

APPROVED BY
By Order of the Ministry of the Environment
“Approval of the National Radiation Safety Development Plan 2018–2027, the National Radon Action
Plan, the National Action Plan for Radioactive Waste Management and the Implementation Plan
of the National Radiation Safety Development Plan 2018–2027
for 2018–2021”

NATIONAL ACTION PLAN FOR RADIOACTIVE WASTE MANAGEMENT

TALLINN 2019

ANNOTATION

Updating of the National Action Plan for Radioactive Waste Management

The National Action Plan for Radioactive Waste Management was approved by Order No. 688 of the Minister of the Environment on 21 July 2015. The purpose for updating the action plan is to renew the action plan as a result of the amendments to the Radiation Act that became effective on 1 November 2016 and in relation to the new developments in the treatment of NORM waste. The updating was also prompted by the preliminary studies of the decommissioning of the reactor sections of the former nuclear site in Paldiski and the final radioactive waste storage site, which were completed in 2015, and found that the only way to safely store radioactive waste is to establish a final storage site in Estonia. Based on these studies, the Government of the Republic made the decision to establish a final storage site in Estonia at the cabinet meeting of 28 April 2016. Therefore, the information related to the demolition of the reactor sections of the former nuclear site of Paldiski and to the establishment of the final storage site of radioactive waste has also been specified in this action plan. The action plan was also updated on the basis of EU directives and national legislation. The structure of the action plan remained unchanged. The National Action Plan for Radioactive Waste Management is one of the Annexes of the National Radiation Safety Development Plan (NRSDP) for 2018–2027, as is the National Radon Action Plan and the Implementation Plan of the NRSDP for 2018–2021.

In addition to the NRSDP, the National Radon Action Plan, and the updating of the National Action Plan for Radioactive Waste Management, the strategic evaluation of the environmental impact of those planning documents were also initiated by Order No. 61 of the Minister of the Environment of 18 January 2017. The strategic environmental assessment (hereinafter “SEA”) of the 2018–2027 KORAK, the National Radon Action Plan and the National Action Plan for Radioactive Waste Management will be conducted by Alkranel OÜ, which will also compile the SEA report.

The need to establish a National Action Plan (Programme) for Radioactive Waste Management arose from Directive 2011/70/Euratom (hereinafter “Directive 2011/70 Euratom”) establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, which became effective in 2011 and stipulates requirements for the preparation of a national action plan for radioactive waste management. In 2013, the European Commission also prepared guidelines for Member States for the preparation of the action plan specified in the directive in order to ensure a uniform structure of the plan and the extent of topics covered. Therefore, the draft of the action plan was also updated according to the requirements of the directive and guidelines. Safe and coordinated management of radioactive waste is the most important activity for Estonia in terms of ensuring radiation safety.

The action plan forms the basis for radioactive waste management and the aim of the plan is to offer decision-makers and waste handlers specific solutions for the systematic management of radioactive waste and to reduce its quantity in the Republic of Estonia. The plan also offers enough information for the wider public about the radioactive waste generated and to be generated, as well as its management.

The action plan covers the following topics:

- 1) national policies;
- 2) stages and timetable;
- 3) inventory;
- 4) concepts or plans and technical solutions from generation to disposal;
- 5) post-closure plans for the radioactive waste storage site;
- 6) research and development;
- 7) obligations and responsibility, performance indicators;

- 8) cost estimate;
- 9) financing scheme;
- 10) transparency policy or process;
- 11) agreements;
- 12) steering document.

The action plan presents the sub-objectives of the described elements, measures and expected results until 2050. The responsible institutions and the costs of the action plan are also described.

The National Action Plan for Radioactive Waste Management is a source document, which in addition to the above gives an overview of the legislation in force and directions for supplementing them. The existing institutional organisation, financial means and their need in the future have been indicated in the action plan. As the management of radioactive waste is of interest to different interest groups (both domestically as well as internationally), the action plan is a good tool for communicating with them, for example, distributing information to the interest groups and introducing the current situation and future plans. As the interest groups were involved in the preparation of the action plan, the document serves as an agreement that promotes the future development of the field.

The action plan is regularly reviewed and updated, taking into account the achievements of technology and research, as well as recommendations by experts, best experiences, and good practice. According to Directive 2011/70/Euratom, the national framework, competent regulatory body, national programme and its application are assessed regularly and at least once in ten years for achieving a high level of the safety norms of the safe management of spent fuel and radioactive waste, and the help of international experts is used for it. The results of expert assessments will be communicated to the European Commission and other Member States and these are made available to the public without breaching the fundamental principles of law.

The preparation of the action plan was coordinated by the advisers of the Ambient Air and Radiation Department of the Ministry of the Environment Evelyn Mürsepp and Reelika Runnel, and chief specialists Krista Saarik and Maris Arro. Head of A.L.A.R.A. AS Joel Valge and Environmental Technology Adviser Ivo Tatrik, Head of the Radiation Department of the Environmental Board Ilmar Puskar, Head of the Radiation Department Karin Muru and Head of the Radiation Monitoring Bureau Monika Lepasson, and Head of QPRE OÜ and qualified radiation expert Merle Lust participated in the work as experts. The plan has been coordinated with the Ministry of the Interior, the Ministry of Economic Affairs and Communications, and the Ministry of Finance. The Minister of the Environment will approve the action plan by an order. The action plan is coordinated with the European Commission.

A relevant press release will be published after the completion of the action plan. A summary of the action plan will also be uploaded on the website of the Ministry of the Environment.

The coordinators of the work would like to thank everyone who participated in the preparation of the action plan for their contribution to the completion of the document.

Contents

Introduction	6
1. International and national obligations.....	7
1.1. International conventions and directives.....	7
1.2. National legislation.....	8
2. Policy for managing radioactive waste and spent fuel	9
2.1. Decision-making process and responsibility.....	9
2.2. Reduction of waste volumes	10
2.3. Waste management.....	12
2.4. Effect of the new activities on the national policy	15
2.5. Resources necessary for implementing the policy	15
2.6. Involving the public	15
3. Stages and time schedule of the planned activities	16
4. Inventory.....	19
4.1. Existing and necessary means.....	19
4.2. Existing radioactive waste on the Paldiski object.....	21
4.3. Existing NORM residue and waste	27
4.4. Short-lived radioactive waste generated in medical institutions	29
4.5. Summary of the radioactive waste existing in Estonia	30
4.6. Radioactive waste generated in Estonia in the future	31
4.7. Human resources	36
5. Plans and technical solutions from waste generation to final storage.....	38
5.1. Reactor sections.....	38
5.2. Metal containers.....	38
5.3. Concrete containers	39
5.4. Sea containers	42
5.5. 200-litre metal barrels.....	43
5.6. Liquid waste	44
5.7. Bulky waste located at the Paldiski object.....	44
5.8. NORM residue and waste	45
5.9. Short-lived radioactive waste generated in medical institutions	47
6. Post-closure plans for the radioactive waste storage site	50
7. Research and development	52
7.1. Sources	52
7.2. Organisation of R&D in the Ministry of the Environment	52
7.3. Funding instruments	54
8. Obligations and responsibility, performance indicators.....	58
8.1. Participants and their obligations.....	58
8.2. Environmental Board.....	58
8.3. Environmental Inspectorate	59
8.4. A.L.A.R.A. AS	59
8.5. Radiation practice licence holders	60

8.6.	Qualified radiation expert	60
8.7.	Division of responsibility.....	60
8.8.	Performance indicators	61
9.	Cost estimate.....	70
9.1.	The development of the waste characterisation system	70
9.2.	Reactor sections.....	71
9.3.	Melting of contaminated metal	72
9.4.	Concrete mixer	72
9.5.	Concrete containers	73
9.6.	The establishment of the place of final storage.....	73
10.	Financing scheme	74
11.	Transparency policy or process	76
11.1.	Involvement	76
11.2.	Environmental impact assessment and strategic environmental assessment	76
11.3.	Ensuring awareness	77
12.	Agreements	79
13.	Steering document	80
13.1.	Introduction	80
13.2.	National policy	80
13.3.	Stages and time schedules.....	82
13.4.	Inventory.....	83
13.5.	Plans and technical solutions from waste generation to final storage	84
13.6.	Cost estimate.....	86
13.7.	Financing scheme	86
14.	References	89
	Annex 1. General principles of radioactive waste management	91

Introduction

Radioactive waste are substances or items that contain radioactive substances or have been contaminated with them, their activity or activity concentration exceeds the clearance levels established on the basis of the Radiation Act, and they are not planned to be used in the future. Radioactive waste is generated as a result of various activities, the activity and volume of the radioactive waste generated also varies to a great extent. The radioactive waste generated may be in solid, liquid or gaseous form. In Estonia, radioactive waste is classified as follows:

- 1) cleared waste – waste generated during radiation practices with its activity, specific activity or surface-specific activity being smaller than the clearance levels established in the Radiation Act;
- 2) NORM (Naturally Occurring Radioactive Material) waste – radioactive waste generated as a result of processing raw materials with naturally occurring radionuclides (Th-232 and U-238 and radionuclides which belong to their decay chain), the special activity of which is higher than the clearance levels specified in the Radiation Act;
- 3) short-lived radioactive waste – radioactive waste containing less than 100-day half-life radionuclides, which decompose below the clearance levels established in the Radiation Act within five years;
- 4) short-lived low- and intermediate-level radioactive waste – radioactive waste containing less than 30-year half-life beta and gamma emitters and a limited amount of long-lived alpha emitters (not more than 4,000 Bq/g in one waste packaging and not more than an average of 400 Bq/g per total amount of waste);
- 5) long-lived low- and intermediate-level radioactive waste – radioactive waste containing greater than 30-year half-life radionuclides with their specific activity being higher than that of short-lived low- and intermediate-level radioactive waste and for which the amount of heat generated by the radioactive decay is less than 2 kW/m³;
- 6) high-level radioactive waste – radioactive waste for which the amount of heat generated by the radioactive decay is greater than 2 kW/m³.

Waste existing and generated in Estonia is primarily low- and intermediate-level solid waste. Liquid radioactive waste is generated to a small extent.

