PROJECT ’PURCHASE OF STUDIES FOR THE PREPARATION OF A DESIGNATED SPATIAL PLAN AND THE ASSESSMENT OF IMPACT’

PROJECT PART: STUDIES NECESSARY FOR THE ESTABLISHMENT OF THE RADIOACTIVE WASTE REPOSITORY

ACTIVITIES 1-3. Determining the three most optimal locations for the repository. Studies of the three repository locations. Comparison of the repository locations

FINAL REPORT

Revision No: 1
CPV Code: 71240000-2, 71313400-9
Consultant’s Contract Number: Nr. 58
Client: AS A.L.A.R.A.
Registration Number: DSP-08-3.5-EN
Date of development: November 17, 2023

Euroopa Liit
Ühtekuuluvusfond

Eesti
tuleviku heaks

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APPROVAL SHEET

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REVISION SHEET

Revisions of this document are made by replacement of the complete document, including the title page with signatures. Replacement of individual pages is not permitted.

Current revision is indicated in the header of all pages.

The reasons for the release of a new revision and/or main modifications to the current revision and the pages concerned are recorded in the list revision below.

Rev.	Reason for revision	Date of issue
1	Original issue	17 November 2023

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Abbreviations

ALT	Altküla site
BOSS	Borehole Disposal of Disused Sealed Sources
IAEA	International Atomic Energy Agency, an organ of the United Nations competent in fields of radiation protection, nuclear safety, and management of radioactive waste.
ICRP	International Commission on Radiological Protection
IDDF	Intermediate Depth Disposal Facility
NSDF	Near Surface Disposal Facility
PAL	Paldiski site
PED	Pedase site
DSRS	Disused Sealed Radioactive Source
FPNS	Former Paldiski Nuclear Site
NL	Not Limited (the calculated limiting activity exceeds the specific activity the radionuclide). It is also used if the particular radionuclide is not available in the considered waste stream
NORM	Naturally Occurring Radioactive Material
NSDF	Near Surface Disposal Facility
NSR	Near Surface Repository
PAL	Paldiski site
PED	Pedase site
SAR	Safety Assessment Report
SEA	Strategic Environmental Assessment
WAC	Waste Acceptance Criteria

Relevant Definitions

Closure means the completion of all operations at some time after the emplacement of radioactive waste in a disposal facility, including the final engineering or other work required to bring the facility to a condition that will be safe in the long term.

Disposal means the emplacement of radioactive waste in a facility without the intention of retrieval.

Disposal facility means any facility or installation the primary purpose of which is radioactive waste disposal.

Engineered barrier means a feature made or altered by humans which delays or prevents radionuclide migration from the waste or the disposal structure into its surroundings; it may be part of the waste package or part of the disposal structure.

Institutional control means control of a radioactive waste site by an authority or institution designated under the law. This control may be active (monitoring, surveillance, remedial work) or passive (land use control) and may be a factor in the design of a facility.

Intrusion, inadvertent or intentional, means the process by which living organisms, including humans, may come in contact with disposed or stored waste.

Pre-operational period of the disposal facility includes concept definition, site evaluation, Safety Assessment and design studies. The pre-operational period also includes the development of programmes and procedures required in support of the application for a licence for construction and initial operation of a disposal facility. During this period, the monitoring and testing programmes that are needed to establish baseline conditions should be put in place.

Operational period of the disposal facility begins when waste is first received at the facility. From this time, radiation exposures may occur as a result of waste management activities, and these are subject to control in accordance with the requirements for protection and safety. In the operational period, construction activities may still take place at the same time as waste emplacement in and closure of other parts of the facility. This period may include activities for waste retrieval, if considered necessary, prior to closure, activities following the completion of waste emplacement and final closure, including backfilling and sealing of the facility.

Post-closure period begins at the time when all the engineered containment and isolation features have been put in place, operational buildings and supporting services have been decommissioned, and the facility is in its final configuration. After closure, the safety of the disposal facility is provided for by means of passive features inherent in the characteristics of the site and the facility as well as of the waste packages. A monitoring and surveillance programme is aimed at confirming that the disposal system is performing as expected. Monitoring may also be carried out to enhance confidence in, and therefore acceptance of, the disposal process. For near surface disposal facilities, institutional controls are put in place to prevent intrusion into the facility.

Safety means the protection of people and the environment against radiation risks, and the safety of facilities and activities that give rise to radiation risks.

Scenario means a possible series of events or conditions which describe means of human intrusion or other contact with disposed waste after the closure of the site and following the institutional control period.

Waste Acceptance Criteria mean quantitative or qualitative criteria specified by the regulatory body, or specified by an operator and approved by the regulatory body, for the waste form and waste packages to be accepted by the operator of a waste management facility. Waste acceptance criteria specify the radiological, mechanical, physical, chemical and biological characteristics of waste packages and unpackaged waste.

Waste conditioning means the process which converts the waste into an acceptable concentration and stable form for packaging, shipment and disposal. The process may involve solidification of the waste and/or encapsulation in a stable matrix such as concrete.

Worker means any person who works, whether full time, part time or temporarily, for an employer and who has recognized rights and duties in relation to occupational radiation protection.

Introduction

The Euratom Treaty establishing the European Atomic Energy Community provides for the establishment of uniform safety standards to protect the health of workers and of the general public. To assure implementation of this principle in practice the Council of the European Union has adopted Directive 2011/70/EURATOM establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste. The main objective of this Directive is to ensure that Member States provide for appropriate national high-level safety measures in radioactive waste management to protect workers and the general public against the dangers of ionizing radiation and to avoid imposing undue burdens on future generations. The Member States should establish national programmes to ensure timely implementation of all steps of radioactive waste management from generation to disposal.

In Estonia, the disposal facility is scheduled to be operational in 2040. Waste disposal operations are foreseen at least until 2050 when the decommissioning of the two reactor compartments of the FPNS is planned to be complete. After finishing waste disposal activities the disposal facility should be closed. The ultimate goal of the project is to select the most suitable location of the establishment of the disposal facility for the radioactive waste accumulated Estonian.

The IAEA recommends to follow a step-by-step approach to the development of a disposal facilities for radioactive waste. They shall be developed, operated and closed in a series of steps. Four stages are admitted in the siting process for a radioactive waste disposal facility: (i) the conceptual and planning stage; (ii) the area survey stage; (iii) the site investigation stage; (iv) the stage of detailed site characterization leading to site confirmation for construction of the disposal facility. Each step shall be supported by iterative evaluations of the site, technical options for disposal design, and performance and safety of the disposal system.

The siting of the disposal facility is to be performed using a step wise approach. Identification of the site suitability requirements and selection criteria is a key component of the conceptual and planning stage. At the area survey stage, these features and limitations are used to focus on selection of few potential sites in a region of interest. The site should be selected by narrowing the region of interest and focusing on areas with appropriate features. This step should lead to the elimination of unsuitable areas and the identification of potentially acceptable locations. A goal of **Activity 1** is to propose three optimal locations for the disposal facility.

The potentially suitable sites should be characterized to an appropriate level of detail to provide the necessary information to ensure that the disposal facility can meet the safety requirements for disposal of the intended type of waste. Detailed site characterization should be carried out to provide the site specific data necessary to support the safety assessments of the long term containment and isolation of the waste within the disposal facility. The main objective of **Activity 2** was to study suitability of the previously identified potential locations and to acquire the data necessary to make a decision in principle on the disposal site, i.e. to provide a basis for the strategic assessment of environmental impact of the establishment of the disposal facility and the preparation a designated spatial plan. The potential effects of erosion, flooding, seismicity and other disruptive processes should be sufficiently understood. An account should be taken of the likelihood of future disturbances and radiation protection of people who could be affected by the release of radionuclides from the disposal facility. The disposal facilities should comply with the requirements for protection of the environment. The site should be located so that the environment will be adequately protected for the entire lifetime of the facility and so that potential adverse impacts can be mitigated to an acceptable degree, technical, economic, social and environmental factors being taken into account.

The selection must be in accordance with the local government designated spatial plan and the related assessment of impact, including the strategic assessment of environmental impact of the establishment of the repository. By implementing Activity 2 “Studies of the three repository locations” the necessary data were collected that will serve as the basis for the preparation of these documents and making a decision in principle.

Purpose of **Activity 3** is analyse and compare the available alternative options considering data obtained during the implementation of Activities 1 and 2, and to propose the most suitable one. In addition, an outline for future detailed studies of the selected disposal site has to be prepared in order to get ready to designing the repository and preparing the final Safety Assessment Report and the Safety Case needed for a licence application. Site characterization is undertaken in order to understand the natural features, events and processes at a site. The site characterization should provide information on the effects the natural environment will have on the containment and isolation of radionuclides.

1. ACTIVITY 1. ‘Determining the three most optimal locations for the repository’

As the siting of the disposal facility is to be performed using a step wise approach, Activity 1 includes the initial studies devoted to identification of several locations potentially suitable for construction of the disposal facility for the radioactive waste. The goal of the studies is to identify three potentially suitable locations in the Lääne-Harju county, that would be the subject of further investigations on their suitability. Detail results on the selection process are presented in the Interim Report for Activity 1 completed in 2022.

1.1. Basic Design Options for the Disposal Facilities

Due to the very different properties of the wastes to be disposed of (primarily due to the very different content of radioactive substances in the waste), two different disposal concepts are to be applied in Estonia. The both disposal concepts are flexible, easily adaptable to different waste volumes and waste packages as well as to site specific environmental conditions. Considering the small amount of waste and looking for the most efficient means of operation and maintenance, it was decided to locate the two facilities on the same site [1]. This decision reduces total land area occupied by the disposal facilities and thus reduces overall environmental impact, however, it complicates the site selection process as the site must meet the criteria of both facilities.

The conditioned Low Level Waste is to be disposed of in the NSDF consisting of reinforced concrete vaults built above ground water level with a protective clay layer, Figure 1.1. According the available experience such facilities demonstrate better performance comparing with similar facilities in water saturated zone. A geological environment needed for the facility is such that there is little moisture saturation, good sorption of radionuclides and possibility for water to be drained effectively. Various geological media can be used for hosting the NSDF, for example: till, sand, gravel, limestone, clay. After finishing waste emplacement activities, the vaults will be closed by installation of a multifunctional capping system. The multi-layer system is to protect against infiltration of water, erosion and intrusion (human, animal or plant) [2].

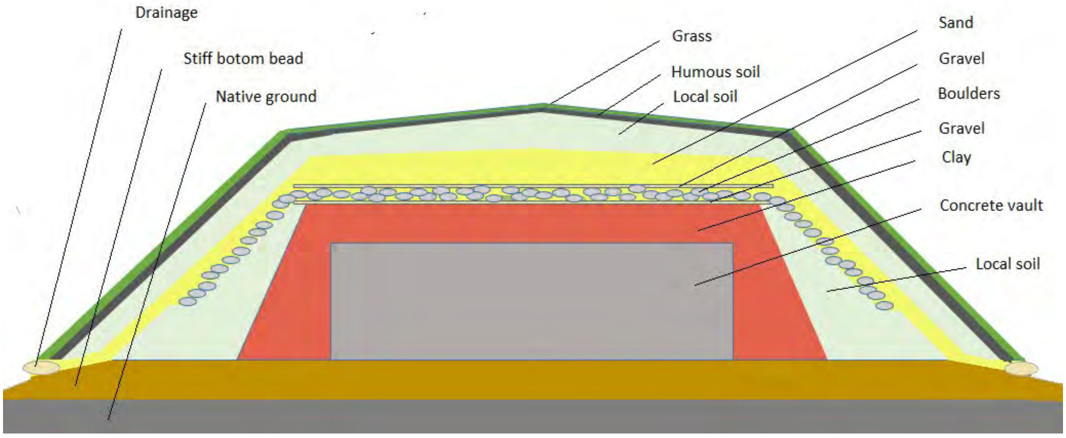

Figure 1.1. Conceptual design of NSDF: cross section of closed concrete vault and the main engineered barriers of the multilayer capping system

The NSDF is a disposal option suitable for waste that contains such an amount of radioactive material that robust containment and isolation is needed for limited periods of time up to a few hundred years are required. The safety relies on a significant radioactive decay during the period of reliable containment and isolation provided by the engineered barriers, the site and institutional controls. The appropriate time periods of active and passive controls following closure of the NSDF are 100 and 200 years respectfully (300 years in total).

Intermediate Level Waste contains long lived radionuclides in quantities that need a greater degree of containment and isolation from the biosphere than is provided by NSDF. Disposal in a facility at a depth of between a few tens and a few hundreds of metres is recommended for such waste [3]. Considering very small amounts of wastes requiring intermediate depth disposal, an Intermediate Depth Disposal Facility (IDDF) of shaft type (Figure 1.2) has been proposed [4].

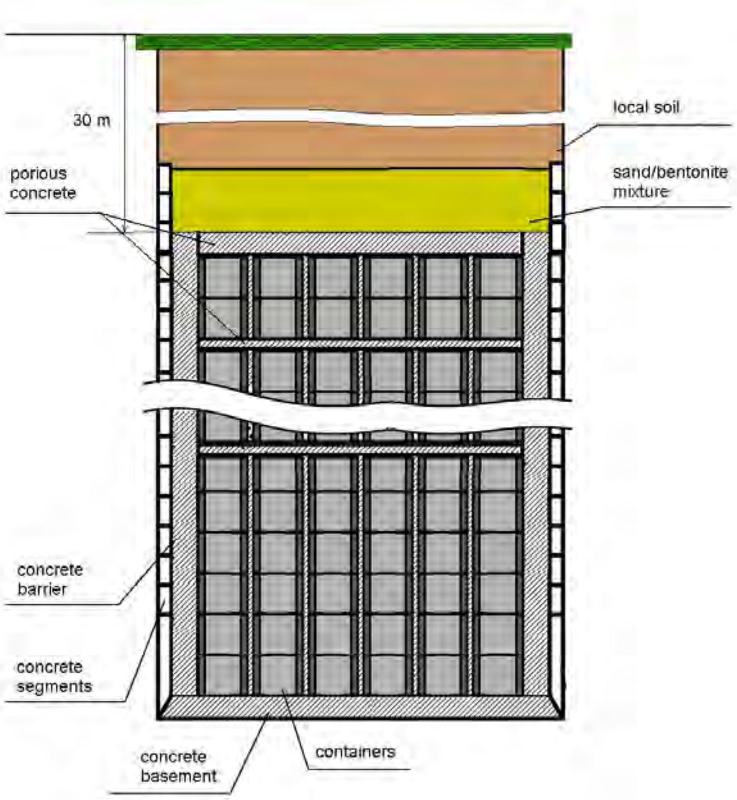

Figure 1.2. Conceptual design of IDDF: cross section of closed shaft-type disposal facility [4].

The foreseen minimal depth of the IDDF is 30 m. Such depth has been accepted as the lower level of the normal residential intrusion zone (a depth beyond which human intrusion is limited to drilling and significant excavation activities, such as mining, tunnelling and quarrying), therefore is commonly used to differentiate between near surface and intermediate depths disposal. Disposal at such depths has the potential to provide a long period of isolation from the accessible environment. In particular, there is generally no detrimental effect of erosion and other surface related processes at such depths in the short to medium term. Another important advantage of disposal at intermediate depths is that the likelihood of inadvertent intrusion is greatly reduced. Consequently, long term safety for disposal facilities at such intermediate depths will not depend on the application of institutional controls.

1.2. Methodology for the selection of the optimal sites

The territory of Lääne-Harju municipality which includes territory of FPNS has already been identified in the Radioactive Waste Disposal Program of Estonia as the region where the Estonian Radioactive Waste Repository will be located. Therefore, all potential sites in this region are taken to the next siting step consisting of screening of the identified region. Lääne-Harju Rural Municipality Council initiated the local government designated spatial planning and strategic environmental impact assessment on 28.01.2020.

The FPNS has been pre-selected candidate for evaluation as one of the three most optimal sites. The recognition of this territory as a potentially suitable was mainly because it is already being used by the waste disposal organization and is (partially) owned by this organization, there is no need to transport the waste, it is supported by existing infrastructure and the local community is used to the existence of the nuclear facility.

Objective of the current screening process is to find other two candidate sites for further evaluation. The most optimal locations for the future disposal are to be identified in a pre-selected region using Estonian national policy options, local municipality development plans, national and local data bases, public information sources as well as outcomes of previous technical studies. These two sites are to be identified by implementing the following steps:

1. Excluding areas where legal requirements and the municipality comprehensive plans may not allow the implementation of such a disposal facility (“negative screening”) and identifying potentially suitable area (or areas) for further investigations (investigation territory).
2. Studies of the identified investigation territory. The following features will be analysed: topography, geomorphology, hydrology, climate tectonics, seismic properties, mineral resources, hydrogeological structure, environmental conditions, social situation, roads and infrastructure.
3. Identifying several candidate sites in the investigation territory. This selection would be based on expert judgement, taking into account available information and discretionary criteria that are easy to assess (such as information on land use, population density, availability of access roads). Only areas that are readily accessible for geological exploration and thus suitable for detailed characterization will be selected for further considerations.
4. Ranking of the candidate sites using discretionary criteria identified as relevant for the site selection in order to identify two most favourable sites in addition to the FPNS.

Exclusion Criteria and the Discretionary Criteria are used in the selection of the potential disposal sites. They are defined on the basis of the IAEA documents but also on the analysis of legal requirements and comprehensive plan of Lääne-Harju municipality. Some criteria are also set by expert’s judgment.

The first screening stage of the territory of Lääne-Harju municipality will be carried out using a geo-information system and Estonian national and local data bases collecting public information on environment and infrastructure. Then, compliance with each Discretionary

Criterion will be assessed by raking of the available sites in order to identify the two favourable, in addition to the FPNS. This assessment will be based mainly on expert’s judgment.

The potentially suitable sites should be characterized to an appropriate level of detail to provide the necessary information to ensure that the disposal facility can meet the safety requirements for disposal of the intended type of waste. Sufficiently detailed site characterization should be carried out to provide the site specific data necessary to support the safety assessments of the long term containment and isolation of the waste within the disposal facility. The site selection will be based on the actual results of the investigations survey and the concept complying the most adequately with the safety requirements and the site characteristics.

The final site will be approved within the public process of Lääne-Harju municipality’s designated spatial plan. The first stage of the planning procedure is pre-selection of the local government designated spatial plan.

1.3. Site selection criteria

1.3.1. Exclusion Criteria

The Exclusion Criteria are mandatory requirements used to exclude those areas, whose application is not feasible due to exiting legal, environmental, social, demographic restrictions as well as characteristics do not ensuring the full compliance with the technical and safety requirements. The Exclusion Criteria are used to discard sites that are unacceptable on the basis of attributes relating to issues, events, phenomena or hazards for which there are no generally practicable engineering solutions. The following general requirements must be fulfilled for the selected waste disposal site:

1. The constructed waste disposal facility must be safe;
2. The stakeholders must agree to the location; and
3. It must be possible to construct, operate and close the disposal facility without undue difficulty.

Screening by the Exclusion Criteria enables areas with unfavourable characteristics to be excluded from further consideration. The Exclusion Criteria are listed in Table 1.1. These criteria are based on: (i) international and national legal restrictions, (ii) requirements of comprehensive plans, (iii) expert knowledge and experience of other countries.

Table 1.1. Exclusion Criteria to be used for territory screening

Feature	Basis for exclusion	Legally established protection zone	Proposed buffer zone for the disposal site
Protected areas of wildlife: 1.Protected areas 2. Limited-conservation areas 3.Species' protection sites 4.Individual protected natural objects 5.EU Natura 2000 network areas 6.Natural objects protected at the local government level 7.Protected species 8. Planned protected areas	Nature Conservation Act, EU Directive 2009/147/EC, Directive 92/43/EEC	No protection zones	Can be established during SEA process considering site specific conditions
Key habitats in forests: 1.KH areas on the state land 2.KH areas on municipality land and private land, where the agreements exist	Forest Law	No protection zones	Can be considered taking into account site specific conditions
Territories and objects of cultural monuments:	Heritage Conservation Act	50 to100 m, depending on the	Can be considered in detailed spatial

Feature	Basis for exclusion	Legally established protection zone	Proposed buffer zone for the disposal site
1.Historical monuments 2.Archaeological monuments 3.Architectural monuments 4.Art monuments 5.Technical monuments 6.Historical natural sacred sites		monument type	plan and SEA process if needed
Milieu areas: locally protected cultural areas	Lääne-Harju comprehensive plan	No protection zones	Can be considered in detailed spatial plan and SEA process if needed
Graveyards	Heritage Conservation Act: protected graveyards as territories of cultural monuments Lääne-Harju comprehensive plan: common graveyards	50 m	Can be considered in detailed spatial plan and SEA process if needed
Water bodies: Sea, lakes, rivers, brooks, springs, artificial recipients of land improvement system	Nature Conservation Act	Limited management zone: - 200 meters on the shores of the Baltic Sea - up to 100 meters on the banks of lakes and other water bodies (depending on size)	Can be considered in detailed spatial plan and SEA process if needed
Wetlands: bogs and bog-a-like wet areas, bog forests, peat areas, canebrake areas.	Exclusion is based on expert judgment considering safety implications.		No uniform distances are proposed; the drainage conditions are to be assessed on case by case basis
Flood hazard areas	Estonian Land Board data	-	-
Residential areas: densely populated areas and other residential areas with significant amount of population (currently existing as well as envisaged by the comprehensive plan)	Lääne-Harju comprehensive plan	-	700 m to reduce a risk of intrusion and to gain better public trust
Industrial and retail/business areas:	Lääne-Harju comprehensive plan:	-	Can be considered in detailed spatial plan and SEA

Feature	Basis for exclusion	Legally established protection zone	Proposed buffer zone for the disposal site
business and retail land use, mixed land use, industrial area for solar power land use, mining land use			process if needed
Recreation and public facility areas: green areas and forest parks, protected forest areas, locally protected forest areas, natural green areas, recreation areas, public buildings, publicly used areas	Lääne-Harju comprehensive plan	-	Can be considered in detailed spatial plan and SEA process if needed
Mining areas and territories containing valuable mineral deposits	Earth's Crust Act	No protection zone	Can be considered in detailed spatial plan and SEA process if needed
Military and defence areas	Decree of the Ministry of Defence Lääne-Harju comprehensive plan	25-2000 m	Can be considered in detailed spatial plan and SEA process if needed
Airfields	Estonian Aviation Act	The protection zone depends on the size of the airfield	-
Water supply and sewage systems: existing and planned water supply and sewage pipework, water wells in communal use	Building Code	Vary between 2-5 m	Not proposed
Gas installations and pipelines: existing and planned	Building Code	Vary between 1-10 m	Not proposed
Electrical installations: transmission lines and others,	Building Code	Vary between 2-40 m	Not proposed
Communication installations: existing and planned towers and lines	Building Code	1 m	Not proposed
Roads and railroads (existing and planned)	Building Code Lääne-Harju Comprehensive Plan	Vary between 10-50 m for roads 30 m to 50 m for railroads	Can be considered in detailed spatial plan and SEA process if needed

Feature	Basis for exclusion	Legally established protection zone	Proposed buffer zone for the disposal site
Dangerous and hazardous enterprises: petrol stations, terminals with dangerous goods, cold storage plants, grain drying plant, fur farms etc.	Chemical's Act	Vary between 50-2000 m, depending on the enterprise	Can be considered in detailed spatial plan and SEA process if needed
Special geological forms: tectonic fracture zones, karst areas	Expert judgment	-	1 km zone on both sides from the mapped capable fracture edge
Human activities: Construction PHES in Paldiski	Expert judgment	-	Can be considered in detailed spatial plan and SEA process if needed
Small land plot: area is less than 5 ha or of unsuitable geometry (plot width is less than 220 m)	Judgement of Stakeholders and local experts	-	-

Protected areas, territories of cultural monuments, water bodies, wetlands and flood hazard areas, residential, recreation areas and Industrial as well as related infrastructure, mining areas and territories containing valuable mineral deposits, unfavourable geological forms (tectonic fracture zones, karst areas), military areas, airfields and National Border areas are to be excluded. Usually, the excluded areas and objects have legally established protection zones. However, experts recognise that in many cases these legislative zones are far insufficient [16]. There are several reasons why large protection (or buffer) zones need to be established: enhancing safety and security of the repository, minimising ionising radiation doses to members of the critical group due to waste disposal activities and increasing public acceptancy. Dimensions of the proposed "buffer" zones (Table 1) should be mainly based on judgment of experts taking into consideration experience of siting programs of other countries.

