volume – 2000 m^3) and one canyon is of 1000 m^3 capacity (working volume – 800 m^3). Three canyons are empty and one is partially filled. At the second floor there are tubular communication ducts with pipelines, technological equipment rooms, and also auxiliary service rooms. Storage facility is connected to waste treatment facility (building 150) via gallery with three communications ducts and pipelines, designed for bituminized RAW transfer.

One of the main tasks during the transformation of the bituminized RAW storage (building 158) into a repository is the installation of engineered barriers that protect the repository from ingress of water (rain, melting snow, etc.), possible external impacts caused by accidental or deliberate human activity, and limiting the ionising radiation exposure and the releases of radionuclides into the environment. Three types of barriers are used during the construction of repositories: 1) surface (hill type), segregating and isolating waste from surface processes, 2) vertical (cut-off walls that are installed in proper depth around the site), limiting horizontal waste dispersion and potential access to waste zone from the side 3) underground horizontal barriers installed below waste in order to limit radionuclide dispersion down to ground water or on the contrary, in order to prevent waste zone from groundwater water percolation. Underground bottoms are generally constructed in line with vertical barriers. The second and the third barrier types are used when waste is immobilized and disposed of below ground surface. It is planned to transform Ignalina NPP bituminized waste storage, that is constructed above earth surface, into a repository by construction of surface engineered barriers. Construction of surface engineered barriers is a well-analysed and widely used method of isolating radioactive waste from the environment in global practice.

1.4 Stages of Activity and Implementation Period of Proposed Economic Activity

During the implementation of the proposed economic activity, the conversion of the bituminized radioactive waste storage facility of Ignalina NPP into a repository will be carried out in stages, which will include the preparation of the storage facility for reconstruction, the installation of engineered barrier structures, the formation of the engineered barrier (multilayer cap) and institutional control period. The following activity stages and their implementation periods are identified:

1) Filling in all the unfilled canyons of the Storage Facility (preliminary term 2028 – 2029).
2) Dismantling of the second floor of the Storage Facility (preliminary term 2028 – 2029).
3) Covering of all flooring and exterior walls of the Storage Facility with waterproofing material (preliminary term 2028 – 2029).
4) Conservation and maintenance of the Storage Facility (preliminary term 2029 – 2039).
5) Installation of engineered barrier supports of future Repository on the flooring of building 158 (preliminary term 2039 – 2040).
6) Installation of engineered barrier of the Repository (preliminary term 2039 – 2040).

7) Period after Repository closure, i.e. institutional control period (100 years – active control and 200 years – passive).

Before the installation of engineered barriers of the Repository (Stage 6) the nearby buildings 150, 151, 156 and 158/2 must be dismantled (see Figure 1.3). The dismantling of these adjacent buildings will be carried out in accordance with the "Final decommissioning plan" [8] of Ignalina NPP, which foresees that these buildings 150, 151, 156 will be demolished by 2037. The dismantling of building 158/2, which is currently used for the storage of cemented liquid radioactive waste and is planned for temporary storage of the graphite waste that will be generated during the dismantling of reactor channels, will only be able to commence when all cemented radioactive waste has been transferred to the low and intermediate level radioactive waste near-surface disposal facility (it is expected that such a disposal facility will be commissioned in 2028-2029) and the graphite has been transferred to another storage or disposal facility. The presence of adjacent buildings does not affect the implementation of Stages 1–5 of the proposed economic activity, however the beginning of the implementation of Stage 6 directly depends on the dismantling of the adjacent buildings and may be later than tentatively planned. According to EIA Program of Ignalina NPP Decommissioning [9], the environmental impact assessment of the dismantling of buildings (150, 151, 156 and 158/2) will be presented in the Ignalina NPP decommissioning EIA report, therefore their environmental impacts are not assessed in the EIA report of this proposed economic activity.

Since the Stage 6 of the proposed economic activity is expected to start no earlier than after 15 years, during this entire period the necessary repair work of the storage facility (building 158), maintenance of required technical state, environmental monitoring, periodic safety assessment will be carried out.

1.5 Demand for Resources and Materials

The required amounts of materials and resources depends on the stage of EIA implementation (see section 1.4). The greatest need for them will be during the installation of the support structure for the repository engineering barrier on the roof of the building 158 and during the formation of the multilayer cap (Stages 5 and 6). The preliminary quantities of materials required for the installation of the engineering barrier (cap) of the repository are presented in Table 1.1. The quantities presented in Table 1.1 are preliminary and will be specified during the preparation of the Technical Project. The amount of electricity required for PEA will be supplied from the 0.4 kV power distribution networks of Ignalina NPP. Vehicles and construction equipment, that will be supplied with diesel fuel from external sources, will be used for the removal and transportation of the 2nd floor dismantling waste, transportation of installation materials for the engineering barrier components, and the formation of the cap.

It should be noted that even after the finishing Ignalina NPP decommissioning activities (planned in 2038), the interim storage facilities of the spent nuclear fuel of the Ignalina NPP will be in operation (until ~2065), institutional control of the near surface repositories for the very low-level radioactive waste and for the low- and medium-level short-lived radioactive waste will continue until ~2140 and ~2330, respectively. Bituminized radioactive waste repository will be integrated into the infrastructure that is required for the operation of these facilities (environmental monitoring system, physical protection, fire safety system, engineering networks, access roads, offices, etc.).

Table 1.1. Components of the engineered barrier of the repository

Component	Purpose	Material	Thickness. m	Volume, m^3
Vegetation layer	Protects against climatic factors (freezing, defrosting, erosion). Protects against water infiltration.	Soil, plants	0.2	~ 4 800
Drainage layers	Protect against human and (or) animal intrusion.	Crushed stones, sandy gravel, dusty sand	0.8 m (crushed stones)	~ 19 000
	Remove water against its infiltration into repository.		0.6 m (sandy gravel)	~ 14 200
	Protect against direct radiation.		0.6 m (dusty sand)	~ 7 800
Protective layer against external impacts	Protects against human intrusion. Protects against water infiltration. Protects against direct radiation.	Moraine clay	0.7	~ 6 200
Drainage layer	Remove water and thus limiting the water flow through the insulating layer.	Gritty sand	0.3	~ 2 500
Insulating layer	Protects against human intrusion. Protects against water infiltration. Protects against direct radiation.	Clay	1.5 – 2.4	~ 17 500
Gas removal layer	Remove the gas if generated in the repository thus contributing to the integrity of the facility.	Sand	0.2	~ 1 200
Reinforced concrete layer	Protects against human intrusion. Protects against water infiltration. Protects against direct irradiation	Concrete	0.2	~ 1 200
Supporting metallic constructions (H-beams HEB1000B)	Even distribution of the mass of the layers installed above over walls of the canyons. Contribution to the integrity of the facility.	Steel	1.0 (height)	~73
Hydro isolation layer	Protect against moisture.	Waterproof material of the high density	-	~ 7500 m^2
Side slopes	Protect against human intrusion. Protect against water infiltration.	Local ground	0.01 - 11	~ 100 000

Component	Purpose	Material	Thickness. m	Volume, m^3
	Contribution to the integrity of the facility.			
	Protect against direct irradiation.			

1.6 Potential sources of environmental pollution

The potential sources of environmental pollution of the proposed economic activity are summarized in Table 1.2.

Table 1.2. Potential environmental pollution related to the planned economic activity

Type of pollution	Source of pollution	Remarks
Ionizing radiation	Additional ionizing radiation is possible due to: - direct (external) exposure from radioactive waste in building 158; - the penetration of radionuclides through the barriers of the Repository and migration to the environmental water; - in case of inadvertent intrusion into the Repository; - from NFs located at neighbourhood of the Repository site.	Values of the exposure dose to a member of the reference group of the population will be compared to the design criterion 0.1 mSv per year (see section 2.2) set for the planned repository and which is less then effective dose constraint of 0.2 mSv/year defined in Lithuanian hygiene standard [6] for the population during operation and decommissioning period of nuclear facilities. The value of the design criterion is set taking into account the fact that in addition to the bituminized radioactive waste repository, other nuclear facilities are (or will be) in operation at the site of Ignalina NPP. According to Lithuanian hygiene standard [6] when estimating the 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 analysed reference group. Therefore, the exposure of the member of reference group must be distributed in such a way that the total annual dose caused by all nuclear facilities cannot exceed the dose constraint. 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 [7].

Type of pollution	Source of pollution	Remarks
Non-ionizing radiation	Significant impact of pollution of such type to environmental components during the reconstruction and transformation of building 158 into a Repository is not expected.	–
Noise	Significant impact of pollution of such type to environmental components during the reconstruction and transformation of building 158 into a Repository is not expected.	–
Biological pollution	Not expected.	Small-scale controllable pollution is possible due to the release of treated domestic sewage into the environment.
Other pollution of environmental components	Significant impact of pollution of such type to environmental components during the reconstruction and transformation of building 158 into a Repository is not expected.	Possible air pollution from mobile sources during the reconstruction and transformation of building 158 into a Repository. Minor environmental pollution is possible due to fuel leaks from vehicles and other mechanisms and storage of construction materials.

Thus, the main source of pollution of the proposed economic activity, whose impact on environmental components is assessed in detail in the EIA report, is the radioactive waste located in building 158.

1.6.1 Radioactive waste in building 158

After the transformation of building 158 into a Repository, the bituminised RAW (i.e. the waste already loaded in the nine canyons) will be disposed of and in the remaining three empty ones (canyons 7-9, see Figure 1.4) it is intended to place inert materials (e.g., sand; the final decision will be made during the preparation of the Technical Project) whose density would be close to the density of bituminised RAW, thus providing more even loading to the building structures and reducing the negative effects of residual moisture. In the absence of a final decision, the disposal of other radioactive waste or inert materials in the empty canyons is not considered.

1.6.2 Bituminised radioactive waste

In compliance with the waste classification system [4] bituminised radioactive waste is attributed to solid radioactive waste of classes B and C [8], i.e. to short-lived low and intermediate level radioactive waste. In accordance to requirements on radioactive waste management [4] RAW of classes B and C should be disposed in the near surface repository. It is conservatively assumed that bituminised radioactive waste from decommissioning will be class C waste.

Physical properties of bituminised RAW are provided in Table 1.3.

Table 1.3. Physical properties of bituminised RAW [11]

Parameter, units	Value
Salt fraction (mass proportion) in waste, %	35 – 45
Moisture content, %	0,5 – 2 (1 [a)])
Density, kg/m^3	1 155 – 1 215
Working (transportation) temperature, °C	100 – 129
Ignition temperature, °C, above	200 [a)]
Combustion temperature, °C, above	250 [a)]
Self-ignition temperature, °C, above	400 [a)]
Working pressure, kg/cm^2	1 – 2

[a)]– According to requirements from document [12].

Bitumen is considered to have favourable chemical and physical properties to act as a fixation material for radioactive waste. The diffusion of radionuclides in bitumen is insignificant and the diffusion of water vapour in bitumen is also slow. However, during interim storage and subsequent disposal bitumen’s properties may change. This may influence the behaviour of the bitumen matrix, or other barriers in a repository, that has to be considered in a safety assessment. Processes that are usually studied are: radiolytic effects, biodegradation, ageing, water uptake, leaching, gas generation.

Waste quantities in canyons with respected to loading periods are presented in Table 1.4. In the period of 1987 – 2015 approximately 14 422 m^3 bituminised RAW were loaded in the storage facility.

Table 1.4. Canyon (see Figure 1.4) filling process flow and quantities of waste [13]

Canyon No.	Filling period	Volume, m^3	Mass, kg
1	1987 – 1989	1 963	2.34E+06
2	1989 – 1990	2 054	2.47E+06
12	1991	844	1.01E+06
3	1992 – 1994	1 964	2.36E+06
4	1994 – 1996	1 745	2.09E+06
5	1996 – 2001	2 002	2.40E+06
6	2001 – 2006	1 862	2.25E+06
10	2007 – 2014	1 950	2.34E+06
11	2015	38	3.96E+04
	Total:	**~14 422 [1)]**	**1.73E+07**
[1)] Bitumen volume of top and bottom protective layers is included.			

Data on the radionuclide composition and their activities in bituminised RAW according to information provided in [13–16], is presented in Table 1.5. It is shown in the table that total activity of wastes in year 2019 is mostly determined by the ^{137}Cs activity (2.85E+14 Bq). For the conservative assessment of the radiological impact, it has been assumed that the reconstruction activities of the storage facility will start on January 1, 2025, by this date the activity of ^{137}Cs due to radioactive decay will decrease to 2.52E+14 Bq. The actual start of the reconstruction may be 3–4 years later than conservatively assumed, then due to radioactive decay the activity of bituminised RAW, as well as radiological impacts, will be only lower.

Table 1.5. Activities of bituminised waste in the planned repository

Radionuclide	**Total activity, Bq**			
	Estimated for 01-09-2019	**Estimated for 01-01-2025** (start of re-construction*)	**Estimated for 01-01-2125** (after completion of the active institutional control*)	**Estimated for 01-01-2325** (after completion of the passive institutional control*)
^{14}C	4.18E+12	4.18E+12	4.13E+12	4.03E+12
^{36}Cl	4.85E+09	4.85E+09	4.85E+09	4.84E+09
^{55}Fe	4.72E+11	1.20E+11	8.52E-01	4.29E-23
^{60}Co	2.02E+12	1.00E+12	1.94E+06	7.30E-06
^{59}Ni	3.63E+09	3.63E+09	3.62E+09	3.62E+09
^{63}Ni	5.93E+12	5.70E+12	2.77E+12	6.54E+11
^{90}Sr	1.23E+11	1.08E+11	1.00E+10	8.55E+07
^{94}Nb	2.54E+10	2.54E+10	2.53E+10	2.52E+10
^{99}Tc	1.15E+11	1.15E+11	1.15E+11	1.15E+11
^{129}I	1.87E+08	1.87E+08	1.87E+08	1.87E+08
^{134}Cs	3.91E+12	6.50E+11	1.58E-03	9.41E-33
^{137}Cs	2.85E+14	2.52E+14	2.50E+13	2.46E+11
^{234}U	1.03E+06	1.03E+06	1.03E+06	1.03E+06
^{235}U	2.49E+04	2.49E+04	2.49E+04	2.49E+04
^{238}U	3.02E+05	3.02E+05	3.02E+05	3.02E+05
^{237}Np	4.06E+04	4.06E+04	4.06E+04	4.06E+04
^{238}Pu	1.59E+08	1.53E+08	6.92E+07	1.42E+07
^{239}Pu	1.45E+08	1.45E+08	1.45E+08	1.44E+08
^{240}Pu	1.83E+08	1.83E+08	1.81E+08	1.77E+08
^{241}Pu	1.11E+10	8.60E+09	6.98E+07	4.60E+03

Radionuclide	Total activity, Bq			
	Estimated for 01-09-2019	**Estimated for 01-01-2025** (start of re-construction*)	**Estimated for 01-01-2125** (after completion of the active institutional control*)	**Estimated for 01-01-2325** (after completion of the passive institutional control*)
^{241}Am	3.48E+08	3.45E+08	2.94E+08	2.13E+08
Suma:	**3.02E+14**	**2.64E+14**	3.21E+13	5.08E+12

* – Radionuclide activities have been conservatively estimated by assuming earlier dates for the implementation of the PEA stage, e.g. the actual start of the reconstruction may be 3-4 years later, active and passive institutional control may be longer, but radionuclide activities and radiological impacts would then be lower.

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.

1.7 Site Status and Area Planning Documentation

Municipal administration of Visaginas city by order No. ĮV-460 “On the approval of the detailed plan” dated May 19, 2010, 25 plots of land were formed by the detailed plan of the land plots of State Enterprise Ignalina NPP (cadastral No. 4535/0002:5 and 4535/0003:2) located in the village of Drukšiniai in the municipality of Visaginas. 12 plots of land with a total area of 419.1762 ha were assigned for the use of the Ignalina NPP (see Figure 1.5). Other land plots were transferred to JSC “Visaginas AE” and PLLC “Lietuvos Energija”, 2 plots were returned to the State Free Land Fund. Building 158 is located within the industrial area that belongs to State Enterprise Ignalina NPP

The main purpose of the plan change is optimization of land use. Changes in the new version of the detailed plan did not affect the status of the Ignalina NPP industrial area. During the proposed economic activity, the land will be used for its intended purpose.

1.8 Graphic information

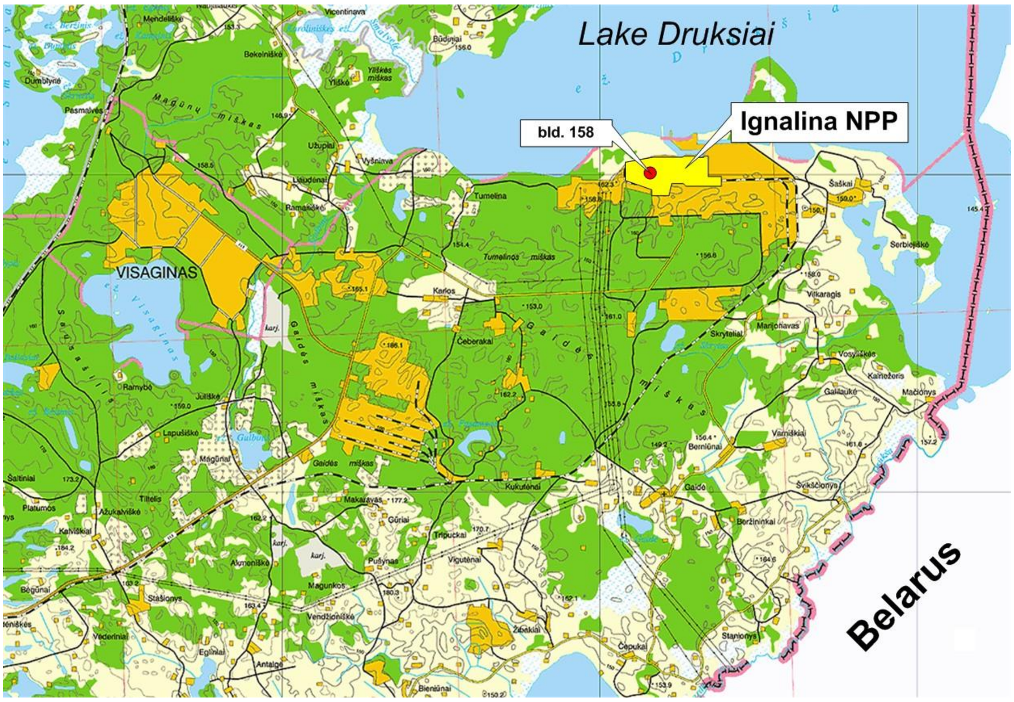


Figure 1.1. Location of bld.158 at the Ignalina NPP area

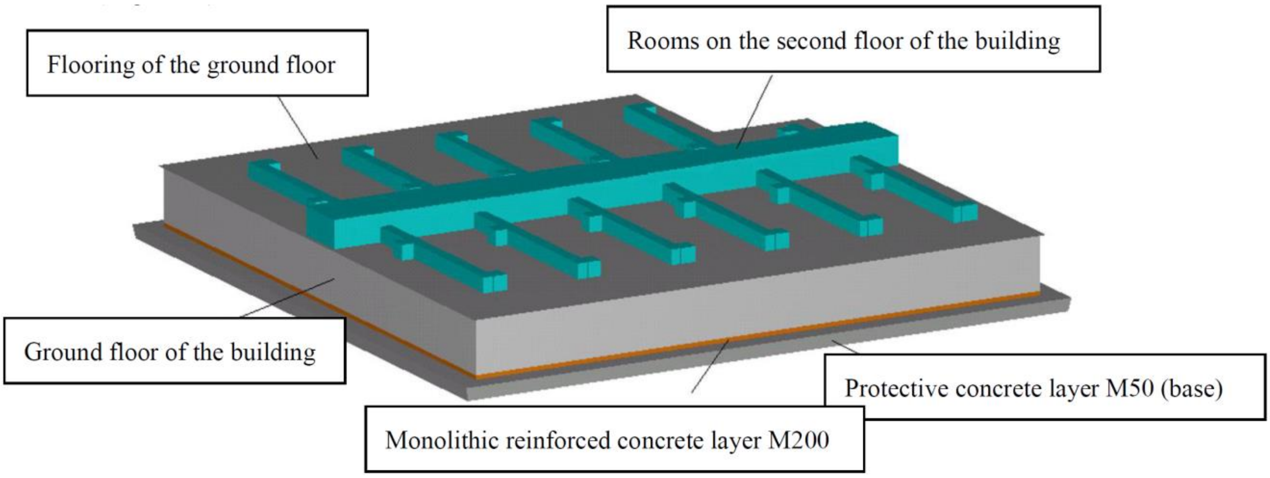


Figure 1.2. Simplified view of Ignalina NPP building 158

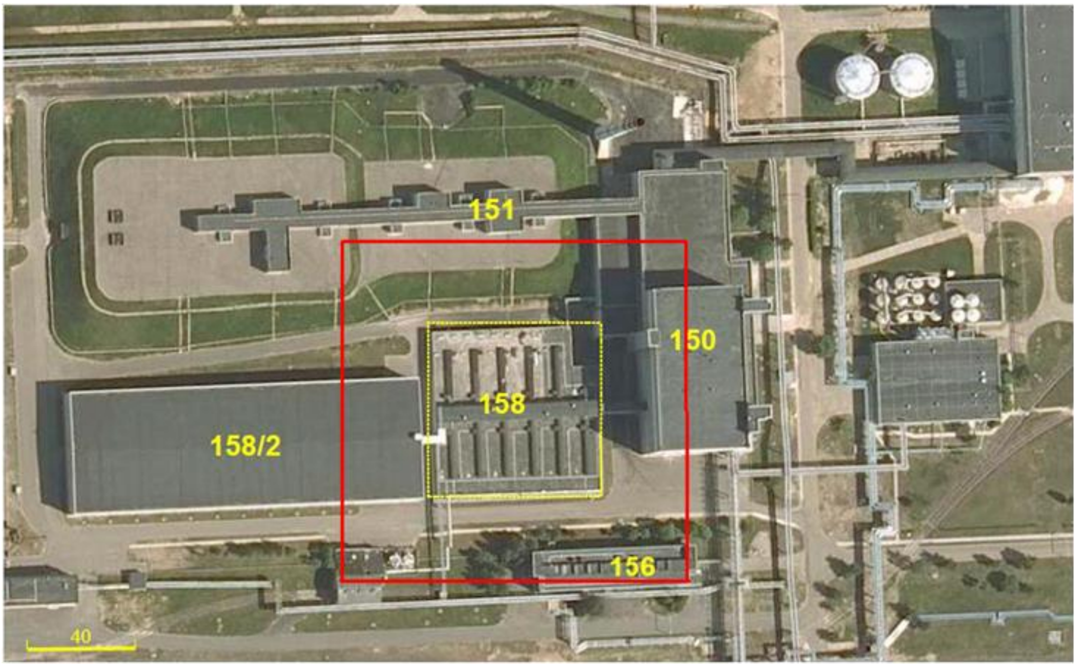


Figure 1.3. Reconstruction of building 158 (bituminised radioactive waste storage facility) into the repository. The red line marks the 36 m wide area around the building, which will be used for the engineered barrier (multilayer cap)

bld. 150 – liquid radioactive waste treatment and bituminization facility; **bld. 151** – drainage water collection tanks; **bld. 156** – special washhouse; **bld. 158** – bituminized radioactive waste storage; **bld. 158/2** – interim storage facility for cemented RAW.

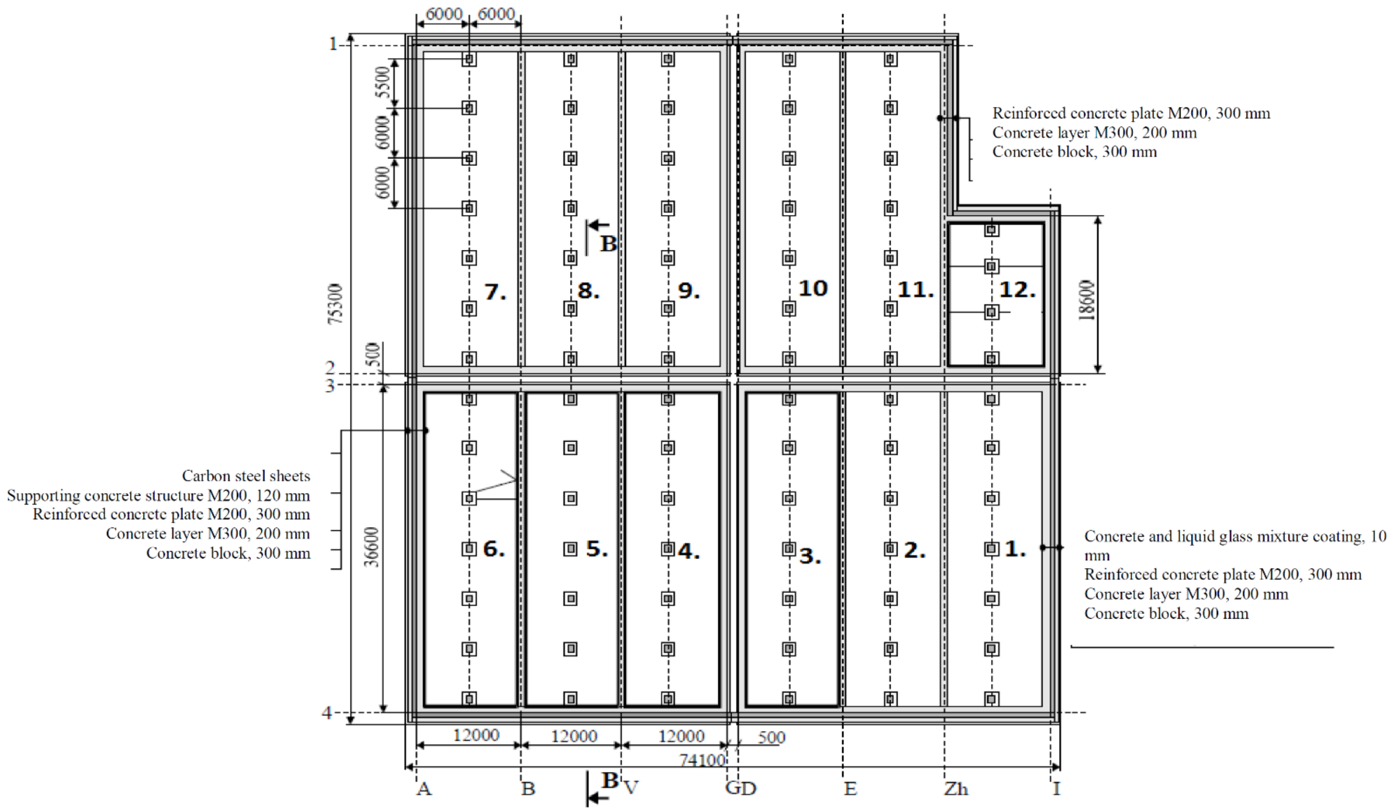


Figure 1.4. Layout of canyons of bld. 158

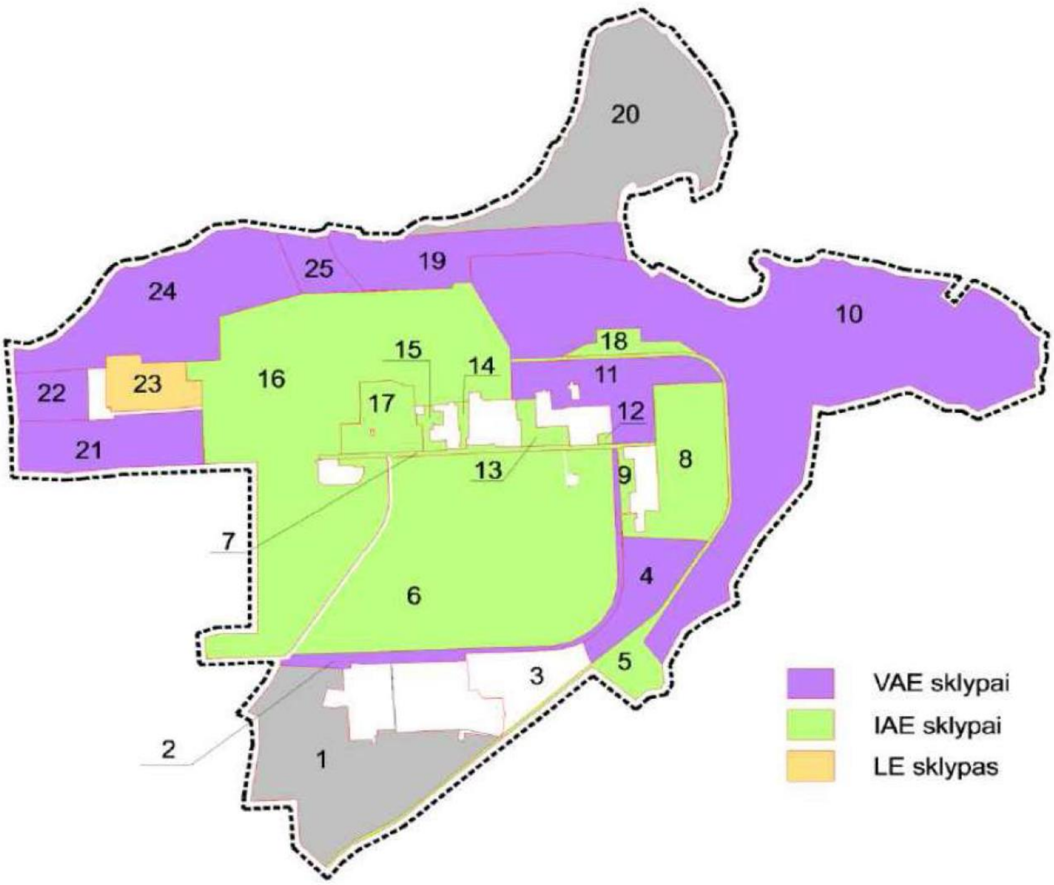


Figure 1.5. Newly formed plots of land and their distribution according to dependence, based on the 2010 version of the detailed plan (“VAE sklypai” – plots of Visaginas NPP land; “IAE sklypai” – plots of Ignalina NPP land; “LE sklypas” – plot of Lithuanian Energy land)

2 MAIN EQUIPMENT AND TECHNOLOGICAL PROCESSES

During the proposed economic activity, it is planned to reconstruct and transform Ignalina NPP storage facility (building 158) of bituminised radioactive waste into repository – i.e. implement waste disposal *in situ* approach [24]. It should be noted that bituminized waste loaded in building 158 is biologically and mechanically stable and, except for the impact (load) to the soil, settlement or other movements, causing hazard to safety of storage engineered barriers, are not likely.