There are no nuclear power plants in Estonia and there are also no activities related to and structures operating with nuclear fuel cycle. Since the Paldiski former nuclear object is a training centre, which does not directly fall within the scope of Directives 2009/71/Euratom and 2014/87/Euratom, Estonia must implement the requirements of these Directives on a general level. As ensuring safety is very important for Estonia, the requirements of the Directives will be considered to the maximum extent possible when decommissioning the Paldiski object, and simultaneously ensuring a reasonable administrative burden.

Most of the radioactive waste in Estonia originates from the Soviet era. Nowadays, the main generators of radioactive waste are medical, industrial, and research establishments that hold a radiation practice licence.

In the case of radioactive waste, a distinction is made between artificial and NORM waste/residues. The Radiation Act establishes that NORM waste is radioactive waste containing mainly natural radioactive material, including NORM waste that is not intended for future use, and NORM residues are substances containing or contaminated with a naturally occurring radioactive substance resulting from an activity, the activity or activity concentration of which exceeds the established clearance levels and which are intended to be used in the future. The generation of NORM waste can be avoided by finding ways to clear NORM residues. The management of NORM residues and waste also requires a case-by-case approach, as depending on the origin, they have different chemical and physical characteristics and they cannot be /

should not be managed together with other radioactive waste.

It can be said in summary that the waste streams in Estonia are small and the selection of suitable management methods is relatively restricted. Estonia does not have many options for reducing the volume of the waste generated, because all existing technologies (for example, waste incineration) are very expensive, with a powerful management volume, and the investment into the waste management technologies is likely to be significantly greater than constructing a ground-level final storage site. If possible, however, alternatives must also be found, for example, the processing, dispersion or clearance of waste. These alternatives were also analysed in the course of preparing the action plan.

The action plan provides an overview of existing and future radioactive waste in Estonia, its management methods, sets out a schedule of activities and national policy. The plan also describes the bodies authorised for the safe management of radioactive waste, the technical and financial resources available, the funding scheme and the R&D activities. The National Action Plan for Radioactive Waste Management is carried out through the action plan.

It is presumed that the National Action Plan for Radioactive Waste Management will help to increase public awareness. Interested parties will better understand the problems related to the management of radioactive waste and thanks to that, the awareness of the population may improve and through it, also confidence in this field.

1. International and national obligations

More general and specific principles of the management of radioactive waste have been regulated both at an international level as well as in legislation established in the Republic of Estonia. Estonia joined the International Atomic Energy Agency (hereinafter also “IAEA”) in 1992 and has been a member of the European Atomic Energy Community (Euratom) as an EU Member State since 2004.

1.1. International conventions and directives

Estonia has joined several international conventions in the field of radiation safety, inter alia, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, and the Convention on Nuclear Safety, which was ratified in 2005.

From the position of radioactive waste management, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the aim of which is the protection of residents and the environment against radioactive waste generated in the civilian area and dangers arising from the management of spent fuel, is one of the most important conventions. The parties confirm in the preamble of the convention that the state is responsible for ensuring the safety of the management of spent fuel and radioactive waste in the final stage. The governments must ensure control of the use of radiation sources, including the safe management of orphan sources. To this end, a legal and regulatory system must be created, an independent competent authority (regulative body) must be designated, and the necessary regulations in addition to the Act must be created as well. Aside from the obligations undertaken by joining the convention, participation in the reporting meetings of the convention and the submission of reports are both important.

Legislation of the European Union (hereinafter also “EU”) has a very large impact on establishing national requirements. Namely, a Member State must comply with the regulations, directives, and other documents issued at the EU level. We describe the most important legislation in the area of radioactive waste in more detail below.

Directive 2013/59/Euratom of the Council of the European Union, establishing the basic safety norms for protecting the health of employees and other population from the threats arising from ionising radiation.

It is a legal act, which regulates matters related to the safety of radioactive waste management. The Member States had to enforce the directive by 6 February 2018 at the latest.

The aim of Directive 2014/87/Euratom is to create a Community framework, to maintain and promote the continuing improvement of nuclear safety and its regulation, and to ensure that Member States establish appropriate national rules of high-level nuclear safety for the protection of employees and other population from threats arising from the ionising radiation of nuclear devices.

Directive 2011/70/Euratom coincides with the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management in content. This Directive creates a framework of the European Community for the responsible and safe management of spent fuel and radioactive waste. The Estonian action plan is largely related specifically to complying with the requirements of this Directive.

1.2. National legislation

In the Republic of Estonia, the principles for the radioactive waste management and the obligations related to management are established in the Radiation Act. More specific requirements for reducing the volumes of waste generated and ensuring the safe management of radioactive waste are regulated by the regulations issued on the basis of the Radiation Act and also by the radiation practice licences issued by the Environmental Board and awarded to the generators and handlers of waste.

The most important regulations of the Government of the Republic and the Minister of the Environment are the following:

- Regulation No. 95 of 15 September 2016 of the Government of the Republic “Intervention and activity levels and the reference level of emergency occupational exposure in the event of radiation emergency” establishes the doses for applying protective measures in the event of radiation emergency;
- Regulation No. 96 of 15 September 2016 of the Government of the Republic “Bases for calculation of exemption levels of radionuclides and the exemption levels below which no radiation practice licence is required”. The Regulation establishes the exemption levels by radionuclides, i.e. values of activity and specific activity, and in case these values remain below these levels, it is not necessary to apply for a radiation practice licence. A formula for calculating the exemption level in case of several radionuclides or a mix of radionuclides has been presented in the Regulation as well;
- Regulation No. 97 of 15 September 2016 of the Government of the Republic “Limits of the effective dose of an exposed employee and resident and equivalent doses of the lens of the eye, skin and limbs”. The limits of the effective dose and equivalent dose for exposed employees as well as residents are established in the Regulation;
- Regulation No. 33 of 3 October 2016 of the Government of the Republic “Differences of the deadlines and procedure for processing the documents of the import, export and transit of radioactive waste depending on the country of origin and destination”. The procedure for processing documents for the import, export and transit of radioactive waste is established in the Regulation;
- Regulation No. 34 of 4 October 2016 of the Minister of the Environment “Requirements for the classification, registration, management and delivery of radioactive waste and compliance indicators of radioactive waste packaging”;
- Regulation No. 43 of 27 October 2016 of the Minister of the Environment “Clearance levels of radioactive substances generated during radiation activity or objects contaminated by radioactive substances and the conditions of their clearance, recycling and reuse”;
- Regulation No. 52 of 16 November 2016 of the Minister of the Environment “Requirements for the premises where radiation sources are located, for marking the premises and radiation sources, and

radionuclide activity levels”;

- Regulation No. 54 of 18 November 2016 of the Minister of the Environment “Procedures for the monitoring and assessment of the effective doses of an exposed employee and resident, the values of the dose coefficients of doses caused by intake of radionuclides and of radiation and tissue weighting factors, and the measurement procedure thereof”;
- Regulation No. 57 of 24 November 2016 of the Minister of the Environment “Requirements for radiation safety training of radiation safety specialists and exposed workers”. The Regulation specifies the requirements for training exposed employees, the content of the training session, and also determines the frequency of organising the training sessions;
- Regulation No. 60 of 24 November 2016 of the Minister of the Environment “Detailed requirements for applications for radiation practice licences, application and radiation practice licence forms, and lists of data characterising radiation sources used to keep lists of nuclear materials”. The Regulation specifies the procedure of the radiation practice licence application process and the list of documents submitted together with the licence application;
- Regulation No. 45 of 27 October 2016 of the Minister of the Environment “Curriculum for the radiation safety training of radiation experts, their professional skills requirements, the procedure for application for the certificate, the standard format of applications and certificates”. The Regulation establishes the curriculum for the radiation safety training of radiation experts, their professional skills requirements, the procedure for application for the certificate and the standard format of applications and certificates.

2. Policy for managing radioactive waste and spent fuel

The radioactive waste management policy is presented in this chapter. The main aim of the policy is the reduction of waste volumes generated, which ensures that the amount of waste to be managed and stored is as small as possible. If waste is still generated, it must be managed and stored strategically. The question of liability and the impact of future activity on national policy and the need to involve the public are also considered in this chapter. Estonia does not have a policy on spent fuel management, as there is no nuclear fuel in Estonia. There is, however, the former nuclear submarine training centre together with two reactors in Paldiski, but spent fuel was removed from the reactors and taken back to Russia already in 1995. If a decision is made on taking a new nuclear facility into use in Estonia, a policy must also be developed for the management of the waste and spent fuel generated there.

2.1. Decision-making process and responsibility

The Estonian radioactive waste management policy is based on national legislation and international principles. The policy will be implemented through the radioactive waste management action plan. The need to prepare an action plan is provided in the National Radiation Safety Development Plan approved by the Government of the Republic in 2008 and in the European Union Directive 2011/70/Euratom on responsible and safe management of spent fuel and radioactive waste.

In Estonia, the Ministry of the Environment is responsible for shaping the radiation and nuclear safety policy. As this policy is of significant importance for the state, other ministries, authorities and the public are also involved in this process. The radioactive waste management action plan that directs the policy is approved with a Directive issued by the Minister of the Environment. Pursuant to the Radiation Act, the intermediate and final storage of radioactive waste is organised by the Ministry of Economic Affairs and Communications. Therefore, it is a duty of the state to shape a sectoral policy and establish the necessary legislation and organise the management and the intermediate and final storage of waste.

Radioactive waste is generated by radiation activity, which is generally regulated by a radiation practice

licence. The case is different for materials that contain natural radionuclides (NORMs). In addition to the areas regulated by radiation practice licences (use of NORM materials as raw material and radiation activity), there are also industries in Estonia (e.g. groundwater treatment plants, cement industry), which are not considered activities that require a radiation practice licence and the purpose of which is also not the processing of NORM as a raw material. Pursuant to the applicable Radiation Act, in the event of operations listed in the Act, during which natural radiation sources may cause employees or workers to be exposed to radiation that exceeds the effective dose limit established for a resident under the Radiation Act, the Environmental Board has the right to demand the employer to submit a radiation safety assessment. If the Environmental Board considers the implementation of measures established in the Radiation Act to be insufficient and employees may be exposed to a greater annual effective dose than the resident effective dose limit, the employer shall apply for a radiation practice licence. Since the area of activity of the company engaging in such operation is not usually qualified as radiation activity, the radiation safety requirements required based on the radiation safety assessment can be established for regulating the activity of the company in another environmental licence issued beforehand. However, general application for an environmental licence is carried out under the provisions of the General Part of the Environmental Code Act, which does not require the submission of a radiation safety assessment upon applying for an environmental licence. In order to ensure more efficient preventive control over avoidance/reduction of possible NORM residue/waste, it is necessary to stipulate a requirement in the General Part of the Environmental Code Act for the submission of a radiation safety assessment upon applying for a licence for operations listed in the Radiation Act.