Events and processes that do not pose a danger in Estonian conditions (for example, tsunamis, volcanic eruptions) are not considered as reasons for exclusion. Seismic hazard is not an exclusive factor in the context of Estonia too. However, resistivity to ground motion due to seismic waves of different types, resulting from potential earthquakes are subject to be considered at later stages of the disposal facility development programme.

Areas smaller than 5 ha or with inappropriate geometries should also be excluded. For security reasons, the territory of the disposal facility must be fenced off. In addition, there must be sufficient space to establish a restriction zone around the repository if a decision is made to establish such a zone. The optimal shape of the plot is a rectangle with a shorter side, no shorter than 220 m.

1.3.2. Discretionary and Ranking Criteria

The Exclusion Criteria are supplemented by non-mandatory Discretionary Criteria. They are associated with attributes related to issues, events, phenomena, hazards, or other adverse aspects for which protective engineering solutions are available, i.e. by modifications of the facility design. The main purpose is to decrease the number of possible candidate sites if their number is too large and to conduct the comparison and ranking of the sites. When there are a large number of potential candidate sites, these criteria should facilitate the selection process by removing less favourable ones.

The Discretionary Criteria (presented in Table 1.2) were defined analysing international recommendations, internationally available experience and expert knowledge. The Discretionally Criteria included the following conditions: geological, hydrogeological, geochemical, tectonics, surface processes, meteorological conditions, human activities, transport of waste, land use and ownership, population, environmental protection, historical heritage importance. These same characteristics formed the basis of the Ranking Criteria (Table 1.3) used to finalize the two candidate sites. The same features made Ranking Criteria to be used for the final selection of the two candidate sites. The Discretional and Ranking Criteria are detailed in Interim Report for Activity 1 Part 1.

Table 1.2. List of Discretionary Criteria to be used for screening of Lääne-Harju territory

Feature	Rationale	Discretionary criteria	Comments
Geology	The geology of the disposal site should contribute to the isolation of waste and the limitation of release of radionuclides to the biosphere. It should also contribute to the stability of the disposal system and should provide sufficient volume and favourable properties (geological, mechanical, geochemical, hydrogeological, etc.) for disposal.	Predictability of geological features	Simple, predictable and easy to characterise geology is preferred
Hydrogeology	The hydrogeological characteristics of the host site should include low groundwater level and long flow paths in order to restrict the migration of radionuclides. Possibilities of contaminating water intended for human consumption should be excluded. Expected changes in important hydrogeological conditions (e.g. hydraulic gradient) due to natural events and the construction of the disposal facility should be	Simple geological setting making characterizing and modelling of the hydrogeological system easier and more reliable. Low and stable ground water table. Not expected changes in important hydrogeological conditions due to	Simple geological setting, easy to characterise and model is preferred Low and stable ground water table is preferred

Feature	Rationale	Discretionary criteria	Comments
	evaluated.	natural events or human activities	
Geochemistry	Chemical composition of groundwater and the geological media should contribute to limiting the release of radionuclides from the disposal facility and should not significantly reduce the longevity of engineered barriers. Chemical interactions within the disposal system (i.e. corrosive action of groundwater on the engineered barriers) must be investigated.	Environment with moderate pH and Eh levels (nonaggressive to ordinary concrete) Absence of chemical conditions facilitating fast migration of radionuclides Absence of soils of low bearing strength, soil stability according to construction requirements	Nonaggressive chemical environment not facilitating migration of radionuclides is preferred Chemical interactions within the disposal system must be investigated in the stage of site characterisation
Tectonics	The site should be located in an area of low tectonic activity such that the isolation capability of the disposal system will not be endangered. The design of the disposal facility should take into account tectonic stability and seismic activity of the site that could adversely affect the proposed disposal system.	Low potential for adverse tectonic events, absence of recent or historic evidence of active faulting, tectonic processes.	Territories characterised with low tectonic hazard are preferred
Surface processes	The site for NSDF must be well drained and free of areas of flooding or frequent ponding. Accumulation of water in upstream drainage areas due to precipitation or snowmelt and the failure of water control structures, channel obstruction or landslides should be evaluated and minimized so as to decrease the amount of runoff that could erode or inundate the facility. Surface processes such as landslides, flooding of the disposal site, or erosion should not occur with such frequency or intensity that they could affect the ability of the disposal system to meet safety	Topographical and hydrological features that preclude the potential for flooding and limit erosion, i.e surface inclination is modest. Absence of soils of low bearing strength, soil stability according to construction requirements.	Smooth topography, modest surface inclination are preferred

Feature	Rationale	Discretionary criteria	Comments
	requirements.		
Meteorology	The meteorology of the site area should be characterized such that the effects of unexpected, extreme meteorological conditions can be adequately considered in the design and licensing of the disposal facility. The potential for extreme meteorological events should be evaluated. Closed NSDF can be sensitive to extreme weather conditions (i.e. heavy rainfalls, droughts, very deep freezing) not foreseen in the facility design	Extreme weather condition frequency and impact.	Sites with low potential impact due to extreme weather conditions are preferred
Human activities	The site should be located so that activities carried out by present, or future, generations at or near the site will not be likely to affect the isolation capability of the disposal system. Areas in the immediate vicinity of major hazardous facilities, airports or transport routes carrying significant quantities of hazardous materials should be evaluated for suitability of waste disposal. The sites should be evaluated for valuable geological resources or potential future resources, including groundwater suitable for drinking or irrigation, that are likely to give rise to interference activities resulting in a release of radionuclides in quantities beyond the acceptable limits.	Distance from hazardous facility Distance from airports Distance from major routes with frequent movement of hazardous material. Low potential for future territory development Low mining potential Low potential for ground water use	The following sites are preferred: - located away from the hazardous facilities, airports, major roads and territories of foreseen development - having low development, mining and ground water extraction potential
Transport of Waste	The site should be located so that the access routes will permit the transport of waste with minimal risk to the public	Availability of suitable roads	Preference will be given to minimal transportation distance
Land use	**Development areas** designated in the Comprehensive Plan[1] could further spread in nearby areas	Potential for future territory development is assessed by the distance to existing and known	Site with low potential for future development is preferred

Feature	Rationale	Discretionary criteria	Comments
		business, industrial, residential, pulblic use etc	
	E9 hiking trail	The possible impact is assessed in SEA	Preventive measures if needed can be proposed during SEA procedure
	Valuable agricultural land designated in the Comprehensive Plan[1]	Potential site in valuable agricultural land	It is preferred that they are used as agricultural land, but if the state's and municipality's interest is to build something else there, it could be discussed
	Additional national defence areas, not designated in the Lääne-Harju comprehensive plan, however included in the Land Register[2]		Preference is given to sites that are not expected to be used for defence purposes
Land ownership	Jurisdiction over the land, or land ownership, may be a significant factor in some States with respect to the financial viability and public acceptance of the disposal facility	Existing possibilities for state and unreformed state land	Building repository on state land is the easiest. Unreformed state land incorporates more complex procedures. Using municipality land needs agreement from municipality. Planning and building on private property incorporates complex procedures: collaboration with the owner, possible expropriation
Population	Consideration should be given to avoiding areas of high population density	Current population density and population grow potential need to be considered	Preference is given to sites that are farthest from the densely populated areas
Environment	The site should be located so that the environment will be adequately protected for the entire lifetime of the facility and so that potential adverse impacts can be mitigated to an acceptable degree, technical, economic, social and environmental factors being	Strictly protected areas are excluded, the possible impact is assessed in SEA	Certain activities (e.g. building the repository) might influence the habitats, so the buffer zones or preventive/mitigation measures can be given

Feature	Rationale	Discretionary criteria	Comments
	taken into account. Near surface disposal facilities should comply with the requirements for protection of the environment.		during SEA procedure.
	Protected areas of wildlife: Species of category III	Protected areas of wildlife (species of category III)	Certain activities (e.g. building the repository) might influence the habitats, so the buffer zones or preventive/mitigation measures can be given during SEA procedure. The buffers should be discussed and approved by the Environmental Board.
	Green network area (designated in comprehensive plan)	Existing green network areas	Green network areas are designated in comprehensive plan. In general waste disposal areas are not welcome in those areas, but exceptions are possible. Restrictions might apply for fencing and depends on the location, e.g. the planned object must not deteriorate green network performance.
	Valuable landscapes designated in comprehensive plan	Existing valuable landscapes	Traditional village landscape milieu should be preserved. The planned object must harmonise with the surrounding area and not deteriorate the protected values.
	Key habitats in forests (according the Estonian Forest Law)	Strictly protected areas are excluded, the possible impact is assessed in SEA	Certain activities (e.g. building the repository) might influence the habitats, so the buffer zones or preventive/mitigation measures can be given during SEA procedure.

Feature	Rationale	Discretionary criteria	Comments
Historical heritage	Locally protected heritage objects: hereditary culture objects, last century architectural objects, farmstead architecture objects, military heritage objects, ancient history objects, holy places	Strictly protected areas are excluded, the possible impact is assessed in SEA	It's preferred that those objects should not be deteriorated but certain combinations with repository is possible. Those objects need to be further analysed.

Table 1.3. Ranking criteria to be used for selection of the three potential sites

Discretionary criteria	Ranking criteria		
	Min value Score 0	**Interim value Score 1**	**Max value Score 2**
Geology			
Predictable geology	Limited information	Substantial uncertainties in interpretations of geological structure	Sedimentary sequence with simple structure
Ability to be characterized with geological investigation technics	Difficult physical access to the investigation territory	Access is moderately difficult	Easy physical access to the investigation territory
Hydrogeology			
Simple geological setting making characterizing and modelling of the hydrogeological system easier and more reliable	Unknown water bearing units and hydrogeological features, no hydrogeological observation wells in vicinity	Limited information on the hydrogeological features	Single and well know water bearing unit; well known features of aquifers; existing modelling (for scientific, industrial or water supply reasons), water wells or boreholes available in vicinity
Low and stable ground water table. Not expected changes in important hydrogeological conditions due to natural events or human activities	High and unstable ground water table. Changes of hydrogeological conditions are possible	Ground water table is relatively stable, at depths of about 1 m Changes of hydrogeological conditions are of low probability	Low (at least 3 m deep) and stable ground water table Not expected changes in important hydrogeological conditions due to natural events or human activities
Geochemistry			
Geo- and hydro chemical environment with moderate pH and Eh levels (nonaggressive to commonly applied	Unknown chemical conditions	Existing information or predictions on chemical aggressiveness to commonly applied	Existing information or predictions on low chemical aggressiveness to commonly applied

Discretionary criteria	Ranking criteria		
concrete)		concrete, however the impact can be minimised by application of resistive concrete	concrete
Absence of chemical conditions facilitating fast migration of radionuclides	Unknown chemical conditions		Retention of relevant radionuclides is expected (i.e. high pH, presence of clayey particles)
Tectonics			
Potential for adverse tectonic events	Located just beyond exclusion limit. Recent or historic evidence of active faulting, tectonic processes	Moderate distance from active faults	The site furthest from the active faults Low potential for adverse tectonic events, absence of recent or historic evidence of active faulting
Potential for seismic events	Historical earthquakes of such magnitude and intensity that, if they recurred, could adversely affect isolation of the waste	Not applicable	No evidence of soil liquefaction in seismic loads and indications on presence of soils with high liquefaction potential
Surface processes			
Topographical and hydrological features that preclude the potential for flooding and limit landsliding and erosion	Slopes more than 10% or less than 2%	Inclination is only slightly differs from the limiting values	A hill with modest slope inclination
Absence of soils of low bearing strength	Unknown properties of basement rocks	Not applicable	Stiff basement rocks
Meteorology			
Extreme weather conditions	Frequency of extreme weather conditions is low	Frequency of extreme weather conditions is moderate	Extreme weather conditions are common
Human activities			
Distance from hazardous facility	Located just beyond exclusion limit	Medium distance	No facility at less than 2 km
Distance from airports	Located just beyond airport exclusion limit	Medium distance	The site furthest from the airport
Distance from major routes with frequent movement of hazardous material	Located just beyond exclusion limit	Medium distance	No movement of hazardous material at less than 2 km

Discretionary criteria	**Ranking criteria**		
Transport of waste			
Availability of suitable roads	Limited access route is available	Improvement of existing roads is needed	Roads are suitable for waste transportation and emergencies
Land use and ownership			
Low potential for future territory development	Located just beyond exclusion limit	Moderate development potential of the territory	No potential for development areas
Low mining potential	Located just beyond exclusion limit	Medium distance	The furthest distance from identified potential mining areas and valuable mineral deposits
Low potential for ground water use (low potential for water extraction wells)	Existing potential	Moderate potential for water extraction in future	No such potential
Valuable agricultural land	The site is on valuable agricultural land	Not applicable	The site is outside valuable agricultural land
Distance from land improvement system	Located just beyond exclusion limit	Medium distance	There is no drainage system in proximity of the site
Land ownership	Municipality land and unreformed state owned land	Not applicable	State owned land
Population			
Densely populated areas	Site next to densely populated area	Site is at intermediate distance from densely populated area	Site is far away from densely populated area
Environmental protection			
Protected areas of wildlife (species of category III)	The site is in the protected area	Not applicable	The site is outside protected area
Green network area	The site is in the green network core area	The site is in the green network corridor	The site is outside green network area
Valuable landscape	The site is in the area of valuable landscape	The site is next to valuable landscape area	No valuable landscapes in vicinity
Constructability			
Land plot size	Less than 6 ha	More than 6 ha but less than 10 ha	Over 10 ha

Screening of Lääne-Harju territory will be carried out to identify the two most optimal sites using public databases, geographic information systems, archives, results of earlier performed studies, expert's knowledge and specific evaluations, also with the aim to confirm the absence of excluding elements not identified in the phase of application of the exclusion criteria. Then the resulting candidate sites should be placed in an order of preference through an exercise of comparison and ranking using appropriate Ranking Criteria.

1.4. Selection of three candidate sites for the disposal facility

1.4.1. Negative Screening by Exclusion Criteria

The screening of the territory of Lääne-Harju municipality was mainly based on existing legal restrictions and plans using the defined Exclusion Criteria. Areas not readily accessible for geological exploration and thus not suitable for detailed characterization were screened out in addition.

Results of the territory screening according to the exclusion criteria are presented in Figure 1.3. There are 18 sites left as potentially suitable in the territory of Lääne-Harju municipality after the screening. The sites that were relatively close to each other, were grouped under one area and named after a village or cadastral unit name, and three letter abbreviations are added: Keibu (KEI), Alliklepa (ALL), Vihterpalu (VIH), Pedase (PED), Altküla (ALT), Lemmaru (LEM), Ingeri (ING), Tallinn (TAL) and Kadaka (KAD).

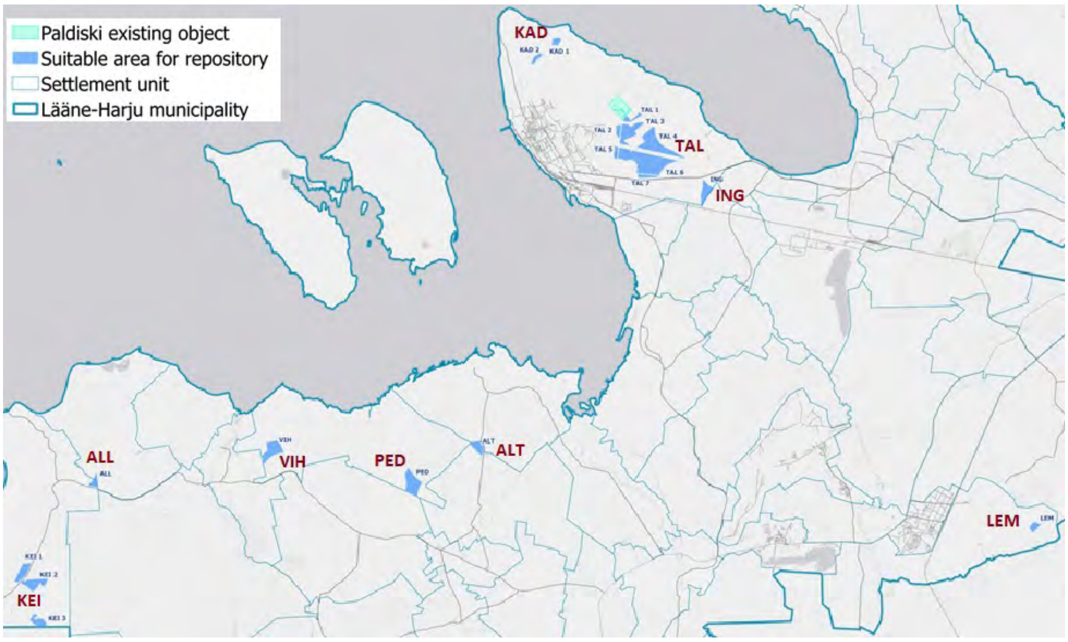

Figure 1.3. Results of negative screening using the exclusion criteria.

As a result, 9 areas in the territory of Lääne-Harju municipality are proposed for comparison and in order to determine two most optimal sites for the repository, while the third area is already pre-selected. These three sites will be proposed for further planning and SEA procedure.

1.4.2. Analysis using the Discretionary Criteria

The analysis and evaluation showed that, at the current level of knowledge, all potential sites are very similar in many aspects. All the sites have predictable geology and their sedimentary sequence is with simple structure, the basement rock for NSDF is stiff limestone in all sites. All sites have single and well known water bearing unit, well known features of aquifers and water wells or boreholes available in vicinity. Water resources and movement has already been evaluated. All sites have similar geo- and hydro chemical characteristics with moderate pH and Eh levels. There are predictions on chemical aggressiveness to commonly applied concrete, however the impact can be minimised by application of resistive concrete. All sites have similar situation regarding potential seismic events. There is no evidence of soil liquefaction in seismic loads and indications on presence of soils with high liquefaction potential. Potential for adverse tectonic events is low. The detailed data are presented in Interim Report for Activity 1 Part 2.

1.4.3. Evaluation and ranking of the sites

Based on the regional characterisation of Lääne-Harju municipality, application of discretionary criteria and their developments for Lääne-Harju municipality specific and publicly available data, sites that were left after applying exclusion criteria were ranked; the ranking results are presented in Table 1.2. The site evaluation process is detailed in Interim Report for Activity 1 Part 2. The aim of the ranking is to propose two possible locations to be considered and compared in the pre-selection phase of the spatial planning process for choosing the optimal location for the disposal facility. As a result, the VIH and PED areas received the highest overall ratings (46 points and 44 points, respectively), followed by ALT (43 points) and ALL (42 points).

Table 1.4. Site ranking results

Location	**VIH**	**PED**	**ALT**	ALL	KEI	TAL	ING	KAD	LEM
Score	**46**	**44**	**43**	42	41	40	40	38	35

1.4.4. Consideration of Stakeholder’s opinion

Views of relevant stakeholders play an important role in the selection of sites for nuclear installations. According to opinion of the local Lääne-Harju municipality administration, the sites VIH, ALL, KEI were deemed unsuitable for waste disposal, because nearby Keibu, Alliklepa and Vihterpalu villages have a lot of public interest to be used as a recreation area. The local municipality’s vision is to keep those areas for local recreation. Nearby forests are meant to be protected and preserved and the sea coast must be considered precious due to its high recreational value. Therefore, waste disposal function is not complying with the areas land use plans.