Main objectives for installation of surface barriers are the following:

- Limiting surface moisture (rain, melting snow, etc.) infiltration to the repository and at the same time minimizing solving of waste and waterborne spread of radionuclides;
- Protection against direct contact with potential recipients (human, fauna, flora);
- Control of gas releases that may be generated in waste.

Surface barriers of one-layered or multilayer type may be installed. Construction and materials are selected according to requirements raised to lifetime of repository and functioning of barriers. They may vary to different countries, however, the main requirement is the same everywhere, while waste causes hazard, operation of the barriers should be reliable and adequate. Depending on structure of engineered barriers and type of disposed waste, due to possible settlement, erosion, climatic factors, and deep-rooted plants or intrusion of burrowing animals, during institutional control period of the repository it is required to periodically check the state of surface barriers.

Barriers of one-layered structure are mainly used as a temporary means for interim waste isolation, while the decision about their final disposal is made. In this case soil, asphalt, concrete or synthetic materials may be used for formation of one-layered hill. Clay used for multilayer structures is not suitable in this case, because during under the influence of temperature (cold/heat) and humidity (rain/draught) changes it cracks and loses its hydro-isolation properties.

Barriers with multilayer structure are installed when it is planned to dispose of long-lived waste that needs to be isolated from environment. In this case barriers have to withstand erosion for hundred years or for a longer period and not to lose their hydro-isolating qualities.

In general, a multilayer structure comprises three main layers: upper layer, drainage layer, and low permeable bottom layer. Every mentioned layer may be composed of a variety of components. Upper level generally consists of soil and plants. Drainage layer is formed of sand and small-grained gravel. Low-permeable bottom layer may be formed of synthetic (geomembrane from PVC, low or high density polythene, and etc.) or natural compacted material (clay). If gaseous releases are expected from disposed RAW, then between low-permeable layer and waste a high-permeability layer (similar to that of drainage) is laid to provide a vent for gas from the repository. The necessity of other additional layers is determined by waste characteristics, site peculiarities, and requirements for functioning of surface engineered barriers.

Depending on the properties of material used and requirements applied to repository design, surface barriers are mainly formed as dome-type installations or hills with lower inclination.

The possibilities of transforming the bituminised radioactive waste storage facility at Ignalina NPP into a repository have been evaluated since 2007, when a feasibility study for transforming the storage facility into a repository was prepared [25]. Later, an IAEA expert mission was organised in 2015 to assess the feasibility of converting the storage facility into a repository, and in 2019-2022 the conceptual design of a repository [10] was prepared, the safety justification of the repository concept [16] and an evaluation of the repository site [17] were performed. Taking into account the characteristics of the bituminised radioactive waste and the features of the site, the conceptual design of a repository [10] considers possible technical solutions for the installation of engineered barriers during the transformation of building 158 into a repository. Engineered barriers of different thicknesses and layers were also analysed taking into account the peculiarities of the constructions of the building 158, the possible loads of engineered barriers, the requirements for ensuring radiation safety, and the external impacts of the environment. It was determined that the optimal option for the transformation of building 158 into a repository would be to install steel-reinforced concrete structures on the reinforced concrete upper cover of building 158 (the general view is shown in Figure 2.1), which would support the 5.8 m thick engineering barrier (multilayer cap) installed above the building.

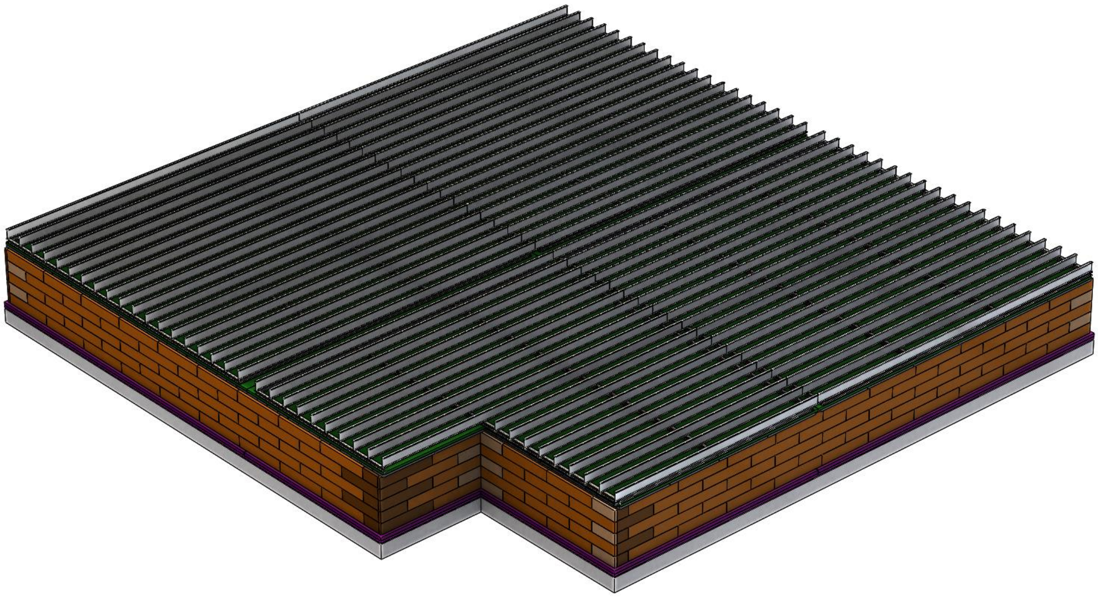


Figure 2.1. Transformation of the Storage Facility (building 158) into the Repository: general view of the metal support structure supporting 5.8 m thick engineering barrier [10]

Soil layers of different purposes and properties would be poured layer by layer on the above-mentioned supporting structures and an engineering barrier would be formed by compacting them (the structure of the multilayer cap is shown in Figure 2.2). After construction of surface engineered barriers, it is foreseen to install a drainage system at the repository site, designed for groundwater drainage as well as monitoring and equipment for repository radiation control. Composition and functions of the engineering barrier (see Figure 2.2) are as follows:

- 1 – Gas removal layer (sand layer). Designed for the removal of moisture that has penetrated surface engineering barriers or discharge of gases, since the possibility of gas release from bituminised waste cannot be completely excluded. The layer shall be formed with the required slope to ensure proper water drainage. Layer thickness – 20 cm;
- 2 – Insulating clay layer. It is a waterproofing layer of the repository made of natural material. It shall protect the repository from moisture ingress. Layer thickness from 2.4 m along the centre of the storage facility to 1.5 m along the perimeter;
- 3 – Drainage layer for water removal. Drainage layer shall be formed of gritty sand. Layer thickness – 30 cm.;
- 4 – The protective layer is designed to protect against external actions, such as human intrusion, water infiltration. The protective layer would consist of moraine clay. Layer thickness – 70 cm.;

- 5-7 – Drainage layers for water removal. The layers are also intended for protection against intrusion of humans and / or animals. The drainage layer would consist of crushed stone (thickness of 80 cm), sandy gravel (thickness of 60 cm) and dusty sand (thickness of 60 cm). The total thickness of the drainage layers is 2 m.;
- 8 – Vegetation layer. The vegetation layer is designed to protect against climatic factors such as freezing, thawing and erosion. The vegetation layer would consist of soil and plants. Vegetation layer – 20 cm.

Before the installation of the engineering barrier, the 2nd floor of building 158 will be dismantled after the project has been prepared and permission for dismantling has been obtained. A more detailed description of the dismantling works of the 2nd floor of the building 158 will be provided in the Technical Design for the procurement of services for the preparation of the Design Documents for Reconstruction of Ignalina NPP Bituminised Radioactive Waste Storage Facility and its Conversion into the Repository [14]. Once the 2nd floor of building 158 is removed, all storage flooring and exterior walls will be covered with a waterproofing coating (e.g., chemical coating for waterproofing, protection and repair of concrete). Taking into account that the dismantling of buildings 150, 151, 156 and 158/2 that are located near the Bituminised Radioactive Waste Storage Facility may last until 2037, building 158 will be preserved and an inspection of the storage structures will be carried out every 2 years, an assessment of the technical condition of the building and, if necessary, the required repair works will be performed.

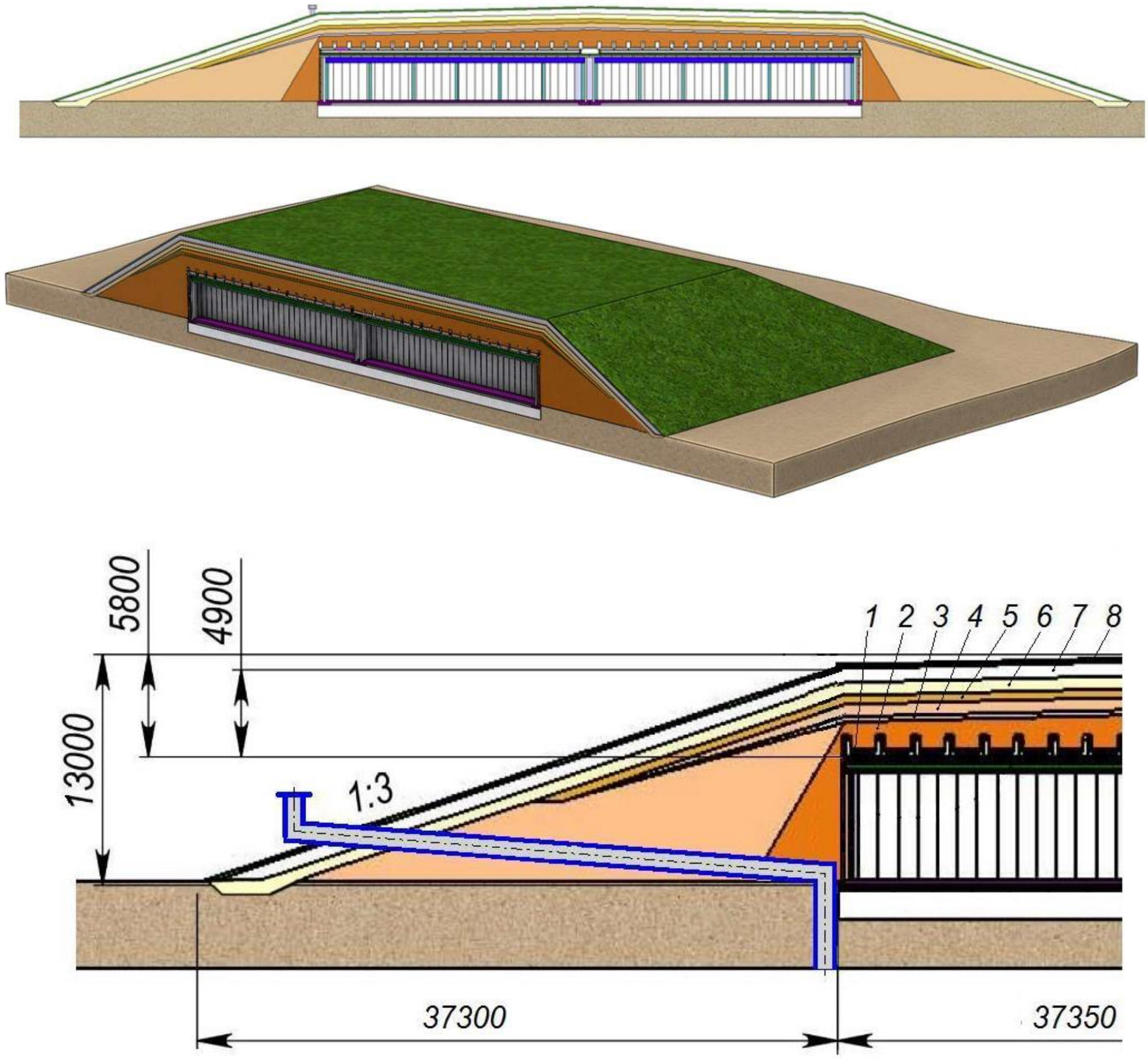


Figure 2.2. Images and composition (cross-section) of the 5.8 m thick engineered barrier after transformation of the storage facility (bld. 158) into the repository:
1 – drainage layer (0.2 m of sand); 2 – insulating clay layer (1.5 – 2.4 m); 3 – drainage layer (0.3 m of gravelly sand); 4 – protective 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 [10]

3 WASTE GENERATION AND MANAGEMENT

During the proposed economic activity, waste will be generated during the dismantling of the construction and communication structures of the 2^{nd} floor of building 158 and the removal of unnecessary roof layers. The generated construction waste will be sorted, characterized and, depending on its activity, managed according to waste management requirements [4].

It has been preliminarily estimated that the following amounts of waste will be generated during various dismantling works of the 2^{nd} floor:

- After dismantling brick walls (by extracting bricks) – 630 m^3;
- After dismantling the walls from small blocks – 630 m^3;
- After dismantling monolithic reinforced concrete partitions – 465 m^3;
- After dismantling pipelines – 80 tons;
- After dismantling the frames – 120 tons;
- After dismantling the equipment – 25 tons.

Ignalina NPP (the organizer of the proposed economic activity) strives to convert the waste generated during any decommissioning project into secondary raw materials as much as possible. This PEA is not an exception, the generated waste as much as possible will be to convert into secondary raw materials or reusable materials.

4 COMPONENTS OF THE ENVIRONMENT THAT MAY BE IMPACTED BY PROPOSED ECONOMIC ACTIVITY

4.1 Water

4.1.1 Overview of Hydrological and Hydrogeologic Conditions

Building 158 is located at the distance about 600 m south from the Lake Drūkšiai. The Lake Drūkšiai is the biggest lake in Lithuania; its hydrographical watershed scheme is shown in Figure 4.1. 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 [26].

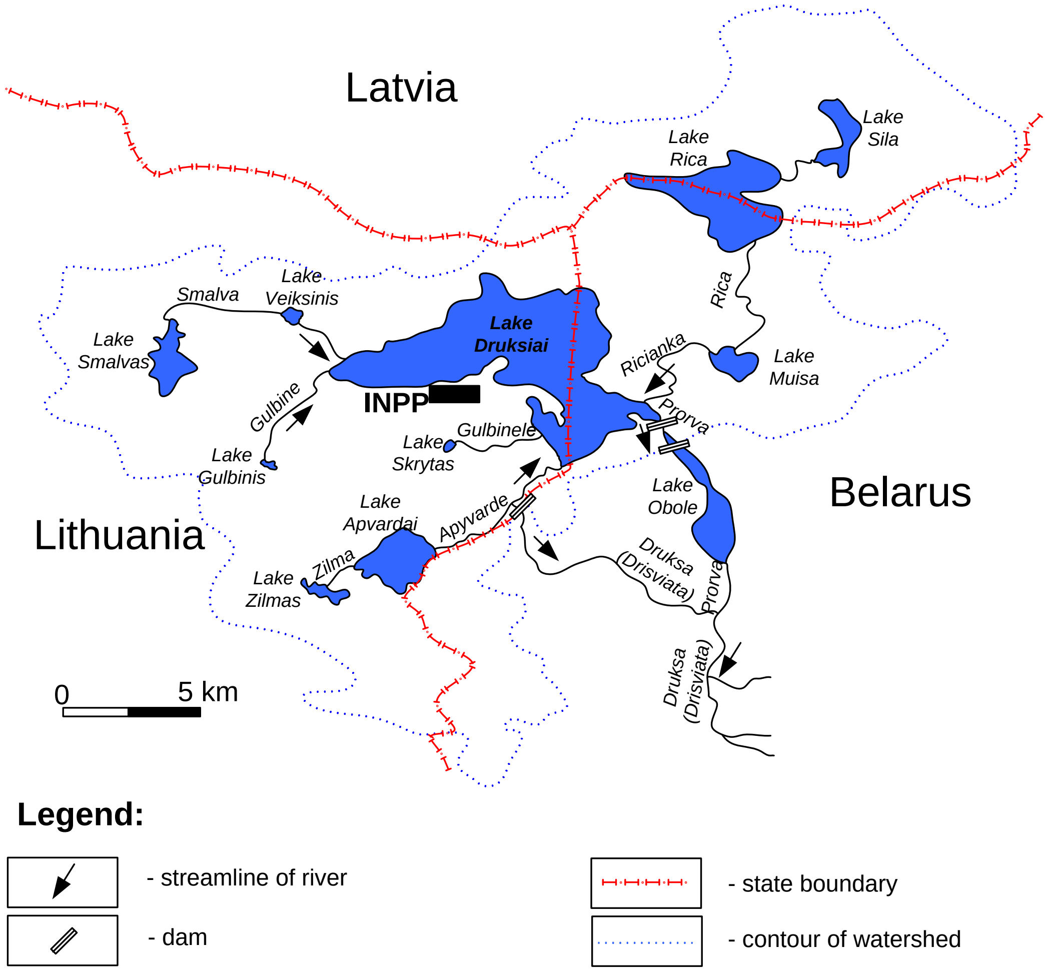


Figure 4.1. Hydrographical scheme of Lake Drūkšiai watershed [26]

There are 11 tributaries to the Lake Drūkšiai and 1 river that outflows it (the Prorva). Main rivers that flow into Lake Drūkšiai are Ricianka (Ricia), Smalva, Apyvarde and Gulbine [26].

Nearly all surface discharge (74 %) flows to the south part of Lake Drūkšiai by way of the rivers Ricianka (Ricia) and Apyvarde. The rest of the surface discharge goes to the west ridge from the tributaries of the rivers Smalva and Gulbine. Discharge from the Lake Drūkšiai goes by way of the river Prorva through the south ridge of the lake. The summary of the main characteristics of Lake Drūkšiai is presented in Table 4.1 [26].

Table 4.1. Main characteristics of Lake Drūkšiai

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 Drūkšiai 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 Drūkšiai approx. 0.3 m to the current level of 141.6 m [26]. The probability of the water level rise to 143.5 m is below 2.12E-08 [26].

The area of the Lake Drūkšiai watershed, see Figure 4.1, 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 Drūkšiai is slow. Outflow is mainly through the River Prorva (99 %). Further the effluents from the Lake Drūkšiai through the long and rather complicated way of 550 km length reach Riga‘s bay in the Baltic sea [26].

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 Drūkšiai [26].

Active artesian wells in the INPP region presented in Figure 4.2, do not fall into direction of underground water flow from bld. 158 towards Lake Drūkšiai [26].

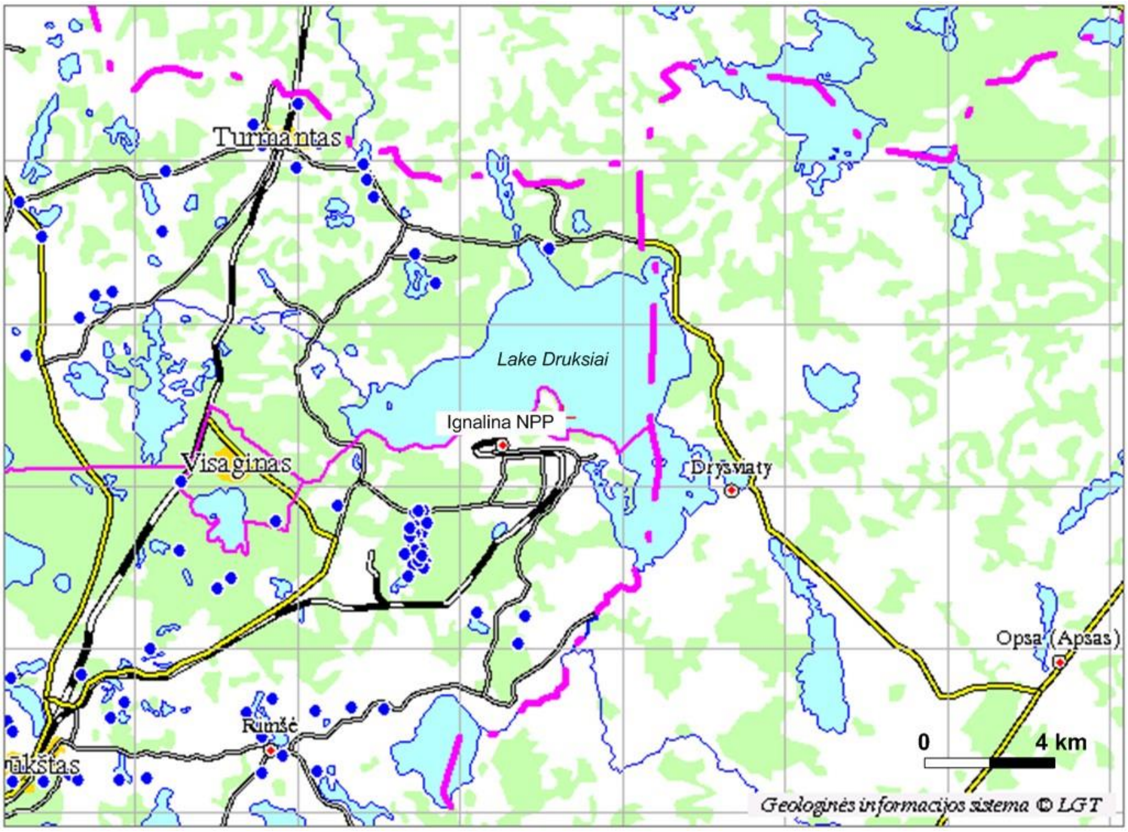


Figure 4.2. Active artesian wells (marked as blue circles) [26]

In the site of investigation there were drilled many boreholes of different purpose and correspondingly of different depths (Figure 4.3), 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 developed [27]. The data from up-to-date EGG investigations [27, Vol. 1] of wells (No. 1 and No. 3) installed next to the bld. 158 are used for developing of these above-mentioned cross-sections.

Figure 4.3. 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) [27]

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 [27].

To estimate the flow paths of radionuclides in the geosphere is used both, an available information from IGG investigations at the site as well as hydrogeological modelling results [27, Appendix 2]. Summarized available information on hydrogeological situation at the site and its vicinity as well as results obtained from hydrogeological modelling are enough to estimate the flow paths of radionuclides in the geosphere in a reliable way.

It is indicated in the report [27] that According to A–B profile (Figure 4.4), the first layer from the earth's surface is till deposits (gIIInm3): loam (borehole No. 47857 44.4 m thick), dusty (borehole No. 47860 – 1.8 m thick) and clayey and sandy loam (borehole No. 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 (Figure 4.4). In order to get additional information about hydrogeological situation next to the bld. 158 JSC “Geotestus” have installed two new hydrogeological wells [27, Vol. 1]. For development of the hydrogeological cross-sections next to the bld. 158 descriptions of new wells No. 3 and No.1, 15 m depth, have been used in addition to the data from the wells installed previously. The developed cross-sections are intercrossing beside the well No. 3 where the upper part of the section is composed of technogenic soil (tIV) (IGS1). The technogenic soil is found at the depth from 0.2 m to 6.2 m. Thus the layer of the technogenic soil is the deepest one in the well under consideration. According to the cross-section of well No. 3 below the technogenic soil layer and according to the cross-section of well No. 1 below the moraine layer (gIIInm3) (IGS2) there is the layer of sandy aquifer deposits (fIIInm3) (agIIIgr) (IGS3). 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 A-B, the top of the gIImd layer is at the 18.4–22 depth, and bottom at the 25–54.4 m depth [27].

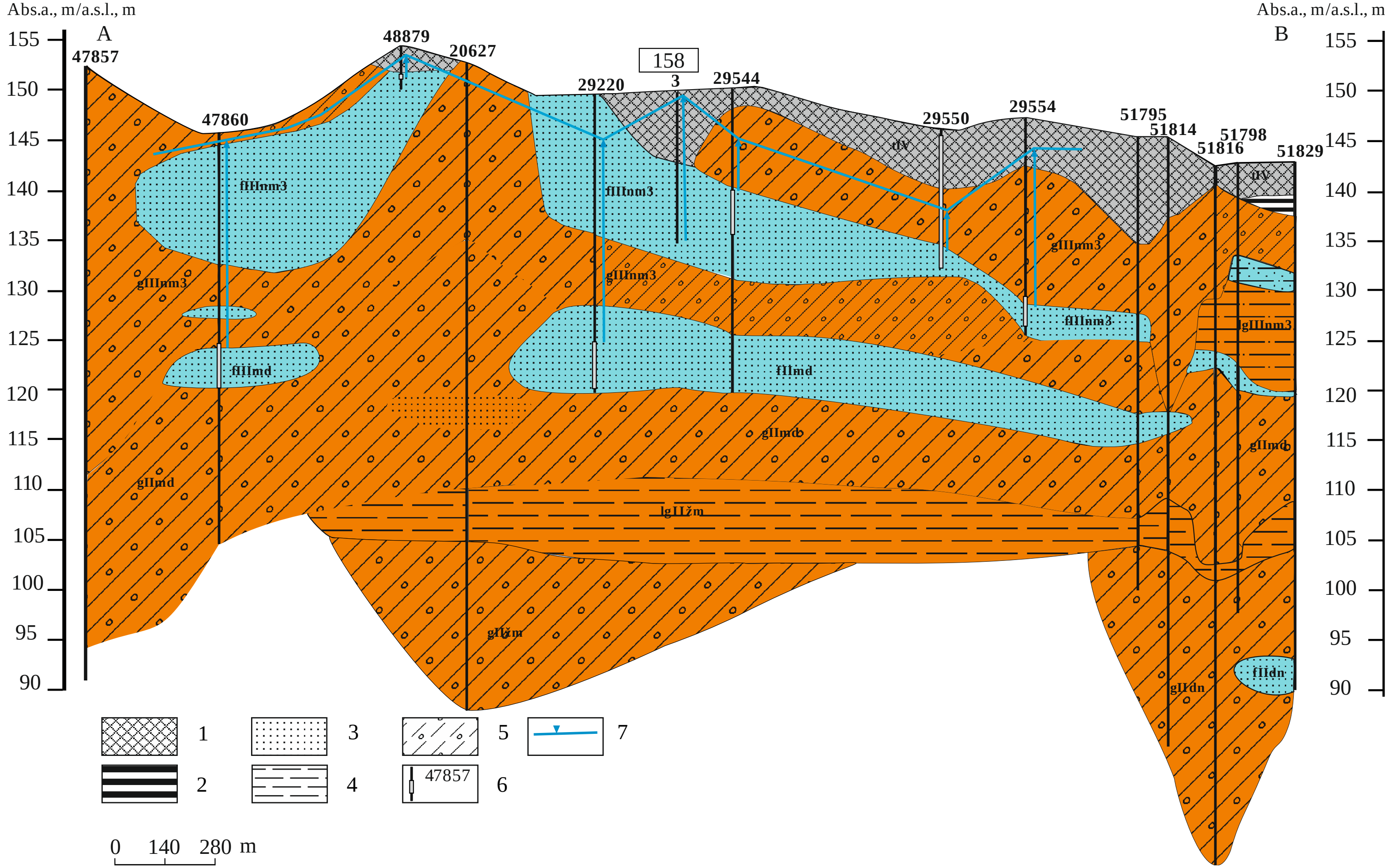


Figure 4.4. Hydrogeological cross section (blue aquifers; brown aquitards) according to line AB (see Figure 4.3) 1 – technogenic soil; 2 – bog sediments; 3 – various sand; 4 – clay; 5 – sandy loam, clayey loam; 6 – borehole number and filter interval; 7 – groundwater level [27]

Note: Two layers, i.e. technogenic soil (tIV) (IGS1) and sandy aquifer deposits (fIIInm3) (agIIIgr) (IGS3) composed of the dense fne sand with interlayers of medium coarse and dusty sand are detected next to the bld. 158 beside the well No. 3, 15 m depth.

According to the data provided in the report [27], Most boreholes of the C–D profile (Figure 4.5) 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 literatures [27].

The hydrogeological cross section C–D (Figure 4.5) 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 Drūkšiai [27].

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 [27].

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 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 [27].

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 [27].