Namely, for production that may be related to increased natural radiation, it is necessary to have a licence regarding the use of the environment (environmental licence, excl. radiation practice licence, integrated environmental permit or other licence) and, during the process of applying for a licence for the use of the environment, the Environmental Board has the right to demand a radiation safety assessment in the event of operations set out in the Radiation Act (in which NORM may occur). This should, inter alia, provide an overview of the materials contaminated with natural radionuclides, which are generated as a result of the planned activity. A radiation safety assessment would enable to decide on the need for technology and/or radioactivity monitoring of the material, and the monitoring conditions would be established in the licence for the use of environment (environmental permit, excl. radiation practice licence, integrated environmental permit or other licence).

According to national policy, the generator of the waste is responsible for the management of radioactive waste. If, however, it is historic waste, i.e. waste, which the Republic of Estonia took over with the restoration of independence, or waste the owner of which cannot be ascertained, the state is responsible for its management. If the owner of the waste can be identified later, then the owner must compensate for the state's expenses. Appropriately processed and packed waste is stored in the state-owned intermediate storage site of radioactive waste.

2.2. Reduction of waste volumes

In this action plan, the assessment of the aspects regarding the avoidance, re-use, management and storage of waste is based on the waste management hierarchy (Figure 1) and the principles set out in the National Waste Plan 2014–2020.



Figure 1. Waste management hierarchy

Pursuant to the Radiation Act, it must be ensured that the activity and amounts of the radioactive waste generated is as small as possible. When planning any activity (including radiation activity), the applicant for the licence must prefer technology, which ensures the optimisation of the amount of radioactive waste generated. Nowadays, the main generators of radioactive waste in Estonia include medical, industrial, and research establishments, which own a radiation practice licence.

The purpose of the various provisions of the Radiation Act is to ensure that the amount of radioactive waste generated in the course of any radiation activity is as small as possible. The applicant for the licence must prove in the course of processing the radiation practice licence application that the main principles of radiation safety are used as the basis for planning the activity.

As the amounts of waste generated can be reduced by reusing materials that contain radioactive substances, it must be preferred over waste storage, if possible. For example, radioactively contaminated metal must be collected at the Paldiski intermediate storage site and when a sufficient volume level is reached, the waste must be sent for remelting to a country with relevant capabilities. Concentrated radioactive waste generated in the course of melting is managed in Estonia.

Such a practice is based on expert assessments, showing that decontaminating the metal on site is not effective.

Another option for reducing the volumes of waste is separating waste by type, which, in turn, simplifies management. The management of mixed waste is generally much more expensive and the separation requirement is established on the basis of the IAEA's recommendations also in Estonian law and compliance with it is also checked when processing the radiation practice licence application and in the course of later inspection.

Most of the current waste in Estonia originates from the Soviet Union time, which is why the volume and activity of the waste is sometimes difficult to assess. Therefore, the most urgent national activity in need of a resolution in terms of reducing the volumes of existing as well as generated waste is related to the characterisation of waste.

The precise data received as a result of waste characterisation gives the answer on which part of the existing waste can be cleared in the future and which part is subject to final storage. This allows to save resources and the burden on the environment is also reduced. According to the Radiation Act, the radioactive substances generated in the course of radiation activity, if they are with such a low activity or activity concentration that their management and storage as radioactive waste is not necessary from the point of radiation safety, they may be exempted from the requirements of the Radiation Act. The

precondition for exemption is the characterisation of waste (ascertaining the radionuclides and activity concentrations). The gamma spectrometric characterisation commenced at the facility of the radioactive waste handler in 2017. This is followed by the preparation of release procedures. The clearance of waste also allows optimising the amount of radioactive waste that is subject to final storage, which, in turn, also means better use of existing financial means.

2.3. Waste management

The reduction of the generation of radioactive waste/residue and the initial management thereof begins at the generator (in most cases, they own a radiation practice licence).

Waste volume can be reduced by returning used radiation sources to their manufacturer. Pursuant to the Radiation Act, during procurement of a radiation source, the holder of a radiation practice licence shall favour a manufacturer who is willing to include in the sales contract a clause on the return of the radiation source to the manufacturer. Upon the purchase of a high-level radiation source, the holder of the radiation practice licence shall enter into a contract with the manufacturer upon acquiring the radiation source, pursuant to which the manufacturer shall take the radiation source back within 15 years after the import of the radiation source at the latest, provided the activity of the radiation source exceeds 10 MBq ten years after its import to the country. In the case of short-lived waste, it is possible to store these at the location of the licence holder until the activity has decreased below the clearance levels established by the Radiation Act. In exceptional situations, for example, in hospitals, it is also possible to implement on-site management, dilution, etc. This all takes place on the basis of national legislation and a radiation practice licence.

Radiation sources, which cannot be returned to the manufacturer or exempted from the requirements of the Radiation Act, will continue to be managed at the Paldiski radioactive waste management facility and thereafter stored in the intermediate storage site located in the same place. On the basis of the Act, the holder of the radiation practice licence has an obligation to deliver the waste to the storage site within five years after its generation. This requirement does not apply to NORM waste, since the Environmental Board decides the way of management of NORM residues and waste separately each time during the processing of the radiation practice licence application. Such a difference in comparison with other radioactive waste arises from the fact that the NORM waste that is generated during various activities related to increased natural radiation have a very different composition in terms of physiochemical as well as radiological properties, therefore their treatment is addressed on a case-by-case basis.

In this action plan, the assessment of the aspects regarding the avoidance, re-use, management and storage of NORM residue/waste is based on the waste management hierarchy (Figure 1) and the principles set out in the National Waste Plan 2014–2020. For the prevention of NORM residue and waste, the accompanying economic aspects, its efficiency and optimality, and the ratio of generated revenue and costs incurred must be taken into account. Prevention and minimisation of the generation of residue and waste can commence by modifying the processing processes which include, for instance, use of additives, chemical/physical decontamination or adoption of new technology.

For the reduction of NORM residue and waste, sufficiently tested technologies should be preferred. Although the Radiation Act does not mention the concept of “best possible technology”, the choice of technology must support the activity in a manner that the principles of radiation safety and management of radioactive waste are met, i.e. the radiation dose from radiation activities exposed to the radiation employee or resident must be as low as reasonably achievable (ALARA principle) and the volume of radioactive waste generated should be kept as low as possible. The technology should be reasonably available to the user. In Estonia, activities related to increased natural radiation, during which NORM residue and/or NORM waste are generated or may be generated, have been established in the metal

industry (processing of niobium-tantalum ore), cement industry and water industry (operation of groundwater treatment plants where the water is taken from the Cambrian-Vendian water complex).

The final storage of the NORM waste generated in the Estonian water industry in existing regular or hazardous waste storage facilities is becoming increasingly topical, as it has been revealed that the generation of NORM waste in Cambrian-Vendian water complex water treatment plants is rather a rule than an exception, especially since there is currently no sustainable re-usage solution for the filter material generated in water companies. There are no plans to establish a NORM waste storage site in Estonia.

In Estonia, the radioactivity of building materials is regulated by two Regulations:

- 1) Regulation No. 49 of 26 July 2013 of the Minister of Economic Affairs and Communications “Requirements to construction materials and products, and procedure for attestation of conformity”, which stipulates the requirements for gamma radiation arising from construction products and by which the activity concentration index of a construction product shall be lower than 1, except if the Environmental Board permits the use of a product with a higher radiation level due to the planned purpose of use of the construction product;
- 2) Regulation No 74 of the Minister of Economic Affairs and Infrastructure of 22 September 2014 “Requirements to road construction materials and products, and procedure for attestation of conformity”, which stipulates the key characteristics (including radioactive emission) that are to be declared of road construction material and products used for road management work pursuant to the area of application, as well as the procedure for attestation of key characteristics.

So far, no problems have occurred in relation to natural radionuclide content in building materials of Estonian origin. The decay chain nuclides of U-238 and Th-232 contained in the building materials analysed in the study “Study for the preparations for transposing requirements of Directive 2013/59/EURATOM on natural radiation substances (NORM) into national legislation”, conducted by the University of Tartu and completed in 2017, or contained in the raw material of building materials of Estonian origin, do not set any restrictions of the use of those building materials as the I-index used for the characterisation of the building materials is significantly below the reference value of $I=1$. However, the information on imported construction materials and raw material is insufficient, which is why this aspect should be given more attention in the future. The state is also planning to compile an additional study of the radioactivity of building materials in order to prevent the use of materials with increased radioactivity and production of radioactive waste at a later time.

Sealed radiation sources are not produced or reused in Estonia. If they cannot be returned to the manufacturer, they are stored at the Paldiski radioactive waste intermediate storage site, where A.L.A.R.A. AS, which is under the administration of the Ministry of Economic Affairs and Communications, is engaged in their management.

The liquid radioactive waste located at the national waste management centre are characterised by A.L.A.R.A. AS and further management can be planned on the basis thereof. If the activity concentrations of the waste fall below the clearance levels, they must be managed as hazardous waste after clearance. The volumes of liquid waste generated in the future are so small and random, that it is not practical to obtain expensive liquid waste management technology for it. The solidification of liquids by way of concreting must primarily be used if that type of waste is suitable for it by its chemical composition, and also the tactics of waiting for radioactive decay. The liquid waste generated will be stored in an indestructible collection container and afterwards in a metal barrel surrounded by absorbent in the Paldiski intermediate storage facility.