Taking into account the position of the local municipality and existing indications on the negative public opinion, the areas VIH, ALL and KEI were recognized as unsuitable for waste disposal and excluded from the further siting process. Therefore, the second and third top-ranked sites (PED and ALT, respectively) are proposed for further studies as candidates for construction of the disposal facility (Figures 1.4 and 1.5). In addition to the existing and pre-selected site on Pakri peninsula, the candidate sites to be compared in the next planning and SEA procedure are PED site near Harju-Risti and Padise villages and ALT site in territory of Altküla village.

Figure 1.4. Access to PED site.

Figure 1.5. ALT site after snow melting.

1.5. Conclusions

1. The location of the radioactive waste disposal facility shall comply with the basic requirements:

- the disposal facility must be safe,
- the location must be agreed upon by the stakeholders; and
- it must be possible to construct, operate and close the disposal facility without undue difficulties.

2. The main requirements for the geological environment are sufficient bearing capacity of rocks and low chemical aggressiveness to concrete structures. In addition, other properties must be considered such as water permeability, intensity of water flux, radionuclide retention, distance of ground water flow to discharge zone.

3. The chosen disposal concepts for Low Level Waste and Intermediate Level Waste are highly flexible. They can be easily adapted to different geological environments and waste inventories.

4. After thorough examining the available information gathered through the implementation of Sub-activities 1.2, 1.3 and 1.4 it was found that due to various factors (safety, social, environmental, technical and others), most of the territory of the local Lääne-Harju municipality is not suitable for the construction of the radioactive waste disposal

facility. Only about ten areas, including the territory of the FPNS, were identified as potentially acceptable.

5. After comparison using the methodology developed under sub-activity 1.1 and consultations with the administration of the local municipality, priority is given to two sites, PED and ALT, located in the central part of the municipality. They are proposed for further investigation of suitability for waste disposal together with the FPNS. There are indications that a safe radioactive waste disposal facility can be constructed at any of these three sites, using commonly applied techniques, while potential for human intrusion and damage from hazardous activities is also low.

6. Site-specific studies (Activity 2) should provide information that affects complexity of the design, construction, and ultimately the cost for waste disposal.

7. The final conclusion on suitability of a particular site for disposal of radioactive waste can only be taken after detailed investigations of the site specific conditions and comprehensive Safety and Risk Assessments (subjects for Activity 2). The decision on the selection of a site for the disposal facility for radioactive waste must be taken considering protection of present and future generations, protection of environment and with the active participation of the local people in the selection process.

2. ACTIVITY 2. ‘Studies of the three repository locations'

As a result of Activity 1, "Determining the three most optimal locations for the repository," two possible sites, Altküla (ALT), and Pedase (PED) were selected for the future disposal facility. Paldiski (PAL) as the current location of the naval nuclear reactors and radioactive waste interim storage facility was pre-selected by the stakeholders as one potential repository site. Characterization of the three candidate sites has been performed during implementation of Activity 2 of the current Project. One of main objectives of Activity 2 is to provide a basis for the strategic assessment of environmental impact of the establishment of the disposal facility and the preparation a designated spatial plan, i.e.to make a decision principle on the disposal site.

It included comprehensive geological, hydrogeological, hydrological, geochemical, environmental and social studies, as well as an overview of the available infrastructure. In addition, potential safety implications, including radiological impacts on neighbouring countries, were examined taking into consideration characteristics the sites. The conducted studies can be conditionally divided into four packages: geological conditions, environmental conditions, social environment and availability of infrastructure and radiation protection and safety.

Based on the results of Activity 2, the three alternative potential repository sites are compared. The results of the comparison form the basis for preparing the spatial plan and assessing the environmental impact of the establishment of the repository.

2.1. Mapping specific tectonic features

The purpose of sub-activity 2.1 [5] was to provide information on the geological history of the area, the structural geological conditions, neotectonic processes, and the nearest volcanic activity for the three possible candidate sites (PAL, ALT and PED) for future disposal facility.

Estonia is situated in the East European Platform, where the Precambrian crystalline basement is overlaid by a layer of Paleozoic sedimentary rocks and Quaternary sediments, ranging in thickness from 100 to 780 meters. All three sites are positioned within the West-Estonian structural zone, which is part of the Svecofennian-aged (1.9-1.77 Ga) and rapakivi rifting and intrusion related crystalline basement. The crystalline basement, the crystalline basement beneath the three sites consists of amphibole gneisses and amphibolites. The boundary between the crystalline basement and the overlying sedimentary sequence can be found at an approximate depth of 160 meters below sea level (PAL) and around 190 meters below sea level (PED and ALT).

The geologic map of the basement reveals four faults in the territory of LHLM. Among these, two faults, identified through geophysical data, are associated with Svecofennian or rapakivi-time deformation and do not affect the sedimentary cover.

None of the three selected sites for the future disposal facility are located on buried valleys identified through geological mapping. The PAL and PED sites are situated in areas with a relatively thin cover of Quaternary sediments. However, the ALT site is positioned on top of an old and extensive incision that was occupied by a proglacial lake and sea for an extended period after deglaciation.

The formation of the bedrock topography commenced in the late Devonian. Alongside long-term crustal movements and various continental denudational processes, the final shaping of the topography was influenced by glacial erosion during the Pleistocene epoch. The recent uplift of the crust in northwestern Estonia provides evidence of glacioisostatic relaxation. Alongside vertical movements, minor horizontal deformations of the crust occur, specifically in the form of intraplate horizontal displacement towards the southeast at a rate of approximately 1.15 mm/year in northwestern Estonia. Most of the horizontal movements are attributed to plate tectonics. The combined sum of plate and intraplate shifts amounts to approximately 23-24 mm/year, resulting in a northeastern shift of the territory.

Estonia is situated in an intraplate position, with the closest active plate boundaries located more than 2000 km away in northern Italy (Alp Mountains) and the Atlantic Ocean (Iceland). As a result, there has been no volcanic activity within the country since the formation of the crystalline basement.

The main findings of the study [5]:

1. The three sites are relatively close to each other, with a distance of approximately 14 km between PAL and PED, and only 2.5 km separating ALT and PED. Therefore, the deep structure of the Earth crust is nearly identical for all three sites.

2. **The features of all three sites are favourable for waste disposal:**

- **There are no known active faults in the vicinity of the sites. The speed and movement direction are almost identical, producing no tectonic stresses.**
- **The nearest modern volcanic activity in Iceland is about 2100 km apart.**
- **The sedimentary cover is uniform and predictable.**

2.2. Seismic analysis

The purpose of sub-activity 2.2 was to provide an overview of known seismicity in the region surrounding the three possible candidate sites for the future disposal facility. It outlined the background for assessment of seismic hazard [6]. Also, possible seismic phenomena related to man-made activities were discussed.

Ground vibration and possible induced seismicity related to construction and use of PHES require attention particularly in regard with PAL, because of its planned location at approximately 2 km distance. The distance to other candidate sites is ~10 km to ALT and ~12 km to PED, and they are less likely to be affected.

Environmental assessment of construction-related vibration of PHES has been carried out. Potential induced seismicity and measures for its prevention and mitigation have been studied separately. Possible issues can be anticipated and prevented or mitigated with careful planning and use of the underground PHES system.

The catalogue of seismicity in the study area, within the radius of 50 km from any of the radioactive waste disposal facility candidate sites, PAL, ALT and PED, spans almost 200 years. However, the first ~180 years of the earthquake list has considerable data gaps. Detection of all events down to magnitude ~1 has been reality only during the latest two decades. Statistical analysis of known seismic activity contains large margins of error.

The study area experiences modest seismicity. Sporadic occurrences of minor earthquakes (magnitude < 3) can be expected. The magnitude-4.5 Osmussaar event shows that occurrence of earthquakes large enough to cause damage to sensitive structures cannot be ruled out. However, their return periods are likely to be long: several hundreds of years for an earthquake of magnitude 4.0 or larger. The existing dataset does not allow making more precise predictions regarding future seismicity.

Circumstances regarding seismicity are similar for all the three candidate sites and the risk level due to earthquake activity is small. Accordingly, seismicity is not the decisive factor in the choice of the final location. Distance to the epicentre of the Osmussaar earthquake is more than 30 km to all of them. Historical earthquakes with magnitudes ≥ 3 have taken place at distances of ~40 km away or more, furthest away from PAL.

Failure in Earth’s brittle crust is likely to occur as reactivation of old zones of weakness. None of the three candidate sites are located near known major faults. This decreases the possibility for sizeable earthquakes in their vicinity, for either natural or man-made causes, including induced/triggered earthquakes. Low natural seismicity is possibly a useful indicator for low tendency for felt or damaging induced events. Accordingly, if earthquakes (either natural or induced) occur near these locations, they are likely to be small in magnitude, not causing structural damage.

The final result of seismic analysis [2] is that low natural seismicity is a useful indicator for all locations. In this respect, all three places are about equal.

The ultimate result of the seismic analysis [6]: **low natural seismicity is a useful indicator for all sites.** In this respect, all three sites are about equal.

2.3. Analysis of the geological-lithological composition of the Earth's crust

The aim of the sub-activity was to specify the geological structure of the three sites proposed for a disposal facility of radioactive waste in the following aspects [7]:

- analysing the lithology, mineral and geochemical composition, and natural gamma intensity variation of the sedimentary rocks exposed in drillcores,
- testing the mineral solubility of the characteristic lithologies,
- mapping the locations of potential clay layers, and
- assessing the nature, quantity, and location of possible mineral resources at the potential locations.

Results of investigations of the lithological composition are shown in Figure 2.1. The studied locations do not contain valuable mineral resources that are being actively mined, nor have they been registered as proved or probable reserves, nor explored as potentially useful resources. However, future projections suggest that the limestones of the Kõrgekalda and Väo formations in the PAL core site could be considered as potential reserves for building limestone and aggregate production. Furthermore, at all three studied sites, there are 4-5 meter-thick Türisalu Formation black shales, which are rich in U, Mo, and V, occurring at depths between 25 to 60 meters below the ground surface. These black shales are not currently explored but represent a potential metal resource in the future.

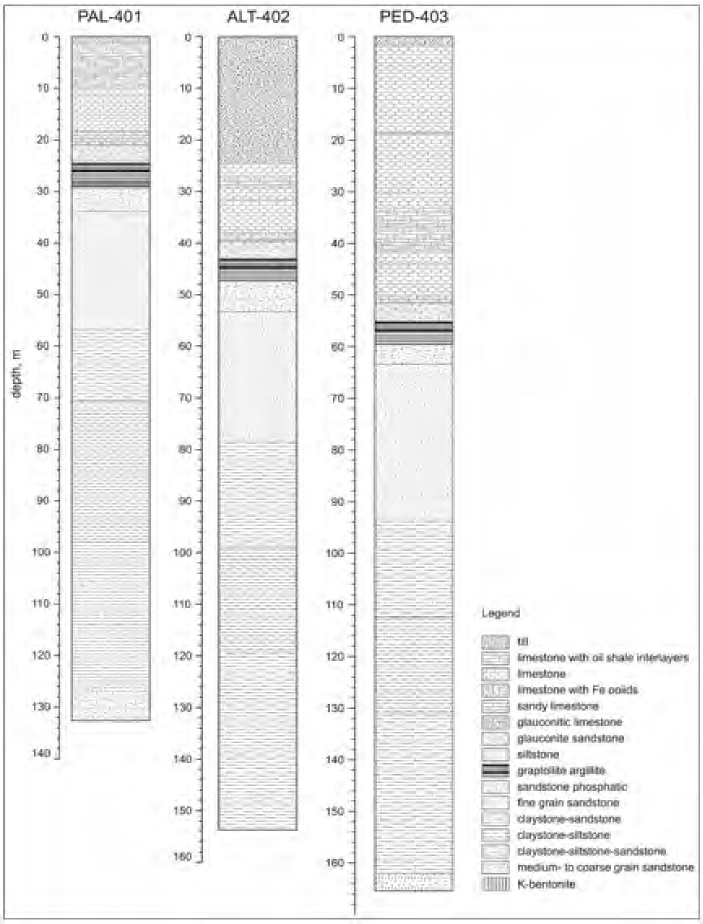

Figure 2.1. Lithological columns of drill cores.

The main findings of the study:

1. The vicinities of the site do not currently contain valuable mineral resources that are being currently mined, nor explored as potentially useful resources. However, future projections suggest that the limestones from the PAL site could be considered as potential reserves for building limestone. In future projections extending to hundreds of years is cannot be hypothetically excluded that given a shortage of the high-quality limestone resources in northern Estonia that mining of the limestones becomes profitable at the depths exceeding 10 m as at the PAL site and this area could be considered as containing future limestone reserves.

2. Furthermore, at all three studied sites, there are 4-5 meter-thick layer of black shales, which are rich in U, Mo, and V, occurring at depths between 25 to 60 meters below the ground surface. These black shales are not currently explored but represent a potential metal resource in the future.

3. Due to the regional geological structure of the Estonian bedrock, there are differences in the depth of geological units between three sites. The most substantial and thickest clay-rich interval, known as the Lontova Formation, which is the most suitable for the IDDF, occurs at depths of 57-98 m, 78-119 m, and 93-131 m at PAL, ALT, and PED sites, respectively. In the PAL site, the transition from sandstone-dominated formation to clay-rich one is sharp, and the overall thickness of the unit is the same as in the PED and ALT sites.

4. In addition, there are clay rich intervals at all three sites:

- 4-5 m thick organic rich shales in upper part of the successions at the depths between 25 to 60 m in different studied drill cores;
- 40-45 m thick clayey interval composed of 14-12 m thick unit of alternating claystone and siltstone to fine-grained sandstone; and a succeeding 18 to 27.5 m thick claystone at the depths between 60 to 100 m;
- about 20 m thick unit of clayey sandstones at the depths between 104 to 160 m in different studied drill cores.

They create aquitards that protect against the vertical flow of water.

5. At the most preferred PAL site the thickest clay-rich unit is at the shallowest depth and the clay-rich interval is the most homogenous, and with well-defined lithological boundaries. The least preferred ALT and the PED sites are similar in terms of overall lithology and both show a gradual transition from sandstone dominated lithology to the claystone in the thickest clay-rich interval that also occur at a greater depth compared with the PAL site.

The main result of the analysis of the geological-lithological composition of earth’s crust [7]: **the preferred PAL site as the thickest clay-rich unit is at the shallowest depth and the clay-rich interval is the most homogenous.**

2.4. Analysis and geodetic surveys of surface terrain

The objective of the surface topography analysis (sub-activity 2.4) was to study surface features relevant for safety of waste disposal facility [8]. Surface inclination, and presence of kettle holes were identified using LIDAR data digital elevation models. Dangers of potential rising of the Sea level was considered in addition. Additionally, the risk of potential sea level rise was considered.

The topographic survey confirmed that the surface is smooth with a minor inclination of a few degrees. As a result, there is no risk of landslides in any of the sites.

Topographical analysis reveals a significant concern regarding the ALT site. Its proximity to the current sea level, combined with the anticipated rise in sea levels and more severe storm events, poses a growing threat to the site within the next century. However, it's important to note that North Estonia experiences considerable isostatic land uplift, with a rate of 3.2-3.3 mm/year in the region, which helps counteract the global sea level rise. This land uplift is estimated to reduce the predicted 1 m global sea level rise by 2100 by approximately 25 cm. Nevertheless, in the long term, it may not be sufficient to mitigate the risks fully.

The PED site, although situated at a higher elevation, remains vulnerable in the long term if the current worst-case predictions for global sea level rise (+15 m by 2500) come to fruition. The site is located on a regional slope and contains numerous karst sinkholes within and around its borders. This abundance of karst features, coupled with the significant difference in height, is expected to result in intensive groundwater flow, which is a negative characteristic for the disposal site.

On the other hand, the PAL site is located at a higher elevation, making it safe even under the predicted worst-case scenario for sea level rise. The topographic analysis did not reveal any significant negative aspects associated with this site.

In terms of drainage, the ALT site presents the most complex and risky situation. Being situated in the middle of an extensive flat plane, the site relies on an artificial ditch network for drainage. However, due to its low altitude, the slope of the drainage system is minimal, and any obstructions such as beaver dams between the Baltic Sea and the site would have a significant adverse effect. Conversely, the PED and PAL sites, being located on slopes or in close proximity to them, are generally well-drained or require only minimal artificial drainage.

The impact of terrain on the local climate is relatively insignificant, as the landforms in the area are relatively small. However, the PED site is slightly more exposed to prevailing westerly winds due to its elevated location and aspects within the potential site.

The main findings of the study:

1. There is no risk of landslides in any of the three sites.

2. Potential sea level rise over the next century, combined with severe storms, poses a growing threat to the NSDF if built on the ALT site. The PED site is situated at a higher

elevation, remains potentially vulnerable in the long term if the current worst-case climate change predictions.

3. Abundance of karst features, coupled with the significant height difference leading to intensive groundwater flow, results in significant threat to the stability of NSDF if it is built on the PED site.

4. The topographic analysis did not reveal any significant negative aspects associated with the PAL site. It is located at a higher elevation, making it safe even under the predicted worst-case scenario for sea level rise.

The main results of the analysis and geodetic surveys of surface terrain [8]:

- **Potential sea level rise poses a threat to the NSDF built on ALT site,**
- **Abundance of karst features poses a threat to the stability of NSDF built on the PED site.**

2.5. Analysis of specific geomorphological features

The objective of the study [9] is a detailed overview of the landforms at the three potential disposal facility locations and overall ranking of candidate sites in terms of specific geomorphological features. The work includes an overview of landforms and sediments at the three candidate sites and an assessment of geohazards as well as comparison of the sites terms of specific geomorphological features.

Due to the almost flat terrain at the sites and in the surroundings, it is obvious that neither rock falls or -slides nor unconsolidated mass movements, including landslides, pose a threat to the current terrain. The most active cliffs with rapid mass wasting processes (rock falls) are located ~5 km from the PAL site, and the rate of cliff recession has been measured at ~25 cm/yr. This dynamic geomorphic process creates no risk to the PAL disposal facility site. In the reasonably foreseeable future, climate change and sea-level rise will not change these processes catastrophically. In some scenarios, active wave erosion and cliff recession will decrease considerably as more resistant to erosion limestones will be abraded instead of soft sandstone.

There are no footprints of (surface) karst phenomena in the PAL and ALT sites. The PED site is located at a bedrock elevation with extremely thin sediment cover, favouring rapid recharge and surface water movement into deeper rocks. In this site, recharge is concentrated into karst surface depressions and is moving deeper through the swallow fissures, indicating possible karstification in the deeper rocks. Thus, karst phenomena pose a threat to the PED site. The predicted increase in temperature is ~2.73 to 4.28 °C, and an increase in mean annual precipitation by 14 – 19% by the end of 2100 will speed up the surface karstification in the future but not necessarily in deeper rocks. The karst phenomenon questions the suitability of the PED site as a disposal facility location.

The possibility of extreme floods (~2 m) on the southern coast of the Pakri Bay at the mouth of the Kloostri River must be considered a potential hazard for the ALT area. The PAL and PED potential disposal facility sites are deemed not to be at flood risk caused by coastal flooding or the overbank flooding in river systems. The predicted RSL rise of 2 m is a clear risk to the ALT site (no drainage from the site), and the RSL rise of 5 m, predicted for the year 2300, will inundate the area. According to the 5°C warming scenario, the lowermost part of the PED area will be flooded or remain within the storm surge zone (1.9 m by ELB) by 4000 AD.

Due to the tectonic stability of the Estonian territory, the very flat terrain and the location in the transition zone of the temperate maritime and continental climate, dynamic geomorphological processes that are active, fast and/or with catastrophic consequences, are rare. GIA-induced coastline displacement and corresponding areal change in wave activity have been a major dynamic geomorphic process. Predicted future RSL rise in connection with the climate change is the main future threat to the geomorphological features and any facilities at the candidate sites. Thus, the predicted RSL rise may inundate the ALT site by the year 2300-2400 AD and the storm surge area may reach the PED site by the year 2400 AD. PAL potential depository site will remain at the safe altitude during the period relevant for the safety of disposal facility.

The argument is the sites' topography, sediment stratigraphy and soil cover which all have been artificially affected while negative impact to the site by means of geomorphology, due to development, is the smallest. The most important argument is the location of a site at a sufficient altitude, which insures the safety in the light of predicted climate change and future RSL rise even the worst scenarios are to be realized.

The most relevant findings:

1. **In terms of specific geomorphological features, the preferred site for the disposal facilities is the PAL candidate site.**

2. ALT and PED sites less acceptable for construction of NSDF than the PAL site, and are roughly equivalent in preferences if flood risk is not considered.

2.6. Analysis of hydrogeological conditions

This study [10] is devoted to description of the hydrostratigraphical settings of NW Estonia, and hydrogeological conditions and groundwater flow of the three selected disposal facility locations.

Studies of groundwater monitoring wells and hydrogeological modelling results indicate that the Leetse-Türisalu, Lükati-Lontova and Sämi aquitards have very good hydraulic isolator capabilities in natural condition. Even though the lower two aquitards are cut by deep valleys, the valley-filling varved clays and other glaciolacustrine sediments fill the gap in aquitard. These observations are supported by isotopic and chemical composition of groundwater indicating glacial meltwaters being still present in O-Ca and deeper aquifers. Also, continuity of groundwater depressions across the valleys indicate no or only limited leakage through the buried valleys in the neighbourhood of Pakri peninsula. Thus, contaminant spillage into one aquifer does likely not threaten another aquifer.

The main findings:

1. All three sites are equally suitable for construction of the IDDF as bedrock aquifers and aquitards have similar hydrogeological conditions and possible contaminant transport is slow.

2. Conditions vary for the NSDF. None of the sites provide natural low-permeability barriers against accidental contaminant leakage. In all cases the leaked contaminant transport occurs at shallow depth and could be discharged at a few hundred meters to one kilometer away. PAL and PED site remain above sea level for longer time whereas ALT site will be probably submerged in a few centuries. Therefore it is less preferable, while PAL and PED sites are considered equally.

The main results of the analysis of hydrogeological conditions [10]:

- **All three sites are equally suitable for IDDF,**
- **For NSDF PAL and PED sites are considered equally, while ALT is less preferable**.