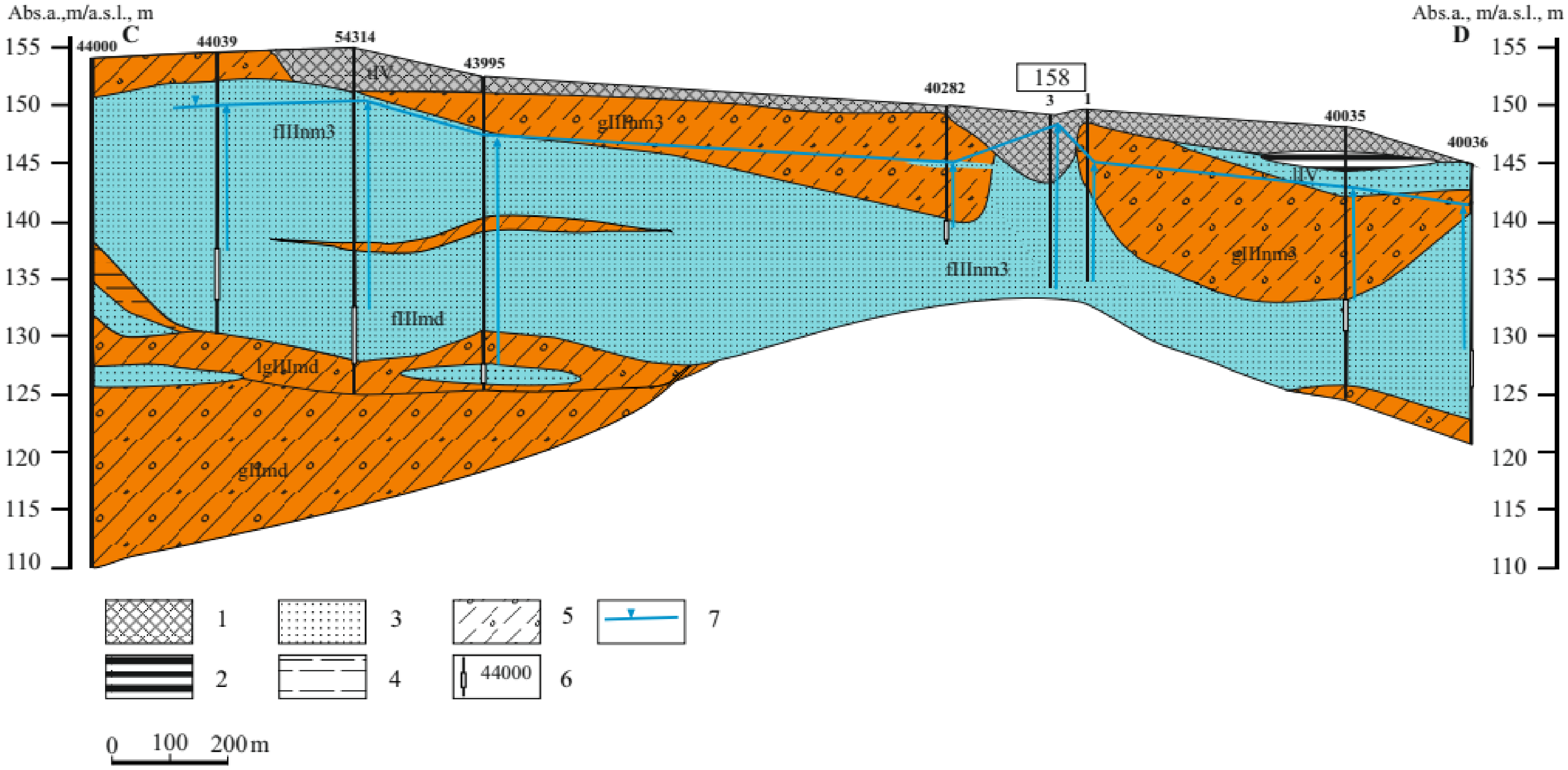


Figure 4.5. Hydrogeological cross section (blue aquifers; brown aquitards) according to line CD (see Figure 4.3) 1 – technogenic soil; 2 – bog sediments; 3 – various sand; 4 – clay; 5 – sandy loam, clayey loam; 6 – borehole number and filter interval; 7 – groundwater level [27]

Note: Two layers, i.e. technogenic soil (tIV) (IGS1) and sandy aquifer deposits (fIIInm3) (agIIIgr) (IGS3) composed of the dense fne sand with interlayers of medium coarse and dusty sand are detected next to the bld. 158 beside the well No. 3, 15 m depth. Three layers, technogenic soil (tIV) (IGS1), IGS2 – medium solid moraine fine-grained soil of low plasticity, with prevailing sandy dusty clay interlaying with sandy clay and sandy-clayey silt and sandy aquifer deposits (fIIInm3) (agIIIgr) (IGS3) composed of the dense fne sand with interlayers of medium coarse and dusty sand are detected next to the bld. 158 beside the well No. 1, 15 m depth.

It is stated in the report [27] that a groundwater level was observed at the depth of 3 – 5 m from the ground surface in the close vicinity of bld. 158 during period 2012 – 2018. The groundwater level of both layers decreased during quinquennium (2012 – 2016), a tendency of increase of the water level was observed in 2017 and decrease again in 2018. In general, a tendency of water level variations is corresponding to variations of annual amount of precipitation.

Ignalina NPP performs environmental monitoring and presents the results of measured radionuclides concentrations in various environmental components in its annual radiological monitoring reports. Water samples are taken and radionuclide concentrations are measured in the water of Lake Drūkšiai, in the discharge water of the Ignalina NPP, in drinking water, in the water of monitoring wells in the territory of the Ignalina NPP and in the Maišiagala radioactive waste storage site, in the water of the industrial rain sewers and industrial sewage of the Ignalina NPP territory. The total activity of radionuclides, mainly determined by Cs-137 and Co-60, in the released wastewater into Lake Drūkšiai in 2022 (including unbalanced waters) was $5.0 \cdot 10^{10}$ Bq/year (0.33% of the release limit, $1.50 \cdot 10^{13}$ Bq/year) [39]. Annual emissions of radionuclides from Ignalina NPP into Lake Drūkšiai during the decommissioning period (2010–2022) are presented in Figure 4.6.

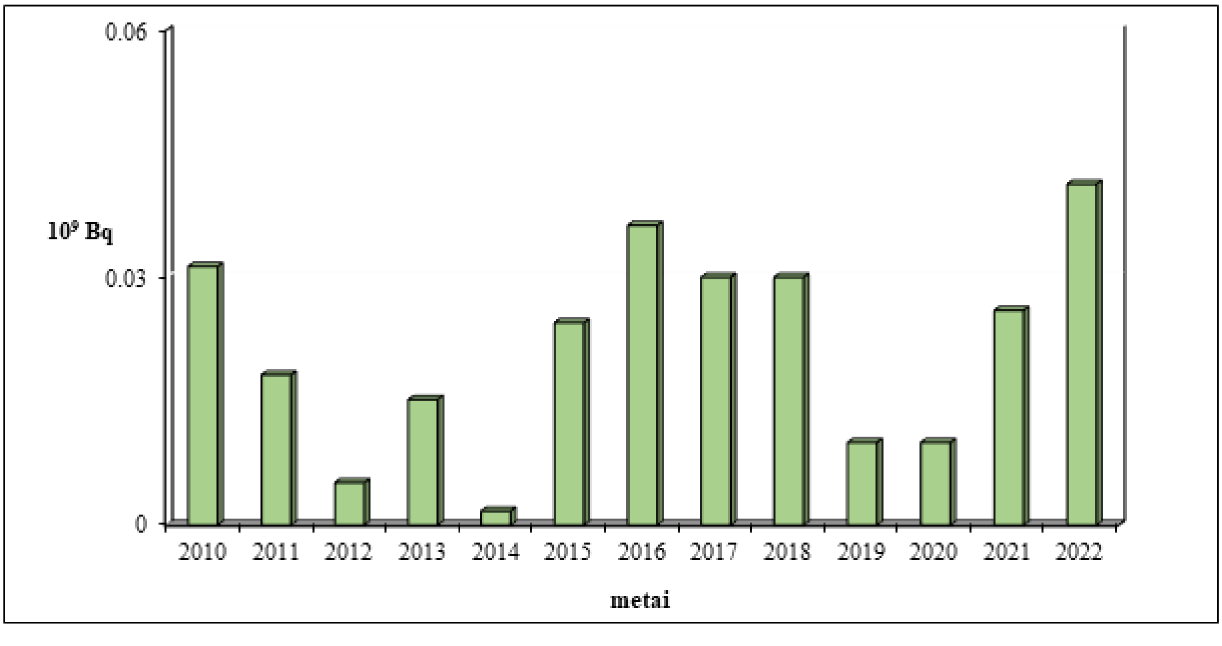


Figure 4.6. Release of radionuclides into Lake Drūkšiai with wastewater in 2010 – 2022

The groundwater monitoring network at the Ignalina NPP site consisted of 35 boreholes at the beginning of the operation of the power plant operation, and currently the network consists of 114 monitoring boreholes [28]. The two most recent monitoring boreholes No. 72399 and 72400, were drilled in 2019 in the vicinity of building 158, and all the groundwater monitoring wells in the vicinity of the bituminized radioactive waste storage facility are shown in Figure 4.7. Samples taken from the boreholes are subjected to a general chemical analysis of the water (specific conductivity, temperature, pH, oxygen concentration, total hardness, permanganate index, dry residue, major anions and cations, nitrogen compounds, petroleum product index, etc. are measured), concentrations of radionuclides (Cs-137, Co-60, Sr-90, H-3) and heavy and toxic metals (Al, Zn, Cu, Cr, Pb, Ni, Mn, Cd, Hg) are measured as well.

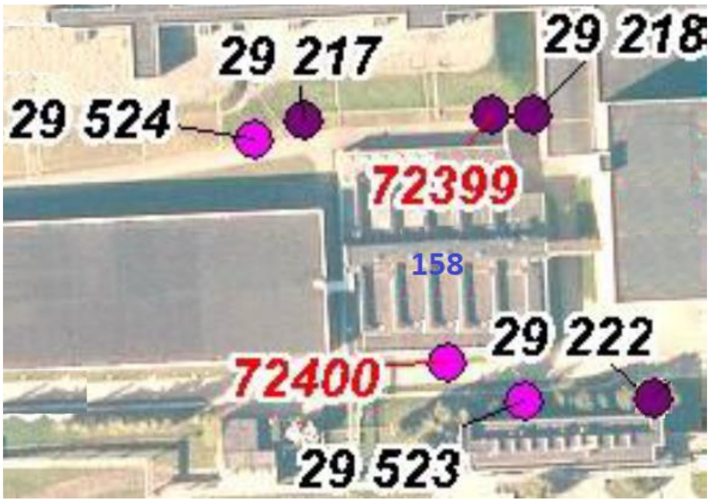


Figure 4.7. Groundwater monitoring boreholes adjacent to Building 158

As the main impact of the proposed economic activity will be radiological, information on the annual average concentrations of radionuclides measured in monitoring boreholes in the vicinity of building 158 between 2016 and 2022 is provided below (see Table 4.2). No gamma nuclides (Cs-137, Co-60) were detected in groundwater samples during all measurement periods (concentrations below the detection limit). The variation of tritium concentrations in water samples from these boreholes for the period 2004-2022 is presented in Figure 4.8.

Table 4.2. Radionuclide concentration (Bq/kg) in the water of monitoring boreholes adjacent to building 158 in 2016–2022.

	29523 (depth 10 m)		**29524** (depth 10 m)		**29217** (depth 30 m)		**29218** (depth 30 m)		**29222** (depth 30 m)		**72399*** (depth 12 m)		**72400*** (depth 12 m)	
	Sr-90	**H-3**	**Sr-90**	**H-3**	**Sr-90**	**H-3**	**Sr-90**	**H-3**	**Sr-90**	**H-3**	**Sr-90**	**H-3**	**Sr-90**	**H-3**
2016	0	0.78	$4.75 \cdot 10^{-3}$	128	$3.35 \cdot 10^{-3}$	21.6	$9.62 \cdot 10^{-4}$	17.4	0	3.57	-	-	-	-
2017	0	1.99	$3.47 \cdot 10^{-3}$	121	$2.07 \cdot 10^{-3}$	17.1	$3.45 \cdot 10^{-4}$	4.97	$1.04 \cdot 10^{-3}$	3.99	-	-	-	-
2018	0	0	$1.66 \cdot 10^{-3}$	15.7	$1.70 \cdot 10^{-3}$	10.3	$1.05 \cdot 10^{-3}$	3.37	0	0.48	-	-	-	-
2019	$4.27 \cdot 10^{-4}$	0.4	$9.10 \cdot 10^{-4}$	14.5	$4.39 \cdot 10^{-4}$	13.5	$9.89 \cdot 10^{-4}$	1.98	$8.50 \cdot 10^{-4}$	0	-	-	-	-
2020	$4.40 \cdot 10^{-4}$	0	$1.11 \cdot 10^{-3}$	29.4	0	14.6	$6.20 \cdot 10^{-4}$	0	$9.26 \cdot 10^{-4}$	20.8	-	-	-	-
2021	$1.36 \cdot 10^{-3}$	0	$2.05 \cdot 10^{-3}$	66.5	$1.18 \cdot 10^{-3}$	6.45	$7.79 \cdot 10^{-4}$	6.95	$9.56 \cdot 10^{-4}$	4.44	$8.38 \cdot 10^{-4}$	7.6	$1.25 \cdot 10^{-3}$	7.7
2022	$3.29 \cdot 10^{-4}$	0	$1.29 \cdot 10^{-3}$	41.4	$1.44 \cdot 10^{-3}$	11.3	$2.09 \cdot 10^{-4}$	0	$6.99 \cdot 10^{-4}$	0	$1.27 \cdot 10^{-2}$	8.1	$1.68 \cdot 10^{-2}$	9.0

* – new boreholes, radionuclide measurements are carried out from 2021.

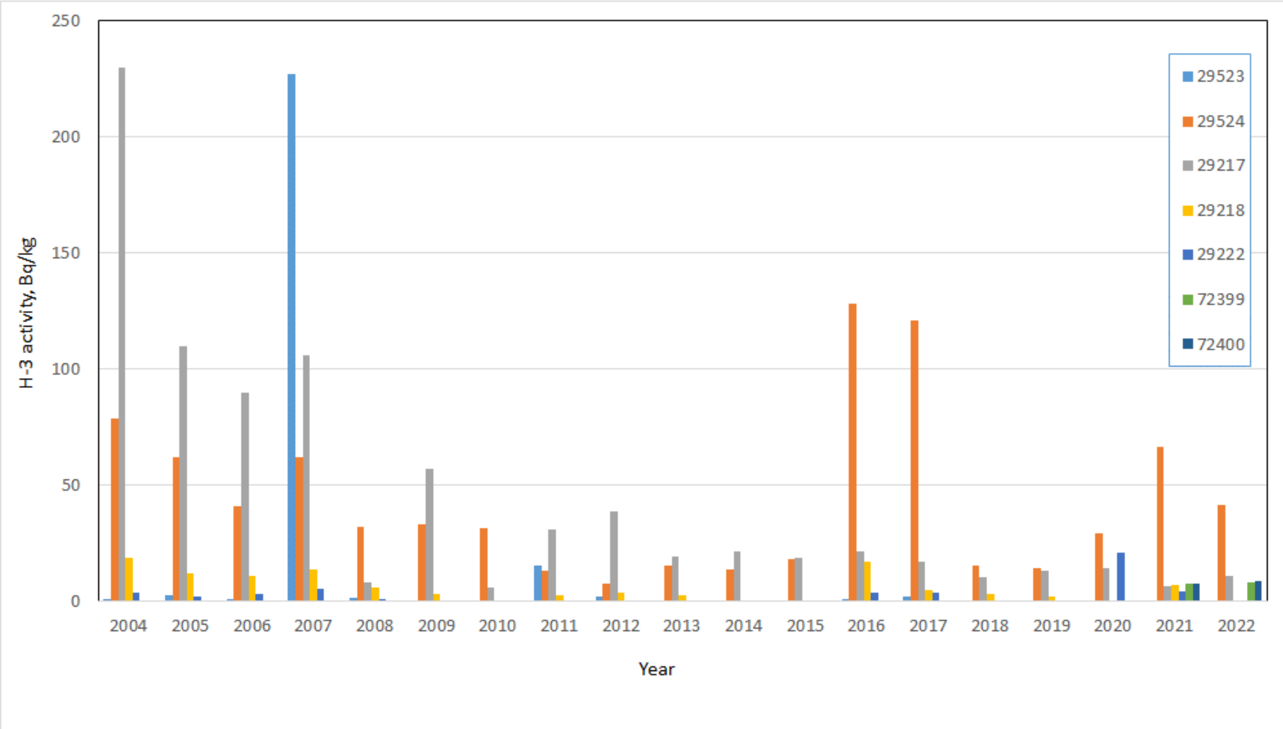


Figure 4.8. H-3 concentrations in groundwater monitoring boreholes adjacent to building 158

4.1.2 Water demand

Surface and artesian waters are used for the operational needs of Ignalina NPP. The source of surface water is Lake Drūkšiai, and artesian water to Ignalina NPP is supplied by SE “Visagino energija” which operates the complex of watering facilities in Visaginas. After shutdown of the Ignalina NPP reactors and after the transferring of all SNF to dry storage facilities, the need for surface water, which is used for cooling the facilities of the Ignalina NPP, has significantly decreased. During the proposed economic activity, surface water will not be used, only artesian water will be used for technological needs and for the sanitary and hygiene needs of the personnel performing the activities. It is expected that there will be no water demand for construction works (mainly concrete pouring), because already prefabricated concrete will be supplied to the site.

4.1.3 Pollution Forecast

During proposed economic activity, i.e. filling in all the unfilled canyons, dismantling of the second floor, installation of engineered barriers and other activities (see Section 1.4) and during subsequential institutional control period no uncontrolled releases to water are expected because an operator shall be monitoring the repository state and if necessary, perform recovery works.

4.1.4 Potential Impact

After termination of institutional control period (its active phase), it is possible to see two repository development scenarios: 1) when its engineered barriers degrade in the natural way, and 2) when degradation of engineered barriers occurs suddenly due to accidental conditions.

According to hydrological and hydro-geologic characteristics of the site and its environment, potential impact to Lake Druksiai is possible due to waterborne radionuclide releases.

However, public water supply of Visaginas city, the boundary of the third sanitary zone of which is at the distance of about 500 meters from bld. 158, may be excluded from the list of potential contamination receivers, as according to groundwater stream direction under planned repository area the public water supply is located at the opposite side.

The potential impact on water depends on the scenarios of the repository development (evolution of engineered barriers), which are developed according to ISAM methodology [23]. According to this methodology the disposal system is subdivided into components (the waste zone, the geosphere and the biosphere), and then possible states of the components are defined. Finally, scenarios are developed after the estimation of the possible states and their interrelation. Computer programs AMBER [29] and COMSOL [30] were used to model radionuclide transport through engineered barriers of the repository, ground water and in geosphere.

The impact assessment methodology and results are comprehensively described in the report [16]. It is assumed, that water penetrating the top multilayer cover and reaching the top of building does not flow through the bitumen compound as pores within bitumen matrix are not formed. Therefore, the infiltrated water flows down along the outer walls of the building. Since the state of the bottom slab of the building and the "pillow" under it is not determined, it is conservatively assumed that these barriers do not prevent the moisture entrance into the canyon. Steel lining as well as layer of the pure bitumen on the top of the bitumen matrix are assumed to be degraded, water uptake of the bitumen compound leads to formation of open pores and radionuclides are free to diffuse out of the bitumen matrix into and through the concrete walls as well as bottom slab (see Figure 4.9). The radionuclides diffusing through the mentioned barriers get into geological layers (IGS) (see Figure 4.10).

Two discharge points of radionuclides are investigated, exactly a well installed in the aquifer (IGS3) at the distance of 50 m from the repository (at the border of the supposed SPZ of the repository) and lake Druksiai located at the distance of 600 m from the repository. The water taken from the well or the water taken from the lake can be used by the humans (members of reference group of population) for their everyday needs and, thus it can become a source of exposure.

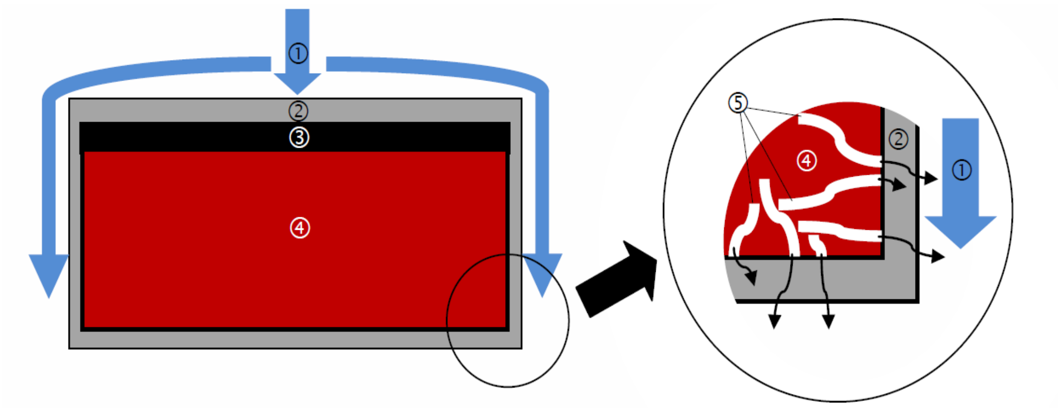


Figure 4.9 Conceptual model of the radionuclide migration (diffusion) from the bitumen compound through the reinforced concrete structures (walls and bottom) of bld. 158: 1 – water flow; 2 – reinforced concrete structures of bld. 158 ; 3 – layer of inert material; 4 – bituminised RAW (bitumen matrix); 5 – formed pores

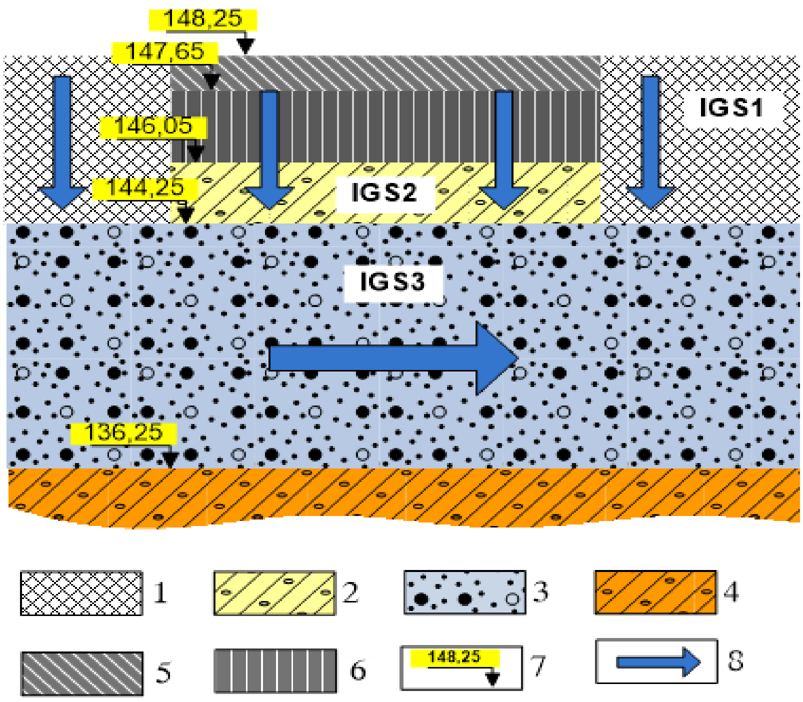


Figure 4.10. Conceptual geological model of the site used for the analysis

1 – technogenic soil (IGS1), 4 m thickness; 2 – fine sediments of moraine formations (IGS2), 1.83 m thickness; 3 – sand of various coarseness, aquifer (IGS3), 8 m thickness; 4 – aquitard; 5 – bottom of Building 158 (slab+leveling layer), 0.57 m thickness; 6 – base of Building 158 (“pillow”), 1.6 m thickness; 7 – absolute altitude, m; 8 – direction of water and radionuclide transport

For bituminised waste Figure 4.11 presents the activity value variations of radionuclides diffused through the side walls and Figure 4.12 presents the activity value variations of radionuclides diffused through the bottom layers and foundation. A variation of the total activity of bituminised RAW released to the geological layers is presented in Figure 4.13. As the figure shows only 12 radionuclides of the 21 in the bitumen compound would be transported to the geological layers due to sorption and radioactive decay processes. Those nuclides are ^{14}C, ^{36}Cl, ^{59}Ni, ^{63}Ni, ^{90}Sr, ^{94}Nb, ^{99}Tc, ^{129}I, ^{137}Cs, ^{234}U, ^{239}Pu, ^{240}Pu. Table 4.3 presents the maximum values of their activities released out through the walls, bottom layers and in total.

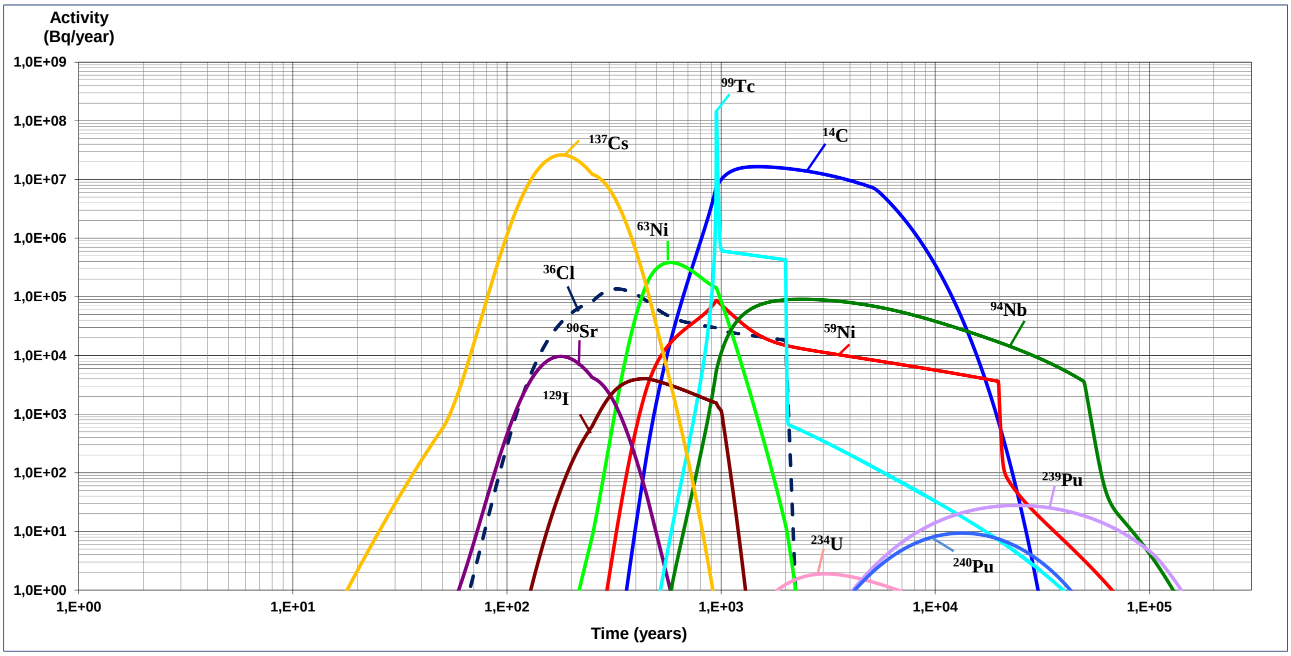


Figure 4.11. Activities of radionuclides diffused from bituminised RAW through concrete side walls of the building in the case of the scenario of natural evolution of the repository

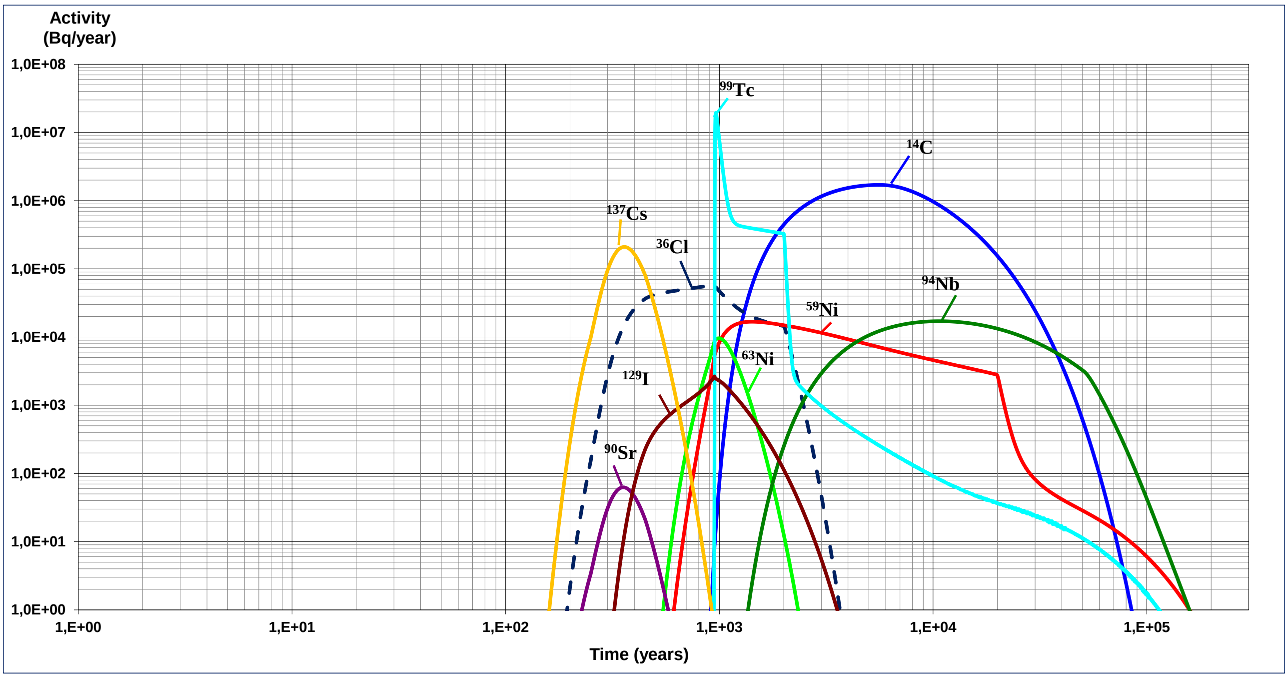


Figure 4.12. Activities of radionuclides diffused from bituminised RAW through bottom layers and foundation of the building in the case of the scenario of natural evolution of the repository