Estonian waste streams are small and the choice of suitable management methods relatively restricted. To reduce volume, waste already generated is almost impossible to be processed, for example, burned, remelted, machine compressed. Investment into such waste processing technologies is significantly greater than, for example, constructing a final storage site close to the ground and large investments into voluminous processing technologies are not the best solution considering the small volumes of waste streams, taking into account economic, social, and environmental aspects. At the same time, certain management techniques are still in use (compressing and conditioning waste through concreting) and their aim is to ensure the long-term safety of waste.

The Estonian waste management policy is based on the principle that the radioactive waste generated in Estonia shall be managed and ensured final storage in Estonia. The national policy also provides that radioactive waste should not be transported to Estonia for disposal. Both mobile management services (for example, the machine compressing of waste) as well as services offered outside Estonia (for example, the remelting of radioactively contaminated metal) may be used for management, however, the concentrated waste generated as a result of this process is still brought back to Estonia for storage.

The long-term safe storage of the reactor sections located at the Paldiski nuclear site shall take place until 2040, after which the sections are to be demolished, the radioactive waste generated are to be managed and stored at the final storage site pursuant to the project “The preliminary studies on the decommissioning of the reactor sectors of the former nuclear site of Paldiski and the establishment of the final storage site for radioactive waste” completed in 2014–2015 (hereinafter “preliminary studies”). It is estimated that depending on the method of dismantling the sections, from 519 to 1545 m³ of treated waste is generated. As it is not possible to store waste of such volume and activity in the intermediate storage site located in Paldiski, a final waste storage site must be established for this purpose by 2040, at the latest. The intermediate storage of radioactive waste, including long-term intermediate storage, is a temporary solution and not an alternative to final storage, i.e. until the final storage site is established, the reactor sections and radioactive waste in Paldiski are in a condition where radioactive contamination of surface and groundwater and soil may occur as a result of an emergency caused by climate change or similar factors.

The preliminary studies resulted in the selection of three possible final storage site locations and the detailed need for intricate environmental, radiological and other studies necessary for the establishment of the final storage site and for the decommissioning of the reactor sections was determined. The establishment of the final storage site must commence right away as it is an extensive and complicated process, during which the request for studies, strategic environmental assessment and practice licences may take up to ten years considering international practices.

Based on the results of preliminary studies, the Government of the Republic decided at the cabinet meeting of 28 April 2016 to establish final storage site for radioactive waste in Estonia and to include as much foreign instruments as possible, including EU funds, for this purpose. Based on the decisions made at the cabinet meeting, the Ministry of the Environment submitted a proposal to the environmental committee of the Riigikogu on 2 May 2016 to amend the draft of the Radiation Act which had passed the first reading at the Riigikogu. Pursuant to subsection 61 (4) of the Radiation Act which entered force on 1 November 2016, the intermediate and final storage of radioactive waste is organised by the Ministry of Economic Affairs and Communications. This determined clear responsibility for the final management of the radioactive waste generated and to be generated in Estonia in the future pursuant to Directive 2011/70/Euratom of the Council of the European Union, establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste.

Until the construction of the final storage site, the radioactive waste is stored at the Paldiski intermediate storage site and the reactor sections of the nuclear object are stored in a conserved form.

A thorough updating of law must also precede the construction of the final storage site, since the current legal framework is insufficient for constructing the final storage site. In addition to the Radiation Act and the regulations issued on its basis, the legislation addressing planning and constructing of constructions must also be changed in order to establish the requirements for the construction of the final storage site.

2.4. Effect of the new activities on the national policy

Over the next years, the launch of new activities is not precluded, for example, in the field of the making of radiopharmaceuticals related to nuclear medicine, which would definitely also affect the radioactive waste streams and sizes characterising them. At the same time, no extremely extensive activities which would affect the national policy are foreseen in the next years. If the radioactive waste streams should significantly change, the radioactive waste policy and action plan must also be reviewed.

2.5. Resources necessary for implementing the policy

Technical, financial, and human resources are necessary for ensuring the safe management of radioactive waste. Sustainable financing must be ensured primarily for the final storage of waste, as the activity must be financed for years after the generation of waste. For safe management, different finance systems can be used to ensure the existence of all the necessary means. The law in force establishes that the generator of waste is responsible for waste management, and a system for requiring a financial collateral has also been created, furthermore, the holder of the licence is obligated to return high-level radiation sources to their manufacturer. This is common practice in other countries, and several European Union Member States have established the same requirement. The question on how to ensure the safe management of the so-called historic radioactive waste is much more complicated. This is radioactive waste, which originates from the Soviet era – mainly radioactive waste that was generated during the decommissioning of the Paldiski and Tammiku objects –, to which the principle that the generator of waste must cover the expenses necessary for the safe management cannot be applied. The state must ensure the management of such waste and if possible, the means of EU Structural Funds are used in addition to state budget resources.

Qualified personnel is needed for the responsible management of radioactive waste. This can only be ensured with the consistent in-service training of the employees. This, however, requires the creation of a new system, since the field of training and in-service training is currently modest in Estonia.

2.6. Involving the public

Since the activities related to radioactive waste, especially the construction of the final storage site are currently under the attention of great public interest, the public must be involved in the initial stage of the activities in order to avoid problems in the future.

3. Stages and time schedule of the planned activities

The solving of questions in relation to the safe management of radioactive waste is a long-term process. Considering the nature of the existing waste in Estonia, the decisions made so far, as well as the economic situation, it is likely that the most time- and capital-consuming activities (decommissioning the reactor sections and constructing the final storage site) will take place during the period of 2037–2050. For the more even distribution of time and resources, the preparations must be commenced now.

The main areas of activity of safe management together with explanations and potential expenses will be determined in the period of 2018–2050.

1. The long-term safe radioactive waste management

The long-term safe radioactive waste management is primarily carried out through consistent training, and thus increasing the competence, of the employees of companies engaged in management and the institutions engaged in granting practice licences and conducting supervision. The constant analysis of the relevance of legislation in the area and the updating thereof, including for taking the final storage site into use, also have an important position. Updating of legislation involves determination of the conditions of the import/export and transit of radioactive waste, waste management responsibility and conditions of environmental monitoring of management places and developing the bases of categorising radiation sources, supplementing and adding provisions concerning NORM materials/residues/waste. In addition, safe management of radioactive waste also requires constant improvement of the quality management system of radiation safety and competent and sustainable administration of the existing intermediate storage site of waste.

Taking into account the radioactive waste existing and generated in the future (including waste generated during decommissioning of the reactor sections), possible disposal options were assessed during the preliminary studies conducted in 2014–2015 and the best solutions for Estonia were determined. When making further decisions, it is important to consider local circumstances and also socio-economic factors. A plan for 2019–2027 shall be prepared for this purpose along with a strategic environmental assessment with the aim to find the best location for the final storage site. The practice licence for the design and construction of the final storage site shall be requested and obtained in 2025–2027. In 2027–2040, the design and construction of the place of final storage shall take place. Based on the results of the plan and impact assessment, the complex of the final storage site has been designed and constructed, including also the facilities for the processing and packaging, as well as for the temporary storage of waste. In addition, existing radioactive waste have been processed and packaged and are ready for storage at the final storage site. The final storage site will be taken into use in 2040.

The environmental impact of the removal of the reactor sections located in Paldiski shall be assessed in 2019–2027. Earlier preliminary studies for the removal of the reactor sections are taken into consideration in the course of these activities, technical solutions are assessed and the most suitable of them is ascertained. The principles of radiation safety and socio-economic factors have to be taken into consideration when making the decision. Activity licences for the removal of reactor sections shall be applied for in 2027–2040 and the reactor sections shall be removed, generated radioactive waste processed and packaged and stored in the final storage site by 2050.

By 2022, the safe inclusion of Tammiku radioactive waste storage facility shall be completed (the waste shall be removed from the facility, the facility shall be decontaminated, demolished, and cleared for general use).

The communication strategy for the construction of the final storage site and the removal of the reactor

sections shall be prepared and implemented from 2019–2040, establishing the goals of communication and identifying target groups. The strategy includes a plan for further activities.

The expenses for the period of 2019–2050 for carrying out the listed works are expected to be approximately 114.2 million euros. Approximately 40 million of it will be spent on planning and constructing the final storage site and approximately 31.2 million on the removal of the reactor sections.

2. Reducing the generation of radioactive waste

In order to reduce the generation of radioactive waste, a gamma measuring system was created at the radioactive waste handler to also characterise other waste besides sealed radiation sources, waste packaging measuring methods were prepared, and the personnel underwent training in the period of 2014–2017. The gamma spectrometric characterisation of waste commenced in 2017. This is followed by the preparation of release procedures. Consistent characterisation of waste with the aim of maximum reduction of the amount of waste before final storage and the suitable processing and packaging of the characterised waste (including sealed radiation sources and soft waste that can be compressed), which allows for their further storage in the intermediate or final storage site, is planned for 2017–2050. The development of the radioactive waste management equipment park and the purchasing of the packages necessary for storing waste is planned for 2018–2020. Contaminated metal is continuously collected into the intermediate storage site and sent for remelting. This will most likely take place twice in the period of 2015–2050. Concentrated waste left over from melting is appropriately processed and packaged, which allows for its further storage in the intermediate or final storage site. To ensure the safe collection of orphan sources and their consistent management, the management system of orphan sources is being developed and kept in operation.

The expenses of carrying out these duties from 2015–2050 are expected to be approximately 8.6 million euros. The greatest expense (estimated at 1.2 million euros) is calculated for 2018–2021, when according to the plan, the collection and remelting of contaminated metal waste takes place.

3. Avoiding NORM residue and waste and ensuring safe management thereof

The University of Tartu has carried out several studies to determine the generation areas of NORM residue and waste and the safe management possibilities therefor. A study was commenced in 2015 to determine NORM industries and to establish proportional defence measures arising from Directive 2013/59/Euratom. In addition, in 2016, the University of Tartu also developed an assessment methodology for assessing the health risk arising from the content of radionuclides in drinking water and also examined the possibility of NORM-free water treatment. In order to find opportunities for the management of NORM residue, the study “Analysis of the management solutions of materials containing naturally occurring radionuclides (NORMs) generated in Estonia” was conducted in 2017, which served as input for updating NORM-related information in the National Action Plan for Radioactive Waste.