2.7. Hydrographic studies

The objectives were to characterise a hydrographic situation in three pre-selected potential disposal facility sites [11], to conduct hydrological relief analyses within the GIS software environment, to identify groundwater infiltration and discharge areas, to delineate sinkholes and seasonally flooded areas, to analyse satellite data products for seasonally flooded areas, to calculate general water balance, and to identify hydrological characteristics of rivers, ditches, or other surface water watercourses relevant for drainage of the three sites and transfer of radionuclides.

The hydrographic analysis of the ALT site reveals a vulnerability to surface water flooding (Figure 2.2). The drainage situation poses a high risk for the site due to its location in the middle of an extensive flat plain. Its current drainage system relies on the artificial drainage network, and the clogging of a culvert or drainage system would result in a rise of water level close to the surface. Additionally, this site is at risk of flooding due to ongoing and anticipated sea level rise, which is expected to pose an increasing threat within the next century (refer to reports 2.5 and 2.4 for detailed information).

Figure 2.2. Spring flooding at Altküla site.

The PED site is situated at a higher elevation and is relatively safe from the risk of surface water flooding. Its location on a steep slope and the presence of numerous karstic sinkholes contribute to efficient surface water drainage and minimise the risk of flooding.

The hydrographic analysis of PAL site also reveals a partial, minor flooding risk. This risk is influenced by several factors, including the partial enclosure of the area by earthworks, the presence of a spring within the PAL site, and the connection to the ditch network through a small culvert, Figures 2.3 and 2.4. The blockage of this culvert and artificial embankment around the site can result in water accumulation during heavy rainfall at the NW corner, contributing to the potential for minor flooding (up to 0.4 m above) in that specific subregion. Upslope from the PAL area, there is a potential water accumulating area (a wetland) that is drained by a culvert. However, even if the culvert is blocked, the water would naturally flow away from the PAL site, over the road to the south direction, as long as the road surface remains current. Additionally, filling the old ditch sections between the PAL site and the wetland would reduce the risk of flooding to a minimum.

Figure 2.3. Drainage ditch at the PAL site.

Photo 2.4. Temporary wetland next to PAL site.

Findings of the study:

1. **ALT site is vulnerable to surface water flooding**. Its drainage system relies heavily on the artificial drainage network. Improper functioning of this network would result in a rise of water level at the site. Additionally, this site is at risk of flooding due to anticipated sea level rise.

2. PED site is situated at a higher elevation on a slope and has efficient natural surface water drainage minimising the risk of flooding.

3. The hydrographic analysis of **PAL site reveals a partial, minor flooding risk. Engineering measures can be needed to exclude or reduce the risk** of flooding to a minimum.

2.8. Studies of the chemical composition and properties of groundwater and surface water

Investigation of water chemical composition and properties are the main objective of the study [12]. The hydrogeological and hydrostratigraphical settings of NW Estonia and chemical composition of groundwater in three potential locations of the disposal facility (PAL, ALT and PED) are provided. One of the objectives of this sub-activity was to assess the potential changes in hydrogeologically or geochemically significant parameters over a 1,000-year timeframe. The strongly negative isotope values provide confirmation of the preservation of glacial meltwater that is at least 10,000 years old in the Cambrian-Vendian and Ordovician-Cambrian aquifer systems. This indicates that the situation is likely to remain relatively unchanged over the next 1,000 years, and significant alterations in the chemical composition of the deep groundwater are not anticipated.

The main findings:

1. Measurements of stable isotope composition of groundwater indicates **very slow water exchange in aquifer systems** relevant for safety of IDDF.

2. The aquifers themselves contain interlayers of clay, or the terrigenous materials forming the aquifers are inherently silty or clayey in nature.

3. Relying purely on the chemical composition of groundwater it is not possible to bring out which of the suggested site is the best. The PAL, ALT, and PED alternatives are roughly equivalent in preference in terms of groundwater chemical properties.

2.9. Study of the soil and its deeper layers

The study aim was to investigate the geotechnical conditions of the Quaternary soils and bedrock in each potential repository location [13]. The geotechnical conditions affecting design of the disposal facility are discussed, and suggestions are provided.

In general, the geotechnical conditions of Quaternary soils in PAL and PED are favorable; however, some recommendations can be presented:

The strong and practically incompressible limestone lies near the ground surface (<2 m); thus, removing the Quaternary soils and placing the foundations of on-ground buildings onto the limestone is recommended.

The heterogeneous fill in PAL should be removed below buildings, roads, and parking lots because its properties are unpredictable. It might be frost susceptible because different natural soils have been used for filling.

The shingles, gravel and sand layers should be compacted before the construction of roads and other facilities supporting this layer because it may have uneven relative density and, as a result, cause uneven settlement of the facilities placed on this layer.

The average frost depth of soil in the area is 1.15 m (max 1.9 m). It should be considered that till is moderately frost susceptible. Also, the coarse-grained soil contains silt in places, making it slightly frost susceptible. The glacial till also exhibits slight plastic properties and may soften in the excavations if exposed to weather conditions.

Compared to the other two sites, the geotechnical conditions in ALT are the most unfavorable:

The uppermost sand (layer 2) has rather fair strength properties, the silty sand/sandy silt (layer 3) has very low relative density and poorer strength properties.

(Varved) clay (layer 4) is very compressible, and settlement due to loads placed above it will occur. The settlement due to the compressible soils must be calculated when designing a near surface disposal facility. If it exceeds the allowable settlement value, a pile foundation supporting onto till or limestone layer should be used instead.

When making excavations, the Quaternary soils must be supported by retaining walls. Sandy silt (layer 3) and clay (layer 4) are prone to soaking, and cohesionless sand must be supported. Till (layer 5) is a relatively strong, cohesive soil, but it is plastic and softens when its water content increases.

Silty sand/sandy silt (layer 3) and till (layer 5) are highly frost susceptible, and clay (layer 4) is moderately frost susceptible. The same frost depth values apply in PAL (average 1.15 m; max 1.9 m). The frost susceptibility of the deeper soils should be considered if the soils are removed and used as fill.

Due to the high shallow groundwater level, excavations must be drained. When excavations reach the till layer, larger water inflow can be expected from the sandy zones occurring in otherwise low permeable till.

The shallow groundwater level was measured 1.2–1.7 m below the ground surface. Currently, its level is controlled by the network of drainage ditches. Still, if the drainage system should be closed or damaged, a significant rise is expected as the area is naturally wet. The laboratory analyses indicated that the pH of the water is acidic (6.0), and due to the presence of aggressive CO_2 the shallow groundwater is moderately aggressive towards concrete.

In PAL, the geotechnical conditions for constructing both the Near Surface and Intermediate Depth Disposal Facilities are most favorable. The thin Quaternary cover characterizes the site, and the most suitable rocks for the Intermediate Depth Disposal Facility (Cambrian claystones) lie the nearest to the ground (57 m). The ALT and PED sites are less favorable than the PAL site. On both sites, the Cambrian claystones lie deeper than in PAL; 78 m in ALT and 98 m in PED. When considering Near Surface Disposal Facility, the conditions in PED are comparable to the PAL site, but in ALT the conditions are poorer. The actual ranking of ALT and PED sites depends on the selected repository type and construction costs, which are unknown now; thus, they are ranked equally.

The main findings:

1. In general, the geotechnical conditions of Quaternary soils in PAL and PED are favorable as strong and practically incompressible limestone lies near the ground surface (<2 m); thus, removing the Quaternary soils and placing the foundations of on-ground buildings onto the limestone is recommended.; however, some recommendations can be presented:

2. It is recommended to remove the heterogeneous fill in PAL site below buildings, roads, and parking lots because its properties are unpredictable. It might be frost susceptible because different natural soils have been used for filling.

3. The shingles, gravel and sand layers at PAL and PED sites should be compacted before the construction of roads and other facilities supporting this layer because it may have uneven relative density and, as a result, cause uneven settlement of the facilities placed on this layer.

4. The average frost depth of soil in the area is 1.15 m, while max depth is 1.9 m. It should be considered that till is moderately frost susceptible. Also, the coarse-grained soil contains silt in places, making it slightly frost susceptible. The glacial till also exhibits slight plastic properties and may soften in the excavations if exposed to weather conditions.

5. Compared to the other two sites, the geotechnical conditions in ALT site are the more unfavorable due to the presence of weak and compressible soil layers in the Quaternary cover making facility design more sophisticated and construction more expensive. The settlement due to the compressible soils at ALT site must be taken into consideration when designing the NSDF (for example, application of a pile foundation supporting onto till or limestone).

6. The groundwater level is very shallow at ALT site (1.2–1.7 m below the ground surface). Currently, its level is controlled by the network of human created drainage ditches. A significant rise is expected in the future, as the area is naturally wet.

7. The ground water at ALT site is acidic, and due to the presence of aggressive CO_2 the shallow groundwater is moderately aggressive towards concrete.

8. Geotechnically, the IDDF can be built in depth of 30 to 50 m in sandstones, carbonate rocks or terrigenous, as foreseen in the Technical specifications, however, **conditions would be more favorable in the deeper-lying Cambrian clayey rocks**. They are dominated by clay- and siltstones of low permeability, which serve as natural confining barrier for the disposal facility.

9. The clayey rocks occur at different depths in the potential sites: in PAL they are closest to the ground (starts at a depth of 57 m in PAL site), in ALT the depth of ~78 m and in PED, they start even deeper (~94 m from the ground).

10. **Precaution measures must be applied during construction when handling graptolite argillite, because of self-ignition properties** (oxygen access must be controlled).

11. When **considering suitability for NSDF, the conditions in PED and PAL sites are similar, while ALT site is more unfavorable**.

12**. Suitability for the IDDF depends on the excavation depth; PAL site is best one**, followed by ALT and PED.

13. Summarizing the findings, the geotechnical conditions for constructing facilities of the both types are most favorable in PAL site.

2.10.Monitoring atmospheric air

The general objective of the current sub-activity 2.10 was to present an overview of the current state of the quality of atmospheric air in the vicinity of the three possible alternative repository locations and to assess the possible impact on air quality during the different phases (construction, operation and closure) of the repository and to assess the projects conformity to the applicable national regulations [14]. The scope of the study consists of:

- Assessing the existing background air quality in the three possible repository locations.
- Assessing the expected emission sources and quantities of pollutants emitted to the atmosphere during the three phases of the project.
- Modelling the dispersion of identified pollutants emitted to the atmosphere during the construction, operation and closure phases of the project.
- Assessing the project's impact on the quality of ambient air in the three possible locations and conformity with national limit values set in the legislation;
- Elaboration of mitigation measures for compliance with national regulations and standards, if needed taking into account the investigation results.

For the assessment of the existing background air quality, short-term continuous measurements of selected pollutants (SO_2, NO_2, CO, O_3, NMHC, PM_{10}, BTX) were carried out at the three candidate locations. The rest of the study results is based on existing data from national databases.

The phases of the project (construction, operation, closure) are all similar for the three sites compared, except for the necessary transport of radioactive waste from the PAL site to ALT and PED sites. In the current context of the assessment, on-site construction works and transport of required materials are considered as the relevant sources of pollution.

According to the results of on-site measurements, the existing air quality level at the three locations is quite good and none of the observed pollutant concentrations exceed the limit values. The measured results depict dispersed pollution from various background sources like industry, transport and local heating, and are not associated with a certain activity or source. The measured values of pollutants correlate to the typical seasonal changes in air quality.

From the available spatial planning documents possible future developments do not impose an important change in air quality level around the three alternative locations.

The emissions to atmospheric air from the construction and closure activities of the repository were calculated and modelled around the sites. The effect of the operational phase of the project was considered negligible and was not included in the assessment. Since currently the design of the repository is on a conceptual level, a number of assumptions were made. From the ambient air dispersion maps it was seen that none of the concentrations of the selected pollutants exceeded the national limit values. The maximum modelled values appeared at the sites while at the nearest sensitive areas (households) the level of air quality is similar to existing background levels. All of the three alternative locations are located quite far from the nearest sensitive areas that results in good conditions for pollution dispersion.

All three alternative locations are equal in terms of air pollution. The effect of construction and closure phase of the repository on the existing air quality level is minimal and application of mitigating measures is not necessary. If the activities related to air pollution are specified in the later stages of the project, the emissions can be re-evaluated.

The main findings of the study:

1. According to the results of on-site measurements, the existing air quality level at the three locations is quite good and none of the observed pollutant concentrations exceed the limit values.
2. All three alternative locations are equal in terms of air pollution. The effect of construction and closure phase of the repository on the existing air quality level is minimal and application of mitigating measures is not necessary.
3. It was found that none of the concentrations of the selected pollutants will not exceed the established limit values.
4. **Future developments at the potential sites do not impose an important change in air quality level** around the three alternative locations.

2.11.Study of the climatic conditions

The main goals of the study were to determine the climatic conditions of the three potential locations and to describe the impact of climate change on the potential sites and the disposal facility in the long term, as well as the associated risks [15].

Weather-related risks are relatively low in the research area and their impact can be easily reduced by engineering and planning techniques. It can be assumed that the risks outlined below are the same in the PAL and PED and ALT areas. The main risks are as follows:

Low air temperature. Although the study area has a relatively milder climate than in Estonia in general, it is necessary to consider the possibility that in winter there may be an air temperature of ≤ -30 °C. Thus, the planned object must have a well-thought-out and active heating system that would remain in working order even in the event of prolonged cold waves. In the coming decades, the risk will decrease, but will not disappear.

High air temperature. Although the study area has a relatively milder climate than Estonia in general, it is necessary to consider the possibility that in summer there may be an air temperature of ≥ +30 °C. Thus, the planned object must have a well-thought-out and active cooling system that would remain in working order even in the event of prolonged heat waves. In the coming decades, the risk will increase.

Extreme snow conditions. Although the study area has a relatively milder climate than Estonia in general, it is necessary to consider the possibility that in winter there may be acute snowfalls and drizzles, which paralyze traffic and cut off the external power connection. Thus, the planned object must have an autonomous power supply, which will allow the normal continuation of activities even in isolation and without external electrical power. In the coming decades, the risk will decrease, but will not disappear.

Summer torrential rains. Although the study area has relatively less rainfall than Estonia in general, it is also necessary to consider the possibility that the region will be hit by heavy rainfall. Thus, the planned object must have a well-thought-out and functional water drainage system that would prevent local flooding from occurring. In the coming decades, the risk will increase.

Spring high water and summer floods. In general, the study area is not threatened by flooding by rivers, but when choosing the location of the object, it is necessary to consider the risk that during spring high water level in the rivers rises much higher than the annual average. However, the overall risk from floods is minimal. When constructing an object, the hydrological network of the area must be thoroughly examined, and a functioning drainage system must be established. In the coming decades, the risk from spring high water will decrease, but will not disappear, the risk of flash floods will increase.

Drought. In the study area, drought is more likely to occur than the Estonian average. This may interfere with the availability of domestic water, especially when surface water is used. In the coming decades, the risk will increase.

Windstorms. The study area is windier than the Estonian average, the average wind speeds are higher here and windstorms are more frequent. Average wind speeds of 25 m/s for 10 min and gusts of ≥ 30 m/s must be considered. The main danger lies in power outages; therefore, the planned object must have an autonomous power supply, which allows the normal continuation of activities even without an external source; external electrical connections should be built as underground lines. When constructing buildings, it must be considered that storm winds occurring here can cause damage to buildings. In the coming decades, the risk will increase.

Stormwater. If the adverse circumstances coincide, the sea level in the study area may rise by up to 2 m, and this will flood extensive beach areas. The risk will increase in the coming decades. Along with rising sea levels, this risk will change to a large area of ALT in the 500-1000 yr perspective.

Tornadoes and other summer storms. In the perspective of 500-1000 years, it is likely that the object will be hit by summer storms and will not depend on the location of the disposal site. However, it is unlikely that this would result in significant destruction if the facilities are planned to withstand gusting winds of ≥ 30 m/s.

Thunderstorm. The study area has a lower-than-average risk of thunderstorms in Estonia. With modern lightning protection systems, the risk from lightning strikes can be effectively mitigated. Somewhat more dangerous may be other extraordinary natural phenomena accompanying convective clouds (gales, torrential rains, hail).

Hail. The study area has a lower risk of hail than the Estonian average. However, in the perspective of 500 to 1000 years, the possibility cannot be ruled out that the disposal area will be hit by some incident of hail, which can cause certain damages to facilities.

Freezing of the soil. In general, the risk of frost heaving in the study area is lower than in the Estonian average. However, at depths of both 20 and 80 cm, negative surface temperatures can occur in harsher winters.

Sea level rise. As the climate continues to warm, Estonia will start to lose land due to the rising sea level. The rise in the water level itself is relatively imperceptible – the change is a few millimeters per year. In the short term, however, rising sea levels act as one of the leverage forces of coastal erosion. In the coming decades, the risk will increase. However, in the perspective of 500-1000 years, the loss of land due to rising sea levels can be significant. This can directly threaten the area ALT.

Coastal erosion. As a result of rising sea levels due to climate change, coastal erosion is intensifying. When adverse circumstances coincide, this process can be extremely extensive for some storms. In the coming decades, the risk will increase. In the short term, it does not threaten any planned disposal site. However, in the perspective of 500-1000 years, both ALT and PED are threatened.

The main findings of the study:

- Based on the analysis, the preferred location for the disposal site is PAL. In this location, climate risks are relatively smaller or easier to manage. The strongest arguments in favor of PAL are the site’s suitability for LULUCF principles and resilience to expected sea level rise and its impacts.

- ALT would be the least desirable of the three alternatives. This also does not comply with LULUCF principles. But in addition, **there is some risk of flooding in ALT site.** The biggest threat could be sea level rise, the effects of which would reach the ALT site significantly earlier than the alternatives PED or PAD.

2.12. Study of the environment

Objectives of the study were to study features of flora, fauna, habitats, habits of species of the three potential sites proposed for location of the disposal facility [16]. The condition of the environment at the sites and the extent of disturbance as well as possibilities of minimising the environmental impacts during the periods of construction, operation, closure and post-closure should be assessed.

The Pedase location alternative area is in the forest landscape around a large forest array. There are no agricultural landscapes in the vicinity of the site. There is an area of the high-voltage overhead line corridor running along the southern border of the site. The area is relatively homogeneous in terms of forest types and age group, with spruce and pine as the main trees, and relatively few deciduous trees. These circumstances rather reduce the assumptions for the species richness of the fauna.

The area's game fauna is characteristic of a large coniferous forest array, but species abundance is probably not high. Branch forests with relatively homogeneous in age and type are relatively poor feeding areas for several game species. Apparently, the low winter abundance of cloven-hoofed animals is also due to the lack of juveniles and more humid forest areas. Compared to the Altküla location alternative area, the fauna of the Pedase alternative area is somewhat poorer in terms of both species and specimen abundance.

The main findings:

- The most preferred alternative from the point of view of vegetation is the existing location of PAL, as the area has been heavily influenced and redeveloped by human activity, and the secondary vegetation cover formed on the site does not have a significant natural value.
- The second-best alternative is ALT, in which a managed forest landscape is spreading, a large part of which consists of a recent clear-cut area and a forest glade. The area is of some natural value due to the swampy and overgrown forests. Due to the forest communities found in the site and the protected orchids, the value of the site is higher than that of the PAL alternative, but slightly lower than the value of the PED site, as the forests of the latter are older and less affected by logging.
- The worst or least preferred alternative is the PED alternative, as the forest communities found in this area are less affected by logging and have a slightly greater value than the forest communities of the ALT alternative, which are more strongly managed. With the PED alternative, the impacts on vegetation in the form of deforestation would be greatest.
- The most preferred alternative from the point of view of fauna is the one with the lowest value as a habitat for fauna and on which the establishment of a radioactive waste disposal facility would therefore cause the least effects.
- The most preferred is the existing location PAL, since the area is heavily influenced by human activities as a habitat and is surrounded by a fence, which prevents game from entering the area. Therefore, the area has the poorest fauna of the candidate sites.

- The second-best is the alternative location PED, whose fauna is somewhat poorer than that of the ALT area, whose fauna is richer due to its landscape layout and the diversity of the stands. However, the area of the PED alternative is significantly more valuable as a habitat for fauna than the PAL area.
- The worst or least preferred alternative is the ALT alternative, since its location on the border of the forest array and the agricultural landscape, together with its alternating age and composition of the stand, results in a richer fauna compared to the PED alternative.
- Overall, the **PAL site, which has a significantly lower value in terms of both flora and fauna, is significantly better than the other alternatives**, and in which the negative impact of biota loss due to development is the smallest.
- ALT and PED sites are roughly equivalent in preference since the flora of the ALT site is of lesser value, but the fauna is of greater value compared to the PED alternative. Therefore, with the choice of one or another alternative, the effects on wildlife will be approximately equal.

2.13. Study of the social situation

The purpose of the study was to determine the social situation of alternatives in order to evaluate which pre-selected site is the most preferred [17]. The study was broadly divided into two parts: (i) creating a profile of Lääne-Harju rural municipality, and (ii) finding out the attitudes of the residents. The following can be said about location preferences:

Existing intermediate storage site:

- Compared to respondents with Russian mother tongue, respondents with Estonian mother tongue are three times more likely to prefer the existing intermediate storage site.
- Men are 1.2 times more likely than women to prefer the existing intermediate storage site.
- People living in a private residence or farm are more likely to prefer this option.
- Respondents who rate the need to find a solution for disposal of radioactive waste in the near future lower are more likely to prefer this option.

More than 20 km from my place of residence:

- People under the age of 40 (so-called young people) are 1.7 times more likely to prefer this location compared to older age groups. The age variable is statistically significant only in this model with low descriptive power.
- People with higher education are more likely to prefer this option than those without higher education.
- In this model, neither awareness nor attitude questions explain location preference.