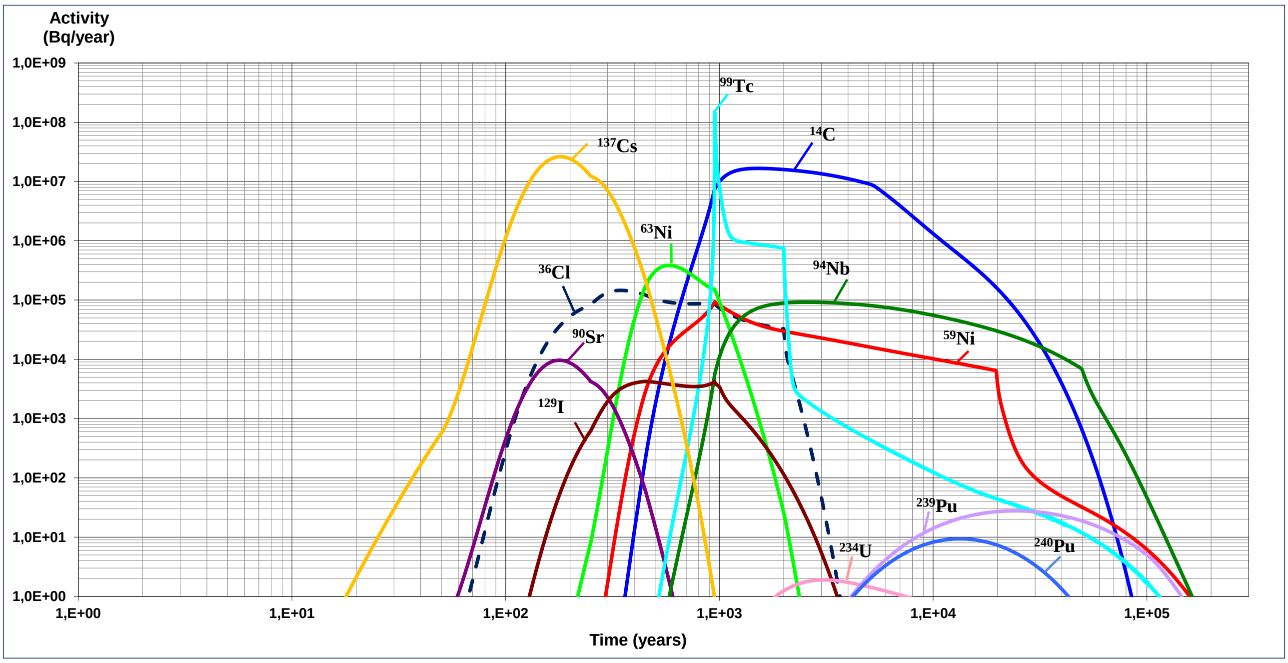


Figure 4.13. Total activity of radionuclides diffused from bituminised RAW out of the canyons to the geological layers in case of the scenario of natural evolution of the repository

Table 4.3. Maximum activity values of radionuclides diffused from bituminised RAW through concrete side walls as well as bottom layers and foundation of the building in the case of natural evolution scenario

Radio nuclide	Through the Walls		Through the Bottom layers and Foundation		Total	
	Max activity, Bq	Max time, yrs	Max activity, Bq	Max time, yrs	Max activity, Bq	Max time, yrs
^{14}C	1.656E+07	1 480	1.702E+06	5 550	1.665E+07	1 520
^{36}Cl	1.366E+05	326	5.845E+04	950	1.455E+05	345
^{59}Ni	8.707E+04	950	1.678E+04	1 420	9.248E+04	950
^{63}Ni	3.843E+05	581	9.606E+03	994	3.843E+05	581
^{90}Sr	9.641E+03	178	6.260E+01	355	9.641E+03	178
^{94}Nb	9.078E+04	2 370	1.709E+04	10 700	9.189E+04	2 560
^{99}Tc	1.463E+08	951	1.947E+07	963	1.468E+08	951
^{129}I	4.018E+03	441	2.652E+03	950	4.242E+03	451
^{137}Cs	2.622E+07	180	2.097E+05	359	2.622E+07	180
^{234}U	1.891E+00	3 070	1.955E-01	13 100	1.893E+00	3 070
^{239}Pu	2.772E+01	24 100	4.958E-01	71 200	2.775E+01	24 200
^{240}Pu	9.356E+00	13 400	1.334E-02	38 400	9.356E+00	13 400

4.1.5 Impact Mitigation Measures

The main preventive measure against potential water contamination during proposed economic activity, resulted from potential waste leaching from repository, will be the monitoring of the state of the repository's engineered barriers and, if necessary, their corrective works; provision of functionality of drainage system, located within the repository area, and its continuous maintenance, up to the end of active institutional control period.

4.2 Environmental Air (Atmosphere)

4.2.1 Overview of Meteorological and Climatic Conditions

Climate of Lithuania is characterized as climate of moderate climatic zone. Since maritime and continent air masses changes occur often, the climate of the region is intermediate – between West European maritime climate and Eurasian continental climate.

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 yearly temperature in the INPP region 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 [39].

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 [26].

In the course of time period of year 2009 – 2022 [34–39]:

- 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 84.7 % in year 2021.

Long term (year 1987 – 2018) average yearly amount of precipitation equals to 683,9 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 (519.8 mm) is recorded in year 2002 [34–39].

A summary (according to [40, 41]) on the assessments of snow cover for period 1981 – 2010 are presented below:

- **Duration of snow cover.** In 1981–2010, during the cold period, snow covered the territory of Lithuania for an average of 82 days. The average number of days with snow cover in separate regions of Lithuania in 1981–2010 was 50 to120 days. Most of the days with snow cover passed in the eastern part of Lithuania, e. g. in Dukstas (Ignalina region) on average 112 days. The average number of days with snow cover in the seaside was the lowest—only 59 days. During the period of 1961–2010, the duration of snow cover in the territory of Lithuania decreased on average by 17 days.

- **Thickness of snow cover.** The average maximum snow cover thickness in separate regions of Lithuania in 1981–2010 was 10–26 cm. The highest average values of the maximum snow cover thickness were recorded in eastern Lithuania (mainly in Dukstas (Ignalina region)—25 cm) and in Samogitia's highlands (26 cm in Laukuva). In the analysed year, Klaipeda stood out with the lowest values of the average maximum snow cover thickness, i. e. only 12 cm. In the period of 1961–2010, the average maximum snow cover thickness in the territory of Lithuania decreased by 3.5 cm.
- **Density of snow cover.** The average density of winter snow is 0.2–0.25 g/cm³. The snow cover is rich in air, so its density is not very high as soon as the snow falls and usually varies from 0.04 to 0.1 g/cm³. Such "fluffy" snow has a particularly low level of thermal conductivity, so the snow cover weakens the heat exchange between the soil and the air. Snow-covered soil maintains a higher temperature, which is highly dependent on the thickness of the snow cover. The density of the snow cover is greatly influenced by the wind speed during the snowfall. Towards the end of the winter season, the snow density increases and can reach 0.3–0.6 g/cm³.

Winds with speeds below 7 m/s dominate in the region – 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 [26]. Western and western-southern winds predominate according to local wind measurements performed during year 2009–2022, Figure 4.14. Prevailing wind direction is not varying significantly within reported period. In general, atmospheric conditions are favourable for dispersion of INPP releases to atmosphere [26].

In the control zone of INPP during reported period of year 2009–2022 strong wind was recorded as follows [26, 34–39]:

- Six 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, January 2019 – 32.3 m/s, May 2021 – 32,0 m/s; November 2021 – 33.6 m/s;
- Nine 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, December 2019 – 25.3 m/s, June 2021 – 25.5 m/s, December 2021 – 26.8 m/s, January 2022 – 29.0 m/s, December 2022 – 28.1 m/s.

Recorded average wind speed is from 2.5 to 4.8 m/s in the control zone of INPP during period 2009 – 2022. Strong winds with speed above 30 m/s constitutes 1.5 %, above 25 m/s - 3%, above 20 m/s – 20 % [26, 34–39].

During the environmental monitoring Ignalina NPP also provides data on radioactive releases into the ambient air and the results of radionuclide concentrations measurements in the air (in surveillance and sanitary protection zones) in the annual radiological monitoring reports [34–39].

4.2.2 Pollution Forecast

Bituminized waste is solidified RAW, therefore, no gaseous radionuclide releases during proposed economic activity are expected. During the operation of 158 building in 1987-2015, periodic safety analysis reports were prepared, air samples were taken through breathers in order to determine the activity of aerosols inside the storage, gas formation due to radiolysis was evaluated. It was found that hydrogen production in the bituminised waste storage canyons due to radiolysis is negligible [10], and aerosol activity inside the storage corresponds to background values [43].

Potential radiological atmosphere air pollution is estimated during inadvertent intrusion scenario into a repository after institutional surveillance period and possible accidental situations. The impact on the population due to radionuclide releases into the environment in case of inadvertent intrusion scenario and possible accidents is assessed in sections 4.9.2 and 7.2.

Non-radiological air pollution may be expected during reconstruction activities of the storage facility and construction of engineered barriers for future repository from mobile sources: lorries, earthmovers, and etc. that will be used for transportation of construction materials and engineered structures, and installing surface engineered barriers of the repository. Due to these activities, NO_x, SO_2, CO, CO_2, solid particles will be released into the ambient air, however the pollution will be local, the zone of reconstruction or installation of an engineering barrier and its surroundings within a radius of ~50 m will be impacted only. Ignalina NPP is performing chemical and radiological monitoring of the ambient air since the start of operation, according to the monitoring results the decommissioning activities at Ignalina NPP site have not had a significant negative impact on the ambient air so far.

4.2.3 Potential Impact

During the proposed economic activities, larger amounts of radionuclides could be released into the ambient air only in case of accidents and inadvertent intrusion into the repository after the end of institutional surveillance period.

The radiological impacts, including possible radionuclides releases into the ambient air, due to the civil airplane crash onto building 158 were assessed and presented in a report [47]. The analysis of structural damage revealed that the impact of a civil airplane (Boeing 747-400 type) of 200 tons mass with impact velocity of 150 m/s to the roof construction of the building 158 under unfavourable impact direction and angle conditions, can destroy the whole construction of the roof. The permissible stress to the roof beam is exceed by factor of 1.9. The roof beams will be damaged and the roof plates will fall inside the building 158. The building 158 model was created and the jet-fuel and RW fire was calculated using the program Pyrosim [44]. The area of fire is conservatively assumed to be the same as the area of bituminized RW, i.e., approximately 3000 m^2. Combustion takes place in open air conditions; the fire required air inflow is sufficient. The fire analysis revealed that the RW fire may continue naturally up to 25 hours. With implementation of the dedicated firefighting actions, the fire may be extinguished in approximately 7 hours. Up to 28% of the stored RW mass can be burned out in this case. The release of radionuclides into the environment was assessed considering RW combustion rate and mobility of radionuclides at elevated temperatures. In the case of accident, the rate of radionuclides release is 4.6E+12 Bq/h. Up to 3.2E+13 Bq can be released during the 7 hours fire. This constitutes approximately 14% from the total activity that is stored in the facility. The major contributor in the released activity is Cs-137. The activity share of this radionuclide is approximately 99.8% from the total activity released into the environment. Other radionuclides, which shares in the released activity are approximately 0.1% each, are C-14 and Cs-134. The atmospheric dispersion and sedimentation of radionuclides onto the ground surface was assessed using the AERMOD modelling system [45] and the Lakes Environmental Consultants Inc. developed user interface AERMOD View [46]. The assessment of a civil airplane crash onto the bituminized RW storage facility (the building 158) accident shows, that the accident resulted radiological impact to the population due to release of airborne activity is insignificant. It should be mentioned that after installation of the engineering barrier (multilayer cap) above the building 158, the consequences of the airplane crash would be less.

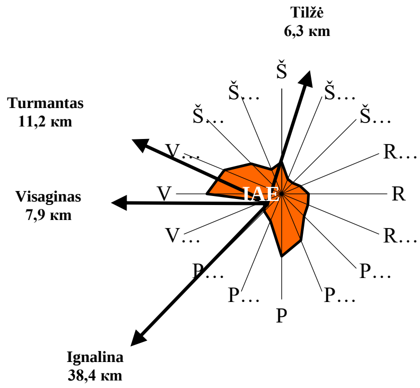
It is expected that an unintended intrusion into the repository can occur after the institutional control period when the restrictions on the land use as well as on activity in the repository site have already been withdrawn. Usually, it is represented by two scenarios, i.e., the on-site residence scenario and the road construction scenario (typical scenarios recommended in IAEA documents [23, 48]. In the case of the road construction scenario, earthworks in the repository site would release airborne particulate matter some of which would be radioactive. In case of on-site residence scenario in the territory of the repository, radioactive gas (C-14 radionuclide in CH_4, CO_2 molecules) would enter the residential premises.

4.2.4 Impact Mitigation Measures

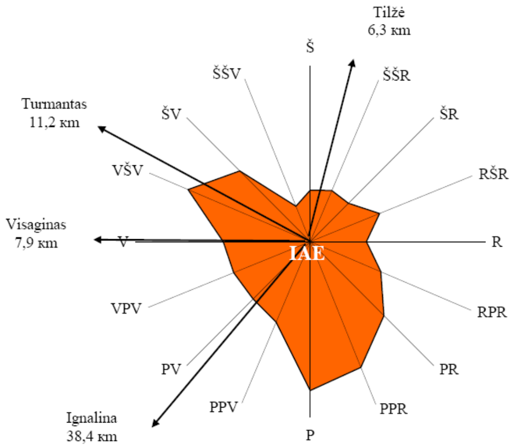
During the proposed economic activity, there will be no significant impact on the air, therefore impact mitigation measures are not required.

4.2.5 Graphic information

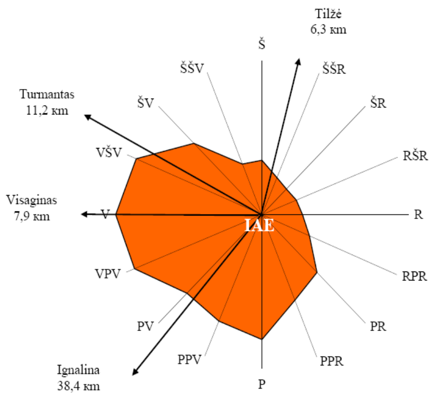
2009



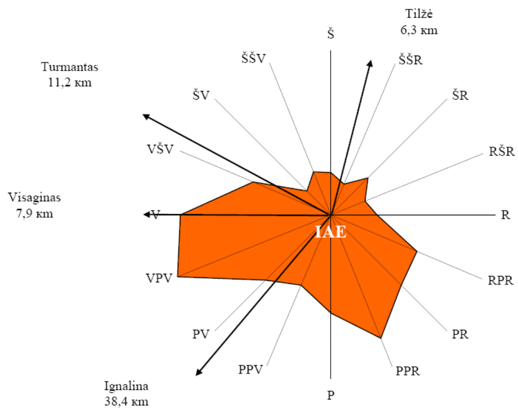
2010



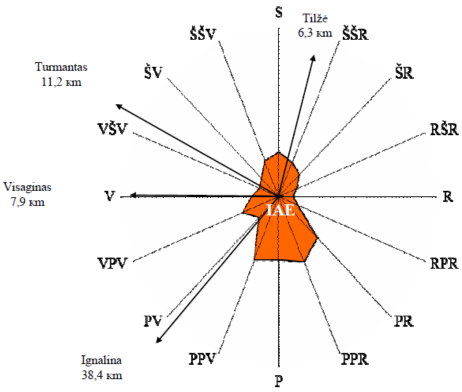
2011



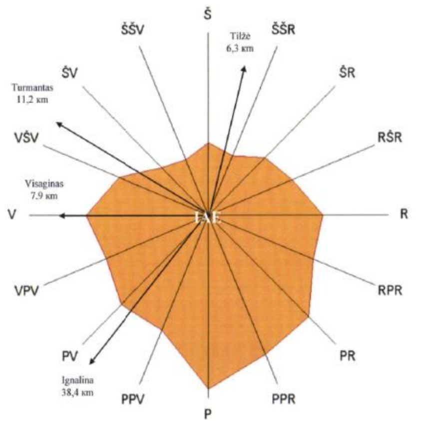
2012



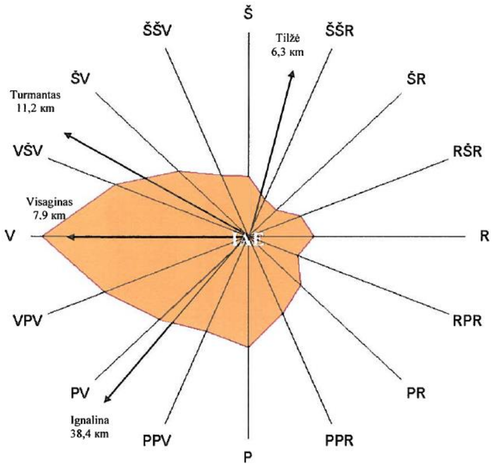
2013



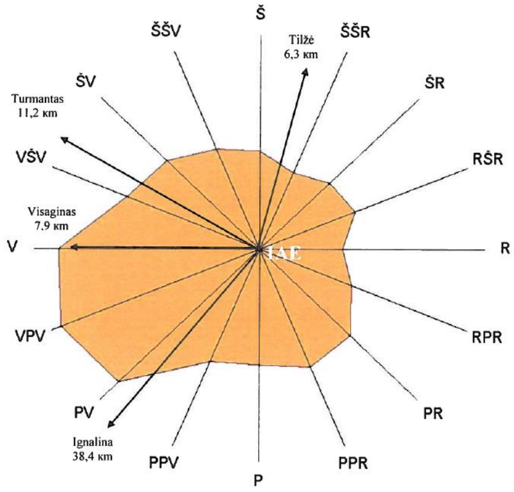
2014



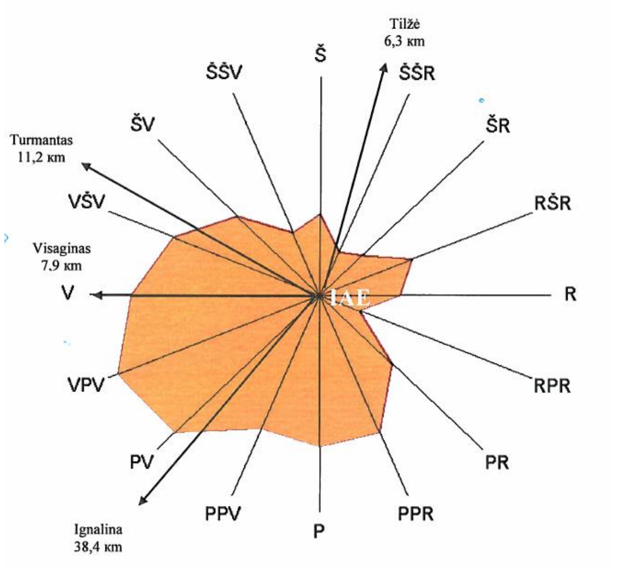
2015



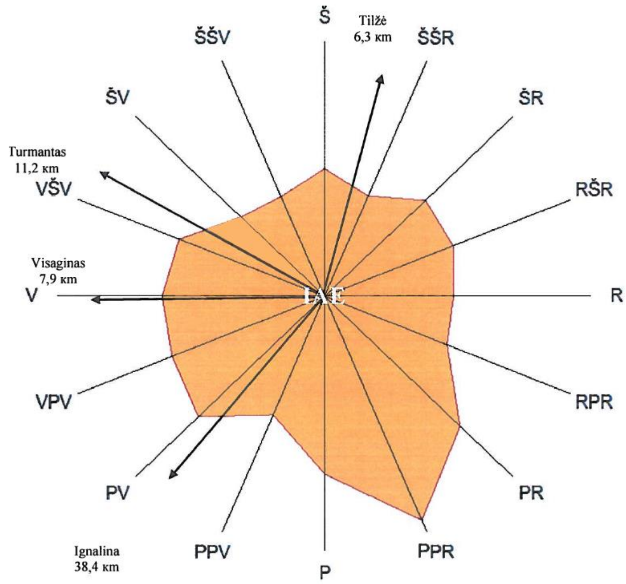
2016



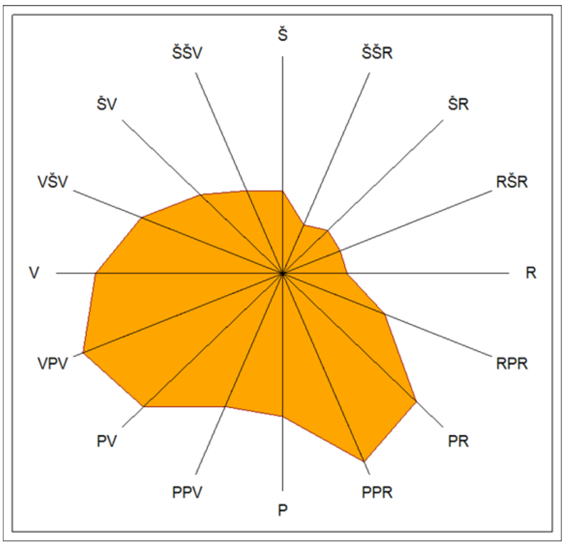
2017



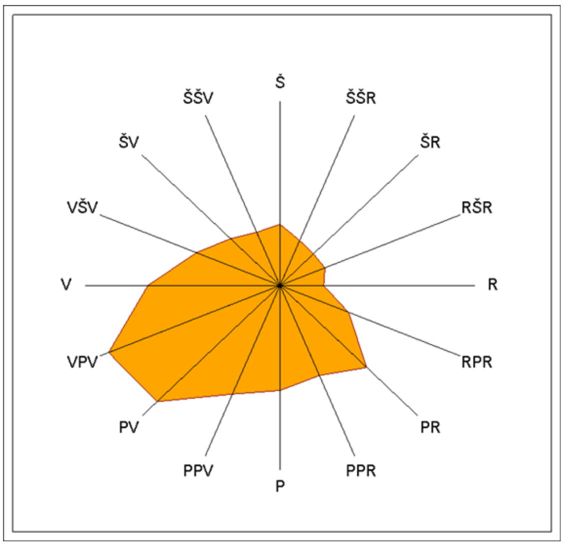
2018



2019



2020



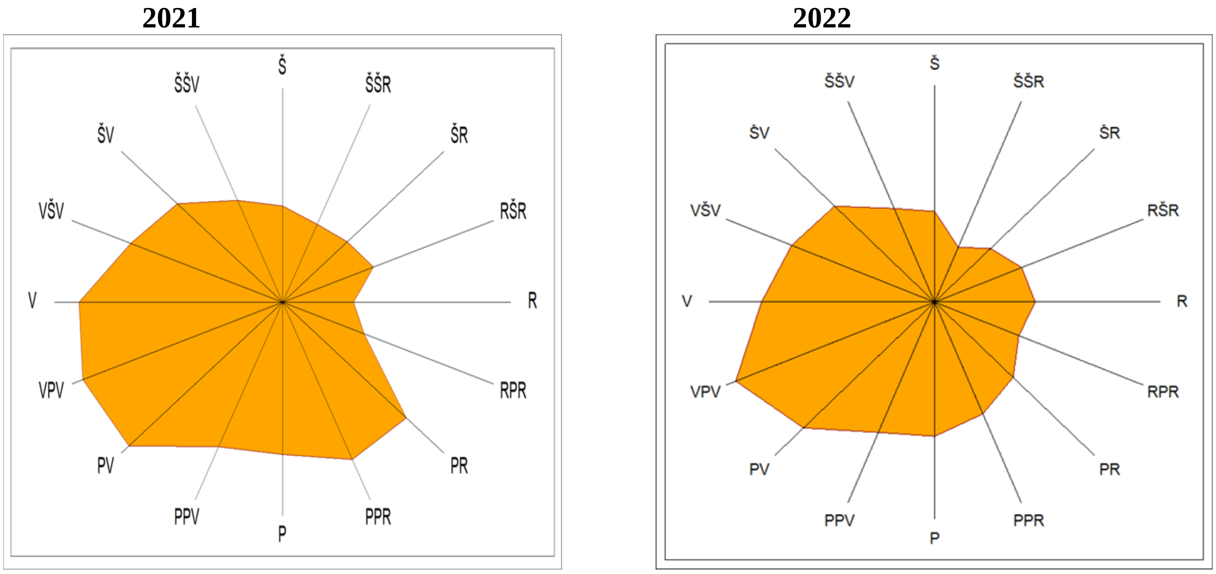


Figure 4.14. Prevailing wind directions at the INPP region (wind direction – off INPP) [34–39]

4.3 Soil

INPP industrial area, where 158 bld. is located and the planned surface engineered barriers that will occupy a part of existing buildings 158/2, 150 and other as well as locations of the roads, is nearly everywhere covered by man-maid ground during INPP construction and operation, therefore there is no natural soil at the site. The man-maid ground contains the mixture of the clayey loam, gravel, pebble, sand and the organic residues in certain places.

As part of environmental monitoring, Ignalina NPP has been carrying out radiological measurements of soil samples in the Ignalina NPP region since 1986 and presents the measurement results of the soil samples in the annual radiological monitoring reports. Soil samples are also taken and analysed at the individual sites of nuclear facilities (buffer storage (B19-1), SWRF (B2), ISFSF (B1), SWTSF (B34), “Landfill” near-surface disposal facility (B19-2)) at Ignalina NPP. As can be seen from the results of radiological monitoring of the Ignalina NPP region (see Table 4.4 and Figure 4.15), the variation of the radionuclides concentrations in the soil samples during the monitoring period is insignificant. The results of naturally occurring radionuclides K-40, Ra-226 and Th-228 are presented for comparison. These radionuclides are not released into the environment from the Ignalina NPP.