In Estonia, the material containing natural radionuclides is generated in the rare earth metals production industry, in which raw materials that contain natural radioactive materials (coltan, tantalite) are used for the production of niobium and tantalum, and the processing of such raw materials generates NORM residue and waste. NORM waste are also generated in water companies whose activity (non-radiation activity) results in the generation of NORM waste, such as the filter material generated in water companies that purify water from Cm-V water intake, and also clinker dust generated during cement production in the cement industry. Considering the radioactive waste management policy set out in point 2.2 of this action plan, the generation of NORM residue and waste must be reduced by the company, if possible, in the event of the aforementioned activities. If it is not possible due to environmental, economic or social aspects, the reuse or recycling of NORM waste shall be preferred and if that proves impossible, only then

is it necessary to find a safe method for the storage of NORM waste in regular or hazardous waste storage facilities.

In 2018–2050, the research and development of the free technology of NORM waste and the management (including storage opportunities) of NORM waste shall be supported by the state.

Approximately 415,000 euros will be spent on the specified works from 2015–2021.

4. Increasing the awareness of radioactive waste

The increasing of awareness related to radioactive waste is ensured through various activities during the entire period (2018–2050). The preparation of information materials and disclosing thorough multilingual information is important: where and in which fields radioactive waste is generated, what are the options for its management depending on the types and characteristics of radioactive waste, what are the requirements for radioactive waste management, how such activities are regulated, what are the procedures for the selection/preparation of the final storage site, how the management of radioactive waste affects surrounding residents, etc. During this period, the experts engaged in radioactive waste are trained, training exercises for reacting to radiation emergencies related to radioactive waste are organised, and development in the field of radioactive waste is pursued. As such development has so far not taken place in a coordinated manner in Estonia, the participants and their interests will be mapped. Joint interests are mapped on the basis of the participants' needs and, for example, further research or the preparation of projects is planned on that basis. Meetings, which ensure the consistency of research and development and also promote information exchange, are organised regularly on the initiative of the Ministry of the Environment.

The costs of these works in the period of 2015–2050 are expected to be approximately 936,000 euros, of which a greater part (nearly 466,000 euros) is spent on the preparation of information materials and raising the population's awareness.

4. Inventory

4.1. Existing and necessary means

Technical, financial, and human resources are necessary for ensuring the safe management of radioactive waste. The need for human resources in different stages of activities is assessed in the action plan and the system to ensure this need is described. Financial means are very important when choosing technical options, primarily in the final storage stage, when the activities still have to be financed years after the generation of the waste. Several financing sources are used to ensure safe management (means of EU Structural Funds in addition to state budget funds as well).

State-owned management sites of radioactive waste include:

- Paldiski radioactive waste intermediate storage site;
- Tammiku radioactive waste storage facility.

In addition, NORM residue and/or waste may be generated in groundwater treatment plants (Cambrian-Vendian water intake), in companies engaged in the processing of niobium and tantalum ore, and in companies engaged in the maintenance of clinker furnaces.

4.1.1. Paldiski radioactive waste intermediate storage site

The receipt, processing, conditioning, and intermediate storage of radioactive waste takes place in the Paldiski radioactive waste management facility (the main building of the former Soviet Union nuclear submarine training centre). The management facility is located on the Pakri Peninsula, which is situated approximately 40 km west from Tallinn. Conserved reactor sections are also located in the management facility. The construction of the main building of the training centre commenced in 1960. The first reactor was launched in 1963 and the second in 1980. The work of both reactors was stopped in 1989. Spent fuel was transported to Russia in 1995 and the reactors were surrounded by a concrete sarcophagus. In September 1995, Estonia took over the management of the object and in 1997, an intermediate storage site for radioactive waste was built in the main building of the Paldiski object with the assistance of Swedish company SKB to store the radioactive waste generated in the course of the deactivation and decommissioning process. In the action plan, the Paldiski object covers the main building together with two reactor sections surrounded by sarcophagi, the gate building, garage and chimney, i.e. the entire area surrounded by a concrete fence. From the takeover, the manager of the site has been A.L.A.R.A. AS who has conducted various works at the Paldiski site over the years:

- a) infrastructure of the object was renovated in 1997–2012;
- b) non-radioactive pollution was removed from the object in 1995–2008 (fuel oil pollution, chemicals and asbestos);
- c) waste management centre was built in 1997;
- d) solid radioactive waste facility was removed in 1997–2000;
- e) radioactive liquid waste processing complex along with the liquid waste facility were removed in 1997–2004;
- f) redundant buildings and constructions were demolished in 1995–2012, the main building of the object was reconstructed in 2005–2008;
- g) the special washing plant and laboratory complex were removed in 2003–2004;
- h) contaminated underground communications (special sewerage and ventilation pipeline) were removed in 2003–2011;
- i) preliminary studies were conducted in 2014–2015 on decommissioning the reactor sections of the

Paldiski nuclear site on the former military area and on the establishment of a final disposal site for radioactive waste.

The waste intermediate storage site and two reactor sections together with the concrete sarcophagi surrounding them, radioactive waste management centre and office rooms are located in the main building of Paldiski management facility. The floor and walls of the intermediate storage site are made of reinforced concrete. The walls and floor of the intermediate storage site reach 1 m below the floor level of the main building, the floor is built directly on the natural limestone layer. The storage site is divided into two sections, which accommodate up to 688 containers (Figure 2) and of which 51% is filled with waste (as at August 2018). Only solid or solidified waste, the activity and specific activity of which is limited according to the waste packages' compliance indicators established with the radiation practice licence, are stored in the storage site.



Figure 2. Radioactive waste intermediate storage site on Paldiski object.

A radio-controlled overhead travelling crane equipped with a special jaw is in use for placing the waste containers into the storage site. Slings the containers by hand is not possible due to the lack of access roads in the facility. The lifting system used and the peculiarities of the facility's construction allow to deliver waste containers that weigh a maximum of 10 tonnes and are equipped with special eyebolts.

All radioactive waste generated in Estonia, excluding radioactive waste containing natural radionuclides (NORM), is managed at the Paldiski object. The main part of the stored radioactive waste is formed of the waste generated during the decommissioning of Paldiski and Tammiku objects. The rest is waste received from other establishments and undertakings. According to assessments, significantly more waste will be generated when dismantling the reactor sections than fit in the existing storage site. For the safe management of radioactive waste, a final storage site must be completed by 2040 before commencing the decommissioning of the reactor sections.

4.1.2. Tammiku radioactive waste storage facility

Tammiku radioactive waste storage facility has been closed for new waste since 1995. The structure used as a RADON-type radioactive waste storage facility is located 12 km south from Tallinn on the territory of the Männiku village in Saku County in a sandy pine forest. The structure was completed in 1963. The facility was managed by Tallinna Eriautobaas until 1995. It was however transferred under the management of A.L.A.R.A. AS in 1995. By construction the structure is an underground facility with concrete walls, which had to fit 200 m³ of solid waste. The volume of the facility is divided into nine

sections with concrete walls, the top edge of which is on ground level, the bottom is at a depth of 3.2 m. During the active use of the construction, there was a relatively primitive steel roof with locked hatches above the fillable sections. A stainless steel underground container was built for liquid waste, which contained aqueous tritium solution with a very small concentration and which was cleared and the container was emptied and demolished in 2001.

The Tammiku radioactive waste storage facility is the storage site for radioactive substances and radiation sources of industrial, medical and research bodies, including sealed radiation sources in shielding containers, smoke detectors, scrap metal, measuring devices and electric switches with a fluorescent face, various filters, etc. The waste was stored without prior conditioning or sorting. Mainly low-level waste was stored in the facility, except in two metal boxes meant for storing sealed radiation sources located in the sixth section. The effective dose rate of up to 1.2 Sv/h was measured in the top part of one such box. The volume of the Tammiku radioactive waste was estimated at 110 m³ and 97 tonnes. Before the beginning of the decommissioning process, the number of sealed radiation sources was estimated at 18,670, and these radiation sources formed approximately 93% of the total activity of the facility.

A metal gable-roofed hall has been installed over the facility since 2005.

The expert assessment of the environmental impact assessment initiated in 2006 recommended that the waste removed from the sections of the waste storage facility and placed in containers should be transported to Paldiski, where its further management, final packaging and further placement in the Paldiski intermediate storage site will take place. The environmental impact assessment report on the safe inclusion of the Tammiku radioactive waste storage facility was approved in 2007 and the safe inclusion works on the facility commenced in 2008.

The decommissioning works of the Tammiku radioactive waste storage facility are viewed in two stages. The removal of the radioactive waste from the facility, pre-sorting and transport for further sorting and management to the Paldiski management centre took place during stage I (2008–2011). The cleaning of the facility's surfaces from radioactive contamination and the total demolition of the facility took place during stage II (2012–2017), as did the exemption of the facility and its territory from complying with the requirements of the Radiation Act (2017–2022). The first part of decommissioning and its preparatory works have been completed, as a result of which waste has been completely removed from the facility's sections and transported to the Paldiski management centre, where its further sorting, management and storing has commenced. By this, all waste has been removed from the facility's sections, followed by the second stage of the liquidation of the facility. Stage II for the decommissioning of the Tammiku radioactive waste storage facility, in turn, consists of three parts:

- 1) preparation of the radiological characterisation (completed in 2012–2015);
- 2) cleaning the facility's surfaces from radioactive contamination (completed in 2015–2017);
- 3) clearing the facility and its territory (commenced in 2017).

4.2. Existing radioactive waste on the Paldiski object

4.2.1. Amounts, activity and classification of waste stored in the reactor sections

Pursuant to the preliminary studies conducted in 2014 and 2015 and based on the 50-year storage strategy of the reactor sections, around 519–1,545 m³ of waste managed is estimated to be generated depending on the method of demolishing the sections. Based on the preliminary studies, the most suitable method for the demolition of the reactor sections is the disassembly thereof along with cutting it into small pieces, whereas reactor vessels will be put into final storage in full. Implementation of this solution will generate an estimated amount of 1,000 m³ of waste managed. The waste generated during the decommissioning of

the reactor sections is classified as short- and long-lived low- and intermediate-level waste according to Regulation No. 34 of the Minister of the Environment.