The location does not matter as long as safety is 100% guaranteed:

- Compared to respondents with Russian mother tongue, respondents with Estonian mother tongue are 1.59 times more likely to prefer this location.
- Women are 1.3 times more likely than men to prefer this option.
- Groups other than salaried workers are 1.4 times more likely to prefer this option.
- Compared to respondents with higher education, respondents without higher education are 1.5 times more likely to prefer the location option.

Somewhere else:

- Compared to respondents with Estonian mother tongue, respondents with Russian mother tongue are 1.5 times more likely to prefer it.
- Compared to other employment groups, entrepreneurs (including self-employed persons) are 1.6 times more likely to prefer this location option.
- People with higher education are more likely to prefer this option than those without higher education. At the same time, an increase in the level of higher education (MA and PhD) does not lead to a greater preference for this option (people with a lower level of education than a Master's and a Doctorate degree are more likely to prefer this option).

- Respondents with higher subjective awareness are more likely to prefer this option (while objective awareness does not explain location option preferences).

The main findings of the focus group interviews are summarized as follows:

- Knowledge of radioactive waste is rather inconsistent. There is no distinction between nuclear fuel and radioactive waste. There are few people who are competent in the topic.
- Existing waste is considered extremely hazardous. There is also no certainty that no waste will be brought from other countries to the proposed final storage site.
- The keywords that pass through in relation to radioactive waste are: eerie, dangerous, unpleasant, polluting, toxic.

The plan to build a radioactive waste disposal facility in the territory of the municipality is accompanied by a certain amount of confusion. The first question is why locations are being considered only in Lääne-Harju municipality and not all over the country. Several participants said they felt cut off from the information, and there is fear that decisions will be made without the knowledge of residents. Not all participants were familiar with the exact locations or the number of location alternatives. Some do not take locations other than the existing one seriously – if the waste is currently in Paldiski, it is logical to secure the existing site.

The main values of Lääne-Harju are considered to be nature, including forest, seashore, silence, image. There is also a lot of dissatisfaction with the developments so far – a lot of the forest has been taken down, etc. There are fears that further development will worsen the situation.

The main recreational habits, including for the residents of Paldiski, are related to nature. The main fears associated with the construction of the disposal facilty vary somewhat from region to region. In Paldiski, fears remained that the existing site would leak at some point. There were also fears of a decline in the value of real estate. From the point of view of entrepreneurs, the construction of a final storage site in Paldiski will not cause problems – it is certain that the risk of leakage is minimized. However, the population of Harju-Risti is afraid of significant disturbance, including large-scale construction with the accompanying infrastructure. In addition, there are fears of the destruction of the natural environment and the reputation of the region.

The population of the Harju-Risti region does not agree under any circumstances to the establishment of a disposal facility in their area. The participants of Paldiski were somewhat more lenient – the construction of the disposal facility was seen as an instrument with which to obtain additional investments from the state. However, in both cases, it must be taken into account that the participants in the focus groups do not represent the entire population of the regions, but, above all, their opinion.

Thus, location preferences generally do not depend on the respondent’s background, but on other factors. The analysis also does not reveal specific location preferences, but various arguments and aspects to take into account. The main ones are presented below, considering the results of both the survey and focus group interviews:

- Lääne-Harju rural municipality is largely a low density area. However, one of the location alternatives is located in an area (Paldiski) from which approximately three-quarters of the population lives within a 10 km radius. The other two are located in sparsely populated areas. In this view, the latter could be preferred, as the number of people potentially directly affected is significantly smaller.
- On the other hand, in the case of Paldiski, it is an industrial area where the final disposal site would be better suited, given the profile. In the case of Paldiski, it would also not be necessary to start building access roads, etc. The residents of the Harju-Risti region are very afraid of the scale of construction works. Deciding in favour of Paldiski would also mean that there would be no need to start transporting the existing waste anywhere.
- The residents of Harju-Risti are very much against the establishment of the final disposal site. If it were decided to establish the site in one of the locations in the vicinity, widespread dissatisfaction can be expected. At the same time, it should be taken into account that a similar situation may arise in the case of Paldiski, in which case the residents of recreation areas (Laulasmaa, Kloogaranna, etc.) would probably also feel affected.

Based on the survey results alone, the most preferred final disposal site is the existing site (27% of the respondents chose this option). At the same time, it must be taken into account that it primarily reflects the opinion of those people who do not live in Paldiski. The latter would prefer a location either somewhere else or more than 20 km from their place of residence.

Many questions are related to people’s awareness:

- 40% of the respondents are not or are very little familiar with the topic of radioactive waste. Before moving on to substantive discussion, it is necessary to raise awareness.
- On average, three-quarters of the respondents consider all kinds of radioactive waste to be very hazardous. Obviously, the less known about the matter, the greater the opposition everywhere.
- Approximately half of the respondents do not believe that the final disposal site is safe. Additional outreach by reliable sources (scientists, international organisations) would probably help to ease tensions.
- Residents do not seem to have complete information about the process (events), results, etc. According to the residents, the name of the project, “Rajala”, also does not unambiguously and clearly reflect its content.

The main findings of the study:

Rather contradicting results are received comparing different aspects of the sites.

1. When the reference is given to locations with fewer people living nearby and fewer services, ALT and PED sites are more preferable than PAL

2. If preference is given to locations whose profile is more suitable for large-scale construction work, where there is decent access and transport connections, PAL site is preferred while other two are nearly equal.

3. If preference is given to locations that were highlighted more often in the survey, order is the following: PAL site followed by ALT and PED sites

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2.14. Assessment of noise and vibration

The objective of the noise and vibration assessment was the assessment of the existing noise and vibration levels at the three disposal locations and an assessment of the project conformity to the applicable national standards and project-based requirements in the construction, operation, and closure phases [18].

As the distances between the possible repository locations and nearest residential buildings are large (≥ 700…2200 m) it is not foreseen that the Estonian noise limits during construction phase will be exceeded.

PAL site. The residential buildings are located 700 m south-west from the possible PAL construction site. The calculated noise levels for the closest residential buildings are ≤ 45 and ≤ 45 dB for day- and night-time respectfully.

ALT site. Since the nearest residential buildings are located ≥1600 m north (Männiku residential building) and ≥2200m south (Kotka residential building) of the Altküla site the calculated construction noise levels for these are ≤ 40 dB during day-time and ≤ 40 dB during night-time.

PED site. The calculated noise levels for the closest residential buildings (Tuipalu and Laane) are ≤ 45 dB for day-time and ≤ 45 dB for night-time. The residential buildings are located ≥800 m west and east from the site.

The main findings:

- All three potential locations are with relatively low existing background noise and vibration levels. However, this could change with the development of additional areas near the disposal locations (for example with construction of new wind parks, Paldiski underground Pumped-Hydro Energy Storage or other developments).
- According to the most recent Lääne-Harju municipality comprehensive plan, the PAL site is situated right next to industrial areas. These areas are currently mostly empty, but this is most probably subject to change in the future once the plans are realized.
- The disposal facility project has to fulfil all of the limit values regarding noise and vibration levels no matter which location will be chosen for the repository. This means that all of the alternatives can be treated as equal from the noise and vibration impact.
- The alternative ALT and PED sites are in remote locations and do not border with perspective industrial, residential etc. areas. No large-scale developments are known nearby. The sites are comparable to each other since they both are in remote locations and at the time of this report no new outside sources of noise and vibration are planned in the vicinity of these locations. This means that ALT and PED sites are preferred from the noise and vibration impact standpoint.

2.15. Analysis of roads and infrastructure

The purpose of sub-activity 2.15 was to provide information on existing communication roads to the potential waste disposal sites relevant for transportation of the waste to be disposed of and materials for construction and closure of the facility [19]. Availability of infrastructure and good communication roads are important in all phases of radioactive waste disposal program: site characterization, construction, operation, closure and post-closure. It makes significant influence to the disposal cost but is safety relevant too. Connection roads are also important in case of emergencies too.

Various modes of transport (water, rail and road) were examined. Road transport (Figure 2.5) has been found the only method suitable for waste transportation.

Figure 2.5. Optimal transport routes and alternative routes for radioactive waste transport from FPNS to Pedase and Altküla alternative sites

In this analysis, study concentrated on the three chosen locations (existing site in Paldiski, alternatives Pedase and Altküla) for disposal facility of radioactive waste. In case of Pedase and Altküla alternatives, radioactive waste must be transported to these alternative locations from the existing site in Paldiski. The optimal route for the transport of radioactive waste was determined with length of about 30 km (nearly equal to the both sites). Most of the routes to the both locations overlap. If disposal facility will be built at Paldiski site, there is no need for transport for radioactive waste on public road, no need for off-site road improvements and no costs related with that, and waste can be transported within one cadastral unit.

Differently from radioactive waste, construction materials for disposal facilities must be transported to all three site alternatives. From this point of view the all three sites are nearly equal.

Application of existing roads (Figure 9) minimises the need for road construction and improvement work, and negative effect on traffic frequency and interfering with transport of other dangerous goods. Some road improvement works are still needed, while for specifying and estimating their price further on-site studies are needed.

In addition, four alternative routes to the optimal routes were proposed.

In addition to road transport analysis, current situation, and further plans in maritime transport (port infrastructure), railroads and airports were analysed. Currently, three proposed locations of waste repository do not contradict or have coeffect with transport infrastructure. According to the spatial planning documents, there are no plans with building new airports to the study area or significantly extend existing airports. There are some plans for extending railroad network, but the plans are still uncertain and do not affect planned activities related to the radioactive waste repository. There are some plans for building additional ports on the coast of Lääne-Harju municipality, especially the plan for liquid gas terminal/cargo port in Pakrineeme. These development plans do not significantly affect the Paldiski radioactive waste disposal facility and the possible transport routes.

The main findings:

1. **The PAL site has the best accessibility**. Construction technique and building materials can be transported to the site via sea, railway and road. The radioactive wastes will be produced on the site, so transportation will not be needed at all. **No road construction is needed for the PAL site.**

2. The both alternative sites (PED and ALT) are only accessible by land. The waste must be transported to these sites on public roads. They are located next to the existing road network, so there is no need for building additional access roads, except roads inside the sites themselves. These sites are equal in terms of accessibility and suitability for transporting waste and construction materials.

2.16. Preparing a safety assessment

The Safety Assessment Report (Sub-activity 2.16) is devoted to investigation possibilities to establish the planned disposal facility at these sites [20]. The SAR is developed in the stage of site selection and its main purpose is to compare suitability of these three sites for waste disposal as well as to investigate suitability of the proposed concept to the local site specific conditions.

The current SAR is based on results of characterisation of the above-mentioned three sites. The characterisation programme included the following investigations: tectonic, seismic, geological, geodetic, geomorphologic, hydrogeological, hydrographic, chemical, climatic, environmental, social studies as well as analysis of roads and infrastructure. It is necessary to point-out that that due to lack of data this SAR has preliminary character only. It has to be significantly updated taking into account results of more detailed characterisation of the site and features of the facility’s Technical Design, i.e. Final SAR has to prepared for licencing purpose.

The detailed safety assessment is presented in Report for Sub-activity 2.16

2.16.1. Safety criteria

Radiation Act of the Republic of Estonia and other legislative documents define the principles and basic safety requirements for protecting people and the environment from the adverse effects of ionizing radiation. The following principles of radiation protection have been established:

- Justification of radiation practices: planned radiation practices have to be justified by proving that they are the best based on their economic, social or other benefits in relation to the potential health detriment they may cause.
- Optimization of radiation protection: any exposure shall be kept as low as reasonably achievable, taking into account the economic and social factors.
- Dose limitation: the sum of exposure doses shall not exceed established limits.

The following effective dose limits are established:

- 20 mSv per year for occupational exposure (for workers).
- 1 mSv per year for the public.

Radiation protection optimisation approaches for post-closure stage of radioactive waste disposal facilities have been elaborated by ICRP. The Commission has recommended dose constraint of 0.3 mSv in a year as a highest dose in normal exposure situations. Constrained optimisation is the main approach to evaluating the radiological acceptability of a waste disposal option.

The dose constraint is not applicable in evaluating the significance of human intrusion. The Commission has advised that an annual dose of around 10 mSv per year may be used as a reference level below which intervention is not likely to be justifiable, while annual dose of

100 mSv per year may be used as a reference level above which intervention should be considered.

2.16.2. Wastes to be disposed of: waste sources and inventories

The National strategy provides technical management solutions for each of the 3 waste sources: legacy waste in storage, currently produced institutional waste, and future waste from decommissioning of the Paldiski reactors. The waste to be managed as part of the National Programme is classified into three main types:

1. Low and intermediate activity short-lived waste (more than 90% of waste amount);
2. Low and intermediate activity long-lived waste (a few percents);
3. NORM waste (contaminated scrap metal), making up to few percents.

Most of the currently available radioactive wastes in Estonia originate from deactivation and decommissioning projects. Fifty percent of the overall waste volume is already characterised and is assessed to have a total activity ca 900 TBq. Uncharacterised waste is mostly low active and its contribution to overall activity is small. Most of radionuclides is concentrated in spent sealed sources of Sr-90, Cs-137, Co-60 and Pu-Be, which account for only ca 10% of the total amount of waste. The total volume of the already conditioned waste is about 460 m^3, In addition, there is about 1180 m^3 of unconditioned waste stored at Paldiski site.

The amount of the decommissioning waste is estimated to be about 395 m^3 by 2040, when the beginning of the decommissioning activities is scheduled. It is also considered that waste streams from the radiation practices will be consistent also in the future (less than 1 m^3 annually) and significant changes are not foreseen.

Tammiku waste disposal facility was in use from 1960 until 1995 for institutional waste disposal. After that the waste was retrieved. Substantial part of the legacy waste (from previous Tammiku and Paldiski dismantling activities) is already conditioned and characterised.

The waste was characterised before cementation using gamma spectrometer. The presence of beta and alpha radionuclides is not controlled. The cementation process is properly documented – each container with conditioned waste has individual passport. There is also characterised and uncharacterised waste from decommissioning of Tammiku site, which is concreted in standard concrete containers. Not fully characterised waste from previous decommissioning activities is concreted inside submarines shells of RC1 and RC2 as well as stored unconditioned in 200 L drums.

Currently, several different types of containers are used for waste conditioning and storage. It is assumed, they will be applied for disposal too.

Standard concrete containers. A concrete container designed by Studsvik Nuclear AB with external dimensions of 1.2 m × 1.2 m × 1.2 m and a wall thickness of 10 cm (Figure 2.6) is the predominant type of container (hereafter referred to as a standard concrete container). The upper 10 cm layer in containers is filled with “clean” concrete to protect waste against dispersion. In addition, a 10 cm thick concrete lid is fixed by bolts on the top of the containers.

Figure 2.6. Standard concrete containers with cemented waste is predominant container type.

Metal containers. Metallic containers with 5 mm thick walls and external dimensions 1.2 m ×1.2 m ×1.2 m are used for storing cemented sediments. To prevent waste from spreading the top 10 cm layer is made of "clean" concrete.

Cylinders. During refuelling the reactor 1, the control rods were replaced. The spent rods are conditioned in cylindrical containers. The containers are made of steel tubes with a diameter of 1.2 m and a height of 2 m. Control rods were loaded and immobilised with concrete.

Big concrete containers. 3 m high concrete containers are made of ferroconcrete. Containers dimensions: height 3.0 m, width 1.2 m and depth 1.2 m; minimum wall thickness 25 cm; weight 8640 kg. This type of container is used for most active wastes retrieved from Tammiku (including DSRS).

Estimated radioactive inventories of NSDF and IDDF are presented in Tables 2.1 and 2.2 respectively. Vessels of the reactors will be disposed of entire, not fragmented. All other dismantled equipment will be fragmented into small pieces and packed into appropriate containers.

Table 2.1. Activities of radionuclides in NSDF (referred to 2041)

Radionuclide	Activity, Bq	Radionuclide	Activity, Bq
H-3	6.2E+10	**Pu-239**	5.0E+05
Co-60	9.3E+09	**Pu-240**	1.4E+05

Ni-59	4.7E+07	**Am-241**	5.9E+09
Ni-63	2.2E+9	**Ba-133**	5.1E+05
C-14	6.1E+08	**Ra-226**	3.9E+09
Sr-90	1.3E+12	**Ra-228**	9.0E+03
Nb-94	3.8E+07	**Th-232**	1.4E+05
Cs-137	2.4E+13	**U-234**	2.2E+03
Eu-152	5.9E+08	**Kr-85**	6.7E+09
Eu-154	9.4E+07	**U-238**	5.8E+08
Pu-238	2.3E+05		

Table 2.2. Activities of radionuclides in IDDF (referred to 2041)

Radionuclide	Activity, Bq	Radionuclide	Activity, Bq
H-3	6.7E+10	**Eu-154**	1.2E+12
Co-60	3.8E+12	**Pu-238**	4.6E+12
Ni-59	1.3E+12	**Pu-239**	2.7E+11
Ni-63	8.1E+13	**Pu-240**	8.1E+07
C-14	1.4E+13	**Am-241**	2.1E+11
Sr-90	6.9E+14	**U-238**	4.6E+12
Nb-94	1.1E+11	**Ra-226**	2.6E+10
Cs-137	1.0E+14	**Kr-85**	1.1E+10
Eu-152	6.9E+12	**Th-232**	2.6E+05

2.16.3. Basic principles for construction, operation and closure

Considering the small amount of waste and looking for the most efficient means of operation and maintenance, it was decided to locate the two disposal facilities of different types on the same site. Both disposal concepts are flexible enough, i.e. easily adaptable to different waste volumes and waste packages as well as to conditions of the particular site.

The conditioned Low-Level Waste is to be emplaced into concrete vaults with protective clay layer. The NSDF would consist of two such disposal vaults located on the ground surface with dimensions of about 15*12.5*6 m. After finishing waste emplacement activities (operation stage) of the NSDF, it will be closed by installation of a multi-layer capping system protecting against infiltration of water, human and bio-intrusion and erosion (Figure 1). A grass-covered "hill"-shaped cover is proposed (Figure 16.2). Vegetation cover is an inexpensive, but highly effective mean in a repository closure cap. Roots of plants reinforce slopes and protect them from erosion caused by wind and water. The grassy slopes are the easiest to maintain. Also, the grass or shrubs covered slopes are the most natural in the landscape of North Estonia. However, trees growing on the “hill” are not desirable as deep penetrating roots of the trees can enter into the disposal system.

Intermediate Level Waste is defined as waste that contains long lived radionuclides in quantities that need a greater degree of containment and isolation from the biosphere than is provided by Near Surface Disposal. Disposal in a facility at a depth of between a few tens and a few hundreds of metres is indicated for Intermediate Level Waste. Disposal at such depths has the potential to provide a long period of isolation from the accessible environment if both the natural barriers and the engineered barriers of the disposal system are selected properly. In particular, there is generally no detrimental effect of erosion and other surface related processes at such depths in the short to medium term. Considering small amounts of wastes requiring intermediate depth disposal, an Intermediate Depth Disposal Facility (IDDF) of shaft type (Figure 16.3) was proposed. The foreseen minimal depth of the IDDF is 30 m. The assumed external diameter of the shaft is about 10.5 m, while height of waste colon is up to 20 m, however, the geometrical parameters can easily adapted according to the amount of waste.

The exact depth of The IDDF depends on site specific geological conditions. During geological investigations, a thick layer clayey sediments was found at all three candidate sites, the results are presented in reports for Sub-activities 2.3 and 2.9. Application of the natural clay barrier minimises need of an additional engineered concrete barrier. The proposed waste disposal depths are approximately 60 to 80, 78 to 98 and 90 to 110 m, respectively for PAL, ALT and PED sites (Figure 2.7). Compacted sand/bentonite mixture or natural clay are proposed for sealing of the disposal shaft after finishing waste disposal activities. The main function of this confining barrier is protection against vertical infiltration of ground water. Assumed thickness of this water impervious layer is about 5 m. The volume above the confining barrier would be filled with the local soil and compacted.

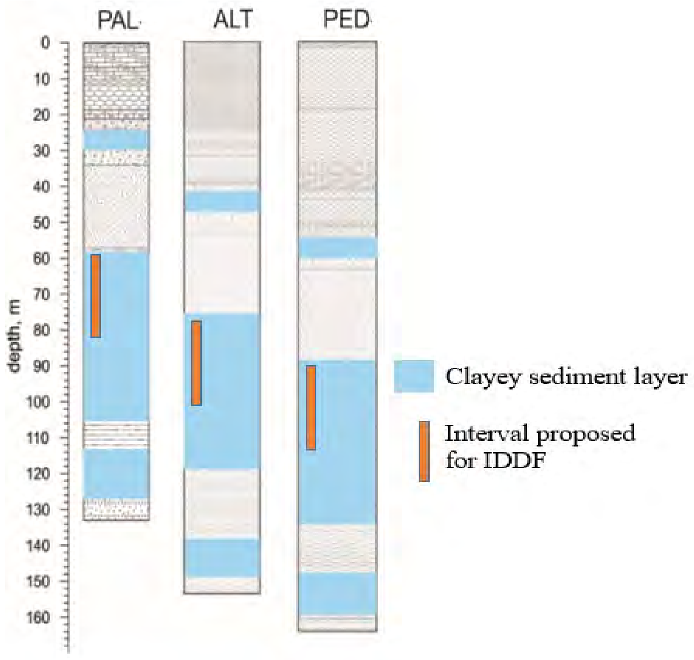


Figure 2.7. Vertical position of the IDDF for the three candidate sites

In order to minimise the negative impact of the atmosphere, temporary shelters will be installed over the disposal vaults and the shaft.

2.16.4. Preliminary Safety Assessment for construction, operation, closure and post-closure

At the stage of the disposal facility siting, when no design of the facility is available, the safety assessment and risk analysis are based on a conceptual design and on some general assumptions regarding properties of the radioactive waste and characteristics of the facilities, their structure and operation. As the goal of the study is comparison of alternative locations, the emphasis is paid to different properties of the locations and their impact on safety rather than specific details of operation. During the later stages of the design when more details about the facilities become clear, the safety assessment and risk analysis are to be updated at a higher level of specific details.