Table 4.4. Radionuclides concentrations in the soil samples in the Ignalina NPP region [39]

Year	Concentration, Bq/kg									Total, except Ra, Th, K	
	Cs-137	Cs-134	Mn-54	Co-58	Co-60	Sr-90	Ra-226	Th-232	K-40	Bq/kg	Bq/m^2
2005	3.38	0	0	0	0	1.49	13.8	18.6	462	4.87	31.3
2006	3.38	0	0	0	0.05	0	22.0	25.6	613	3.43	74.8
2007	2.77	0	0	0	0	0	19.6	21.5	631	2.77	76.7

Year	Concentration, Bq/kg									Total, except Ra, Th, K	
	Cs-137	Cs-134	Mn-54	Co-58	Co-60	Sr-90	Ra-226	Th-232	K-40	Bq/kg	Bq/m^2
2008	3.59	0	0	0	0	3.27	12.1	16.5	399	6.86	262
2009	2.99	0	0	0	0	0.48	38.6	15.9	604	3.47	159
2010	2.88	0	0.34	0	0	0	22.3	24.5	573	3.22	153
2011	1.48	0	0.35	0	0	6.15	37.9	25.1	596	7.98	327
2012	1.81	0	0.19	0	0	1.88	3.91	19.8	442	3.88	80.3
2013	4.84	0	0	0	0	0.49	2.12	29.8	525	5.33	126
2014	2.98	0	0	0	0	3.99	1.38	25.4	541	6.97	324
2015	3.03	0	0	0	0	1.94	0.63	22.3	460	4.97	194
2016	3.17	0	0	0	0	1.54	2.14	29.1	629	4.70	158
2017	3.60	0	0	0	0	1.45	18.9	23.0	744	5.05	153
2018	1.13	0	0	0	0	0.88	16.1	21.9	806	2.01	78.4
2019	2.20	0	0	0	0	0	0	16.3	632	2.20	77.4
2020	0.53	0	0	0	0	0	8.23	9.58	461	0.53	17.3
2021	1.26	0	0	0	0	2.56	583	16.3	14.7	3.82	157
2022	4.73	0	0	0	0	1.92	571	14.8	15.3	6.65	132

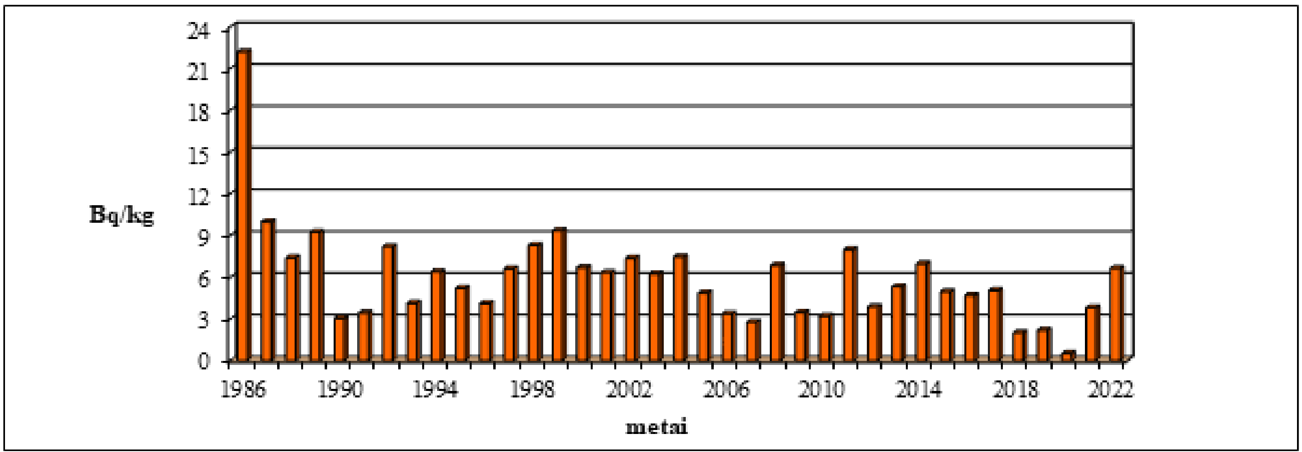


Figure 4.15. Total concentration of the radionuclides in the soil samples in the Ignalina NPP region in 1986-2022 [39]

As it was indicated in the EIA program [3], during the implementation of the proposed economic activity no additional impact, increasing disturbance and contamination of the existing ground layer, is anticipated, therefore the impact on soil is not analysed in the section of the EIA report. Accidental situations and related potential soil radiological pollution that could cause impacts to population are examined in Chapter 7 “Risk analysis and assessment”.

4.4 Underground (Geology)

The geological cross-section of the Ignalina NPP region, Figure 4.16 and Figure 4.17, 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 [27].

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 [27].

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 [49]. At the 5 km distance to the east direction with respect to Ignalina NPP there is the so-called Sauliakalnis gravel-sand-pit. Ignalina NPP industrial site and its surrounding area according to the available information and recent investigations do not possess valuable underground resources [50].

The proposed economic activity will not affect underground (geological) component of the environment.

No valuable natural resources have been found at the site of building 158. The planned economic activity under normal operation conditions will have no effect on possible off-site activities in the vicinity.

No further impact assessment for underground components is planned in the EIA Report.

4.4.1 Graphic information

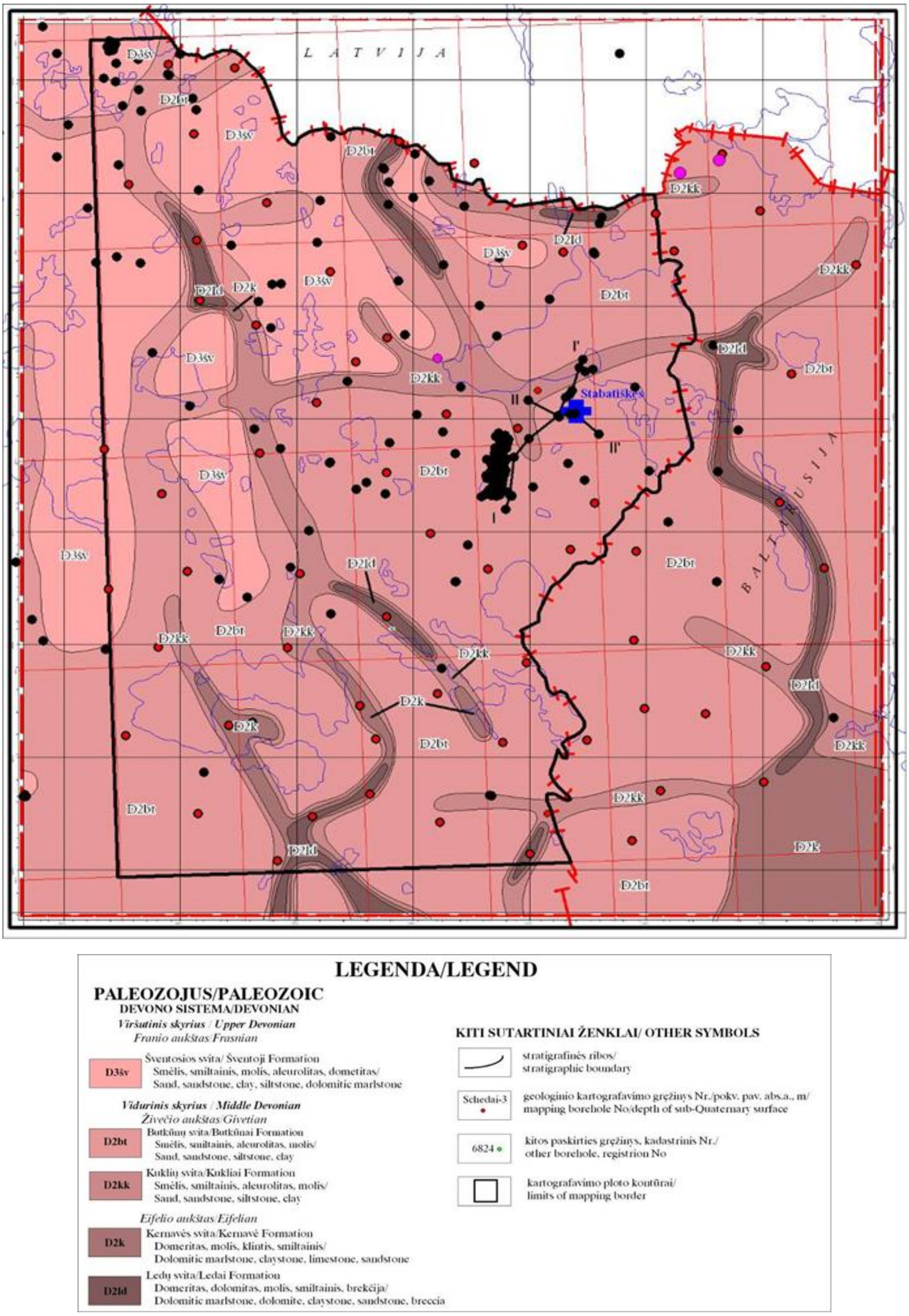


Figure 4.16. Revised pre-Quaternary geological map of Ignalina NPP region (author S. Šliaupa, 2005 [31]; original scale 1:50,000)

Red short lines indicate boundary between Lithuania, Latvia and Belarus, red lines – coordinate scale of the local Lithuanian coordinate system LKS-94

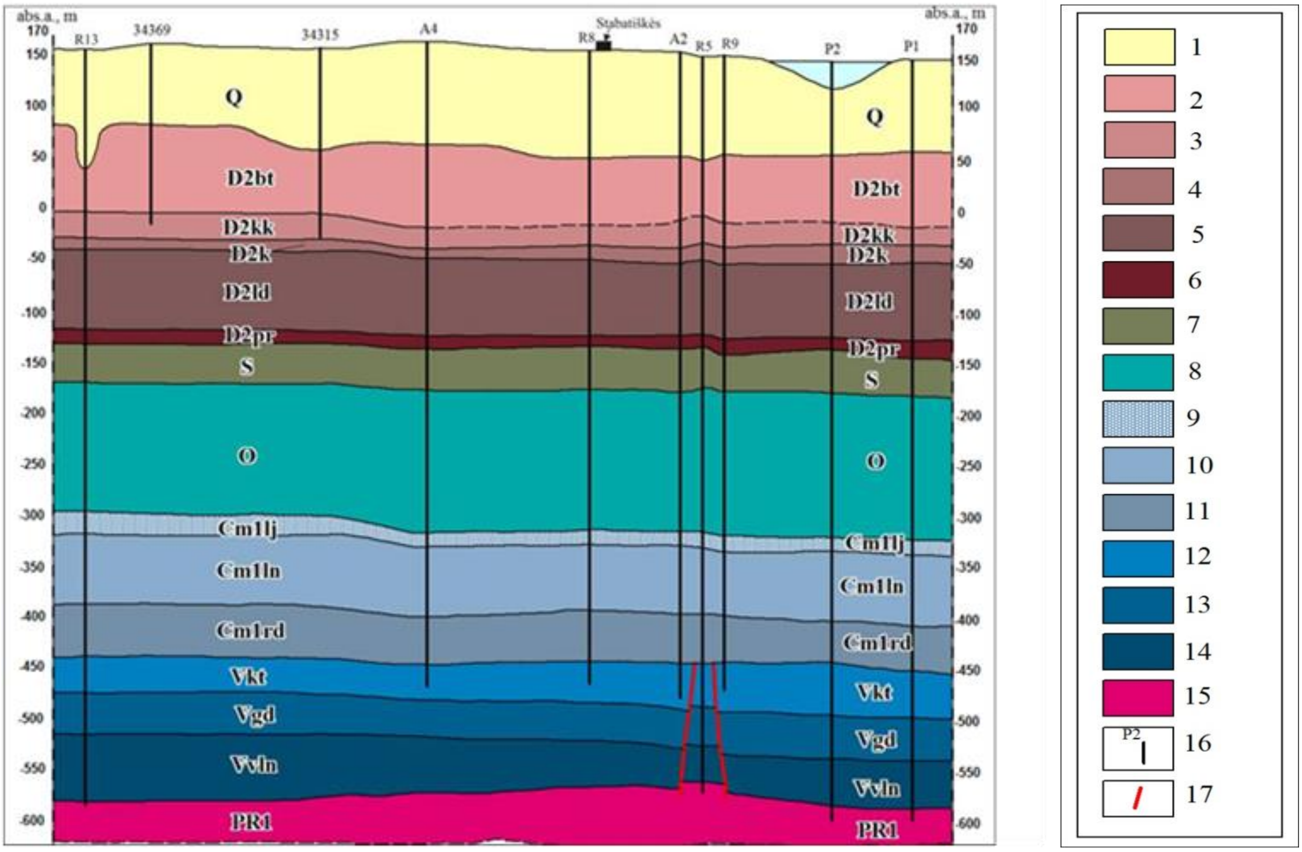


Figure 4.17. Geological cross-section I-I’ of the INPP region (for cross-section location see in Figure 4.16)

Legend:

1 – Quaternary: till, sand, silt, clay.

2-6 – Middle Devonian:

2 – Butkūnai Formation:sand, sandstone with shale and siltstone interlayers;

3 – Kukliai Formation: sand, sandstone, siltstone, shale;

4 – Kernavė Formation: dolomitic marlstone, clay interlayers;

5 – Ledai Formation: dolomitic marlstone, dolomite;

6 – Piarnu Formation: sand, sandstone, dolomite.

7 – Lower Silurian: dolomitic marlstone, dolomite, limestone.

8 – Ordovician: limestone, sandstone and marlstone.

9-11 – Lower Cambrian:

9 – Aisčiai Group Lakaja Formation: sandstone with shale interlayers;

10 – Baltija Group Lontova Formation: shale with sandstone interlayers;

11 - Baltija Group Rudamina Formation: shale with siltstone and sandstone interlayers.

12-14 – Lower-Upper Vendian:

12 –Kotlin Regional Stage: clayey sandstone, siltstone, gravelite, shale;

13 – Gdov Regional Stage: sandstone, gravelite, siltstone;

14 – Volynian Group: sandstone, gravelite, breccia.

15 – Lower Proterozoic: granite, gneiss, amphibolite, milonite.

16 – Borehole.

17 – Fault.

4.5 Biodiversity

4.5.1 Current state

Ecological network “NATURA 2000” is a network of protected areas of the European Community, designated when implementing the Directives of the Council of the European Communities 79/409/EEC [51] and 92/43/EEC [52]. The main objective of the NATURA 2000 network is to preserve, maintain and, if necessary, restore natural habitat types, animal and plant species on the territory of the European Community.

According to the Council Directive 79/409/EEC of 2 April 1979 on the Conservation of Wild Birds (further – Birds Directive) the Special Protection Areas (SPAs) are to be designated. When implementing the Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora (further – Habitat Directive) the Special Areas for Conservation (SACs) are to be established.

Potential “NATURA 2000” territories are areas corresponding the established criteria for selection of Special Areas for Conservation (SACs) and indicated in the list, approved by Minister of the Environment [53], and areas where according to the requirements stated in the Lithuanian Law on Protected Territories [54] Article 24 Paragraph 2, protected areas are established with a purpose to grant them the status of the Special Protection Areas (SPAs).

Prior to establishment of SAC, based on scientific research, potential SAC are selected and the list is presented to the European Commission (EC). After the potential SAC is approved by EC, the Member States commence their establishment. When establishing SPA, first of all based on scientific criteria and research data the most suitable areas are selected. Based on these selected territories the national protected areas are established and later they are granted the status of European SPA.

The nearest to Ignalina NPP SACs of the “NATURA 2000” network are listed in Table 4.5 and shown in Figure 4.18. The details on protected species and the name and code of habitat are also indicated in Table 4.5

Table 4.5. The nearest to INPP Special Areas for Conservation (SACs) of the “NATURA 2000” network

The name of location	**Area, ha**	**Comments on SAC boundaries**	**Code in ”NATURA 2000” network data base**	**Valuable species in the area***	**Preliminary area of the SAC, ha**
Lake Druksiai	3611	Preliminary border is established according to the plan	LTZAR0029	European otter (*Lutra lutra*)	3611

The name of location	**Area, ha**	**Comments on SAC boundaries**	**Code in ”NATURA 2000” network data base**	**Valuable species in the area***	**Preliminary area of the SAC, ha**
River Smalvele and adjacent limy fens	547	The border is the same as for Smalva hydrographical reserve	LTZAR0026	European otter (*Lutra lutra*)	
Lakes and wetlands Smalva and Smalvykstis	2225	The border is the same as for Smalva landscape reserve	LTZAR0025	3140, Lakes with benthic vegetation of *Chara*	354.6
Grazute regional park	26125	The border is the same as for Grazute regional park, with the exception of the zones for recreational, agriculture and other (residential) purposes	LTZAR0024	3130, Light mineralized lakes with helofits	105
Pusnis wetland	779	The border is the same as for Pusnis telmological reserve	LTIGN0001	6230, Mat-grass swards with plenty of species	7.9

* The name and code of species and habitats are indicated as they are used in the Screening Criteria for SAC, approved by Minister of the Environment Ordinance No. 219 of 20 April 2001 (State Journal, 2001, No. 37-1271).

Protected territories in Lithuania comprising Special Protection Areas are approved by the Government [55]. The nearest to INPP Special Protection Areas of the “NATURA 2000” network are listed in Table 4.6 and shown in Figure 4.18. Information on what protected bird species of European importance are found in each SPA is also indicated in Table 4.6. Forbidden activities in the Special Protection Areas are summarized in Table 4.7.

Table 4.6. The nearest to INPP Special Protection Areas (SPAs) of the “NATURA 2000” network

Protected area (or its part) in Lithuania	**Area of SPA**	**Code in ”NATURA 2000” network data base**	**Bird species of European importance**	**Comments on SPA boundaries**
Part of the protected zone for Lake Druksiai	Lake Druksiai	LTZARB003	Great Bittern (Botaurus stellaris)	IBA takes a part of the protected territory. The border is defined according to the plan.
Parts of protected zone for Lakes Dysnai and Dysnyksciai	The limy fens complex of Dysnai and Dysnykstis lake area	LTIGNB004	Corn crake (*Crex crex*)	AIPB takes a part of the protected territory. The border is defined according to the plan.

Protected area (or its part) in Lithuania	Area of SPA	Code in ”NATURA 2000” network data base	Bird species of European importance	Comments on SPA boundaries
Part of Grazute regional park	North eastern part of Grazute regional park	LTZARB004	Black-throated Diver (*Gavia arctica*), Pygmy owl (*Glaucidium passerinum*)	AIPB takes a part of the protected territory. The border is defined according to the plan.
Smalva hydrographic reserve	The complex of Smalva limy fens	LTZARB002	Black Tern (Chlidonias niger)	The border of the IBA is the same as for Smalva hydrographic reserve

Table 4.7. Forbidden activities in the Special Protection Areas (SPAs) nearest to the INPP site

Area of SPA, ”NATURA 2000” code	Bird species of European importance	Forbidden activities [56]
Lake Druksiai, LTZARB003	Great Bittern (Botaurus stellaris)	Reap reeds (in certain areas); Visiting places of above water vegetation overgrowth from ice melting till July 1 (in certain areas); Boating and yachting (in certain areas); Camping, excepting in specially predefined recreational areas, from ice melting till July 1 (in certain areas); Hunting of water and wetland birds excepting cases of regulation of cormorant population in pisciculture waters; Change the land usage main purpose excepting cases of changing to more conservative purpose; Change the hydrological regime if it leads to decrease of habitability area or quality; Plant forest.
The limy fens complex of Dysnai and Dysnykstis lake area, LTIGNB004	Corn Crake (*Crex crex*)	Change the land usage main purpose excepting cases of changing to more conservative purpose; Convert meadows and pastures into plough-land; Change the hydrological regime if it leads to decrease of habitability area or quality; Plant forest.
The complex of Smalva limy fens, LTZARB002	Black tern (Chlidonias niger)	Boating and yachting from May to July; Change the hydrological regime if it leads to decrease of habitability area or quality; Perform water body bed renovation works if it leads to decrease of habitability area or quality.
North eastern part of Grazute regional park, LTZARB004	Black-throated Diver (*Gavia arctica*)	Visiting from ice melting till July 1 (in certain areas); Erect constructions which are not related to purpose of protected territory and expand infrastructure (in certain areas).

Area of SPA, ”NATURA 2000” code	Bird species of European importance	Forbidden activities [56]
	Pygmy owl (Glaucidium passerinum)	Perform general deforesting (in certain areas); Perform deforesting and timbering works from February till May (in certain areas); In case of general deforesting not less than 20 (per hectare) seminal of main group and trees (arranged in biogroups) necessary to maintain biodiversity shall be left (in certain areas).

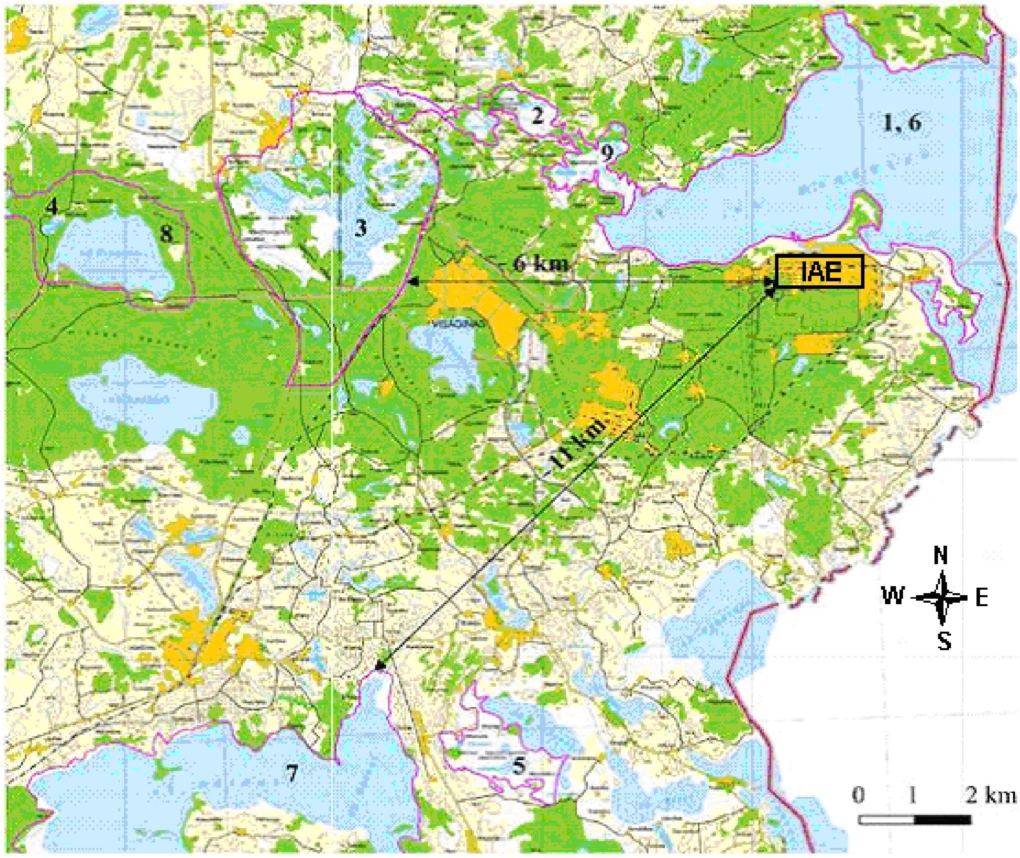


Figure 4.18. The nearest to the Ignalina NPP site “NATURA 2000” network areas (perimeters are indicated in red):

Special Areas for Conservation (SACs): 1 – Lake Druksiai; 2 – River Smalvele and adjacent limy fens; 3 – Lakes and wetlands Smalva and Smalvykstis; 4 – Grazute Regional Park; 5 – Pusnis wetland.
Special Protection Areas (SPAs): 6 – Lake Druksiai; 7 – the limy fens complex of Dysnai and Dysnykstis lake area; 8 – North eastern part of Grazute Regional Park; 9 – the complex of Smalva limy fens

According to the radiological monitoring program of the Ignalina NPP, the specific activity (concentration) of radionuclides is measured in the vegetation, vegetables and food products, and algae in aquatic environments sampled in the region of the Ignalina NPP. The main specific activity of algae is determined by the natural occurring radionuclides K-40 and Be-7; the results of radionuclide concentrations measurements in vegetation, vegetables and food products sampled in

2022 are presented in Table 4.8. Variation of radionuclide concentration in fish from Drūkšiai lake and mushrooms in the Ignalina NPP region since the start of its operation are presented in Figure 4.19 and Figure 4.20.

Table 4.8. Radionuclide concentrations in vegetation, vegetables and food products sampled in 2022 [39]

Sample	Annual consumption, kg	Concentration, Bq/kg					Resulting dose (except K-40), 10^{-4} mSv	Resulting dose (K-40 included), 10^{-4} mSv
		Cs-137	Mn-54	Co-60	Sr-90	K-40		
Grass	-	0	0	0	0.65	802	-	-
Moss	-	14.2	0	0	3.92	124	-	-
Mushrooms	3	10.8	0	0	<0.60	93.5	4.21	21.6
Fish	18	0.98	0	0	0.07	127	2.65	142
Milk (Tilžė)	351	0	0	0	<0.03	44.0	0	958
Cereal crops (Tilžė)	113	<0.7	<0.8	<0.8	0.07	147	2.21	1030
Potatoes (Tilžė)	78	<0.2	<0.3	<0.3	<0.14	129	0	624
Cabbage (Tilžė)	104	<0.5	<0.6	<0.5	0.06	93.3	1.75	602
Total annual dose:							**10,8**	**3376**

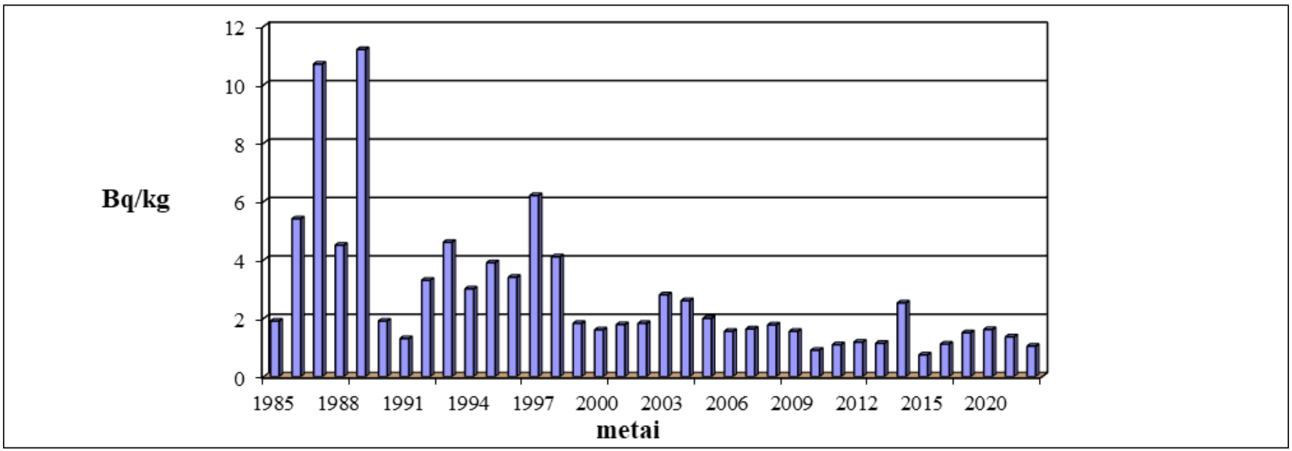


Figure 4.19. Average annual concentration of radionuclides in fish from Drūkšiai lake (natural occurring K-40 is not taken into account)

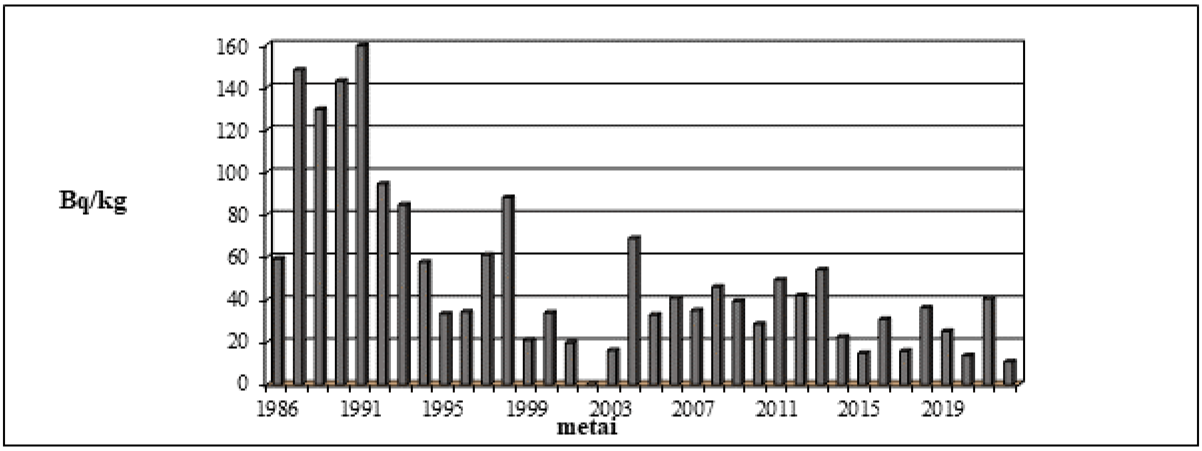


Figure 4.20. Average annual concentration of radionuclides in mushrooms (natural occurring K-40 is not taken into account)

4.5.2 Potential impact

Building 158 is located within the industrial site of the Ignalina NPP, where there is no biodiversity, therefore there will be no impact on biodiversity under normal operating conditions.

Accident situations and radionuclides migration paths through components of biological diversity (vegetables, fish, cattle) which can lead to radiological impacts to the population are considered in Chapter 7 “Risk analysis and assessment”.

4.6 Landscape

The existing storage is located within INPP industrial area, therefore, no other impact on landscape may be expected, than that the storage is to become an artificial hill of about 13 meters high.

Since valuable landscape areas, for instance Grazute Regional Park and Smalva hydrographic reserve are distant from locations of proposed economic activity, thus construction of repository will have no relevant impact on landscape. As it was indicated in the EIA program [3], and no further investigations are planned in EIA Report.

4.7 Social and Economic Environment

4.7.1 Current state

Population and demographic indicators

Based on 2022 data, the total number of permanent residents in the Ignalina NPP region, which consists of Visaginas municipality (58 km^2), Ignalina district (1447 km^2) and Zarasai district (1334 km^2), reached 48 629 (19 707 in Visaginas, 14 263 and 14 659 in Ignalina and Zarasai districts, respectively). Although the IAE region comprises 4.3% of the country's territory, however its population is about 1.7% of the country's population. Thus, the IAE region is referred as one of the regions with a small population and one of the lowest population densities in all of Lithuania, except for the Visaginas town, where the population density reaches 334.6 people/km^2 and significantly exceeds the national average value of 43.0 people/km^2. Since 2008 until 2022 the total population of the Ignalina NPP region decreased by ~29.0% - from 68.8 to ~48.6 thousand residents (see Figure 4.21).