Such waste requires final storage either in a final storage site near the ground or in an underground shaft-type final storage site.

Reactor section No. 1

High level components are located in the removable part of the reactor, such as the compensation lattice, reactor chamber together with the shell and screen, and biological protection (water) container.

In 1995, the representatives of the Russian Federation placed a certain amount of radioactive waste, including sealed radiation sources into both reactor sections in the course of the conservation works of the reactor sections. The list of this waste was prepared in September 1995 and was given to the Estonian authorities together with other documentation upon transferring the nuclear object. On the basis of this list, most of the radioactive waste in reactor section No. 1 is surface-contaminated low-level waste (rags, metal waste, tools, etc.). The amount of this waste in the reactor section is approximately 14 tonnes. Additionally, about 100 sealed radiation sources (used for calibrating radiological measuring devices) were stored in some chambers of this section in five concrete containers. The containers contained:

- 1) neutron radiation sources: ^{238}Pu - ^9Be , ^{252}Cf ;
- 2) gamma radiation sources: ^{60}Co , ^{22}Na ;
- 3) β -radiation sources: ^{36}Cl , $^{90}\text{Sr}/^{90}\text{Y}$, ^{137}Cs , ^{204}Tl ;
- 4) α -radiation sources: ^{239}Pu .

The activity of plutonium and caesium sources was in the range of a few kBq up to a few MBq. The total activity of the radioactive sources located on the nuclear object and stored in reactor section No. 1 was about 4.4 TBq (mainly ^{60}Co) in 1995. All these sources have been placed in concrete containers.

In addition, reactor section No. 1 contains approximately 1,370 litres of radioactive water. A total of 360 litres of it originate from the primary circuit. The activity of the water in the primary circuit is approximately 2.2 MBq/l. The time of determining the estimated activity is probably 1989 and the main radionuclides found in the water are ^{137}Cs , ^{60}Co , ^{90}Sr , and ^3H .

After emptying all the cooling circuits of water, an estimated of 1,000 l of water with a very low activity concentration (approximately 4 Bq/l) was left in the steam generators of the secondary circuit. There is approximately 6 litres of water in the fourth circuit. There is no data on the potential amount of water left in the third circuit.

Reactor section No. 2

The waste stored in the reactor section is mainly surface-contaminated textile, metal waste, tools, etc. Very low-level radioactive lead (lead carbide PbC) and ten PKI isolation chambers (length 4 m) were also stored in reactor section No. 2. The amount of the specified waste is approximately 2.5 tonnes. According to Technicatome & BNFL (2000), sealed radiation sources were not stored in the reactor section, however, this claim is not based on documented evidence but private conversations.

This reactor section contains approximately 2,285 litres of water in addition to solid waste. A total of 600 litres of it originate from the primary circuit. Activity is approximately 1 MBq/l. The time of determining

the estimated activity is probably 1989 and the main radionuclides found in the water are ^{137}Cs , ^{60}Co , and ^{90}Sr .

According the best existing knowledge, the isotopes and activity of the components and waste in both reactor sections is presented in Table 1.

Table 1. Estimated amounts of radioactive waste in the reactor sections; decay as at 31 August 2018.

Radio-nuclide	Total activity Bq							
	Reactor section 1				Reactor section 2			
	Sealed sources	Reactor shell	Cooling water residue	Sarcophagus	Sealed sources	Reactor shell	Cooling water residue	Sarcophagus
^3H			2.10E+06					
^{55}Fe		1.05E+12		2.13+04		0.36E+12		
^{60}Co	0.73+12	12.2E+13	5.16E+05	1.29E+04		3.61E+12	3.00E+04	
^{59}Ni		1.19E+12		3.50E+04				
^{63}Ni		8.38E+13		3.08E+04		3.69E+13		
^{90}Sr	1.41E+07	4.31E+08	3.82+06					
^{93}Mo		1.61E+08					3.03E+05	
^{137}Cs	3.65E+05		3.91E+06				2.28E+05	
^{152}Eu				7.63E+05		3.83E+12		
^{154}Eu				2.25E+04		2.25E+12		
^{238}Pu	1.62E+11							
^{239}Pu	6.10E+04							
^{251}Cf	1.50E+08							

4.2.2. Waste stored in the intermediate storage site

In addition to the waste generated from the decommissioning of the Paldiski and Tammiku object, all radioactive waste generated in all other establishments and undertakings operating in Estonia are also stored in the Paldiski object, which are to be stored in the intermediate facility located on the object in concrete and metal containers with external measurements of $1.2 \times 1.2 \times 1.2$ m (volume 1,728 m³).

Metal containers

The concreted waste generated in the course of the decommissioning works at the Paldiski object are stored in metal containers. There are 117 of such containers and their total volume is 202 m³.

The waste in the containers requires a more detailed characterisation to ascertain, which nuclides are represented in it, and assess its maximum possible activity. Considering that by origin the concreted waste is related to the work of the reactor sections, it can be presumed that the nuclides presented in Table 1 are found to a greater or lesser extent also in concreted waste.

The waste in metal containers is classified as low- and intermediate-level short-lived waste, which requires final storage in a final storage site close to the ground.

Concrete containers

Waste is stored in concrete containers in conditioned (concreted) form, in lead shielding containers, as well as in other packaging (if the sources do not need shielding, for example, sources of smoke detectors, sources of freezing detectors, etc.). The waste originates from the decommissioning works of the Paldiski object (1995–2008), the Tammiku facility, and other Estonian establishments and undertakings.

There are a total of 146 concrete containers in the intermediate facility and their total volume is 257 m³. The waste in the concrete containers is classified as follows:

1. 198 m³ or 77% is low- and intermediate-level short-lived waste, mainly represented isotopes: ¹³⁷Cs, ⁹⁰Sr, ⁶⁰Co;
2. 14 m³ or 5.4% is low- and intermediate-level long-lived waste, mainly represented isotopes: ²³⁸U, ²⁴¹Am, ²²⁶Ra, ²³⁸Pu-⁹Be;
3. 2 m³ or 0.7% – NORM waste;
4. 43 m³ or 16.9% – unknown uncharacterised waste.

There is indirect evidence that the waste in the final group (origin of waste, dose rates, shape of shielding containers) is low- and intermediate-level short-lived waste, but a more precise characterisation is necessary.

Properly described/characterised sources originate primarily from other establishments and undertakings of Estonia and these are sealed radiation sources, of which most are located in shielding containers. The simply identified sealed sources brought from the Tammiku facility in 2008–2011 are also in this subgroup (sources of smoke detectors, sources of freezing detectors, sealed sources of ¹³⁷Cs and ⁶⁰Co). The containers are not concreted and the waste can be relocated, if possible. Most of the containers only contain one nuclide.

The unknown sealed sources originating from Tammiku are probably ¹³⁷Cs and ⁶⁰Co sources located in shielding containers. To characterise the waste, the container's window must be opened and the radionuclide determined with a spectrometer, after which the approximate activity of the source can be calculated on the basis of the dose rate. The metal contaminated with nuclides that radiate alpha particles consists of metal waste originating from Tammiku, of which at least ²²⁶Ra has been identified.

Seven containers in the intermediate facility contain only one source. These are sealed sources, which have been found without a shielding container. In two cases, these are orphan sources and in five cases, a sealed source with a high dose rate brought from the Tammiku facility. In some cases additional shielding has been built in the containers (for example, the source is located in a metal pipe in the centre of the container and it is surrounded by sand).

The containers of beta radiation sources contain unknown sources, which the gamma spectrometer and measurements of alpha radiation have not been able to identify. The metal boxes and S-pipe with a high activity containing radiation sources brought from the Tammiku facility consist of collection boxes of sealed radiation sources and the control pipe used for entering sources into the box, which have been taken out of the shielding container (also contains sources).

It may be presumed that the concreted waste from the decommissioning works of the Paldiski object is similar to the concreted waste in metal containers. They probably contain the isotopes presented in Table 1.

It can be said that the waste located in concreted containers originating from the Tammiku object have not been characterised. Concreted waste primarily consists of contaminated sand. It can be said on the basis of preliminary measurements that β -active isotopes are strongly represented in them, and likely also ⁹⁰Sr which is widely used in scientific institutions, and there is no α -contamination.

4.2.3. Waste stored on the control area of Paldiski object

Sea containers

In addition to metal and concrete containers, the control area of the main building also includes contaminated metal, low-level concrete fracture and 200 l metal barrels stored in sea containers, which contain concreted waste as well as soft, compressed composite waste.

Waste in sea containers is classified as follows:

1. 389,6 m³ or 98% is low- and intermediate-level short-lived waste – low-level short-lived contaminated metal and concrete, isotopes ¹³⁷Cs, ⁶⁰Co, and ⁹⁰Sr;
2. 8 m³ or 2% is NORM waste.

The contamination level of metal waste was 0.6–40 Bq/cm² in 2012. Approximately 92% of such waste originates from the decommissioning works of the Paldiski object. The other 8% of waste mostly originates from the decommissioning works of the Tammiku facility, and to a very small extent from the metal purchasers in Estonia.

The contaminated concrete generated during the decommissioning works of the Paldiski object is stored in the so-called big bags placed in sea containers. Such material amounts to 165.6 m³ and the following circumstances may be mentioned as additional information:

1. α -contamination has not been found on the concrete surfaces, i.e. there are only β - and γ -active nuclides;
2. The cleaning levels of 0.4 (β , γ) and 0.04 (α) Bq/cm² were used as the basis during the decontamination of the surfaces.

Waste stored in 200 l metal barrels

Low-level waste is stored in 200 l metal barrels which in turn are located in a sea container on the control area of Paldiski object's main building (soft compressed waste, wood, small size metal, concreted waste, etc.). The surface dose of the barrels is up to 50 μ Sv/h. There are a total of 446 barrels of 200 l and 362 of them are filled with waste from the Tammiku facility. All waste in these barrels requires characterisation.