2.16.4.1. Construction phase

Soils in Estonia are rich in uranium and radium. Radium decay progeny radon Rn-222 can accumulate in the shaft air and therefore cause exposure to workers. A conservatively estimated dose to the workers can reach about 0.03 mSv/h. The potential doses of workers may exceed the dose limit of 1 mSv/a, depending on the time that people will have to work in the shaft. Therefore, application of protection measures, such as artificial ventilation, can be considered when working in the shaft.

2.16.4.2. Waste transportation

In the case of ALT and PED sites, the containers with radioactive waste must be transported on public roads. This should be done in accordance with the requirements of the Agreement concerning the International Carriage of Dangerous Goods by Road. It can cause exposure of habitants. The estimated doses to reference members of the public due to transportation of radioactive waste to the disposal site is very low (about 0.036 mSv), significantly lower than the annual dose constraint of 0.3 mSv. Transportation of the waste by the public roads would satisfy the requirements and would not exceed the limits for the population and vehicle driver. A favorable feature of the PAL site is that there would be no need to transport waste on public roads.

2.16.4.3. Normal operation of the disposal facility and anticipated operational events and accidents

Doses to workers performing typical jobs associated with waste disposal at NSDF were estimated conservatively. The predicted maximum dose for a worker performing routine activities at the NSDF site during the entire waste disposal process is 5.44 mSv. It doesn’t depend on the disposal site. The estimated maximum dose is far below the annual dose limit of 20 mSv.

The conservatively calculated maximum dose of a worker working at the IDDF established PAL site is about 0.74 mSv only. The woker exposure dose would even lover for ALT or PED sites, however track driver exposure in this case would be similar (about 0.6 mSv). The estimated doses are significantly below the established limits.

There is expected, that anticipated operational events and design based accidents are mostly dependent on internal hazards as well by external hazard (an earthquake). However, the beyond design accidents could be due to external events such as fall of large aircraft and explosion at the disposal sites. A list of possible anticipated operational events, design based accidents and beyond design accidents was screened, appropriate scenarios were selected and consequences were analysed. The summarised exposure doses in case of the selected scenarios are presented in **Error! Reference source not found.** workers, emergency staff and for reference members of the general public.

Table 2.3. Identified operational events and accidents at the disposal facility and expected exposure of workers Identified operational events and accidents at the disposal facility and predicted general population exposure

Event	Dose to members of general population, mSv			Dose to workers emergency staff, mSv		
	PAL	PED	ALT	PAL	PED	ALT
Fault during on site movement at NSDF	0			1.13E-03		
Failure of truck on route to NSDF	0	4.92E-04	1.33E-04	0	4.68E-03	4.68E-03
Spread of contamination at NSDF	4.97E-10	8.32E-10	3.11E-10	2.04E-04		
Fixing problem of incorrect positioning of WP at NSDF	0			1.58E+00		
Fault during on site movement at IDDF	0			8.00E-3		
Failure of truck on route to IDDF	0	4.00E-03	2.00E-03	0	1.65E-02	1.65E-02
Spread of contamination at IDDF	3.90E-09	6.55E-09	2.44E-09	1.99E-04		
Fixing problems at IDDF	0			1.63E-02	6.28E-03	8.34E-03
Earthquake impact to NSDF	1.74E-02			1.09E+01		
Accident during preparation of vault to operate	0.00E+00	9.99E-05	9.99E-05	1.06E-02	6.36E-02	6.36E-02
Transportation of waste to NSDF with dose rate higher than currently determined	0	1.10E-06	1.10E-06	2.33E-04	1.40E-03	1.40E-03
Transport accident during waste transportation to NSDF	0	1.03E-03	4.18E-04	1.31E-02	1.44E-02	1.44E-02
Drop and damage of WP at NSDF site	5.70E-06			2.98E-02		
Hanging of WP at NSDF	5.63E-06			1.58E+00		
Fire at NSDF	2.92E-09			1.29E-03		
WP drop and damage of a vault	1.74E-02			1.09E+01		
Earthquake impact to IDDF	2.05E-05			2.09E+00		
Transport accident during waste transportation to IDDF	-	9.08E-01	6.24E-01	3.22E+00	3.22E+00	3.22E+00
Drop and damage of grouted WP on IDDF site surface	2.05E-05			2.09E+00		
Drop of WP into shaft and its damage	2.73E-05	2.73E-05	2.73E-05	4.23E+00	2.79E+00	3.14E+00
Hanging of container at IDDF	6.43E-05			6.46E-01	6.36E-01	6.38E-01
Fire at IDDF	1.0E-05			1.87E+00		
Damage to packages within the vault (plane crash)	2.44E-05	3.40E-05	1.80E-05	3.30E+01		
Damage to packages within the shaft (plane crash)	1.24E-03	1.24E-03	1.24E-03	3.55E+01	2.36E+01	2.66E+01

The dose estimates for the possible design basis accidents do not exceed 11 mSv and 2.1 mSv respectfully for NSDF and IDDF. These doses are the annual dose limit for workers (20 mSv).

Whereas, in the case of the beyond design accident such as big aircraft crash followed by explosion, the expected doses for the workers are higher and can reach up to 36 mSv, however they do not exceed the reference level for emergency workers (100 mSv) in a single year. The exposure dose does not significantly depend of a site. The estimated doses for the nearest inhabiting population would be insignificant (less than 1 µSv).

No accidents and no considerable exposure of the population are expected in the closure period of NSDF and IDDF at all disposal sites. Worker would receive small doses (0.24 mSv at NSDF and 0.028 mSv at IDDF) during closure period regardless of a site.

2.16.5. Post-closure safety

2.16.5.1. Assessment scenarios

Post-closure safety assessment of a radioactive waste disposal facility is generally undertaken to provide an assurance to stakeholders (such as government, regulatory authorities, the general public and other technical/scientific groups) that the facility has been or will be sited, designed, constructed, operated and closed in such a manner as to ensure protection of humans and the environment over long timescales.

Long time frame is considered when assessing safety of the waste disposal facilities and the scenario, which is a hypothetical sequence of processes and events, is devised for the purpose of illustrating the range of future behaviours and states of a disposal system, for the purposes of compiling a Safety Case. Uncertainty is inherent in any safety assessment at different stages of the safety analysis is a major factor in the acceptance of the safety assessment case by technical audiences including the regulatory authorities. Scenario uncertainty is related to the definition of an exposure scenario and is often a significant source of uncertainty related to the long-term future behaviour of the disposal facility.

For evaluation of the potential impact of the planned NSDF and IDDF through the groundwater pathway, the reference group is considered. The reference scenario considers that the waste can be leached by water infiltrated through the barriers. The contaminants in the leachate can reach the groundwater. In case of near surface disposal the main water pathway relevant to the radionuclide migration within groundwater considers rain water seepage through unsaturated zone and the confining layer downwards to the semi-confined aquifer and lateral groundwater flow towards Baltic Sea. In the case of IDDF shaft diffusion of the radionuclides from the shaft and consequent upward lifting of the contamination groundwater through the fractures and faults towards the well and the Baltic Sea is possible. The use of the water from the well for domestic needs implies that the contaminants may be introduced into the food chain and may therefore contaminate the reference person through ingestion of contaminated food and inhalation of dust.

The post-closure scenarios were assessed for the residential water well, which pumps 510 L/year and is located about 200 m away from disposal facility (at the site boundary), using the RESRAD-Offsite model version 4. The model is used to estimate the radionuclide concentrations and associated doses to reference group taking into account effects of dilution, dispersion, decay, and sorption on radionuclide migration and simulates multiple radionuclides as well as different hydrogeological conditions and behavior scenarios. The model is based on radionuclide specific transfer coefficients, representing transfer of radionuclides from one environmental compartment to another, for example, uptake of the radionuclides from soil to plants (Figure 2.8). The values of transfer coefficients are based on empirical data and literature reviews and have been tabulated by IAEA. Human intrusion was simulated using a model proposed in the IAEA-TECDOC-1380.

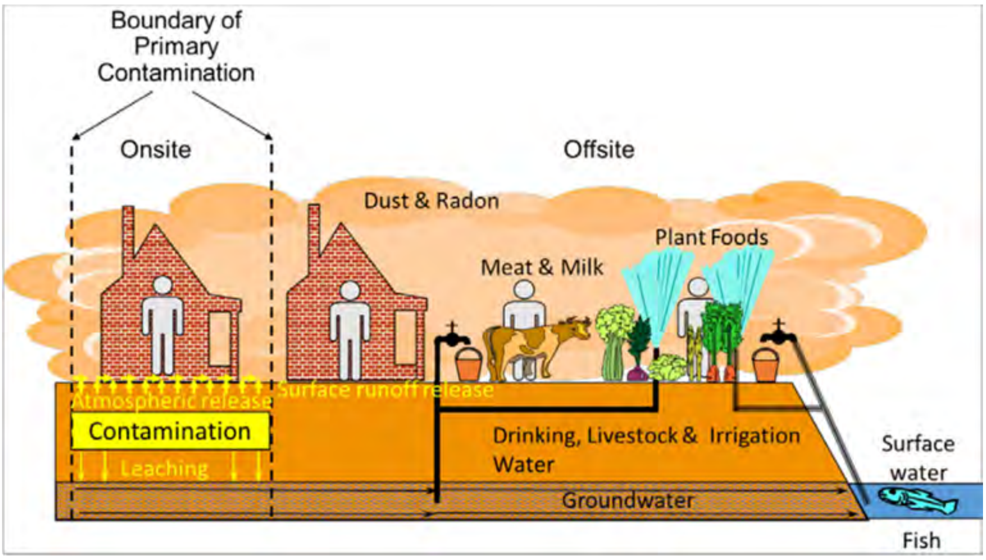


Figure 2.8. Environmental human exposure pathways considered in the model, simulating the exposure due to ingestion of water, plant-derived food, meat, milk, and aquatic food.

Nine different disposal system evolution scenarios were considered (Table 2.4). These include normal evolution of the disposal system (reference scenario), rapid degradation of barrier and potential human intrusion.

Table 2.4. Post-closure safety assessment scenarios

Scenario	Description of simulation
‘Reference’ – Normal evolution	The Reference scenario is one in which change to the repository system occurs solely as a result of the intrinsic dynamics of the disposal system itself. Simulated by RESRAD-Offsite model.
‘Earthquake’ - Early IDDF degradation	The earthquake scenario can be simulated by RESRAD-Offsite model using instantaneous release at 300 years as the early physical degradation of barriers.
‘Inundation’ - Early NSDF degradation	Relevant for at ALT site. Due to potential rising of the sea level the disposal facility can be impacted by the Sea. Marine exposure pathway simulated in Sub-activity 2.19. However, there are additional another exposure pathways, for example, external exposure due to staying on the bank of the sea during process of degradation on “nude” waste making it the most critical scenario. The reference people are, for example, a fisherman, climber on concrete walls or birdwatcher, i.e. recreational habits.

'Bathtubbing' - Early degradation relevant for NSDF	This scenario was simulated following the IAEA-TECDOC-1380 model from 0 to 1000 years.
'Road construction' - Human Intrusion relevant for NSDF	This scenario was simulated following the IAEA-TECDOC-1380 model from 0 to 1000 years.
'Borehole' - Human Intrusion for IDDF	In the case of intact barriers, the borehole drilling through the IDDF to reach the productive aquifer below the IDDF after 300 years simulated by the RESRAD-Offsite model.
'On-site residence' - Human Intrusion, relevant for NSDF	This scenario was simulated following the IAEA-TECDOC-1380 model from 0 to 1000 years.
'Explosion' - Human Intrusion/NSDF	The explosion scenarios are assessed as Beyond Design Basis Accidents for 0 year after closure.
'What if' - instantaneous release from IDDF and NSDF	The instantaneous release at 100 years is simulated by the RESRAD-Offsite model.

2.16.5.2. Assessment results

The starting point is the Reference scenario, which envisages the disposal facility with the near field evolution based on the disposal design and conservative assumptions regarding engineered barriers degradation. Information on the geosphere and biosphere is based on the current understanding, with conservative assumptions regarding human behaviour and diet. Examples of the performed dose simulation resultes are presented in Figures 2.9 and 2.10. A comparison of the maximum doses to members of the reference population obtained from the modelling of different scenarios is presented in Table 2.5.

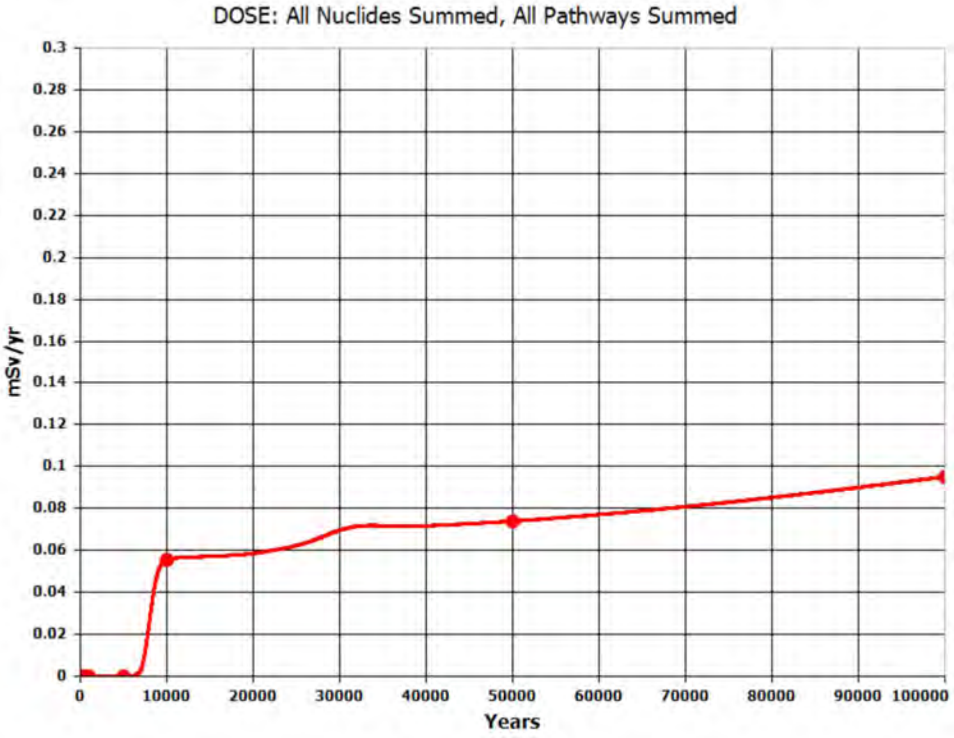


Figure 2.9. Simulated annual dose due to all nuclides for the IDDF at PAL site and 500 years delayed release with the increasing non-linear degradation rate.

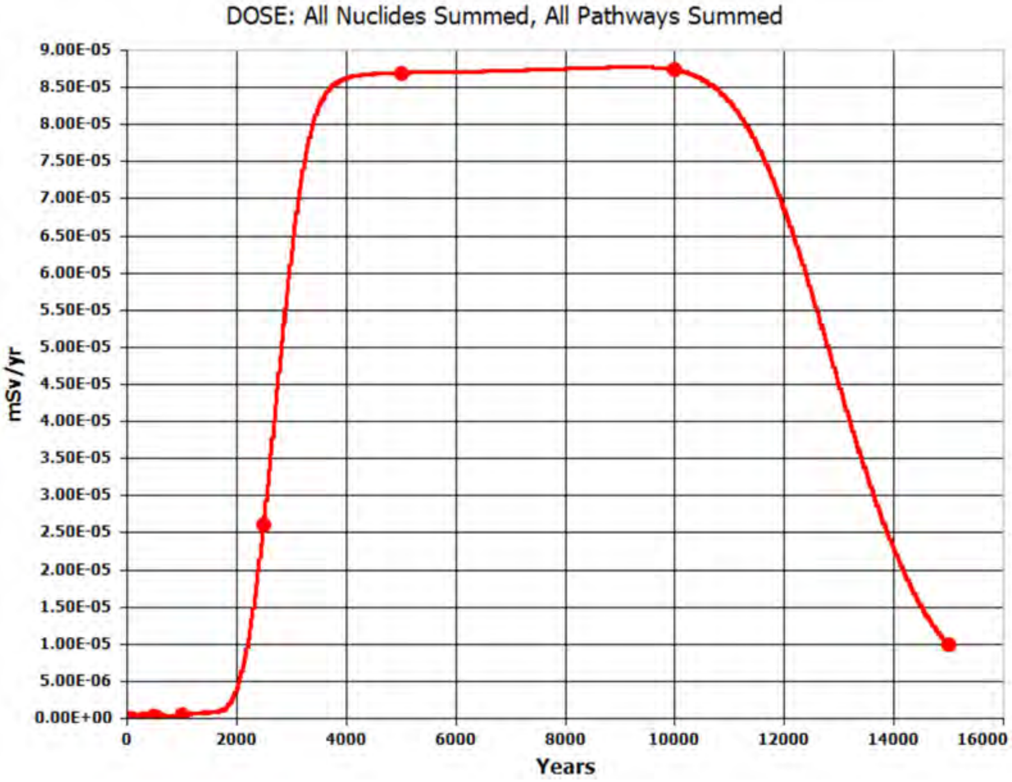


Figure 2.10. Simulated annual dose due to all nuclides for the NSDF at PAL site and 300 years delayed release with the increasing linear degradation rate.

Table 2.5. Maximum doses and expected time of their appearance for the investigated scenarios

Scenario	Most relevant exposure pathway	Maximum dose due to drinking water and intrusion, mSv/y	Peak time, years after repository closure
Reference / Normal evolution: - IDDF after 500 years - NSDF after 300 years	Drinking water	 0.00008 0.877E-04	 After 100000 After 9100
IDDF increased degradation: - linear after 500 years - step-wise after 500 years	Drinking water	 0.094 0.095	 After 100000 After 100000
Inundation / Early degradation/ relevant for NSDF at ALT site	External exposure	60.7	After 100
Bathtubbing/ Early degradation relevant for NSDF	Drinking water	6.7E-03	After 510
Road construction /Human Intrusion/ relevant for NSDF	Drinking water	5.3E-03	After 310
IDDF borehole intrusion after 300 years	Drinking water	0.1789	After 100000
On-site residence for NSDF	Drinking water	1.4	After 310
'What if' instantaneous release: - IDDF at 100 years - IDDF at 300 years - NSDF at 100 years - NSDF at 300 years	Drinking water	 0.0949 0.0945 0.0024 0.877E-04	 After 100000 After 100000 After 330 After 8500

To investigate the effects of **early degradation and human intrusion**, it was assumed that human intrusion into a disposal facility could occur once institutional controls will end. For example, the IDDF can be demerged by a borehole drilling after 300 years of operation. A model, described in IAEA-TECDOC-1380 was used to simulate three early degradation and human intrusion scenarios of bathtubbing, road construction, and on-site residence for NSDF from 0 to 1000 years.

Processes associated with accelerating climate warming threaten to cause significant sea level rise. The sea level rise, along with more severe storms, will begin to threaten the ALT site over the next hundred years as regional isostatic land uplift does not compensate the potential sea level rising. This potential situation is addressed in the 'Inundation scenario'.

Based on the climate warming scenario, was conservatively assumed that intense flood-induced degradation of the NSDF could occur 100 years after site closure, i.e. after the period of active institutional control. It is assumed that during the first hundred years, the effects of sea level rise will be mitigated by active controls. Due to high sea level and frequent storms, intensive wave erosion can destroy the capping system of NSDF and lead to direct contact of the salted sea water with the concrete of engineering barriers. It would significantly accelerate degradation of the vault concrete walls and roof and grouted waste could potentially appear uncovered. It was conservatively assumed in Sub-activity 2.19 that whole inventory of the disposed waste is dissolved in water of Paldiski bay. This situation was assessed as sufficiently safe even for people living near the disposal facility. However, the processes of degradation of the engineered barriers, including the waste matrix and the leaching of radionuclides, can last several decades. During that time, a highly contaminated "hot" spot would exist and a possibility of human presence in this zone becomes very likely. Conservatively assessed dose of external exposure to the reference person may rise up to about 60 mSv/year (Table 16.8). The dose of potential exposure is hundreds of times higher than the dose constraint value (0.3 mSv/year) and is therefore unacceptable.

2.16.6. Waste Acceptance Criteria

An assessments of radionuclide limiting activities are performed for the proposed conceptual design of near surface type disposal facility (NSDF) as well for planned shaft type disposal facility (IDDF), dedicated for disposal of radioactive waste, contaminated with higher levels of long lived radionuclides and for spent sealed sources. Development of WAC for this type of facilities includes analysis of scenarios and calculations of radionuclide dispersion with resulting estimation of the dose rates to the personnel of the facility and the public. “What if” type for the scenarios are not considered in derivation of the resulting limiting activities of WAC, but are presented for the demonstration of the safety margins and robustness of the assumptions. Non-radiological acceptance criteria are also considered.

Limitations for radioactivity in the packages intendent for disposal were derived taking into account all investigated scenarios, except an unrealistic “What if scenario”. The calculation results are presented in Tables 2.6 and 2.7. The limits derived for IDDF are applicable regardless of site selection, while NSDF limits are only applicable to PAL and PED sites only, because the ALT site was excluded from further consideration due to risk of the Sea inundation. The elaborated WAC present maximum total activities in the disposal facilities of two different types and activity concentrations, still satisfying radiation protection limits established in national and international legislation. When the critical scenario is ‘Drop&Damage’ or ‘Road construction’ the activity concentration limit is applies to each individual package, i.e. activity of radionuclide in package divided by its mass should not exceed the limit. Otherwise (for the ‘Earthquake’ and ‘Bathtubbing’ scenarios) it is important not to exceed the limit of total activity in the disposal facility. In this case, the radionuclide activity concentration for specific package may slightly exceed the specified limit, but so that the total activity limit for the entire facility is not exceeded.