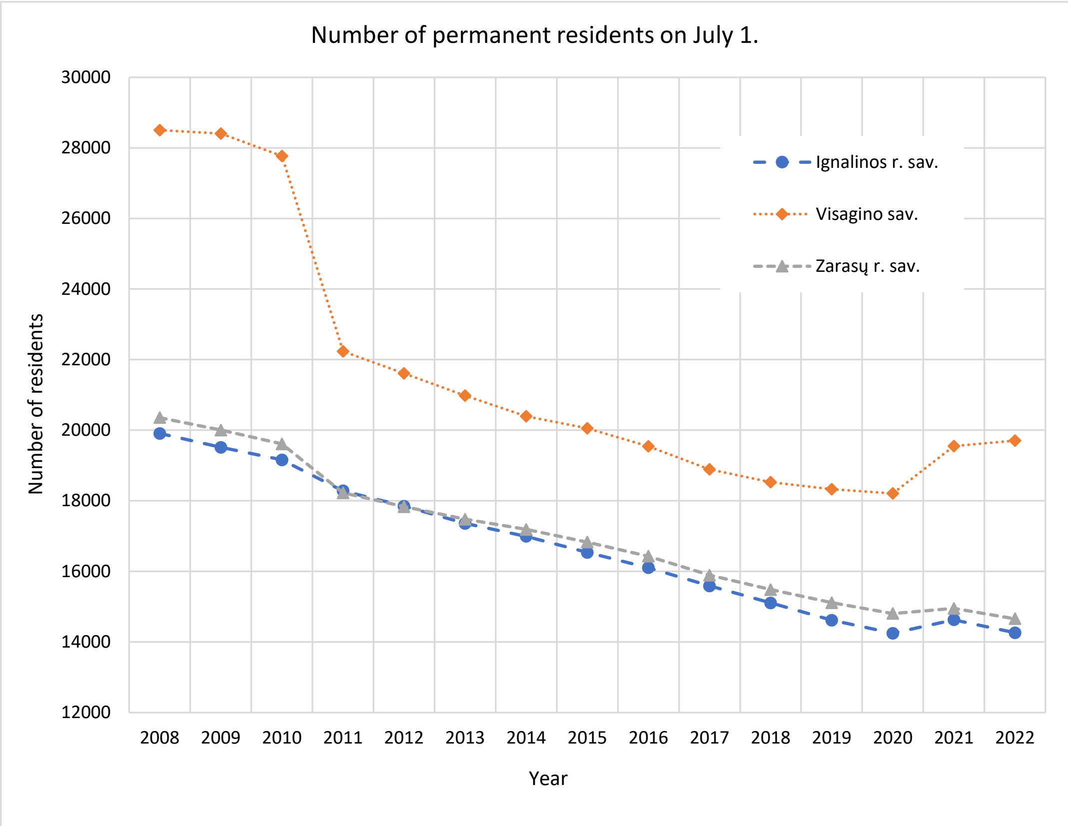


Figure 4.21. Population variation in the IAE region in 2008-2022 (https://osp.stat.gov.lt/)

The demographic situation describes the number, composition, territorial distribution of the population, their changes, and analyses demographic processes (birth rate, death rate, migration). Demographic indicators of the Ignalina NPP region and Lithuania in 2022 are presented in Table 4.9.

Table 4.9. Demographic indicators in 2022 (https://osp.stat.gov.lt/)

Indicator	Visaginas town	Ignalina district	Zarasai district	Utena county	Lithuania
Permanent residents, people	19 707	14 263	14 659	125 639	2 830 097
Population density, people/km^2	334.6	10.0	11.1	17.5	43.0
Population under 14, %	12.8	9.9	11.2	11.2	14.9
Population aged 15-64, %	64.0	63.9	64.9	64.8	65.1
Population aged 65 and over, %	23.2	26.2	23.9	24.0	20.0

Share of men, %	46.5	47.3	47.3	47.0	46.6
Share of women, %	53.5	52.7	52.7	53.0	53.4
Number of births, people	106	68	77	680	22 068
Birth rate per 1000 inhabitants (2021 data)	5.7	4.2	5.6	5.9	8.3
Number of dead, people	312	389	313	2 592	42 884
Death rate per 1000 inhabitants (2021 data)	19.2	25.8	26.4	22.4	17.0
Natural population change, people	-186	-286	-210	-1 711	-17 592
General rate of natural population change per 1000 inhabitants (2021 data)	-13.5	-21.6	-20.8	-16.5	-8.7
Demographic aging factor	181	265	213	214	134
Net migration, people	484	-13	21	1 775	74 003

Economic activity

The INPP region, except for the Visaginas town, is a less developed region in Lithuania from the economic point of view. 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. All Ignalina district has been attributed by the Ministry of agriculture to terrains unfavourable for agriculture in 2004 [57]. The main reasons for this decision are: large part of low fecundity lands in the district (30.9 %), low productivity of corny cultures (1.5 t/hectare), low density of countryside population (10.2 people/km^2), though relatively large number of able-bodied population occupied in agricultural production (29.5 %).

In the Ignalina NPP region no valuable mineral materials (except for quartz sand) were found. The turnover of retail trade is 1.5 times lower and the amount of services is more than 2.5 times lower than the national average. Direct foreign investments (at the end of 2020) to the Visaginas municipality were 10.35 million EUR, Zarasai dist. - 2.73 million EUR, Ignalina dist. - 6.53 million EUR.

Proposed economic activity will be performed within Ignalina NPP industrial area. A sanitary protection zone (SPZ) has been established around the Ignalina NPP within a radius of 3 km, where economic activities not related to the operation and decommissioning of the Ignalina NPP are restricted. Also there are no permanent residents within existing sanitary protection zone of INPP.

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”), garment factory

("Visatex") and medical equipment factory ("Intersurgical"). Visaginas town is distant about 8 km to the west with respect to INPP, see Figure 4.22 [26].

Figure 4.22. Panorama of residential and commercial pursuits [26]:

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; 18 – furniture factory („Visagino linija"), 19 – Intersurgical Ltd.

4.7.2 Potential impact

During the implementation of the proposed economic activity impact on social and economic environment are not expected.

4.8 Ethnic and Cultural Conditions, Cultural Heritage

4.8.1 Current state

Proposed economic activity will be carried out at the Ignalina NPP industrial site in a restricted area. The following cultural heritage objects are located outside the Ignalina NPP industrial site, at a distance of 0.6-2.5 km from the site of the proposed economic activity (see Figure 4.23):

- Petriškės ancient settlement (area of the territory – 8000 m^2, the nature of the valuable characteristics - archaeological).
- Petriškės ancient settlement II (area of the territory – 3100 m^2, the nature of the valuable characteristics - archaeological).
- Petriškės ancient settlement III (area of the territory – 16750 m^2, the nature of the valuable

characteristics - archaeological).

- Petriškės mound (area of the territory – 4800 m^2, the nature of the valuable characteristics - archaeological).
- Grikiniškės ancient settlement (area of the territory – 30800 m^2, the nature of the valuable characteristics - archaeological).
- Grikiniškės ancient settlement II (area of the territory – 49500 m^2, the nature of the valuable characteristics - archaeological).
- Grikiniškės ancient settlement III (area of the territory – 18200 m^2, the nature of the valuable characteristics - archaeological).

Other objects important for cultural heritage (e.g. Čeberakų, Pasamanės mound, Lapusiškės Hill, and etc.) are at the significant distance from the industrial site of the Ignalina NPP.

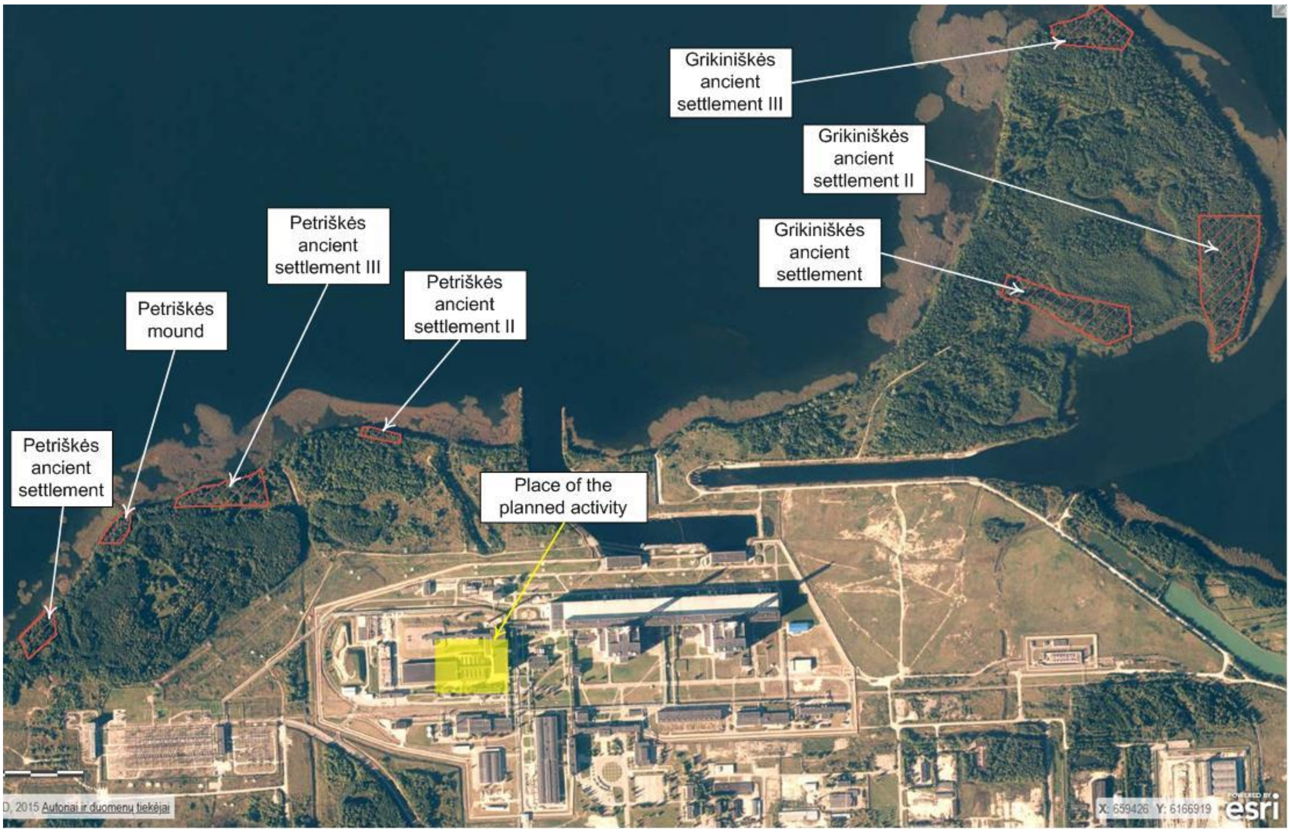


Figure 4.23. Cultural heritage objects located near the Ignalina NPP industrial site (*information from the website https://kvr.kpd.lt*)

4.8.2 Potential impact

The stages of the proposed economic activity (see Section 1.4) will be implemented within the boundaries of the Ignalina NPP industrial site and will not affect the cultural heritage objects mentioned above and the ethnic and cultural conditions.

4.9 Public Health

4.9.1 Current state

The current state of public health is described by presenting and comparing certain statistical indicators of the disease and morbidity of the population of the Ignalina NPP region (Visaginas town, Ignalina and Zarasai districts), Utena county and the whole of Lithuania (see Table 4.10). Disease and morbidity are the main indicators of health statistics, respectively, showing the number of new cases of disease (acute and chronic diseases diagnosed for the first time in life) and the total ratio of all known cases of the disease to the population at a certain point in time. These indicators are publicly accessible in the Public Health Monitoring Information System (https://sveikstat.hi.lt), the official statistics portal of the Lithuanian Statistics Department (https://osp.stat.gov.lt/) and the Health Statistics Data Portal (https://stat.hi.lt/).

Table 4.10. Population health indicators in 2021 (https://stat.hi.lt/)

Indicator	Visaginas town	Ignalina district	Zarasai district	Utena county	Lithuania
Number of ill persons per 1000 inhabitants	879.11	789.44	786.32	775.29	844.32
Morbidity of nervous system per 1000 inhabitants	110.00	177.94	128.61	129.72	143.62
Morbidity of mental illness per 1000 inhabitants	62.91	155.65	128.61	110.63	116.57
Morbidity of respiratory system diseases per 1000 inhabitants	381.43	210.70	224.72	222.44	268.73
Morbidity of blood diseases per 1000 inhabitants	30.13	41.03	33.51	32.75	38.12
Morbidity of malignant neoplasms per 1000 inhabitants	42.83	39.73	36.99	37.77	38.28

In general, Disease and morbidity indicators in most cases in Visaginas town are smaller than in Lithuania, Ignalina NPP region and Utena county. However, morbidity of respiratory system diseases in Visaginas exceeds the Lithuanian average and the indicators of the Ignalina NPP region and Utena county.

According to the general provisions of municipal public health monitoring, approved by the Minister of Health of the Republic of Lithuania in August 11, 2003 by order no. V-488 “On approval of general municipal public health monitoring regulations”, Visaginas municipality conducts public health monitoring in Visaginas municipality and presents the results publicly in annual reports. According to 2021 data, the values of public health monitoring indicators in Visaginas town compared to the Lithuanian average values, are distributed as follows: 33.33% are better than the Lithuanian average, 39.58% of indicators fall into the group corresponding to the Lithuanian average, and 27.09% – to the group of lowest (worst) values.

4.9.2 Potential impact

Proposed economic activity will be carried out at the INPP industrial area, i.e. within radius 3 km of the existing sanitary protection zone, where there are no permanent residents and economic activity is limited. The proposed economic activity site is at a distance of at least 10 km from a more densely populated region (Visaginas city).

The proposed economic activity will not produce any significant impacts of conventional (non radiological) nature, which could affect public health. Impact due to noise or dust during dismantling works and installation of repository engineering barrier is possible only locally at the site and in the immediate vicinity of the repository (about 300 m away from the repository), where there are no inhabitants, and the personnel performing the work will use personal protective equipment to reduce the impact of noise and dust – earmuffs, respirators, protective glasses, etc.

Therefore, the potential public health impact source, which should be considered, is ionizing radiation. Occupational exposure will be analysed in preliminary safety analysis report, based on Technical Design. According to international practice and IAEA recommendations, the safety assessment will be undertaken in conjunction with the planning and design of a proposed activity. The results of the safety assessment will be used to determine any necessary changes in the design so that compliance with safety requirements is assured. As the practically proven radioactive waste management technologies are planned, no problems from technological point of view can be foreseen. Therefore, proposed economic activity can be implemented assuring occupational exposure to be within the limits as prescribed by radiological safety standards in force and in line with ALARA principle.

The purpose of the analysis presented in the EIA 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. Detailed information on the assumptions made in the assessment, the methodology used and the results obtained is provided in reports [16, 17], whereas this section of the EIA reports presents a summary of the scenarios considered and the obtained results.

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 [16]) which is less than effective dose constraint, 0.2 mSv/year, defined in Lithuanian hygiene norm requirements HN 73:2018 for operation and decommissioning of nuclear facilities [6]. Such value of the design criterion was defined taking into account the fact that, in addition to the planned bituminized radioactive waste repository, other nuclear facilities are (or will be) in operation at the site of Ignalina NPP. Therefore, the exposure of the member of reference group must be distributed in such a way that the total annual dose caused by all nuclear facilities at the site cannot exceed the dose constraint.

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 [7].

According to hygiene norm requirements [6], 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 analysed reference group (more details see in document [16]).

The analysed 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 analysed 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 Drūkšiai located at the distance of 600 m from the repository.

The biosphere parameter values considering the local environmental conditions are provided in Table 4.11. The pathways of both external and internal exposure are considered in case of consumption of contaminated water from the well (installed in the aquifer layer (IGS3)) 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 4.11. Main biosphere parameters [16]

Parameter, units	Value
Square of Lake Drūkšiai, m^2	4.9E+09
Volume of Lake Drūkšiai, m^3	3.69E+08
Turnover of Lake Drūkšiai, 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 irradiation of uncovered bituminized radioactive waste would be a member of the reference group in case of inadvertent intrusion into the repository after completion of the institutional control period. A summary of scenarios under consideration is presented in Table 4.12.

Table 4.12 lent. List of scenarios under consideration

No.	Title	Description
	WATER PATHWAY SCENARIOS	
	Reference Scenario	
1.	Natural evolution scenario (Reference scenario)	The assessment of natural evolution of disposal system under consideration taking into account intended design functions and properties of engineered barriers and assuming the following:

No.	Title	Description
		- Gradual degradation of clay layer as well as newly installed reinforced concrete layer on the top after completion of active institutional control period (100 yrs after closure); - Gradual degradation of existing reinforced concrete structures (top slab, side walls, bottom layers and foundation) starting 50 years after repository closure.
	Alternative scenarios	
2.	Alternative scenario, Case 1	All design functions and properties of engineered barriers remains the same as in the reference scenario, but a degradation of all existing reinforced concrete barriers starts earlier, i. e. just after repository closure.
3.	Alternative scenario, Case 2	Sudden degradation of the engineered barriers is considered assuming that: - insulating clay top layer degrades immediately (sudden increase of the hydraulic conductivity) after completion of active institutional control (100 years after repository closure). - reinforced concrete structures degrades immediately (sudden increase of the hydraulic conductivity and effective diffusion coefficient) just after repository closure.
4.	Alternative scenario, Case 3	All design functions and properties of engineered barriers remains the same as in the Reference scenario, but water uptake rate of the bitumen matrix is as much as twice faster starting just after repository closure.
	Hypothetical (“What if”) scenarios	
5.	Hypothetical scenario, Case 1	All design functions and properties of engineered barriers remains the same as in the Reference Scenario but the cap of the repository turns instantly into degraded state **just after repository closure.**
6.	Hypothetical scenario, Case 2	All design functions and properties of engineered barriers remains the same as in the Reference Scenario but bottom slab, leveling layer, foundation (“pillow“), walls as well as the top of the repository turns instantly into state with cracks **just after repository closure**, i.e. no safety function is performed anymore. A cap is also degraded just after repository closure.
7.	Hypothetical scenario, Case 3	All design functions and properties of engineered barriers remains the same as in the Reference Scenario but considering uncertainties of the properties of INPP bitumen matrix the considerably higher water uptake rate of the bitumen matrix in comparison to Reference scenario is assumed.
8.	Hypothetical scenario, Case 4	All design functions and properties of engineered barriers remains the same as in the Reference Scenario, but radionuclides are released from bitumen compound straight into technogenic soil layer (IGS1) next to the canyons and are further transported by this layer up to the lake. An impact of the natural layers (IGS1 and IGS2) to the radionuclide migration is eliminated.

No.	Title	Description
9.	Hypothetical scenario, Case 5	All design functions and properties of engineered barriers as well as natural layers remains the same as in the Reference Scenario, but Kd=0 values are assumed for the layer of technogenic soil (IGS1) from the start point of the analysis. To envelope the uncertainties of properties of technogenic layer at the site, a possible impact of retention property of technogenic soil is eliminated.
10.	Hypothetical scenario, Case 6	All design functions and properties of engineered barriers as well as natural layers remains the same as in the Reference scenario but bitumen matrix does not function just after repository closure and the instant release of radionuclides is assumed.
11.	Hypothetical scenario, Case 7	All design functions and properties of engineered barriers as well as natural layers remains the same as in the Hypothetical scenario, Case 3, but advection phenomena for radionuclide releases from bituminised waste through the bottom engineered barriers to vadose zone is considered.
	INADVERTENT INTRUSION SCENARIOS	
12.	Road construction scenario	A human intrusion into repository during road construction through the repository site after completion of the passive institutional control period (300 years after repository closure) is analysed.
13.	On-site residence scenario	A human intrusion due to building of the house at the repository site (after road construction) after completion of the passive institutional control period (300 years after repository closure) and exposure due to radioactive gas entering the house is analysed.
14.	Drilling scenario	Drilling for archaeological exploration in the far future (for instance to know what is inside the tumulus) is considered. The intrusion event takes place just after completion of the institutional control period (300 years after repository closure) and involves drilling a borehole through the near surface disposal facility as well as further investigations in the laboratory. An exposure to the cuttings or drill core is analysed.

Water pathway scenarios

The conceptual model of radionuclide migration through the components of the disposal system and the processes prevailing in every zone are shown in Figure 4.24.

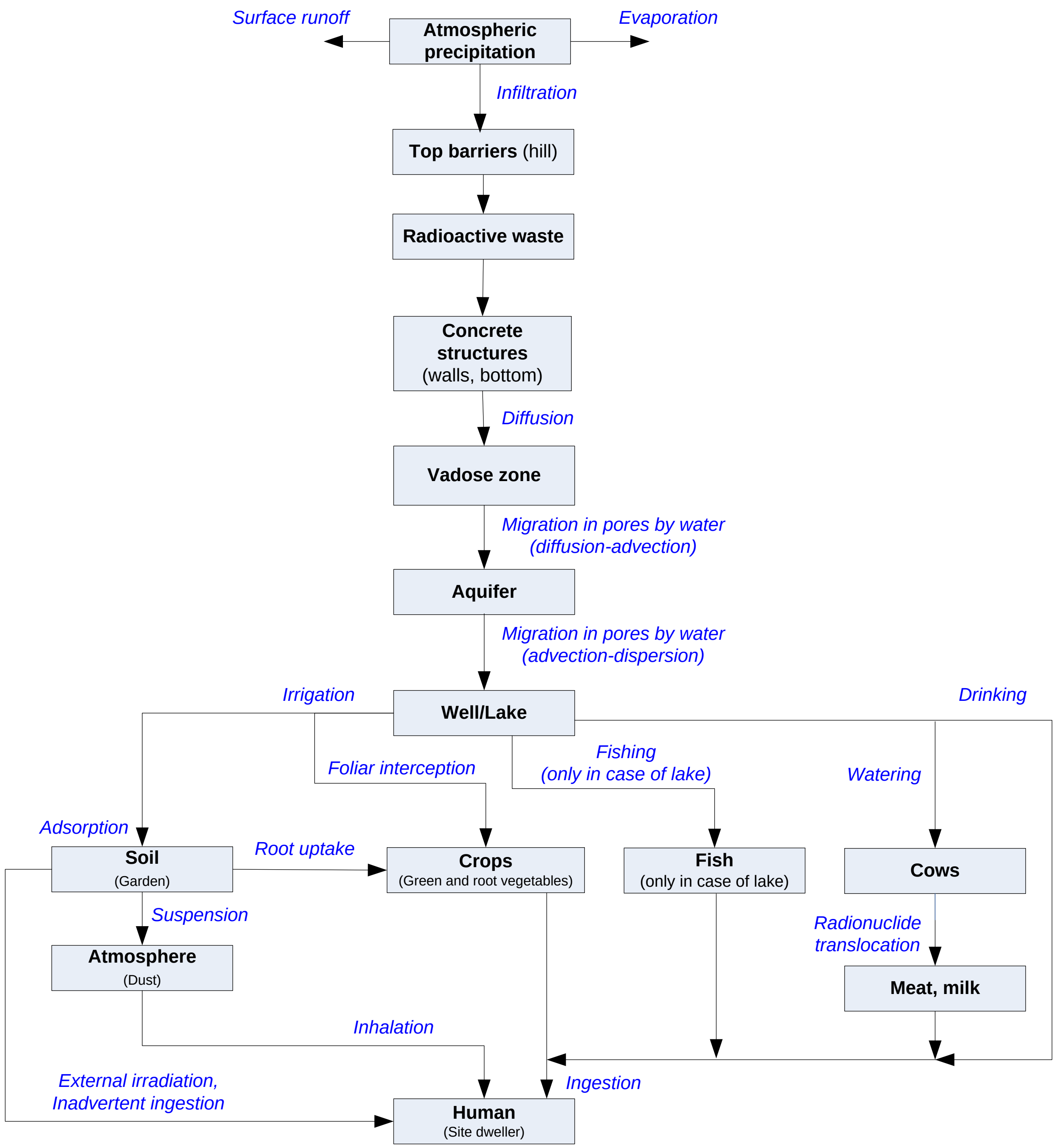


Figure 4.24. Conceptual model of radionuclide migration by water pathway

The conceptual model of radionuclide migration in the well is shown in Figure 4.25.

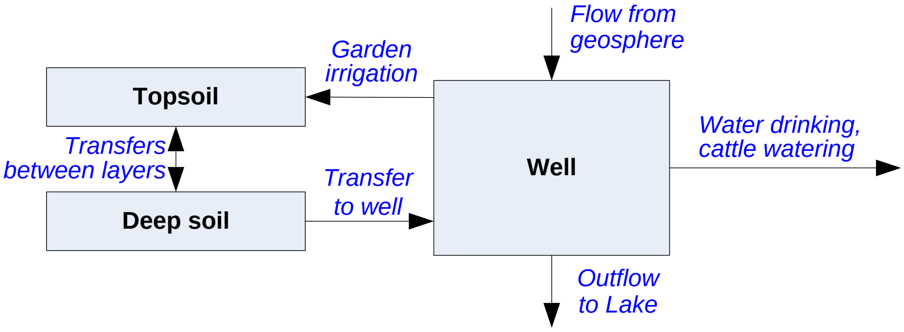


Figure 4.25. Conceptual model of radionuclide migration in the well

The conceptual model of radionuclide migration in the lake is presented in Figure 4.26.

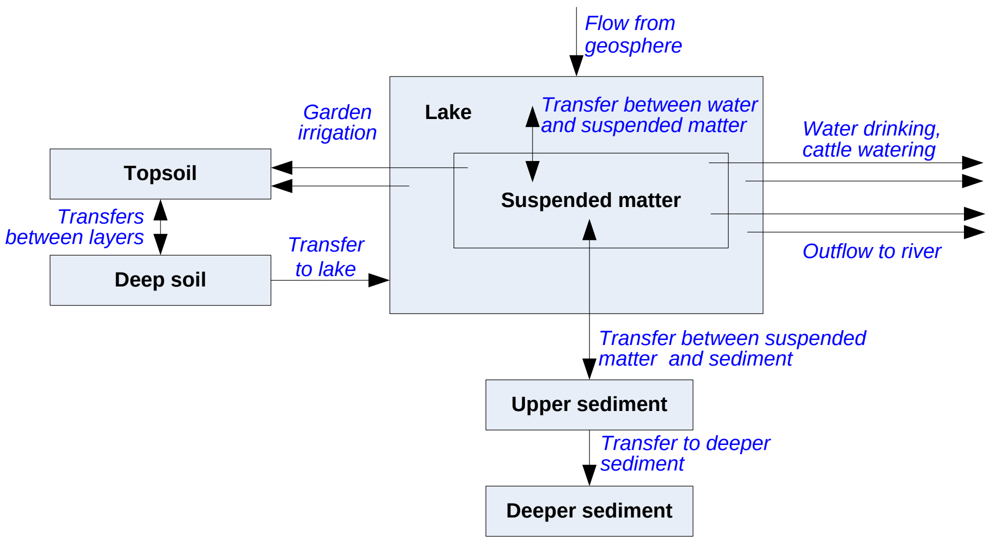


Figure 4.26. Conceptual model of radionuclide migration in the lake

Inadvertent intrusion scenarios

The conceptual model of radionuclide migration and exposure pathways considered in case of road construction in the repository site is presented in Figure 4.27.

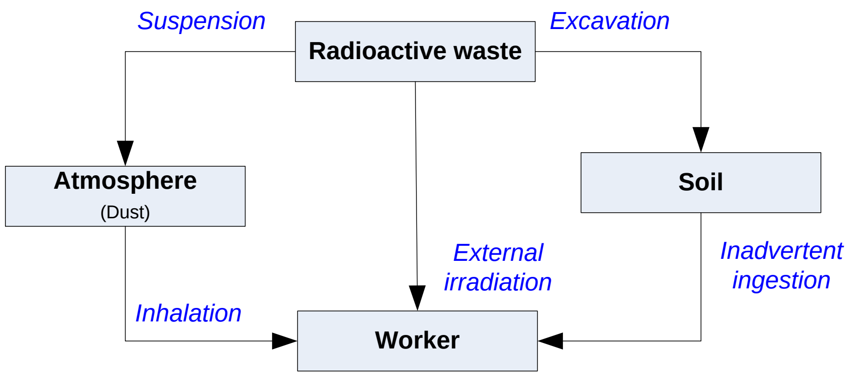


Figure 4.27. Conceptual model of radionuclide migration and exposure pathways in case of a road construction in the territory of the repository

The conceptual model of radionuclide migration and exposure pathways considered in case of on-site residence scenario is presented in Figure 4.28.

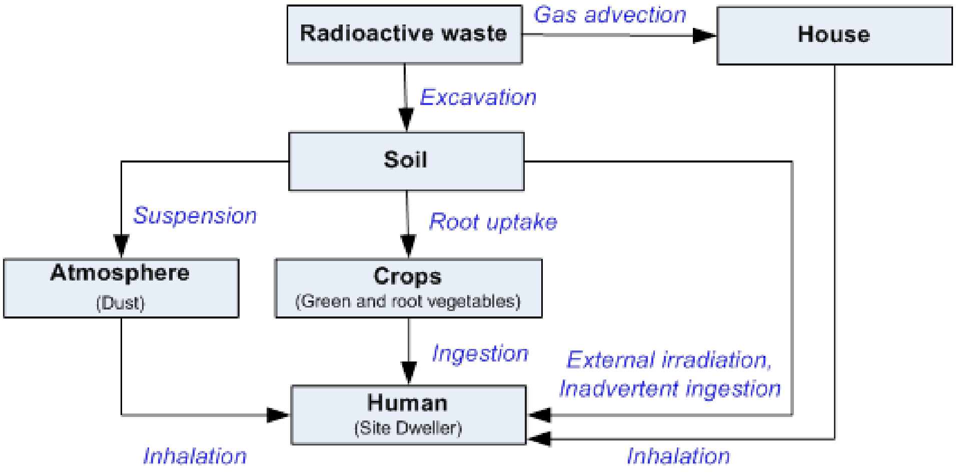


Figure 4.28. Conceptual model of radionuclide migration and exposure pathways in case of on-site residence scenario

The conceptual model of radionuclide migration and exposure pathways considered in case of drilling scenario is presented in Figure 4.29.