The waste packaged in 200 l metal barrels is divided by waste type as follows:

1. 85.4 m³ or 95.7% is low- and intermediate-level short-lived waste (soft compressed waste, wood, sawdust, metal, concreted dust, asbestos), contaminated primarily with isotopes ¹³⁷Cs, ⁹⁰Sr, ⁶⁰Co;
2. 3.8 m³ or 4.3% is low- and intermediate-level long-lived waste (soft compressed waste, metal, faces of indicators), primarily waste contaminated by ²²⁶Ra.

Liquid waste

The amount of stored liquid waste in Estonia is marginal. It consists of the waste found during the sorting of the waste of the Tammiku radioactive waste storage facility and amounts to around 30 litres. The waste management operator A.L.A.R.A AS is planning to characterise liquid waste, which will reveal whether these will be concreted or cleared.

Bulky waste generated by the safe inclusion of the Paldiski object

Bulky waste, which has been generated on the Paldiski object during the conservation and preparation of the reactors for long-term safe storage, is stored separately from other waste. The reactors' conductor rods with a total volume of 8.5 m³ and activity of 3.5 TBq and 8 steam generators with a total volume of 10 m³ and activity of 0.9 GBq are stored in four containers in the nuclear fuel cooling pool. Additionally another 55 HEPA filters with an activity of 0.9 GBq and volume of 20 m³ are stored in a room located next to the cooling pool. Each filter element is located in a wooden box and a concrete belt is cast between the box and the element to avoid the dispersion of contamination from the surface of the element.

The activity of waste has been assessed indirectly (Techicatome & BNFL, 2000) and radioactive decay has not been considered. From isotopes, the radionuclides presented in Table 1 are probably represented. In terms of type, it is considered low- and intermediate-level waste, however, as more precise characterisation has not been conducted, it is not possible to assess whether it is short- or long-lived waste.

4.2.4. Total activity of waste located in the intermediate facility of Paldiski object

On the basis of the work "Assessment of radioactive waste streams" carried out in 2009 and considering the waste added in 2010–2013, a summary can be made about the radioactive waste stored in the intermediate storage on the Paldiski object (Table 2). The summary covers sealed sources, the activity of which is based on the source's passport or is determined considering the dose rate and distance.

Table 2. The activity of characterised waste stored in the intermediate storage of Paldiski object (as at 31 December 2013)

Isotope	Activity, Bq	Proportion, %
Sr-90	6.20E+14	68.89
Co-60	1.11E+14	12.35
Cs-137	1.56E+14	17.29
Pu-238	1.25E+13	1.39
Pu-239	1.95E+11	0.02
U-238	5.30E+07	< 0.01
Am-241	1.60E+11	0.02
Kr-85	2.77E+10	< 0.01
Ra-226	4.91E+09	< 0.01
Ni-63	1.09E+09	< 0.01
Fe-55	6.66E+07	< 0.01
Pm-147	1.08E+07	< 0.01
Ru-106	8.28E+06	< 0.01
Ir-192	1.05E+01	< 0.01
Eu-152	3.62E+04	< 0.01
Tl-204	2.52E+04	< 0.01
Ba-133	3.02E+06	< 0.01
Na-22	8.22E+02	< 0.01
U-234	2.19E+03	< 0.01
Cd-109	2.57E+02	< 0.01

Th-228	6.40E+00	< 0.01
H-3	2.85E+11	0.03
I-125	4.08E+09	< 0.01
TOTAL	9.00E+14	100

The greatest proportion of the activity of the radioactive waste is formed by radionuclide ^{90}Sr (~68.9%), followed proportionally by nuclides ^{137}Cs (17.3%), and ^{60}Co (12.3%). In terms of other nuclides, the activity of nuclide ^{238}Pu is also notable, forming up to 1.39% of the total activity. The total activity of the other 19 radionuclides forms 0.11% of the total activity of radioactive waste.

High-level sealed radiation sources (HSR) are located in the intermediate facility in 16 concrete containers. Most of the ^{60}Co and ^{137}Cs sources are stored in separate containers by isotope, but these sources are stored together in some containers to save space. ^{90}Sr and ^{238}Pu sources are located in separate containers. The overview is in Table

3. It has to be added as clarification that these containers are already considered in the concrete container inventory by volume.

Table 3. HSR inventory (as at 31 August 2018)

Isotope	Total activity, Bq	Number of sources	Number of containers
^{60}Co	64×10^{12}	61	6
^{90}Sr	4.57×10^{14}	37	3
^{137}Cs	1.31×10^{14}	350	12
^{238}Pu	1.13×10^{13}	17	2

Among uncharacterised waste, a significant part in terms of activity is held primarily by 2 metal boxes and an S-pipe with sealed radiation sources from the Tammiku facility (they can be considered as HSRs by characteristics) and 4 containers with the reactors' conductor rods.

Even though the data on the Tammiku waste storage facility is incomplete, it still allows to assess the nuclides stored in the facility and their approximate activity, and the majority of activity is likely contained precisely in these 2 metal boxes and S-pipe.

A total of 96.3% of the characterised HSRs are formed of intermediate-level short-lived waste and 3.7% by intermediate-level long-lived waste.

4.3.Existing NORM residue and waste

The Physics Institute of the University of Tartu completed a study in 2015–2017 on the preparation of the adoption of the requirements regarding natural radioactive materials (NORM) set out in Directive 2013/59/Euratom into national legislation. Ordering of the study was based on the obligation laid upon Member States by Article 23 of Directive 2013/59/Euratom to identify the activities, during which there is potential generation of NORM waste and then establish protection requirements for employees or residents. The study revealed the industries and companies, in which NORM residue and waste have been or may be generated.

Arising from Annex VI to Directive 2013/59/Euratom – “List of industrial sectors involving naturally-occurring radioactive material as referred to in Article 23” – and the areas identified in the state, the following areas of activity were included in the study:

- combustion of oil shale for the production of electricity and heat, and maintenance of combustion

- boilers;
- production of shale oil;
- cement industry and maintenance of clinker furnaces;
- processing of niobium and tantalum ore;
- groundwater treatment plants (Cambrian-Vendian water intake);
- oil shale mines;
- burning of solid and gas fuel in central boiler plants and combined plants for the production of electricity and heat.

The study revealed that the radioactive material and/or residue originating from natural sources is most likely to occur in Estonia during the processing of niobium and tantalum ore, the work of groundwater treatment plants (Cambrian-Vendian groundwater layer), and during the maintenance of clinker furnaces. In terms of the studied industry sectors, it must be taken into account that the occurrence of NORMs that exceed the exemption levels is largely dependent on the production technology used and in the event of changes in raw materials or technology, the content and compliance with limit values of NORMs must be reassessed.

Processing of niobium and tantalum ore

Only one company falls under the more specific concept of this area in Estonia. The amount of production residue concentrated with natural radionuclides (NORM residue) generated during the production process of this company amounted to 463.33 t as at the end of 2017 (generated since 2004), and this residue is stored in 200 l and 400 l metal barrels. The residue consists of a solid rough powder.

Groundwater treatment plants (Cambrian-Vendian water intake)

About 39% of all groundwater use in Estonia is satisfied precisely at the expense of the groundwater of the Cambrian-Vendian water complex (approximately 500 bore wells) and there are no other water supply sources in many local government areas. At the same time, the groundwater of precisely this water complex has an increased radium isotope content, which have also been confirmed by research results. Considering the quality requirements of drinking water (mainly concerning iron and manganese), the water must be processed in advance. The primary problem during processing is the concentration of radionuclides in filter materials to such an extent that the activity concentration of radionuclides exceeds exemption levels (potential NORM residue) and its further processing requires implementation of radiation safety and protection principles.

There is currently one company whose activity in filter materials has been regulated by a radiation practice licence. There are 5 water purifying lines in the water treatment plant of this company. One water purifying line consists of two filtering levels, the material Filtersorb FMH with catalytic manganese dioxide (MnO₂) coating is used at the first level and natural zeolite Everzit Zeolite N is used as the filter material in the second level. According to the inventory data for 2017, a total of 152 t of filter material is being used and 44 t of radioactively contaminated filter material has been stored at the territory of the company.

Naturally contaminated metal items

Old metal drinking water pipes have also been contaminated with substances containing natural radionuclides. The amount of metal objects contaminated by natural radionuclides can be considered quite remarkable, however, a similar problem does not seem to occur with new plastic pipes. Considering the geological and physicochemical conditions, it is rather a North Estonian problem and it concerns precisely metal pipes. As a lot of pipes have been replaced by plastic pipes in the last decade and this trend continues, the amount of waste generated reduces considerably. It is estimated that the waste amount generated by

such pipes can extend to a couple of hundred tonnes. Currently, the pipes collected so far are stored on its territory by A.L.A.R.A AS. It became evident as a result of an analysis made in 2012 that there is 8 m³ of such metal waste. These are sent for remelting during the period of 2018–2020. Concentrated radioactive waste (slag, filters) is returned and must be managed and stored in the intermediate storage site.

Mineral construction materials

So far, no problems have occurred in relation to natural radionuclide content in building materials of Estonian origin. The decay chain nuclides of U-238 and Th-232 contained in the building materials analysed in the study “Study for the preparations for transposing requirements of Directive 2013/59/EURATOM on natural radiation substances (NORM) into national legislation”, conducted by the University of Tartu and completed in 2017, or contained in the raw material of building materials of Estonian origin, do not set any restrictions of the use of those building materials as the I-index of the building materials is significantly below the reference value of I=1. However, the information on imported construction materials and raw material is insufficient, which is why this aspect should be given more attention in the future. In Estonia, the Ministry of the Environment in cooperation with the Ministry of Economic Affairs and Communications are planning to map the situation concerning construction materials with increased radioactivity and develop specific monitoring terms and requirements, if necessary. The aim is to ensure the thorough monitoring and quality checking of construction materials to avoid the taking into use of material with heightened radioactivity and the generation of waste and if necessary, to also establish additional requirements. The specific activity indexes of the materials used must be < 1 so that the construction waste generated would not constitute radiological risks and so it could be processed as regular waste. The specific activity index is a dimensionless size characterising a material’s radioactivity.