Table 2.6. Calculated waste activity limits for the NSDF

Radio-nuclide	Limiting activity concentration, Bq/kg	Limiting total activity for two vaults, Bq	Critical scenario
H-3	4.7E+13	2.5E+20	Earthquake
Co-60	1.4E+06	7.5E+12	Drop&Damage
Ni-59	7.9E+06	4.2E+13	Earthquake
Ni-63	6.2E+09	3.3E+16	Bathtubbing
C-14	3.8E+07	2.0E+14	Earthquake
Sr-90	3.1E+08	1.7E+15	Bathtubbing
Nb-94	1.1E+06	5.9E+12	Bathtubbing
Cs-137	7.3E+06	3.9E+13	Drop&Damage
Eu-152	3.5E+06	1.9E+13	Drop&Damage
Eu-154	2.9E+06	1.5E+13	Drop&Damage
Pu-238	1.4E+08	7.3E+14	Road construction
Pu-239	2.6E+05	1.4E+12	Earthquake
Pu-240	1.1E+07	6.0E+13	Road construction
Am-241	2.2E+07	1.2E+14	Road construction
Ba-133	1.6E+07	8.7E+13	Drop&Damage
Ra-226	7.9E+04	4.2E+11	Bathtubbing
Ra-228	NL	NL	
Th-232	1.2E+07	6.3E+13	Road construction
U-234	3.1E+05	1.6E+12	Earthquake
Kr-85	NL	NL	
U-238	3.8E+05	2.0E+12	Earthquake

Table 2.7. Calculated waste activity limits for the IDDF

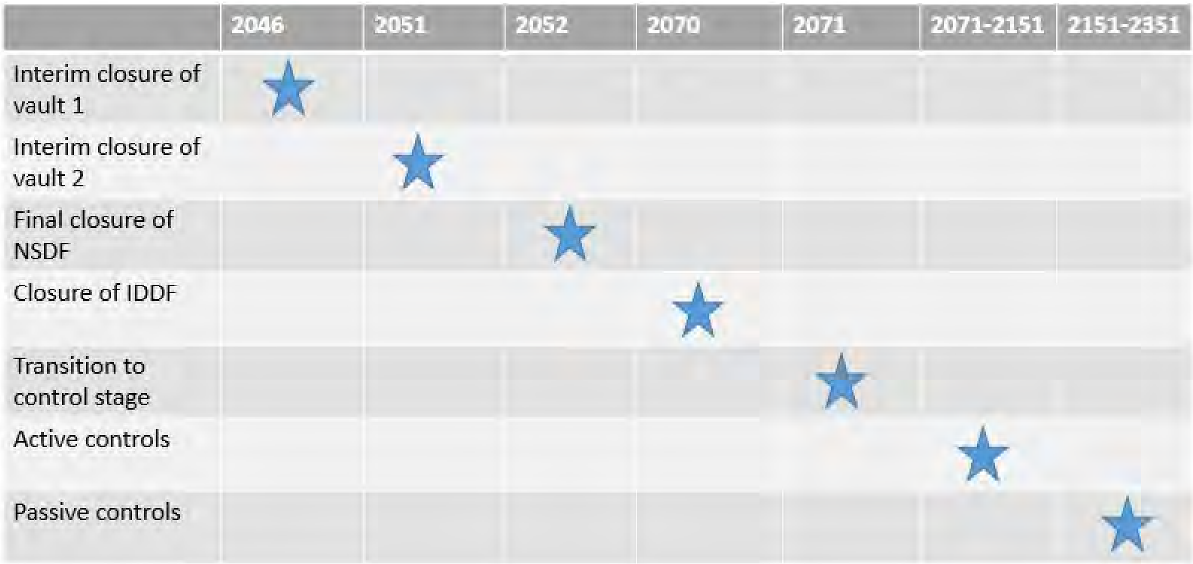
Radio-nuclide	Limiting activity concentration, Bq/kg			Limiting total activity, Bq			Critical scenario
	PAL	PED	ALT	PAL	PED	ALT	
H-3	6.5E+17	9.7E+17	8.7E+17	1.0E+24	1.5E+24	1.3E+24	Drop&Damage
Co-60	3.9E+14	5.8E+14	5.2E+14	6.7E+17	9.0E+20	8.0E+20	Drop&Damage
Ni-59	9.0E+07	9.0E+07	9.0E+07	1.4E+14	1.4E+14	1.4E+14	Earthquake
Ni-63	6.1E+15	NL	8.1E+15	9.4E+21	NL	1.2E+22	Drop&Damage
C-14	1.8E+09	1.8E+09	1.8E+09	2.8E+15	2.8E+15	2.8E+15	Earthquake
Sr-90	7.6E+13	1.1E+14	1.0E+14	1.2E+20	1.8E+20	1.2E+20	Drop&Damage
Nb-94	6.0E+08	6.0E+08	6.0E+08	9.3E+14	9.3E+14	9.3E+14	Earthquake
Cs-137	3.0E+14	4.5E+14	4.0E+14	4.7E+20	7.0E+20	4.7E+20	Drop&Damage
Eu-152	3.8E+14	5.7E+14	5.0E+14	5.8E+20	8.7E+20	5.8E+20	Drop&Damage
Eu-154	2.5E+14	3.7E+14	3.3E+14	3.8E+20	5.8E+20	3.8E+20	Drop&Damage
Pu-238	1.1E+10	1.7E+11	1.5E+11	1.7E+17	2.5E+17	1.7E+17	Drop&Damage
Pu-239	5.5E+06	1.5E+11	1.3E+11	1.5E+17	2.3E+17	1.5E+17	Drop and Damage
Pu-240	1.0E+11	1.5E+11	1.3E+11	1.5E+17	2.3E+17	1.5E+17	Drop&Damage
Am-241	1.3E+09	1.9E+11	1.6E+11	1.9E+17	2.9E+17	1.9E+17	Drop&Damage
Ba-133	NL	NL	NL	NL	NL	NL	
Ra-226	1.3E+12	1.9E+12	1.7E+12	1.9E+18	2.9E+18	2.6E+18	Drop&Damage
Ra-228	NL	NL	NL	NL	NL	NL	

Th-232	NL	NL	NL	NL	NL	NL	
U-234	NL	NL	NL	NL	NL	NL	
Kr-85	NL	NL	NL	NL	NL	NL	
U-238	7.9E+06	7.9E+06	7.9E+06	4.2E+13	4.2E+13	4.2E+13	Earthquake

2.16.7. Preliminary closure plan: time schedule of the closure and costs

Estonian Radioactive Waste disposal program includes several stages: construction (2027 – 2040), operation (2041 – 2050) and closure (2050 – 2060). According to the Program, waste disposal will last up to 10 years, until 2050. It is expected that by this date all the reactor decommissioning waste as well as the stored waste will be disposed of. Based on the provided Program, it is assumed that the first vault of the NSDF will be filled with the waste in 2046, followed by its interim closure. The interim closure of the second vault is planned for 2051, immediately after the decommissioning of the reactor and waste disposal. Based on these assumptions, the final closure of the NSDF could begin in 2052. Immediately after finishing the reactor decommissioning and the disposal of suitable wastes interim closure of the second vault in 2051 is foreseen. Based on these assumptions, the final closure of the NSDF can be started in spring 2052. The proposed sequence of the closure steps is shown in Table 2.8.

Table 2.8. Schedule of stepwice closure of the disposal facility and post-closure



	2046	2051	2052	2070	2071	2071-2151	2151-2351
Interim closure of vault 1	★						
Interim closure of vault 2		★					
Final closure of NSDF			★				
Closure of IDDF				★			
Transition to control stage					★		
Active controls						★	
Passive controls							★

It is also assumed that all the wastes from decommissioning requiring intermediate disposal will be emplaced into the IDDF in 2050 too. However, certain small amount of the institutional waste will be produces even after decommissioning of the reactors. Therefore, a disposal possibility must be maintained for few decades more. As the future waste properties are unknown, it would be reasonable to leave the IDDF operational for another 20 years. This facility is more universal, suitable for accommodation of wide range of wastes. In addition, it is less sensitive to atmospheric impacts.

After closure of the NSDF in 2052, institutional control program should be implemented. However, the control measures will be overlapping with operation of the IDDF, the institutional control program should take it into account. Therefore, the institutional control program must be revised after closure of the IDDF in 2072.

2.16.8. Conclusions

1. The operational safety analysis shows that the safety standards (dose limits for workers and the general public) would not be violated regardless of the chosen location. The differences between the analyzed candidate sites are minor.

2. As a result of the post-closure assessment the all three candidate site are acceptable for IDDF. From the safety point of view the differences are insignificant.

3. The results of the post-closure assessment of the NSDF has shown that the inundation scenario is the most critical one. The estimated doses potential exposure of members of the public due to progressive degradation of the facility’s structures are unacceptably high. As only **ALT site may be inundated under predicted global warming, it is recommended to exclude it** from further considerations. The other two sites PAL and PED are rather equally suitable for near surface waste disposal.

3. **Waste disposal cost is largely determined by the depth of the IDDF**. Disposal of intermediate-level waste at PAL would be the least deep and therefore much cheaper than disposal at the other two sites.

4. An additional **advantages of the PAL site are possibilities to use the infrastructure existing** on the site and to optimize waste disposal-related processes. Implementation of the disposal program at this site can be faster.

5. Overall conclusion is that the PAL site is better than PED site, while ALT site can be used for intermediate depth disposal only.

2.17. Environmental and Radiation Monitoring

Environmental and radiation monitoring is the continuous surveillance of the status of the environment and the factors affecting it. The monitoring program was developed within sub-activity 2.17. It involves environmental observations, collection, processing and storage of data, analysis and storage of the results [21].

Environmental Radioactivity Monitoring must begin before the start of waste disposal and continue until the end of the period of active institutional control. The duration of the period of active institutional control is 100 years. Monitoring results should be stored until the end of passive monitoring, i.e. 300 years. During closure of the facility the environmental monitoring program has to be significantly modified and adapted to the post-closure needs. Periodic revisions of the program are recommended taking into account the available results of monitoring.

The Environmental Radioactivity Monitoring should cover the normal operation of the disposal facility as well as emergencies.

The monitoring activities must not compromise performance of the disposal system. Installation and operation of monitoring system should not violate integrity of the engineered barriers and natural barriers and not create additional pathways of radionuclide spread. These aspects have to be taken into account during development of the Technical Design of the disposal facility.

The most common worldwide approach is that the license holder is responsible for monitoring of environmental radioactivity. However, the Radiation Act of the Republic of Estonia stipulates that the Environmental Board performs the monitoring of radioactive waste disposal facilities.

The main findings:

Considering the complexity of the monitoring program, there are no significant differences between the three studied sites. However, priority is given to the PAL site, the same monitoring system will serve both the disposal facility and decommissioning of the reactor. Therefore, in this case optimization of the monitoring system is possible. Moreover, there will be no need to expand the sea monitoring program.

2.18.Risk analysis and assessment

When the candidate sites are identified, next tasks are to compare them by different attributes and properties and to choose the most suitable one [22]. Risk analysis allows to compare emergency events that are expected for the considered candidate sites, by their probabilities and possible consequences. A risk, that is actually a combination of probability and consequences of an event, allows to measure and compare undesirable events.

The main findings:

- Ten emergency scenarios based on anticipated operational events, design basis and beyond design basis accidents provided by Safety Assessment Report were analysed, including seven internal scenarios and three external scenarios. All the scenarios have insignificant severities, all of them being below the annual dose limit (20 mSv/year) for personnel and most of them being below the annual dose limit (1 mSv/year) for population. Most of the scenarios have very low probabilities sometimes several orders of magnitude below the criterion for “very low” probability provided by Regulation No. 28.
- There are no internal or external emergency scenarios of significant, high or very high-risk categories. One internal scenario belongs to the “average” risk category. Nine scenarios, including six internal and three external events scenarios, belong to the “low” risk category.
- The scenario belonging to the “average” risk category, namely “Hanging load” has very high probability resulted from conservative assumptions and reliability data of the electromechanical equipment used to estimate a probability of an overhead crane stopping during load handling.
- Risk preventive measures were suggested for all considered scenarios. Implementation priority might be given to risk preventive measures for the higher-risk category.

The main result of the risk analysis and assessment [22] is that a**ll three locations are nearly equal.**

2.19.Possible impact of the repository on neighbouring countries

An estimation of the transboundary impacts is in line with the requirements of International Conventions and Treaties. The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, Convention on Environmental Impact Assessment in a Transboundary Context as well as EURATOM Treaty require that the potential impact to other countries of radioactive waste disposal is assessed and authorization for the disposal of radioactive waste is granted by a competent national authority.

The purpose of this work is to assess potential transboundary impact of radioactive waste disposal. Possible impacts and suitability of previously proposed three candidate sites (PAL, ALT and PED) is compared [23].

Obtained in simulations doses to human from seafood consumption, which can be caused by groundwater flow of radionuclides from the Near Surface Radioactive Waste Disposal Facility and Intermediate Depth Disposal Facility to the Gulf of Finland, are very low and are far below all allowable limits.

In the scenario of hypothetical flooding of the NSDF located at the ALT site due to rise of sea level resulted from climate change in coming centuries, the maximal annual dose to human from seafood consumption will be 6.7 microSv for the first year after flooding. Such a dose will be received by Estonian people living near the ALT site. Maximal annual dose to Finnish people will be 0.37 microSv for second year after flooding followed degradation of the facility.

Calculations of radioactive contamination of water, bottom sediments and fish in the Gulf of Finland and the corresponding doses to the population as a result of the transboundary transport of radioactive releases from the planned NSDF and IDDF by groundwater showed very low, almost negligible effects on the environment and public health in Finland. Even dissolving by seawater of all radionuclides placed in NSDF due to flooding of the ALT site caused by the sea level rise resulted from climate chance after 100 years of storage will not provide doses to human that exceed allowable limits in Estonia and in neighboring countries. However, this will lead to the release of a significant activity of radionuclides into the marine environment.

The calculations were carried out for Finish people living in settlements located at a distance of about 65–75 km from the potential release source through the Gulf of Finland. The distance from the source to the borders with other neighbouring states by the marine pathways is about 200 km to Latvia, 280 km to Sweden, and 230 km to Russian Federation. With an increase in the distance, the concentrations of radionuclides in all components of marine environment and the associated exposure doses to the population will decrease. So, it can be said with certainty that the conclusions about the fulfilment of the established safety criteria for the population, obtained as a result of calculations for Finland, will be all the more true for other countries.

The main findings of the study:

1. Based on the simulation results, it can be said that none of the selected locations for the disposal facility will have significant negative impact on neighboring countries. All three sites are acceptable for construction of the disposal facility, because the radiation protection limits would not be violated. However, the decision to dispose of the wastes at the ALT site can be interpreted as a violation of the London Convention, which bans the dumping into sea of radioactive wastes.

2. **PAL and PED sites are evaluated nearly equally suitable: the associated exposure doses in the neighboring countries would be significantly below the exemption level**.

2.20.Conclusions

1. Overall conclusion of the comparative analysis of the three potential sites is that the PAL site is the preferable location for the radioactive waste disposal facility. It has obvious advantages over the PED site.

2. ALT site is not suitable for the radioactive waste disposal facility and should be excluded from the comparison.

3. ACTIVITY 3. Comparison of the repository locations

Introduction

The objectives of Activity 3 are to further study the suitability of previously identified potential sites by conducting a comparative analysis of alternatives, including the “zero” option, taking into account the data obtained during the implementation of Activity 1 and Activity 2. In addition, another goal is to outline the future detailed studies in order to get ready to designing the repository and preparing the final Safety Assessment Report and Safety Case needed for licence application.

3.1. Analysis and comparison of alternative options

3.1.1. Zero alternative: an overview, if the repository will not be established

The “zero” option is an alternative to disposal of radioactive waste. It considers situation when, without the construction of a disposal facility for radioactive waste, the conserved dismantled reactor compartments and the available radioactive wastes will continue to be stored at the Paldiski site. The objective of the conducted study (Sub-activity 3.1) was an analysis of safety, environmental, economic and other factors, evaluation of the possible disadvantages and advantages related to the implementation of the "zero" alternative, compared to the construction of the disposal facility according to the plan. This option becomes relevant when, for some reason, a site for the radioactive waste disposal facility is not selected and a decision on the establishment of the facility is not taken or postponed for a certain period of time. The detailed results are presented in Report for Sub-activity 3.1.

According to the approved plan, the reactor compartments will be dismantled in 2040-2050. By that time Estonia should have a radioactive waste disposal facility, which could accommodate waste arising from decommissioning of the reactor compartments. Meaning of the “zero” option in the framework of the current activity is that the disposal facility is not constructed as scheduled (i.e. by year 2040). It can happen due to the following reasons:

1. failure of the siting programme (the proposed site and disposal program is not agreed with stakeholders and not confirmed);
2. no available funding for construction of the disposal facility;
3. appearance of new relevant factors in Estonia influencing the radioactive waste disposal program, for example, identification of new radioactive waste sources which require other disposal solutions.

Based on preliminary considerations within Sub-activity 5.1 of the current project, it was concluded that the optimal prolonged storage period of reactor compartments is up to 2100 years. It was assumed that the life of the Main Technological Building under “zero” option will expire by 2100 (140 years from the reactor commissioning date). Throughout the entire storage period the Main Technological Building, the structures of sarcophagi and the temporary storage of radioactive waste must act as barriers to the possible spread of radioactive substances and ensure the safety. Based on the experience of assessing the durability of similar type of building structures, the recommended time from the moment of construction of the structures to the exhaustion of its resources for industrial buildings made of reinforced concrete structures is estimated to be about 100 years. Considering ageing process a new engineering study has to be done if prolongation of the storage until 2100 would be decided. To ensure the safe storage of the reactor compartments and radioactive waste in the facility after 2050, large-scale reconstruction of the facility will be required.

A rather different situation could arise if, for some reason, a decision was made to dismantle the reactors without making a decision to build a disposal facility. For example, this could potentially happen if it is decided that the reactors are unsafe and the only way is to decommission them. In this case a new radioactive waste management facility will be needed. It would include equipment for waste handling and conditioning as well as premises for new interim storage.

3.1.1.1. Compliance with EU policy

The COUNCIL DIRECTIVE 2011/70/EURATOM of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste states that it should be an ethical obligation of each Member State to avoid any undue burden on future generations in respect of radioactive waste, including any radioactive waste expected from decommissioning of nuclear installations. Through the implementation of this Directive Member States have to demonstrate that they have taken reasonable steps to ensure that that objective of the Directive is met. The Directive also states, that the storage of radioactive waste, including long-term storage, is an interim solution, but not an alternative to disposal.

In conclusion, it is necessary to note that, considering the international obligations and national policy, a clear priority must be given to disposal over long-term storage. Long term storage is not regarded as a sustainable solution.

3.1.1.2. Safety and security

Containment and isolation of the waste is provided by means of a number of physical barriers of the disposal system. The engineered and natural barriers that make up the radioactive waste disposal system are the waste form, the packaging, the backfill, and the host environment including geological formation. The performance of these physical barriers is achieved by means of diverse physical and chemical processes together with an option of operational controls. Safety functions are provided by means of a physical or chemical properties and process that contributes to containment and isolation, such as: water impermeability; limited radionuclide dissolution, leach rate and solubility, retention and retardation of radionuclide migration. The overall performance of the disposal system is not unduly dependent on a single safety function. The physical elements and their safety functions are complementary and work in combination.

The main advantage of waste disposal over waste storage is the application of the principle of passive safety in the concepts of waste disposal. The long-term safety of the disposal facilities after closure is ensured by passive means to the fullest extent possible. The disposed wastes are much less vulnerable in case of human breach. An important safety factor is the significant increase in recent years of the threat of terrorism or sabotage. Underground disposal facilities are much less vulnerable than above ground storage facilities or closed reactors. Therefore, waste disposal is preferred in order to achieve the highest safety level and minimize risks.

3.1.1.3. Environmental factors

Possible environmental impacts were analysed in detail in Activity 2 of this project. The conducted studies did not reveal any significant impact. Only minor amount of energy resources will be needed for surveillance, maintenance and monitoring of the closed disposal facility. No other resources will be needed. In contrast, the energy resources are needed to maintain the reactor building in the safe condition (for ventilation, humidity control and similar). It results in minimisation of the carbon and environmental footprints. In addition, the closed disposal facility will have appearance similar to a natural landscape and will not make a negative visual impact.

3.1.1.4. Knowledge and memory preservation

The reactors were built and operated by foreign military forces of a country, which does not exist anymore. Smooth transfer of design and operation details has not been assured. However, over the past decades, Estonian specialists have been able to gain significant knowledge of the situation through the implementation of a number of international projects. Loss of competence and knowledge is possible due to natural change and aging of staff or reorganizing existing institutional structures. Early waste disposal is preferred because it is difficult guarantee the preservation of knowledge and transfer for several generations.

3.1.1.5. Economic factors

Evaluating economic factors is quite a difficult task because it is necessary to compare the costs that will be incurred over a very long period of time. Forecasting future inflation and wage changes is practically impossible for such a long time period, so comparing costs would be incorrect. Therefore, only current costs were taken into account without adjustment for possible inflation and possible price change.

The cost of disposing of radioactive waste will be lower in relative terms (not adjusted for inflation) in 2100 compared to 2040. This reduction is influenced by the following factors: a reduction in the amount of waste due to the decay of radionuclides (larger amount of waste could be suitable for management as non-radioactive waste) and simplification of used equipment. During the extended storage of waste, the process of decay of radionuclides will take place. The amount of waste for intermediate depth disposal is determined exclusively by the presence of long-lived radionuclides and therefore will not change, or the change will be insignificant. However, the amount of waste in the NSDF, and at the same time the disposal cost, would decrease somewhat.

The main scenario studied was reactor decommissioning in 2100 followed by waste disposal. Taking into account the effect of radionuclide decay on the amount of metallic waste arising from the reactor compartments, in 2040 the most important radionuclides (defining the amount of waste in the NSDF) will be Cs-137, Sr-90, Am-241 and Co-60. After an additional 60 years of decay, the amounts of Cs-137 and Sr-90 will decrease by a factor of 4 and will continue to prevail, while the activity of Co-60 will decrease by more than three orders of magnitude and will lose its importance.