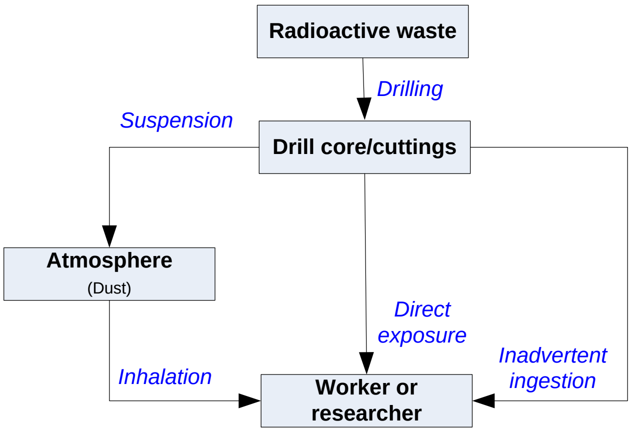


Figure 4.29. Conceptual model of radionuclide migration and exposure pathways in case of drilling scenario

Radiological impact to the population – water pathway scenarios

Table 4.13 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 of the natural evolution scenario of the repository.

Table 4.13. 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, mSv/year	**Maximum time after repository closure, years**	**Maximum dose value, mSv/year**	**Maximum time after repository closure, years**
^{14}C	2.776E-03	1 540	1.194E-05	1 550
^{36}Cl	3.044E-05	367	3.762E-09	378
^{99}Tc	1.165E-05	25 200	9.502E-10	40 300
^{129}I	1.073E-04	962	2.439E-08	971
Total:	**2.925E-03**		**1.197E-05**	

As Table 4.13 shows, the total maximum dose value obtained due to consumption of the contaminated water from a well is lower by two orders of magnitude compared to the design criterion – 0.1 mSv per year. The maximum dose is determined by ^{14}C, and is expected to appear 1 540 years at the earliest past the repository closure. Total maximum dose obtained due to consumption of the contaminated water from a lake is lower by two orders of magnitude in comparison to maximum dose value obtained due to consumption of the contaminated water from a well.

A contribution of different exposure pathways to the maximum dose of ^{14}C in case of the consumption of contaminated water from a well as well as in case of the consumption of contaminated water from a lake is presented in Table 4.14.

Table 4.14. A contribution of different exposure pathways to the maximum dose of ^{14}C in case of the consumption of contaminated water from well and water from lake

Exposure pathway	Contribution to the maximum dose, %	
	In case of well water consumption	**In case of lake water consumption**
External exposure	0.00	0.00
Inhalation of contaminated soil	0.00	0.00
Ingestion of meat	**13.99**	**6.69**
Ingestion of milk	8.07	2.46
Ingestion of root vegetable	**45.22**	0.85
Ingestion of leaf vegetables	8.28	0.16
Ingestion of water	**24.31**	0.46
Inadvertent ingestion of soil	0.13	0.00
Ingestion of fish	-	**89.38**

A most contribution due to ingestion of meat, root vegetable as well as water is observed in case of the consumption of contaminated water from well and, due to ingestion of fish as well as meat in case of the consumption of contaminated water from lake.

Maximum dose values in case of Alternative scenario, Case 1, are presented in Table 4.15.

Table 4.15. Exposure dose values obtained by a member of the reference group due to consumption of contaminated water in the case of Alternative scenario, Case 1

Radionuclide	**Due to well water consumption**		**Due to lake water consumption**	
	Maximum dose value, mSv/year	**Maximum time after repository closure, years**	**Maximum dose value, mSv/year**	**Maximum time after repository closure, years**
^{14}C	2.773E-03	1 540	1.193E-05	1 550
^{36}Cl	2.859E-05	328	3.533E-09	339
^{99}Tc	1.165E-05	25 200	9.502E-10	40 300
^{129}I	1.058E-04	962	2.408E-08	971
Total:	**2.919E-03**		**1.196E-05**	

As Table 4.15 shows, the total maximum dose value obtained due to consumption of the contaminated water from a well is lower by two orders of magnitude compared to the design criterion – 0.1 mSv per year. The maximum dose is determined by *^{14}C*, and is expected to appear 1 540 years at the earliest past the repository closure. Total maximum dose obtained due to consumption of the contaminated water from a lake is lower by two orders of magnitude in comparison to maximum dose value obtained due to consumption of the contaminated water from a well. Negligible difference is obtained in comparison to maximum doses resulted from Reference scenario. This is because the transportation of radionuclides from the repository to the environment is mainly determined by diffusion from the bituminised RAW and not strongly depended on earlier degradation of the concrete structures of the repository.

Maximum dose values in case of Alternative Scenario, Case 2, are presented in Table 4.16.

Table 4.16. Exposure dose values obtained by a member of the reference group due to consumption of contaminated water in the case of Alternative scenario, Case 2

Radionuclide	**Due to well water consumption**		**Due to lake water consumption**	
	Maximum dose value, mSv/year	**Maximum time after repository closure, years**	**Maximum dose value, mSv/year**	**Maximum time after repository closure, Years**
^{14}C	2.762E-03	1 540	1.188E-05	1 540
^{36}Cl	2.489E-05	114	3.053E-09	130
^{99}Tc	1.165E-05	25 200	9.502E-10	40 300
^{129}I	1.022E-04	963	2.328E-08	972
Total:	**2.901E-03**		**1.191E-05**	

It noticed from the data presented in Table 4.16 that estimated total doses due to consumption of contaminated water from the well as well as from the lake are very close to those as in case of natural evolution scenario and remain below the design criterion 0.1 mSv per year at least by three orders of magnitude. This is because the transportation of radionuclides from the repository to the environment is mainly determined by diffusion of radionuclides from the bituminised RAW and not much depended on sudden degradation of the repository engineered barriers.

Maximum dose values in case of Alternative scenario, Case 3, are presented in Table 4.17.

Table 4.17. Exposure dose values obtained by a member of the reference group due to consumption of contaminated water in the case of Alternative scenario, Case 3

Radionuclide	**Due to well water consumption**		**Due to lake water consumption**	
	Maximum dose value, mSv/year	**Maximum time after repository closure, years**	**Maximum dose value, mSv/year**	**Maximum time after repository closure, years**
^{14}C	5.548E-03	1 540	2.387E-05	1 550
^{36}Cl	6.077E-05	367	7.510E-09	379
^{99}Tc	2.328E-05	25 200	1.898E-09	40 300
^{129}I	2.143E-04	962	4.872E-08	971
Total:	**5.846E-03**		**2.392E-05**	

As Table 4.17 shows, the total maximum dose value obtained due to consumption of the contaminated water from a well is lower by two orders of magnitude compared to the design criterion – 0.1 mSv per year. The maximum dose is determined by ^{14}C, and is expected to appear 1 540 years at the earliest past the repository closure. Total maximum dose obtained due to consumption of the contaminated water from a lake is lower by two orders of magnitude in comparison to maximum dose value obtained due to consumption of the contaminated water from a well. A difference approx. by factor 2 is obtained in comparison to maximum doses resulted from Reference scenario. The main reason is twice higher water uptake rate and as result the transportation of radionuclides from the repository to the environment is approx. by factor 2 higher in comparison Reference scenario case.

The maximum dose values to a member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario when the cap of the repository turns into degraded state just after Repository closure (Case 1) are presented in Table 4.18.

Table 4.18. Maximum exposure dose values to a member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario (Case 1)

Radionuclide	Maximum dose value, mSv/year	Maximum time after repository closure, years
^{14}C	2.776E-03	1 540
^{36}Cl	3.041E-05	367
^{99}Tc	1.165E-05	25 200
^{129}I	1.073E-04	962
Total:	**2.925E-03**	

As Table 4.18 shows, the total maximum dose value obtained due to consumption of the contaminated water from a well is the same as in case of Reference scenario and remains below the design criterion 0.1 mSv per year at least by three orders of magnitude. This is because the transportation of radionuclides from the repository to the environment is mainly determined by radionuclide releases from the bituminised RAW which are diffusion driven therefore not much depended on increased infiltration rate through the suddenly degraded cap.

The maximum dose values to a member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario when bottom layers, foundation, walls and top slab of the repository turns into state with the cracks just after repository closure, and the cap is also degraded after repository closure (Case 2) are presented in Table 4.19.

Table 4.19. Maximum exposure dose values to a member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario (Case 2)

Radionuclide	Maximum dose value, mSv/year	Maximum time after repository closure, years
^{14}C	2.259E-02	67
^{36}Cl	3.747E-05	65
^{99}Tc	1.165E-05	24 800
^{129}I	1.111E-04	93
^{239}Pu	2.758E-06	39 000
Total:	**2.275E-02**	

As Table 4.19 shows, the total maximum dose value obtained due to consumption of the contaminated water from a well is by two orders of magnitude higher in comparison to Reference Scenario, however it remains below design criterion 0.1 mSv per year. A containment safety function is fully performed by bitumen matrix. Maximum dose is determined mainly by ^{14}C, the appearance of which could be observed after 67 years after repository closure.

The maximum dose values to a member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario when bitumen matrix suddenly degrades just after repository closure (Case 3) are presented in Table 4.20.

Table 4.20. Exposure dose values to a member of the reference group of population due to consumption of contaminated well water in the case of the hypothetical scenario (Case 3)

Radionuclide	Maximum dose value, mSv/year	Maximum time after repository closure, years
^{14}C	2.760E-02	1 540
^{36}Cl	3.034E-04	368
^{99}Tc	1.155E-04	25 200
^{129}I	1.063E-03	962
Total:	**2.908E-02**	

As Table 4.20 shows, the total maximum dose value obtained due to consumption of the contaminated water from a well is higher in comparison to Reference Scenario approximately by factor of 10, however it remains below design criterion, 0.1 mSv per year. Maximum dose is determined mainly by ^{14}C, the appearance of which could be observed after 1 540 years after repository closure.

Maximum exposure dose values received by member of the reference group of population due to consumption of contaminated lake water for daily needs in the case of the hypothetical scenario when radionuclides released from the repository are transported just through the technogenic soil layer (IGS1) (Case 4) are presented in Table 4.21.

Table 4.21. Maximum exposure dose values received by member of the reference group of population due to consumption of contaminated lake water for daily needs in the case of the hypothetical scenario (Case 4)

Radionuclide	Maximum dose value, mSv/year	Maximum time since start of reconstruction, years
^{14}C	1.930E-05	1 290
^{36}Cl	4.624E-09	375
^{99}Tc	1.037E-09	43 300
^{129}I	3.210E-08	478
Total:	**1.934E-05**	

It is noted from Table 4.21 that total dose received due to consumption of contaminated lake water is higher by factor 1.6 in comparison to Reference Scenario (lake case), and remains below design criterion, 0.1 mSv per year. Maximal dose is determined mainly by ^{14}C, and could be observed after 1 290 since start of reconstruction activities.

Maximum exposure dose values received by member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario when Kd=0 values are assumed for the layer of technogenic soil (IGS1) from the start point of the analysis (Case 5) are presented in Table 4.22.

Table 4.22. Maximum exposure dose values received by member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario (Case 5)

Radionuclide	Maximum dose value, mSv/year	Maximum time after repository closure, years
^{14}C	2.776E-03	1 540
^{36}Cl	3.044E-05	367
^{99}Tc	1.527E-04	1 030
^{129}I	1.073E-04	962
^{137}Cs	5.415E-04	237
Total:	**3.608E-03**	

Table 4.22 shows that the total maximum dose value obtained due to consumption of the contaminated water from a well is higher in comparison to Reference scenario by factor 1.2, however it remains below design criterion, 0.1 mSv per year. Maximum dose is determined mainly by ^{14}C, the appearance of which is expected after 1 540 years after repository closure.

Maximum exposure dose values received by member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario when instant release of activity from bitumen matrix is assumed (Case 6) are presented in Table 4.23.

Table 4.23. Maximum exposure dose values received by member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario (Case 6)

Radionuclide	Maximum dose value, mSv/year	Maximum time after repository closure, years
^{14}C	6.787E-02	1 280
^{36}Cl	1.532E-03	330
^{99}Tc	4.324E-04	20 700
^{129}I	5.524E-03	961
Total:	**7.536E-02**	

Table 4.23 shows the total maximum dose value obtained due to consumption of the contaminated water from a well in the case of the hypothetical scenario when instant release of activity from bitumen matrix is assumed one order of magnitude higher in comparison to Reference scenario, however it remains below design criterion, 0.1 mSv per year. Maximum dose is determined mainly by ^{14}C, the appearance of which is expected after 1 280 years after repository closure. Containment is fully ensured by the cap as well as concrete structures of the repository while no safety function is credited for bitumen compound in this case.

The maximum dose values to a member of the reference group of population due to consumption of contaminated well water for daily needs in the case of the hypothetical scenario when bitumen matrix suddenly degrades just after repository closure and advection phenomena for radionuclide releases through the bottom engineered barriers to vadose zone is considered (Case 7) are presented in Table 4.24.

Table 4.24. Exposure dose values to a member of the reference group of population due to consumption of contaminated well water in the case of the hypothetical scenario (Case 7)

Radionuclide	Maximum dose value, mSv/year	Maximum time after repository closure, years
^{14}C	3.482E-02	2 460
^{36}Cl	3.811E-04	336
^{99}Tc	1.155E-04	25 200
^{129}I	1.365E-03	508
Total:	**3.668E-02**	

As Table 4.24 shows, the total maximum dose value obtained due to consumption of the contaminated water from a well is higher in comparison to Reference Scenario approximately by factor of 16, however it remains below design criterion, 0.1 mSv per year. Maximum dose is determined mainly by ^{14}C, the appearance of which could be observed after 2 460 years after repository closure.

Overall impact resulted from existing and planned nuclear facilities at INPP site to the population

It is expected that the following nuclear facilities will in operation at the Ignalina NPP site during the implementation of the proposed economic activity [8]:

- a new interim spent nuclear fuel storage facility (ISFSF) (B1);
- solid radioactive waste management and storage facility (SWMSF) (B3/4);
- buffer storage facility for very low-level radioactive waste (VLLW) (B19-1);
- VLLW disposal units (B19-2);
- near surface repository (NSR) (B25);
- old spent fuel storage facility (SFSF).

Forecast of the maximal annual effective dose to the member of reference group of population due to overall impact resulted from the above-mentioned nuclear facilities at INPP site during the implementation period of proposed economic activity are summarized in Table 4.25.

Table 4.25. Forecast of impact resulted from the existing and planned nuclear facilities at INPP site during the implementation of PEA

Nuclear energy facility	Effective dose, mSv/y	Peak time during PEA, years
ISFSF (B1)	4.15E-04 [1)]	1 – 30
SWMSF (B3/4)	2.94E-03 [1)]	1 – 30
VLLW buffer storage facility (B19-1)	3.60E-02 [2)]	1 – 30

VLLW disposal units (B19-2)	6.75E-04 [3)]	< 100 (^{14}C)
NSR (B25)	2.21E-02 [4)]	300 – 400 ($^{14}C_{org}$)
Old SFSF	3.40E-03 [1)]	1 – 30
[1)] Data from [18]. [2)] Data from [19]. [3)] Data from [20]. [4)] Data from [21].		

As it is indicated in Table 4.25 the most contribution to the total dose would be due to impact of VLLW buffer storage facility as well as NSR (B25) (in case of natural evolution scenario). A peak time is forecasted in the 300 – 400 years period.

After the assessment of total impact resulted from the existing and planned nuclear facilities at INPP site, it is reasonable to apply limiting dose of 0.1 mSv/year as design criterion for the bituminized radioactive waste repository. The limiting dose is obtained by subtracting annual dose values estimated for VLLW buffer storage facility (B19-1) and for NSR (B25) (overall approx. 0.1 mSv) from the dose constrain 0.2 mSv [6].

Radiological impact to the population – inadvertent intrusion scenarios

Table 4.26 presents the assessment results in the cases of considered inadvertent intrusion scenarios. The table shows only the doses of those radionuclides that have values higher than 1.0E-20 mSv/year.

Table 4.26. Estimated maximum doses to a member of the reference group in the cases of considered unintended intrusion scenarios

Radio nuclide	**Total dose, mSv/year**						
	Road construction	**On-site residence**			**Drilling**		
		Adult	**Child**	**Infant**	**Worker**	**Researcher No.1**	**Researcher No. 2**
^{14}C	6.635E-05	2.392E-01	2.515E-01	3.507E-01	1.009E-05	2.128E-05	
^{36}Cl	2.150E-07	2.456E-02	3.690E-02	7.838E-02	1.677E-08	3.969E-08	
^{59}Ni	6.001E-09	7.526E-06	9.941E-06	2.182E-05	7.932E-10	1.980E-09	
^{63}Ni	2.625E-06	3.050E-03	4.307E-03	9.176E-03	3.870E-07	8.747E-07	
^{60}Co	2.655E-17	1.925E-15	1.250E-15	9.022E-16	1.514E-19	2.480E-19	1.590E-19
^{90}Sr	8.726E-08	1.951E-03	4.062E-03	5.563E-03	7.895E-09	2.219E-08	
^{93m}Nb	4.855E-16	1.310E-13	2.123E-13	5.258E-13			
^{94}Nb	1.853E-03	1.331E-01	8.398E-02	5.761E-02	4.454E-04	7.485E-04	4.612E-04
^{93}Zr	1.261E-09	1.784E-07	1.080E-07	1.867E-07			
^{99}Tc	3.062E-06	7.477E-01	1.161E+00	2.967E+00	5.300E-07	7.786E-07	3.815E-09

Radio nuclide	Total dose, mSv/year						
	Road construction	On-site residence			Drilling		
		Adult	Child	Infant	Worker	Researcher No.1	Researcher No. 2
^{129}I	3.668E-07	2.107E-03	2.773E-03	2.240E-03	1.125E-07	3.807E-07	8.466E-08
^{134}Cs	5.461E-18	4.343E-16	2.695E-16	1.852E-16			
^{135}Cs	3.614E-13	5.157E-10	3.317E-10	3.187E-10			
^{137}Cs	6.771E-03	5.800E-01	3.596E-01	2.528E-01	1.980E-03	3.343E-03	2.101E-03
^{234}U	1.673E-07	1.587E-05	2.731E-05	3.058E-05	2.398E-08	2.226E-08	8.960E-12
^{235}U	2.221E-08	8.511E-07	8.932E-07	8.616E-07	5.179E-09	3.109E-09	1.669E-10
^{238}U	7.980E-08	7.284E-06	1.250E-05	1.399E-05	1.164E-08	1.060E-08	1.948E-12
^{237}Np	1.324E-08	1.033E-07	1.208E-07	1.174E-07	2.981E-09	1.736E-09	5.658E-11
^{238}Pu	1.887E-06	7.477E-06	9.948E-06	5.859E-06	4.397E-07	2.432E-07	7.540E-11
^{239}Pu	2.078E-05	8.216E-05	5.801E-05	6.207E-05	4.844E-06	2.674E-06	6.029E-10
^{240}Pu	2.556E-05	1.010E-04	7.133E-05	7.634E-05	5.960E-06	3.293E-06	8.492E-10
^{241}Pu	2.124E-05	9.551E-05	1.273E-04	8.554E-05	4.937E-06	2.723E-06	
^{241}Am	2.475E-05	1.113E-04	1.484E-04	9.965E-05	6.043E-06	3.697E-06	3.155E-07
^{244}Cm	1.823E-10	7.202E-10	9.665E-10	5.445E-10			
Total:	**8.791E-03**	**1.733E+00**	**1.905E+00**	**3.724E+00**	**2.459E-03**	**4.128E-03**	**2.563E-03**

Table 4.26 demonstrates, that the total exposure dose to a worker working in road construction in the repository site is lower than the dose limit 10 mSv/year by four orders of magnitude. The most significant contribution to the total exposure dose value is resulted from ^{94}Nb and ^{137}Cs.

In case of on-site residence scenario the doses estimated for all age groups are below the value of 4 mSv/year, i.e. below the dose constrain, 10 mSv/year. A highest dose value would be received by infant and, the most contribution to the total exposure dose would be resulted from ^{99}Tc.

In case of drilling scenario, the estimated doses for all considered recipients are below value of 0.5E-03 mSv/year, i.e. much below the dose constraint, 10 mSv/year.

Summarized results of considered scenarios

The summarized results of the radiological impact to population assessment of the considered scenarios are presented in Table 4.27. In all cases, the calculated annual doses to a member of the reference group of population are below the permissible limits.

Table 4.27. Maximal doses for scenarios considered

No.	Title	Max dose, mSv/year	Comment
	WATER PATHWAY SCENARIOS		
	Reference Scenario		
1.	Natural evolution scenario	2.925E-03	Expected gradual degradation of the cap as well as concrete structures is considered. Approx 95% of the total dose ir determined by ^{14}C. A most contribution due to ingestion of meat, root vegetable as well as water is observed.
	Alternative scenarios		
2.	Alternative scenario, Case 1	2.919E-03	A degradation of all existing reinforced concrete barriers starts earlier in comparison to Reference scenario. No significant difference of maximum dose value is observed in comparison to Reference scenario due to transportation of radionuclides from the repository to the environment is mainly determined by diffusion from the bituminised RAW and not strongly depended on earlier degradation of the concrete structures.
3.	Alternative scenario, Case 2	2.901E-03	Insulating clayey layer of the cap degrades immediately after completion of active institutional control. Reinforced concrete structures degrades immediately (sudden increase of the hydraulic conductivity and effective diffusion coefficient) just after repository closure. No significant difference in comparison to Reference scenario. This is because the transportation of radionuclides from the repository to the environment is mainly determined by diffusion of radionuclides from the bituminised RAW and not much depended on increase of water infiltration rate after sudden degradation of the repository engineered barriers.
4.	Alternative scenario, Case 3	5.846E-03	Water uptake rate of the bitumen matrix is as much as twice faster starting just after repository closure in comparison to Reference scenario. Consequently, maximum dose value is higher in comparison to Reference scenario factor by 2.
	Hypothetical ("What if") scenarios		
5.	Hypothetical scenario, Case 1	2.925E-03	Cap of the repository is degraded just after repository closure. No significant difference in comparison to the dose obtained from the Reference scenario. This is because the transportation of radionuclides from the repository (mainly determined by bituminised RAW) to the environment is mainly determined by diffusion of radionuclides from the bituminised RAW and not much depended on sudden degradation of the repository cap.
6.	Hypothetical scenario, Case 2	2.275E-02	All concrete structures are with cracks and the cap is degraded just after repository closure. Due to this reason maximum dose value is by two orders of magnitude higher in comparison to Reference Scenario.
7.	Hypothetical scenario, Case 3	2.908E-02	Water uptake rate of the bitumen matrix is one order of magnitude higher in comparison to Reference scenario. Therefore total maximum dose value is higher in comparison to Reference Scenario approximately by factor of 10.

No.	Title	Max dose, mSv/year	Comment
8.	Hypothetical scenario, Case 4	1.934E-05	Radionuclide releases from bitumen compound are going straight into technogenic soil layer (IGS1) next to the canyons and are further transported by this layer up to the lake bypassing natural geological layers. It is observed that total dose received due to consumption of contaminated lake water is higher by factor 1.6 in comparison to Reference Scenario (lake case).
9.	Hypothetical scenario, Case 5	3.608E-03	Kd=0 values are assumed for the layer of technogenic soil (IGS1) since start point of the analysis. Total maximum dose value is higher in comparison to Reference scenario by factor 1.2.
10.	Hypothetical scenario, Case 6	7.536E-02	Bitumen matrix does not function just after repository closure and the instant release of radionuclides is assumed. Maximum dose is one order of magnitude higher in comparison to Reference scenario.
11.	Hypothetical scenario, Case 7	3.668E-02	Water uptake rate of the bitumen matrix is one order of magnitude higher in comparison to Reference scenario. In addition advection phenomena for radionuclide releases from bituminised waste through the bottom engineered barriers to vadose zone is considered. Therefore total maximum dose value is higher in comparison to Reference Scenario approximately by factor of 16.
	INADVERTENT INTRUSION SCENARIOS		
12.	Road construction scenario	8.791E-03	Road construction through the repository site after completion of the institutional control. The most significant contribution to the total exposure dose value is resulted from ^{94}Nb and ^{137}Cs. The most critical exposure pathway for the worker constructing the road across the repository site would be the external exposure from the discovered and dispersed waste
13.	On-site residence scenario	3.724E+00	Living in house which is built at the repository site after completion of the institutional control period, A highest dose value would be received by infant and, the most contribution to the total exposure dose would be resulted from ^{99}Tc.
14.	Drilling scenario	4.128E-03	Drilling for archaeological exploration is considered. Max value of the total dose would be for researcher No. 1 in the laboratory.

5 ANALYSIS OF ALTERNATIVES

The objective of the proposed economic activity is the reconstruction and transformation of the existing bituminized radioactive waste storage facility into a repository. The reasonable alternatives for this activity are location, i.e. to construct the repository in another site (then the bituminized RAW should be removed from the existing storage facility, placed in packages and transported to the new repository), and “zero”, i.e. bituminized RAW continues to be stored in building 158 (the building is not reconstructed, additional engineered barriers are not installed). As a technological alternative, engineered barriers with different properties (e.g. thickness, composition, load-bearing structures) could be used to transform building 158 into the repository [10]. However, the installation of these barriers with different properties is more related to the structural features of building 158 than to the potential impacts on environmental components, and therefore these technological solutions are not further considered as an alternative to the proposed economic activity.

A previous analysis of the long-term safety of building 158 [5] has shown that after evaluating the storage structures and environmental conditions, waste properties and changes in properties in the long-term perspective, building 158 will start to degrade under the influence of external climatic factors. If the drainage system stops working, the rising groundwater would contact the reinforced concrete bottom of the storage facility and, if it penetrates through, would leach bituminized radioactive waste. Therefore, the “zero” alternative is relevant for a relatively short period of time, and then the bituminized radioactive waste will have to be managed – either by transforming the existing storage facility into a repository or by constructing a new repository at another site. Thus, the main alternative with potential impacts on environmental components that are compared to the PEA by assigning relative impact significance values is the location alternative.

As the main option for the location alternative, it is assumed that the new repository is constructed at the Ignalina NPP site, however the potential impacts if the repository would be constructed outside the Ignalina NPP site is also discussed. In either location alternative, the bituminized RAW would have to be removed from building 158, placed in appropriate packages, transported to the new repository site and disposed of at the repository. After unloading bituminized RAW from building 158, storage structures contaminated with radioactive materials would remain, which would need to be decontaminated, dismantled (demolished) and the resulting waste managed. Table 5.1 presents a summary comparison of what additional activities would be required while implementing the location alternative. It shall be noted, that experience of retrieval of bituminized waste, its transfer, and disposal at another site currently is not well-known in the world practise, but cases of transformation of storage facilities into repositories have been successfully implemented in

France, Great Britain and the USA [58–60].

Table 5.1. Comparison of the main activities in the case of the implementation of the location alternative

Activity	Location alternative	Storage transformation
Opening of bituminized RAW stored in building 158, retrieval from canyons and placing into appropriate packages	YES	NO
Dismantling of technological and service rooms and equipment of building 158 (2nd-floor)	YES	YES
Deactivation and dismantling of building 158 canyons (1st-floor)	YES	NO
Bituminized RAW transportation	YES	NO
Interim storage of bituminized RAW	YES	NO
Construction of repository vaults	YES	NO
Bituminized RAW placement into the repository	YES	NO
Installation of surface engineered barriers	YES	YES
Institutional control after repository closure	YES	YES

As can be seen from Table 5.1, in the case of location alternative additional activities related to the retrieval and transportation of bituminized RAW, the construction of a new repository, etc. will be necessary. The implementation of these activities would require additional materials and resources, this would also cause additional radiological and non-radiological negative impacts on environmental components. A comparison of the impacts of the PEA with the location alternative by assigning relative impact significance values (ISV) to certain component is presented in Table 5.2. The accepted impact significance values are described in Table 5.3.