Currently, only rather conservative estimations of radioactive waste inventory is available. A part of available waste is still not characterised, i.e. radionuclide composition is not known. Big uncertainties are associated with predictions of the reactor decommissioning wastes. Therefore, only very rough estimates of reduction of waste amount and consequently the cost are possible. According to the overview of the implementation of the “zero alternative” for the decommissioning of reactor compartments (Sub-activity 5.1), by 2100 the amount of decommissioning waste will decrease by no more than 20%.

In cost estimation of a disposal programme, a distinction between fixed and variable costs should be made. Variable costs are those that vary with the amount of disposed waste while fixed costs remain the same regardless of the amount of disposed waste. The fixed cost must be paid irrespective of the total capacity of waste in the facility. This cost includes: disposal program management, site selection and characterisation, development of technical design, quality assurance, Safety Assessment, Safety Case and Environmental Impact Assessment, equipment for waste characterisation and handling, monitoring, institutional control measures, physical protection measures, offsite infrastructure including access roads, electrical power and water supplies, telecommunication, on-site transportation routes and connections.

Cost for construction, waste emplacement and closure make up variable costs, nearly proportional to amount of disposed of waste. They include labour costs for waste transportation, handling and disposal, filling the disposal structures, inspection of waste packages, radioactivity monitoring. According to rough estimates considering small size of the disposal facility in Estonia the fixed cost makes up to about 30 to 40% of the NSDF cost. The assumed savings due to a possible reduction in disposal costs may amount to 500 - 600 kEUR.

The cost for the maintenance of the main technological building of the reactor compartments and engineering systems in safe conditions over a period of 50 years is estimated (Sub-activity 5.1) to be up to 34 million euros (on average about 680 kEUR per year). This is about 10 times more than the costs of post-closure institutional control of the disposal facility: the estimated cost of maintenance, surveillance and monitoring of the closed disposal facility amounts to 60-65 kEUR per year. Additionally, 75 million euros will be needed for reconstruction of the Main Technological Building for safe storage of the reactor compartments and radioactive waste.

For safety reasons, a decision to dismantle the reactor compartments can be taken without an approved solution for waste disposal. For example, this could potentially happen if it is found that the storage of the reactors are unsafe. In this case a new radioactive waste management facility will be needed. It would include equipment for waste handling and conditioning as well as new a radioactive waste storage facility. Cost of such a facility is around 5,4-5,8 MEUR (4,4 MEUR for waste treatment facility and 1-1,4 MEUR for new interim storage). It would include an engineered storage that is a building, sufficiently shielded, with a solid floor, adequate safety features for inspection of packages and including packaging handling equipment, safety equipment, arrangements to prevent leakage of water, ventilation and temperature control. The service life of commonly used storage facilities is 50-60 years. At the end of the storage period, the waste must be disposed of.

Additional earnings are possible through the conversion and reclamation of unused land. Current land plot of PAL site is almost 30 ha. An estimated footprint of the closed disposal facility and area needed to assure physical protection (fences) is about 1.7 ha. Therefore, after decommissioning the reactor compartments and closure of the disposal facility, it will be possible to use the rest of territory (up to about 28 ha) for other purposes. The average forest land hectare price in Estonia ranges between 3 – 10 kEUR [24]. With the right management, the forest and land in Estonia can generate annual profits ranging from 3-

10%. Thus, according to present prices the cost of land that will be no longer needed for storage of waste and reactor compartments and potentially can be used for other purposes will make 84 to 280 kEUR in addition to the potential increase in land prices with time.

Therefore, it is evident, that delayed waste disposal has no economic advantage.

3.1.1.6. Public acceptancy

The results of the survey conducted in Sub- activity 2.13 show that despite the fact that the Estonian population is not sufficiently informed about the policies and methods of radioactive waste management, and the opinion of the population is quite contradictory, they do not strongly oppose the disposal plan implementation at the Former Paldiski Nuclear Site, but the opposition may appear as the construction of the disposal facility approaches.

On the other hand, the results of a representative investigation of public opinion indicate, that the problem of radioactive waste disposal must be solved in the near future not leaving it to future generations. Therefore, delaying the disposal until 2100 would be against this idea. Finalizing it can be pointed-out that public acceptancy of waste disposal is not investigated sufficiently. It is recommended to look for possibilities to increase public knowledge about safe waste management solutions.

3.1.2. Comparison of potential locations

Characterization of the three candidate sites has been performed during implementation of Activity 2 of the current Project. It included comprehensive geological, hydrogeological, hydrological, geochemical, environmental and social studies, as well as an overview of the available infrastructure. In addition, potential safety implications, including radiological impacts on neighbouring countries, were examined taking into consideration characteristics the sites. The main objective of Sub-activity 3.2 is to compare suitability of the three identified locations and to provide a basis for the strategic assessment of environmental impact of the establishment of the disposal facility and the preparation a designated spatial plan, i.e.to make a decision principle on the disposal site.

3.1.2.1. Geological conditions

Several sub-activities, namely 2.1 ‘Mapping specific tectonic features’, 2.2 ‘Seismic analysis’, 2.3 ‘Analysis of the geological-lithological composition of the Earth's crust’, 2.5 ‘Analysis of specific geomorphological features’, 2.6 ‘Analysis of hydrogeological conditions’, 2.8 ‘Studies of the chemical composition and properties of groundwater and surface water’ and 2.9 ‘Study of the soil and its deeper layers’, were devoted to studying the geological, tectonic, seismic, hydrogeological and geochemical properties of the three sites. The detailed results are presented in the corresponding Sub-activity reports.

As far as distance between the candidate sites is very small, many characteristics (such as seismic, tectonic, chemical) are nearly identical for all three sites. They are suitable for the disposal facility. However, the PAL site is preferred because the thickest clay-rich unit is at the shallowest depth and the clay-rich interval is the most homogeneous. Also, hydrogeological conditions at ALT site are less suitable for NSDF.

3.1.2.2. Environmental conditions

Comprehensive studies of the physical environment included the following sub-activities: 2.4 ‘Analysis and geodetic surveys of surface terrain’, 2.7 ‘Hydrographic studies’, 2.10 ‘Monitoring atmospheric air’, 2.11 ‘Study of climatic conditions’, 2.12 ‘Study of the environment (biota)’ and 2.14. ‘Noise study’. The study results are presented in the Sub-activity reports.

The performed investigations did not reveal any significant negative aspects associated with the PAL site. However, suitability of ALT site for NSDF is compromised because of sea level rise due to potential climate change and complicated water drainage conditions. Therefore, the order of suitability is as follows: PAL, PED, ALT.

3.1.2.3. Social environment and availability of infrastructure

Sub-activity 2.13 ‘Study of the social situation’ included investigations of important communities, the purpose of use of the land, land ownership rights, economic aspects, cultural heritage related aspects and other relevant features, while Sub-activity 2.15 ‘Analysis of roads and infrastructure’ is specifying roads and infrastructure at the three selected locations.

The results are detailed in the Sub-activity reports. Rather contradicting results are received comparing different social aspects. PAL site is slightly preferred while other two are nearly equal. Also, the PAL site has the best accessibility and infrastructure. The other two sites are nearly identical.

3.1.2.4. Radiation protection and safety

Four Sub-activities are aimed to investigation of safety and potential impacts of ionising radiation: 2.16 ‘Preparing a safety assessment’, 2.17 ‘Environmental and radiation monitoring’, 2.18 ‘Risk analysis and assessment’ and 2.19 ‘Possible impact of the repository on neighbouring countries’.

Most of safety features are rather similar for all three sites. However, because of the potential inundation risk ALT site is not suitable for NSDF. Additional advantage of PAL site is that there would be no need to transport the waste on public roads. Overall priority is given to PAL site.

3.1.2.5. Disposal cost

The purpose of sub-activity 2.21 ‘Assessment of the disposal facility construction cost for three candidate sites’ was to provide a site specific estimate of the cost associated with establishment of the disposal facility.

The cost of construction and closure of radioactive waste disposal facilities depend of facility type, waste properties and conditions of the site. The cost estimate of the Estonian repository was prepared considering the current costs for labour, materials and equipment, as well as the available technologies. It takes into account design development, equipment, devices, materials, machinery, transportation, labour, contingencies as well as overheads and company’s profits, while VAT and inflation were not included in the calculations. The performed estimation results are in Table 3.1. The most expensive waste disposal is at the PED site. Disposal at the ALT site is only slightly cheaper. The lowest disposal price was obtained for the PAL site. The construction and closure of the facility here will be about 25% less expensive than at the two alternative sites. This difference is because of more favourable geological conditions and availability of suitable infrastructure on the territory of the former Paldiski Naval Center.

Table 3.1. Estimated disposal facility construction and closure costs in EUR

	Activity	**PAL**	**PED**	**ALT**
1	NSDF construction	1 836 312	1 836 312	1 842 729
2	IDDF construction	6 996 643	8 737 554	8 042 200
3	Infrastructure	708 330	2 252 043	2 186 713
4	NSDF closure	2 359 597	2 359 597	2 430 893
5	IDDF closure	387 289	446 009	422 521
6	Dismantling of infrastructure	0	700	700
	Total cost	**12 288 172€**	**15 632 214 €**	**14 925 754 €**

3.2. Preparing draft technical specification for the specific studies of the repository location

The already performed studies (Sub-activities 1.2 to 2.19) provide a basis for the strategic assessment of environmental impact of the establishment of the disposal facility and the preparation a designated spatial plan. The conducted surveys results are mostly sufficient for further planning and design and fulfill the requirements of the IAEA Specific Safety Guide No SSG-29 ‘Near Surface Disposal Facilities for Radioactive Waste’, although for the technical design more detailed studies are needed. The current report describes the studies needed for the determination of the building rights, preparing the Technical Design of the facility, and applying for a license for the establishment of the repository. During the preparation of the report, it was determined that the following studies are needed: topo-geodetic studies, geotechnical studies and a study of the water drainage network.

3.2.1. Geodetic survey

In sub-activity 2.4 “Analysis and geodetic surveys of surface terrain” the surface topography was studied at the Paldiski site. The objectives of the surface topography analysis were to describe the nature and properties of the geological structure of the location and give a topographic overview of the region. The study was done with detail sufficient for safety assessment and spatial planning. For the next stage a more detailed and precise measurements are needed. The purpose of the geodetic study is to prepare a topographic-geodetic base map needed for development of the technical design of the disposal facilities and associated infrastructure.

The topographic/geodetic base maps shall reflect the relief, the entire above-ground situation and underground utility networks.

As the geotechnical investigations drilling and testing locations coordinates depend on the exact locations of the facilities, therefore it is suggested that the final positioning of the NSDF and IDDF will be fixed by the Contracting authority after the topo-geodetic survey. This is critical to ensure that the next stage geotechnical investigations will be conducted at the exact location.

3.2.2. Geotechnical investigations

Geotechnical parameters of the site have been described in Sub-activity 2.9 report and the results are sufficient for site selection. However, they are not detailed enough for the next stages (development of Technical Design documentation and the Safety Case). More comprehensive geotechnical investigations are needed to obtain additional data, clarify uncertainties and confirm the geotechnical parameters of the rock mass at the disposal site. The investigation program must be prepared and investigations shall be conducted in accordance with Estonian national regulations.

To ensure the structural integrity of the NSDF and IDDF, geotechnical investigations shall be conducted at their foreseen location. It is recommended that the locations of survey points be adjusted according to the features of the final plot layout, while keeping the number of survey points fixed. Therefore, prior to conducting the geotechnical investigation, the lay-out shall be confirmed by the Contracting authority and the technical designer, considering results of the previous site characterization (water drainage, surface inclination and ground altitude, as well as accessibility) and to be conducted geodetic survey. Additional investigation points may be necessary depending on the dimensions and character of possible service facilities and area if these will be added to the concept in the next stages (for example, access roads and crane rails).

For IDDF geotechnical investigations 1 borehole to the center of the IDDF has been planned (Figure 2). Based on bedrock conditions reported in sub-activities 2.3 and 2.9 and preliminary IDDF design (sub-activity 2.16), the depth of IDDF will be approximately 80 m into the Lontova silt- and claystones. The target depth of the investigation borehole is the upper surface of Kroodi Formation, which based on Sub-activity 2.3 is approximately 126 m from ground surface at the Paldiski site. It is essential to reach Kroodi Formation to determine the possibility of hydrostatic uplift due to water pressure during construction of the facility and emplacement of the radioactive waste.

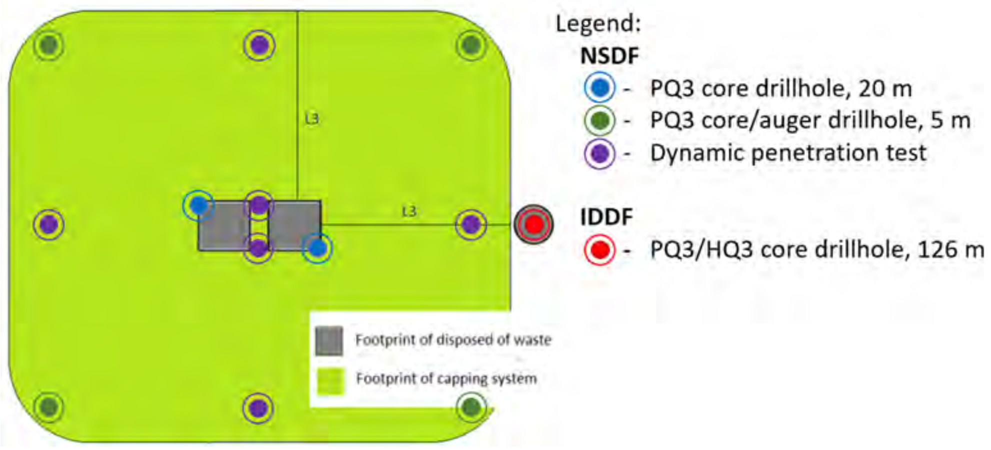


Figure 3.2. Proposed layout of IDDF and NSDF geotechnical investigation points.

The drilling must be conducted with certified drilling equipment and triple barrel wireline diamond core drilling method to ensure high core recovery with as minimal sample disturbance as possible.

For NSDF geotechnical investigations at least a total of 6 boreholes must be drilled (Figure 3.2). Two boreholes of 20 m depth must be drilled to the opposing corners of the two concrete vaults and 4 boreholes at each corner of the planned capping system must be drilled until bedrock surface (up to 5 m).

Downhole natural gamma logging must be conducted in the IDDF borehole. Gamma logging shall be conducted after completion of borehole to confirm the depth in terms of lithostratigraphy and geotechnical units as this method allows additional precision with defining different layers, their dimensions and boundaries between layers.

Dynamic penetration testing must be conducted until the surface of bedrock limestone, to obtain in-situ geotechnical parameters for the loose Quaternary soils described in Sub-activity 2.9. As the shingles, gravel and stiff glacial till layers can be hard to penetrate, the Dynamic Probing Super Heavy method is recommended. These tests should be conducted if the Quaternary cover thickness is > 2 m at the repository location.

Water level must be measured after completion of each borehole. Additionally, as some of the aggressivity factors have not been tested during Activity 2 investigations, water samples for aggressivity testing (HCO_3^-, pH, aggressive CO_2, Mg^{2+}, NH_4^+ and SO_4^{2-}) must be collected from nearby survey wells (PAL-101, PAL-201, PAL-401) opening different aquifers relevant to the construction of IDDF.

3.2.3. Mapping of drainage network

According to Sub-Activity 2.7 (‘Hydrographic studies’) there is a minor flooding risk at the PAL site. The flooding risk should be mitigated and for that the drainage system, its condition and needed work to improve water flow and reduce the risk of flooding should be mapped on site. The aim of the study is to map the possible drainage network directing the excess water to the sea based on field inventory, determine the needed works and possible mitigation measures.

3.3. Assessment of the suitable repository types

Objectives were studies of suitable repository types, considering the existing waste and the waste generated in the course of decommissioning the reactor compartments, the main risks in the disposal of spent sealed sources and the evolution scenarios to ensure the long-term safety of the disposed of sources. Also, issues related with disposal of the most problematic types of waste and the possible technological solutions should be addressed. The detailed results are presented in Report for Sub-activity 2.22 'Additional assessment of the suitable repository types'.

Geological disposal at depths of several hundred meters usually is designated for disposal of High Level radioactive waste including Spent Nuclear Fuel as well as DSRS. Wastes of all other types can be emplaced in geological disposal facilities too. Although this is the safest way of disposal, it is not justified from the point of view of the cost. Especially since there is no waste in Estonia that would require such kind of disposal in particular.

Disposal at intermediate depth (a few tens of meters below ground level and up to a few hundred meters below it) is rather typical waste disposal option. They are designated for disposal of Intermediate Level waste, including DSRS. It has been recognized that depth of 30 m (minimal for such kind facilities) significantly limits intrusion risks. Therefore, the controls are not relevant at this depth.

Several types of intermediate-depth waste disposal facilities are used worldwide: tunnels, silos with access from land through inclined tunnels, silos with large diameter vertical boreholes or shafts with narrow boreholes (BOSS concept). All of them are almost equally suitable for disposal of ILW, including sealed sources, with the exception of narrow boreholes suitable exclusively for DSRS, designed specifically for countries with no other wastes.

Shaft- type Intermediate Depth Disposal Facility suits well for Estonian conditions (features the site and wastes). It is a safe and economically justified disposal solution, suitable for Long-lived waste and DSRS. The applied safety approach corresponds to that of Borehole disposal. Contrary to the BOSS boreholes, it is applicable for waste packages of various dimensions and masses, including entire reactor vessels and spent reactor control rods. In addition, this disposal method is less strict regarding waste characterisation comparing to Near Surface Disposal. In some cases, it can be very difficult in practice to determine the radionuclide composition of the waste, for example cemented radioactive alpha sources for which there are no surviving records of the producer, or reliability is low.

Summarizing it can be pointed out that the vertical shat fits very well to Estonian conditions (features the site and wastes). It is economically justified disposal solution.

Near surface disposal is very common waste disposal option. Due to insufficient isolation it suitable only for Short Lived Low Level Waste. It is a cost effective solution, in Estonian conditions about 4.5 time cheaper than disposal in the IDDF. Prevailing amount of waste in Estonia can be disposed of in the NSDF. However, a significant part of the waste, including spent sealed sources, cannot be disposed of in such a facility due to the relatively large amount of long-lived radionuclides. In the long term (longer than 300), this method of disposal does not provide adequate protection against surface factors (erosion) and possible damage to the disposal system. This method partly relies on active measures to ensure safety (such as territory protection, maintenance) and these can only be guaranteed for a relatively short period of time.

By volume, more than two thirds of the waste in Estonia fits for NSDF. However, by radioactive content it would accommodate only less than 3% of total activity (a sum of all radionuclides).

In principle, all Estonian waste can be dispose of in a single type facility (i.e. IDDF). Obviously, in this case, one shaft would not be enough and at least two would have to be drilled. Since the drilling and installation of the shaft is the main component of the price, roughly it would be approximately about 1.6 time more expensive than application of different type facilities. Therefore, the combination of NSDF and IDDF is seen as the optimal solution for disposal of wastes in Estonia.

The amount of radioactive waste to be disposed of in Estonia is small, but the variety of used packages is large. These are standard concrete and metal containers, large concrete containers, 200 L drums with compressed waste, cylinders with reactor control rods and reactor vesels. Application of not uniform packages packages complicates handling and disposal process as different crane grippers are needed. To simplify waste handling it is recommended to stack the 200 L drums into metallic grids, compatible with the standard containers. Size of two standard containers is an optimal grid form because it accommodates 4 drums. Similar grids can be used for cylinder with the control rods as well. The advantages of this option are application of single-type crane grips for all containers, effective use of the disposal space and faster waste emplacement process.

A safety issue associated with large amounts of organic waste in the drums is the intense gas generation during bio-degradation. The problem of possible accumulation of gas and the increased pressure should be addressed during the preparation of the technical design of the disposal facility and technical measures should be provided for the removal of gas without threatening the integrity of barriers.

3.4. Conclusions

1. Radioactive waste disposal is the only sustainable solution. It avoids any undue burden on future generations in respect of radioactive waste management.

2. Radioactive waste disposal is the safest and most secure long-term option having no alternatives. Delaying the disposal of radioactive waste has no economic, environmental or social advantages. The long-term storage does not eliminate the need for waste disposal in future. It would cause significant additional expenses.

3. Overall conclusion of the comparative analysis of the three potential sites is that the PAL site is the preferable location for the radioactive waste disposal facility. It has obvious advantages over the PED site mainly because of the shallowest depth of the IDDF, availability of relevant infrastructure and simplest waste transportation.

4. ALT site is not suitable for the radioactive waste disposal facility as safety is not guaranteed in a long time perspective and should be excluded from the further comparison.

5. It was found that the following further studies of the site are needed to determine the construction rights, to prepare the Technical Design and applying for a license for the establishment of the repository were identified and described in details: (i) topo-geodetic investigations to detail the surface features, (ii) geotechnical investigations to obtain detailed information on the physical properties of underlying soil and rocks relevant to design earthworks and structures of the facilities, and (iii) investigation of the water drainage network. The estimated cost of the needed studies is about 183 400 € and the studies would take about 24 weeks.

7. Several intermediate depth-type disposal facilities are suitable for disposal of radioactive sources if established deeper than 30 m from the surface. Only narrow boreholes (BOSS) suitable exclusively for DSRS, designed specifically for countries with no other wastes.

8. The shaft-type facility fits very well to Estonian conditions (features the site and wastes). In Estonia it is economically justified disposal solution, while application of BOSS option is not.

9. Near Surface Disposal is very common waste disposal option suitable only for Short Lived Low Level Waste. It is a cost effective solution, in Estonian conditions about 4.5 time cheaper than disposal in the IDDF. Prevailing amount of waste in Estonia can be disposed of in the NSDF (more than two thirds of the waste can be accepted for NSDF).

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