Table 5.2. A comparison of the impacts of the PEA with the location alternative

Environmental component	Storage transformation	Location alternative
Water	The hydrological and hydrogeological conditions of the Ignalina NPP site and its surroundings are well known. The radiological impact is assessed – it is below the permissible limits. (ISV = -1)	In order to ensure that negative impacts are of low significance, legal acts and regulatory documents define requirements and criteria that nuclear facilities must meet. If the repository is constructed on another site, it will be necessary to ensure that the defined requirements and criteria are met. (ISV = -1)

Environmental component	Storage transformation	Location alternative
Environmental air	Larger amounts of radionuclides could be released into the ambient air only in case of accidents and inadvertent intrusion into the repository after the end of institutional surveillance period. (ISV = -1)	Besides the accidental releases and inadvertent intrusion into the repository event, the retrieval, transportation and placement of bituminized RAW in the repository create additional pathways for the radionuclide releases into ambient air. Increased non-radiological air pollution is also likely as a result of the repository construction activities. (ISV = -2)
Soil	There is no natural soil layer around the building 158 at the INPP site. The top layer of the engineering barrier (multilayer cap) formed around and above building 158 will consist of soil and plants. (ISV = +1)	Construction of the repository on another site will involve earthworks and the local soil layer will be affected. (ISV = -1)
Underground (geology)	There are no valuable underground resources at the INPP site and its surroundings. Impact on underground (geological) components is not expected. (ISV = 0)	If a new repository is constructed at the INPP site, there would be no impact on the underground (ISV = 0). However, depending on the choice of the place for the new repository outside the INPP site, a potentially negative impact is possible.
Biodiversity	Building 158 is located within the site of the INPP, where there is no biodiversity. There will be no impact on biodiversity under normal operating conditions (ISV = 0), in case of accidents the impact of low significant can be expected (ISV = -1).	If a new repository is constructed at the INPP site, the impact is the same. Depending on the new place selected outside the INPP site and the biodiversity present within or adjacent to it, the negative impact may be low (ISV = -1) or moderately significant (ISV = -2).
Landscape	Building 158 is located within the INPP site, the transformation of the storage facility into a repository will create a 13 m high artificial hill. Since valuable landscape areas, for instance Grazute Regional Park and Smalva hydrographic reserve are distant from the INPP site, thus there will be no impact on landscape. (ISV = 0)	If a new repository is constructed at the INPP site, the impact is the same. The impact on the landscape depends on the selected place outside the INPP site. It is assumed that there would be no impact on the landscape. (ISV = 0)
Social and economic environment	Impact on or change to social and economic environment are not expected. (ISV = 0)	If a new repository is constructed at the INPP site, the impact is the same. The impact at another place, outside the INPP site, depends on how far the chosen place is from populated areas, commercial facilities, which public roads would be used to transport the bituminized RAW, etc. It is accepted

Environmental component	Storage transformation	Location alternative
		that the impacts on social and economic environment are likely to be negative of low significance (ISV = -1).
Ethnic and cultural conditions, cultural heritage	PEA will be implemented within the INPP site and will not affect the adjacent cultural heritage objects and the ethnic and cultural conditions. (ISV = 0)	If a new repository is constructed at the INPP site, the impact is the same. The impact at another place (outside the INPP site) would depend on the presence of cultural heritage objects at the immediate vicinity of the new place (ISV = 0 or -1).
Public health	The results of the radiological impact assessment show that for all considered evolution scenarios and in case of inadvertent intrusion into the repository, the calculated annual doses to a member of the reference group of population are below the permissible limits. (ISV = -1)	In order to ensure that negative impacts are of low significance, legal acts and regulatory documents define requirements and criteria that nuclear facilities must meet. If the repository is constructed on another site, it will be necessary to ensure that the defined requirements and criteria are met. However, due to additional activities related to bituminized RAW retrieval, transportation, dismantling of storage facility, etc. (see Table 5.1) the radiological impact to a member of the reference group of population would be higher. (ISV = -2)
Total environmental impact scores	-3	-9

Table 5.3. Impact significance values (ISV)

Impact significance	Positive impact	Negative impact
Significant	+3	-3
Moderately significant	+2	-2
Lowly significant	+1	-1
No effect	0	0

6 MONITORING

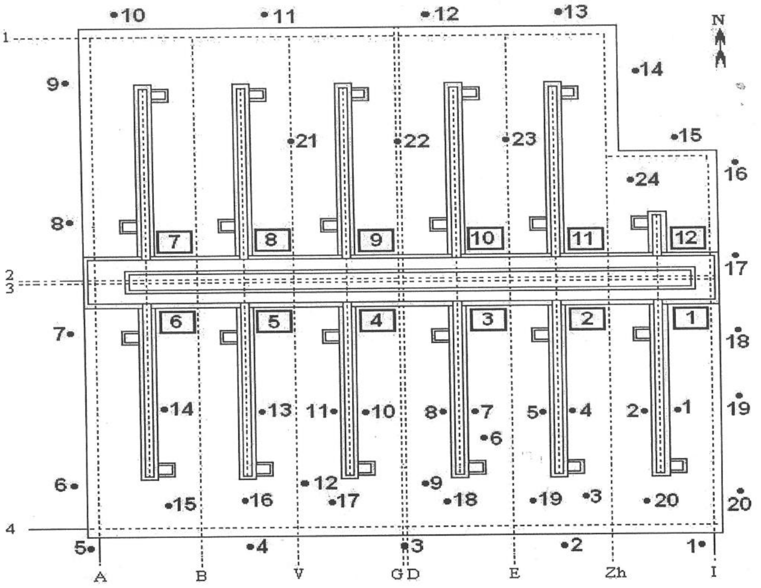
Systematic environmental monitoring is carried out in order to:

- demonstrate that the radiation doses to workers and population do not exceed the defined limits;
- verify that the operating conditions of the surface disposal facility is in accordance with the established ones and to warn of any deviations;
- inform the public about the increased environmental pollution (in the event of radionuclide release from the repository);
- collect the data necessary for the assessment of the exposure doses caused or expected to be caused by the repository;
- identify the contribution of the repository to environmental contamination, distinguishing it from the effects of other sources of contamination.

Taking into account the peculiarities of the operation of building 158, two environmental monitoring processes should be distinguished. From 1987 to the present day, building 158 is a storage facility for bituminous radioactive waste, which is monitored according to the currently valid Ignalina NPP environmental radiological monitoring [61]. In accordance with this program, groundwater samples are taken from boreholes in the vicinity of the building, dose rate values on the roof and walls of the building are measured at defined points (see Figure 6.1), etc. This EIA report provides a conceptual description of environmental radiological monitoring when building 158 will be transformed into a repository, i.e., engineering barrier will be installed, a multilayer cap will be formed. It should be mentioned that monitoring will not be carried out during the period of passive institutional control.

КАРТОГРАММА КРОВЛИ И СТЕН ОТСЕКОВ КАНЬОНОВ ЗД. 158

Дата измерений 2016-8-25 Прибор СРП № 736



№ к.т.	Pγ кровля	Pγ стены	№ к.т.	Pγ кровля	Pγ стены	№ к.т.	Pγ кровля	Pγ стены	№ к.т.	Pγ кровля	Pγ стены
1	0,15	0,12	7	0,12	0,1	13	0,1	0,1	19	0,09	0,13
2	0,13	0,1	8	0,12	0,13	14	0,16	0,13	20	0,12	0,15
3	0,14	0,13	9	0,09	0,1	15	0,09	0,1	21	0,13	
4	0,16	0,12	10	0,14	0,12	16	0,09	0,12	22	0,2	
5	0,18	0,13	11	0,15	0,09	17	0,1	0,1	23	0,2	
6	0,15	0,12	12	0,1	0,09	18	0,1	0,1	24	0,16	
Дополнительные измерения с указанием точек на схеме											

ПРИМЕЧАНИЕ: 1. Измерения Pγ проводились на расстоянии 1 м от поверхности крыши и стены.

2. Единицы измерений: Pγ мкЗв/час

Измерения выполнил: ____________ (Подпись, должность, имя, фамилия)

п. 9.2.18. (2012-сентябрь)

Журнал картограмм зд. 150.doc

Figure 6.1 pav. Cartogram of the walls and roof of bld. 158:

Дата измерений – Date of measurements; Прибор – device; *№ к.т.* – Number of check point; P_γ *кровля* – dose rate on the roof; P_γ *стены* – dose rate from the wall; *ПРИМЕЧАНИЕ* – Note):

1. Measurement P_γ is taken at the 1 m distance from roof or wall;
2. Measurement P_γ units μSv/h.

Environmental monitoring of a repository includes measurements of dose rate, external absorbed dose and radionuclide activities in various environmental components. The selection of environmental objects is determined by the exposure significance of representative member due to the radionuclides they may contain. Automatic electronic devices are usually for dose rates measurements and dose-accumulating devices (thermoluminescent dosimeter) are used for measuring external absorbed dose. Environmental objects shall be sampled for radioisotopic analysis in the vicinity of drainage water and other effluent discharges and in areas of highest probable contamination. The radionuclide composition of the samples shall be determined to assess the contamination of the environment by measuring the specific activities of gamma-emitters. Contamination with beta (^{90}Sr, ^{3}H, ^{14}C, etc.) and alpha (^{239,240}Pu, ^{241}Am, etc.) emitting radionuclides shall be assessed by analysing a selection of representative samples. For measurements of the specific activities of beta- and alpha-emitters, elemental chemical extraction methods shall be used where necessary.

The tentatively proposed environmental monitoring points and the environmental components to be radiologically monitored during active institutional control period of the repository are shown in Figure 6.2 and Table 6.1. A detailed environmental radiological monitoring program will be developed during the preparation of the technical design.

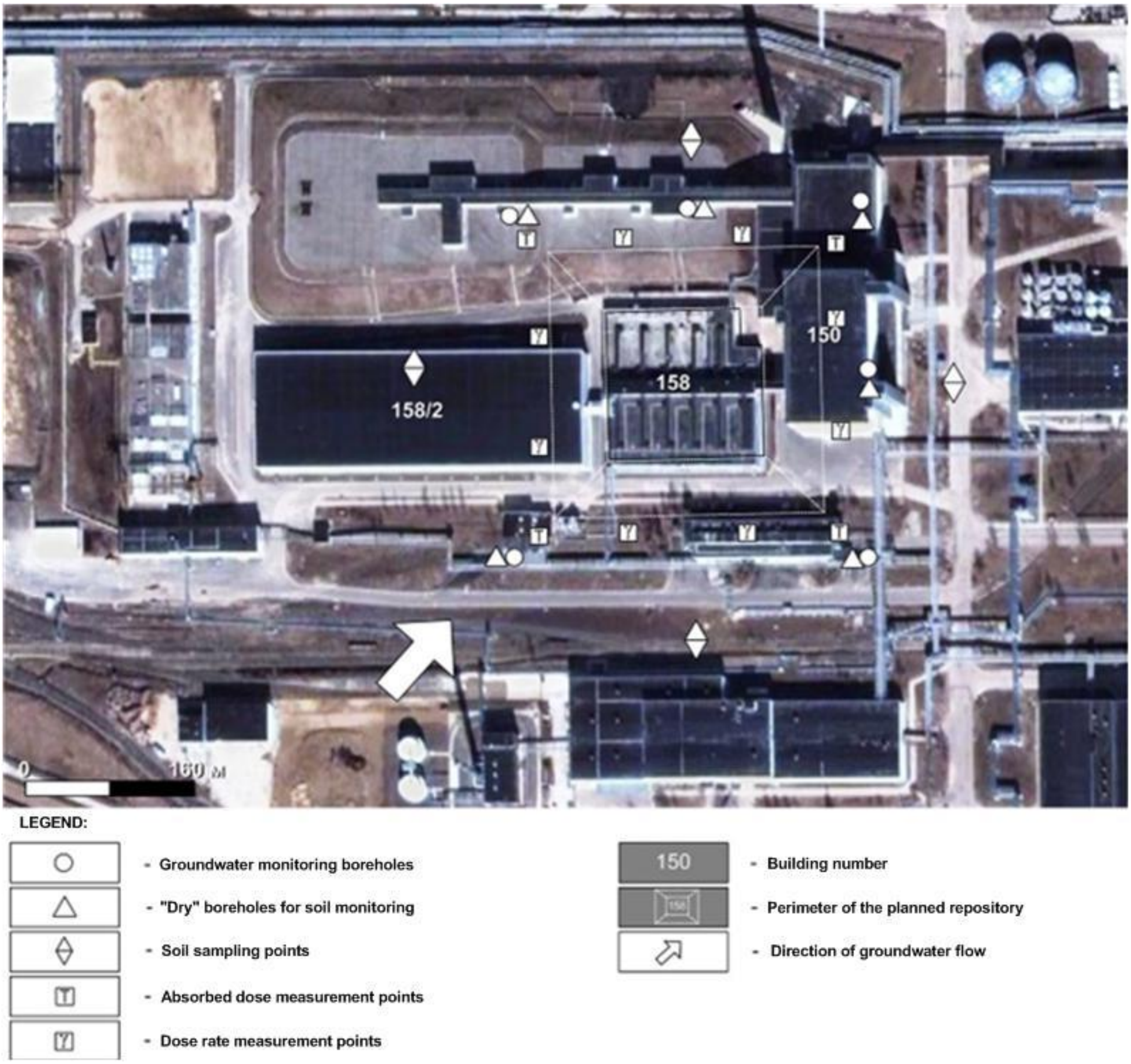


Figure 6.2. Monitoring points for the bituminized radioactive waste repository (during the active institutional control period)

Table 6.1. Monitoring of the bituminized radioactive waste repository (during the active institutional control period)

No.	Object	Measured parameters	Measurement periodicity	Comments
1. Groundwater monitoring				
1.1.	Water from 6 boreholes in the repository area	Gamma nuclides composition	2 times a year (in spring and autumn)	Planned borehole locations are provided in Figure 6.2.

No.	Object	Measured parameters	Measurement periodicity	Comments
2. Rainwater drainage monitoring				
2.1.	Drainage water	Amount	1 time per month	It will be taken into account in the technical design of the rainwater drainage system
2.2.	Drainage water	Chemical properties of water (pH, concentration of basic anions, cations and dissolved oxygen)	1 time per month	Monitoring locations and measured basic anions and cations will be determined during the preparation of the technical design of the repository
		Physical properties of water (temperature, density, electrical conductivity, suspended particles)	1 time per month	
		Specific activities of gamma emitters	1 time per month	
		Total activity of alpha emitters	1 time per month	
		Total activity of beta emitters	1 time per month	
		^{90}Sr specific activity	1 time per month	
		$^{239,240}Pu$ specific activity	1 time per year	
		^{14}C specific activity	1 time per year	
2.3.	Water body (Drūkšiai lake) into which effluents containing radionuclides potentially can be released	Water level	Every quarter	
		Chemical and physical properties of water, concentration of suspended particles and sedimentation rate	1 time per year	
3. Monitoring of other environmental objects				
3.1.	Soil, 4 sampling points around the perimeter of the repository	Gamma nuclides composition	1 time per year (in autumn)	The planned sampling locations are shown in Figure 6.2.
		^{90}Sr specific activity		
		Total activity of alpha emitters (Pu)	1 time in 5 years	
3.2	Grass at soil sampling points around the perimeter of the repository	Gamma nuclides composition	1 time per year (in autumn)	
		^{90}Sr specific activity	1 time per year (in autumn)	
3.3	Ground from 6 “dry” boreholes around the perimeter of the repository	Gamma nuclides composition	Every quarter	The planned sampling locations are shown in Figure 6.2.

No.	Object	Measured parameters	Measurement periodicity	Comments
4. Monitoring of absorbed dose and dose rate				
4.1.	Dose rate at 8 measurement points around the perimeter of the repository	Gamma dose rate	Every quarter	The planned measurement points are shown in Figure 6.2.
4.2.	Absorbed dose at 4 measurement points	Absorbed dose (gamma radiation)	Continuously, data is recorded quarterly	The planned measurement points are shown in Figure 6.2.

7 RISK ANALYSIS AND ASSESSMENT

This section of the EIA report considers possible accidental situations (risks) that may arise during the implementation of proposed economic activity and assesses the potential radiological impact due to the accidents.

The disposal of bituminised radioactive waste *in situ* will avoid the loading/unloading operations of packages, therefore, no accidents related to package drop and radionuclide release will occur. `

Likewise, no accidents related to radionuclide release during construction of surface barriers are foreseen, as the ceiling slab of the bld. 158 will not be damaged. Heavy metallic structures transfer height above this concrete slab will be restricted so that to avoid damage during the event of potential drop of metallic beams.

The following initiating events that potentially can cause the damages of engineered barriers of the repository and radionuclide releases into environment:

- External natural, namely earthquake, ground settlement, increase of atmospheric precipitation;
- External man-induced, namely airplane crash onto the repository;
- Internal man-induced, such as a fire;
- Failure of the equipment and its components, namely malfunctioning of drainage system.

The accidental situations potentially caused by the above-mentioned initial events and their potential radiological impact on the environment are identified below.

7.1 Analysis of initiating events

7.1.1 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 [11]. The formation of cracks in the engineered barriers of the repository could occur in the seismic event. It is assumed that due to an earthquake the side walls as well as the top (cap and concrete top layers of the canyons) and bottom (bottom layers, leveling layer and foundation) engineered barriers of the repository should be completely destroyed and all the surface of the bituminised RAW would appear available to the water uptake. A case of earthquake incident just after repository closure is considered when due to water uptake the radionuclides released from the bitumen matrix are transported directly into the geological layers. The top barriers could be repaired or reconstructed during active institutional control period therefore it is assumed that the cap will be repaired immediately after earthquake accident, however no concrete engineered barrier will be performing the function of radionuclide containment.

It should be noted, that in principle the absence of voids in the building and its transformation into the repository could be equated to a monolithic block buried under a layer of thick soil, therefore seismic loads are not directly dangerous. In this case, the most important factor is the stability of the slopes, which is ensured by a 3: 1 slope and technological measures such as properties of filled soil, slope support barriers, proper drainage of rain and ice-melting water, drainage.

7.1.2 Ground settlement

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. It should be noted that in case of the earthquake it is conservatively assumed that the repository‘s side walls and top slab should be completely destroyed, thus, the radionuclide transport through the side walls and top slab is not taken into account. Only consequences of an earthquake will be considered in the further analysis, meaning consequences of ground settlement under the repository as well.

7.1.3 Increase of atmospheric precipitation

In the analysis of radionuclide migration through the components of the disposal system, it is assumed that due to increase of amount of atmospheric precipitation the water flow passing the layer of technogenic soil (IGS1) increases from the value 1.27E-09 m/s (or 0.04 m/year) to maximum value of hydraulic conductivity 2.12E-04 m/s just after repository closure [17].

7.1.4 Airplane crash

The engineered barriers should be destroyed after the airplane crash in the repository site. The probability of the airplane crash depends on number of the parameters, namely the intensity of flights in the region, effective area of the facility, etc.

An airplane crash analysis provides an estimate of the probability of airplane crash onto the repository [17]. The results of the calculated airplane crash probabilities are presented in Table 7.1.

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 7.1. Probabilities of airplane crash onto the repository of bituminised RAW

Probability type	Value
Airplane crash probability related to the airports located beyond 8 km	**5.65E-10**
Airplane crash probability when the air traffic corridor pass at the distance *s=10 km* from object	**8.88E-10**
Airplane crash probability when airplanes pass the 50 km zone on the straight line touching the 10 km zone around the INPP	**3.01E-08**

Airplane crash probability calculations have showed that in all cases the probability is less than the screening probability level (SPL) (1.0E-07 per year for nuclear objects). The initiating events with a probability of occurrence lower than the SPL should not be given further consideration in spite of their consequences [62].

Nevertheless, radiological consequences due to accident of civil airplane crash in to the bld. 158 have been assessed and provided in the report [47]. The release of radionuclides into the environment was assessed considering RW combustion rate and mobility of radionuclides at elevated temperatures. In the case of airplane crash accident, the rate of radionuclides release is 4.6E+12 Bq/h. Up to 3.2E+13 Bq can be released during the 7 hours fire. This constitutes approximately 14% from the total activity that is stored in the facility. The major contributor in the released activity is Cs-137. The activity share of this radionuclide is approximately 99.8% from the total activity released into the environment. Other radionuclides, which shares in the released activity are approximately 0.1% each, are C-14 and Cs-134. The atmospheric dispersion and sedimentation of radionuclides onto the ground surface was assessed using the AERMOD modelling system [45] and the Lakes Environmental Consultants Inc. developed user interface AERMOD View [46]. Effective doses to the selected representatives include all relevant internal and external exposure pathways (external exposure from submersion into radioactive cloud; internal exposure from inhalation of radionuclides from radioactive cloud; external exposure from onto the ground surface deposited radionuclides; internal exposure from ingestion of radionuclides with contaminated food products). The assessment of a civil airplane crash into the bituminized RW storage facility (the building 158) accident [47] shows, that the accident resulted radiological impact to the population due to release of airborne activity is insignificant. According to the conservative dispersion scenario, the 24 hours exposure of member of the population is 0.001–0.003 mSv. The corresponding annual effective dose is approximately 0.06 mSv. According to the realistic dispersion scenario, the 24 hours exposure of member of the population is less than 0.001 mSv. The corresponding annual effective dose is approximately 0.005 mSv. The highest doses are observed close to the INPP site and in the distance from 2 km to 5 km from the release source (the building 158).

7.1.5 Fire

Engineered barriers installed over the building as well as building structures will restrain oxygen access to the bituminized radioactive waste. As shown in the RAW description section of the document [10] the temperature of bitumen self-ignition is 400 °C. However, investigations have shown that even with up to 45% of evaporator concentrates incorporated into bitumen the possibility of ignition is excluded [24]. Taking into account the factors mention above a fire as a result of self-ignition is not further considered.

The radiological consequences due to an external fire are covered by airplane crash accident scenario, as it has more severe radiological consequences.

7.1.6 Malfunctioning of drainage system

Flooding is not expected even under conservative assumptions (see [27]). 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 geological layers. 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.

7.2 Impact assessment of possible accidents

A list of identified accidental situations included into the further analysis of the potential impact is presented in Table 7.2.

Table 7.2. Identified emergency situations [16]

Initiating event	Potential impact	Consequences of accident	Remark
Earthquake	Collapse of the repository’s engineered barriers	The repository’s concrete structures lost the function of RAW containment, radionuclide release.	
Increase of amount of atmospheric precipitation	Increase of water infiltration into the technogenic soil	Increase of radionuclide activities transported through the geosphere zone.	

Initiating event	Potential impact	Consequences of accident	Remark
Failure of the drainage system	Flooding	Radionuclide transport by surface water into lake Druksiai bypassing geological layers.	No radionuclide migration before incident (conservative assumption)

7.2.1 Damage of engineered barriers due to earthquake or natural ground settlement

It is assumed that an earthquake occurs immediately after the repository closure. The repository‘s side walls as well as top and bottom engineered barriers and are completely destroyed after the earthquake, but the cap will be repaired.. The whole surface of the exposed waste is available for water uptake. Radionuclides are released (diffused) from the bitumen matrix into the geosphere. Transport of radionuclides through the destroyed concrete structures of the facility is not taken into account because they don’t perform the containment function anymore. The conditions of radionuclide transport through the geosphere layers identified in the site) are the same as in case of the reference scenario. The exposure to a member of the reference group of the population resulted from the consumption of the contaminated water from the well for daily needs is assessed.

The assumptions taken into account for the incident are the same as for hypothetical scenario Case 2 when the bottom slab, leveling layer, foundation (“pillow”), walls as well as top slab are with cracks just after the repository closure but the cap would be repaired. Maximum doses received by the member of reference group of population due to consumption of contaminated water from the well are presented in Table 4.19.

7.2.2 Increase of water infiltration through the layer of technogenic soil due to increase of precipitation amount

The increase of water flow through the layer of technogenic soil due to increase of the precipitation is estimated in case of the natural evolution scenario, except value of water flow infiltrated through layer of technogenic soil which in this case equals to 2.12E-04 m/s just after repository closure. The radionuclide activity released from the bitumen compound and diffused out of the building are presented in Figure 4.11. Exposure doses received by member of reference group of population consuming well water in case of extreme precipitation are presented in Table 7.3.

Table 7.3. Exposure doses received by member of reference group of population consuming well water due to maximum flow rate through the layer of technogenic soil in case of extreme precipitation

Radionuclide	Maximum dose, mSv/year	Maximum time after repository closure, years
^{14}C	4.147E-03	1 290
^{36}Cl	3.407E-05	327
^{99}Tc	5.138E-05	6 300
^{129}I	1.100E-04	453
Total:	**4.342E-03**	

Table 7.3 shows, that the increase of the total dose in the considered case is approximately 33% higher in comparison to base case (natural evolution of the repository) scenario (see Table 4.13), and the dose remains below the design criterion, 0.1 mSv per year, by two orders of magnitude.

7.2.3 Flooding due to malfunction of the drainage system

According to the description of the drainage at the INPP industrial site (see [17]) two systems regulating the water regime and water level at the site are operated by technical means at the INPP site – industrial rainwater drainage system (IRD) and drainage system for main buildings. It is intended that the buildings as well as the drainage system for main buildings will be dismantled during INPP decommissioning while IRD likely will remain and will be maintained within active institutional control period. However, the IRD maintenance will not be possible after completion of the active institutional control period; therefore, malfunction of the drainage system just after active institutional control period (100 years) is considered. 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 geological layers. A member of the reference group will receive a certain exposure dose resulted from the consumption of lake water for daily needs as well as due to ingestion of the fish from lake.

All conditions and parameter values are assumed the same as for Reference Scenario, except conservative assumption that during institutional control period of 100 years before flooding starts only radioactive decay is taken into account and no radionuclide releases from the repository are assessed.

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 7.4.

Table 7.4. 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	Maximum dose, mSv/year	Maximum time after repository closure, years
^{14}C	1.938E-05	1 260
^{99}Tc	1.488E-06	956
^{129}I	3.232E-08	452
^{137}Cs	1.246E-04	184
Total:	**1.455E-04**	

The table presented above demonstrates that the total exposure dose is one order of magnitude higher in comparison to Reference Scenario and remains below the design criterion of 0.1 mSv/year by three orders of magnitude in case of flooding. The value of the total exposure dose is mostly determined by ^{137}Cs. The contribution of other radionuclides is negligible.

7.3 Emergency preparedness

According to Nuclear Safety Requirements [63], the organization operating a nuclear facility (NF) (license holder) must ensure the prevention of accidents and incidents, and, in case of an emergency, be prepared to immediately perform the following actions:

- Apply measures to return the NF to a safe state where the long-term performance of safety functions is ensured;
- Protect people present in the NF and its sanitary protection zone;
- Mitigate the consequences of the accident;
- Perform accident classification;
- Inform VATESI and other state bodies of control and supervision involved in the response to the accident about the accident;
- Mobilize the forces and measures of the civil safety protection system to eliminate the accident;
- Use the necessary services and measures from entities outside the NF site to mitigate and eliminate the consequences of accidents;
- Monitor radionuclide pollution inside the NF and in its sanitary protection zone.

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 [64], emergency preparedness of the planned activity will be integrated into the existing INPP emergency preparedness structure. In order to ensure emergency preparedness of the repository the INPP Emergency Preparedness Plan (general and working parts) will be reviewed and updated respectively.

Identified initiating events and accidental situations are estimated in Sections 7.1 and 7.2. The consequences of the external hazards (earthquake, extreme precipitation) as well as the hazards due to human activity (airplane crash, fire, flooding due to malfunction of the drainage system) are considered. 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. All possible emergency situations and their consequences will be analysed within scope of the safety analysis report of the repository during development of the Technical design.

8 POTENTIAL IMPACT ON NEIGHBORING COUNTRIES

Two states, Belarus and Latvia, are relatively close to the site of proposed economic activity (see Figure 8.1). Border between Lithuania and Belarus is about 5 km east and south-east from INPP industrial area. Lithuanian and Latvian state boarder is about 8 km north from INPP industrial area. Other states are at the distance of several hundred kilometres from INPP.

Higher radiological impact for environment water component may be anticipated due to proposed economic activity, i.e. for the Lake Druksiai, part of which is at the territory of the of Belarus. Since the area of the Lake Druksiai is located only within the territory of Lithuania and Belarus, and the Ricianka river, via which water connection with the Lake Rica partly located in Latvia (see Figure 4.1) is possible, flows towards the Lake Druksiai, but not out of it, therefore is no potential radiological impact for Latvian environment components and its population.

The summary results of the evaluation of the radiological impact of the assumed scenarios on the representative member of population are presented in Table 4.27. The scenarios of inadvertent intrusion into the repository are not relevant for residents of neighbouring countries. The maximum annual dose due to the water pathway scenario to the representative member, which daily uses a contaminated water from a well (located 50 meters from the repository) and assuming the very conservative hypothetical case that lower layers, foundation, walls and top slab of the repository is cracked immediately after its closure, and the multilayer cap is also assumed to be degraded immediately after a closure, is about 10 times lower than the dose constrain of 0.2 mSv/year. Taking into account that the nearest neighbouring settlements are more distant (at 5 and 8 km distances) from the site of the proposed economic activity, i.e. further than the distance taken into account for the assessment of the radiological impact on the representative member of population (50 metres away), the health impact on the population of neighbouring countries would be even lower when considering the same water pathways as for the representative in the vicinity of the repository, as the dispersion coefficient shows that the increase in distance from the source of the discharge results in a decrease in the activity concentrations of radionuclides and the resulting doses of radiation exposure. The impact of direct ionizing radiation to the population from the repository is insignificant.

There is no other impact estimated for other environment components in the neighbouring countries during performance of the proposed economic activity.

Figure 8.1. Location of INPP industrial area, where bld. 158 is located, in regard to the neighbouring countries

9 DESCRIPTION OF DIFFICULTIES

There were no problems during the preparation of the EIA program and at this stage of the preparation of the EIA report.

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