Cement industry and maintenance of clinker furnaces

Only one company falls under the more specific concept of this area in Estonia and their main area of activity involves production of cement clinker and various types of cement. Limestone and clay are used as raw materials for the cement production. The primary residue generated at the plant is dust from clinker furnaces, which is caught in electrostatic precipitators. Around 94% of this dust is directed back to the clinker furnace and 6% is extracted from the system and directed into the cinder silo.

Increased concentrations of Pb-210 were established in the clinker dust generated during the production of cement. The values measured exceed exemption levels, therefore the material generated may be classified as a radioactive material containing natural radionuclides (NORM). Such enrichment is likely caused by the combustion-technical specifics. The Environmental Board has requested a radiation safety assessment from the company, it is in preparation.

4.4. Short-lived radioactive waste generated in medical institutions

Radioactive waste is generated in medical institutions as a result of the use of unsealed and sealed sources. Unsealed sources are used in three hospitals in Estonia: East Tallinn Central Hospital (ITK), North Estonia Medical Centre (PERH), and Tartu University Hospital (TÜK).

On the basis of the available information, radionuclides ¹³¹I, ^{99m}Tc, ¹⁸F, ¹²³I, ⁹⁰Y, ⁸⁹Sr, ¹⁵³Sm, ⁵⁷Co, and ¹⁷⁷Lu are mainly used. The total activity used per year is 4.23 TBq and volume approximately 6 l. Their decay below the clearance levels happens very quickly (minutes, hours) and usually takes place already inside the patient and thereafter, these isotopes are released into sewerage. Nuclides with a slightly longer half-life (a few days) are gathered into a separate container and released after the decay of the nuclides to below the clearance levels.

From sealed radiation sources, isotopes ^{133}Ba (total activity 47.2 MBq), ^{152}Eu (18.5 kBq), ^{68}Ge (188 MBq), ^{125}I (185 MBq), ^{192}Ir (988 GBq), ^{106}Ru (108 MBq), ^{90}Sr (156 MBq) are used in medical institutions.

Sealed radiation sources are delivered to a handler of radioactive waste after the end of the time of use or cleared, if the activity level has dropped to below the clearance levels.

4.5. Summary of the radioactive waste existing in Estonia

A very large part of Estonian radioactive waste is uncharacterised. There is 1,130 m³ of waste in the intermediate storage site and control area of the Paldiski object as at 31 August 2018, only 132 m³, i.e. 11.7%, of which have been characterised. Primarily low- and very low-level waste needs characterising. The situation is opposite with the activity of waste. As most of the sealed sources are characterised, an estimated presumption can be made that at least 90% of activity is characterised.

The data of waste held in the reactor sections of Paldiski object and removed from there in the future (2040–2050) in the course of decommissioning are incomplete and information is primarily based on literary sources. The waste packages generated need more precise characterising during packing.

Table 4 describes the situation of the waste existing in Estonia by waste type.

Table 4. Types and amount of waste located at the intermediate storage site of Paldiski

Type of waste	Amount, m ³	% of all waste
Low- and intermediate-level short-lived waste	1045.2	49.1
Low- and intermediate-level long-lived waste	25.0	1.2
NORM waste	24.8	1.2
Low- and intermediate-level waste, uncharacterised waste	1032.0	48.5
TOTAL	2127.0	

Low- and intermediate-level uncharacterised waste (1032 m³) can be considered as part of short-lived waste in primary meaning, as of it:

1. 988.5 m³ (95.7%) is from the Paldiski object (including reactor sections, control rods, steam generators and filters), where according to literature, it is primarily specifically short-lived isotopes (< 30 y);
2. 39.7 m³ of waste is from the Tammiku facility and according to the shape of shielding containers/sources and dose rate, these are sources of ^{60}Co and ^{137}Cs ;
3. 3.8 m³ of waste is from the Tammiku facility and these are beta sources. These are probably sources of ^{90}Sr as one of the most used isotope.

As the waste is still uncharacterised, conclusions are based on indirect assessments.

Short-lived waste has not been reflected in the table, since the waste is released in the place of use in a few months maximum.

4.6. Radioactive waste generated in Estonia in the future

4.6.1. Sealed radiation sources

As the use of radiation sources in Estonia shows a rather reducing than increasing trend, it can be presumed that the proportion of the so-called institutional waste received from establishments and undertakings operating in Estonia continues to reduce consistently. It also has to be considered that in case of sources with a greater activity in the recent years, a direction has been taken rather towards returning the radiation sources to the country of manufacture rather than storing them on site. The nucleic content and total activity of the sources currently on the national register is presented in Table 5.

Table 5. Radiation sources in the users' possession (as at 31 December 2013)

Isotope	Activity, Bq
⁶⁰ Co	1.53E+17
¹³⁷ Cs	6.46E+11
⁸⁵ Kr	3.86E+10
⁹⁰ Sr	1.56E+08
⁶³ Ni	2.22E+09
¹⁹² Ir	9.88E+11
¹⁰⁶ Ru	1.08E+08
¹³³ Ba	4.72E+07
¹⁹² Ir	5.18E+12
Isotope	Activity, Bq
⁵⁵ Fe	1.48E+09
²²² Rn	1.80E+05
¹⁰⁹ Cd	7.4E+08
²⁴¹ Am	1.03E+11

The list is not final, as it is possible that there are still sources originating from the Soviet times in circulation, which are not registered on the national register. This is also confirmed by the results of the collection campaigns of orphan sources. As a rule, these are still sources with a very low activity (indicators of devices containing ²²⁶Ra, smoke detectors containing ²⁴¹Am, and ²³⁹Pu) and their amounts are not large.

Considering the radiation sources in use in Estonia and the waste amounts taken over in the recent years, it can be said that an average of 0.1 m³ of waste a year will be received as sealed sources in the future. It can be presumed that 50% of them are long-lived and 50% short-lived low- and intermediate-level waste.

4.6.2. Metal waste

In 2013–2017, A.L.A.R.A. AS received an average of 1.4 m³ of contaminated metal waste per year from metal purchasers and the Rescue Board. In the future, the increase of the amounts is not perceived, rather a reduction as the state has strengthened the control of transit on the border (measuring gates detecting ionising radiation on the Estonian-Russian border on the railroad, as well as on highways) and the control over the contaminated metal located on the territory of metal waste has improved significantly (a metal detector at the gate of the territory).

In the future, NORM-contaminated metal waste will form an estimated 90% of the volume of waste received. A NORM waste stream of up to 0.4 m³ per year can be expected. Old water and sewerage pipes can mainly be considered the possible source of NORM waste (up to a couple of hundred tonnes by quantity), but no more NORM metal waste has reached A.L.A.R.A. AS in the course of the extensive replacing of water and sewerage pipelines from 2010–2012. It is likely that more active sediment has been removed from the pipes before decommissioning or the concentration of radionuclides has been low enough that the scrap metal purchasers' measuring gates detecting ionising radiation in the collection points do not react to it.

The generation of metal scrap contaminated by artificial nuclides is according to the forecast also rather reducing than increasing and therefore, their proportion of the general volume of metal waste generated in the future has been assessed as up to 10%. By volume, this amount is not greater than 0.05–0.1 m³ per year.

The causes of waste generation are not precisely known, as there are no places of generation of metal waste contaminated with artificial nuclides in Estonia.

Supposedly, it is the transit of scrap metal through Estonia and a small amount of metal contaminated by artificial radionuclides has got into the clean metal, which the measuring gates located on the border and on the purchaser's territory that detect ionising radiation first do not discover and which are only discovered in the course of sorting scrap metal. This is low- and intermediate-level short-lived waste.

If a company generates contaminated metal (e.g. installation of the plant that gets contaminated during the production process), the company shall request clearance after deactivation, for which they shall submit an application to the Environmental Board for the clearance of metal after decontamination. In order to reduce contamination on the surface of materials, for instance, the chemical method is used in deactivation. Cleared metal will go to metal purchasing, from where it should re-enter circulation. The clearance requirement applies to all buildings and equipment used in radiation activity, especially in the case of using unsealed radiation sources (science laboratories, nuclear medicine, radioactive waste handler, NORM-related operations).

4.6.3. Waste generated in the further decommissioning of Paldiski and Tammiku objects

Waste generated in the further decommissioning of the Paldiski object

The amount and activity of the waste kept in the reactor sections of the Paldiski object and removed from there in the future (2040–2050) in the course of decommissioning is described in Chapter 5.2.1.

Waste generated in the further decommissioning of the Tammiku object

The decommissioner of the Tammiku radioactive waste storage facility A.L.A.R.A. AS has removed the waste stored in the sections and transferred it to the Paldiski object for further management and storage. The remaining concrete constructions have been characterised and decontaminated. There were 548 m² of concrete surfaces in need cleaning. The prior experience of A.L.A.R.A. AS, when cleaning the Paldiski object, has shown that the removal of up to 5 cm concrete layer is generally enough when cleaning high-quality concrete walls to below the clearance levels. On the basis of this, up to 28 m³ of concrete scrap will be generated when cleaning the waste facility. It is likely it is the maximum possible volume, which may decrease significantly, as waste is not stored in sections 7–9 and the preliminary studies indicate the cleanliness of the sections. Regulation

No. 43 of 27 October 2016 of the Minister of the Environment “Clearance levels of radioactive substances generated during radiation activity or objects contaminated by radioactive substances and the conditions of their clearance, recycling and reuse” determines significantly higher clearance levels for cleared

concrete surfaces than were applied in the decontamination works on the Paldiski object (e.g. in the case of ^{137}Cs , it was 0.4 Bq/cm^2 before the Regulation entered into force and is currently 10 Bq/cm^2 , in the case of ^{226}Ra , the values are 0.04 Bq/cm^2 , and 1 Bq/cm^2 respectively). On the other hand, a lot of uncertainty is related to Tammiku facility and it may happen that at times surfaces need to be cleaned significantly deeper than presumed so far (floor, connections of walls, and the floor). Therefore, the initial estimate of waste generated is, in fact, 28 m^3 , which may, however, not be the final volume. The waste is generated from 2015–2022. These are low-level waste.

The chance that some part of the pollution has distributed into the environment through the facility's barriers cannot be completely excluded. The environmental survey implemented by A.L.A.R.A. AS has not, however, identified any traces of the distribution of the contamination, but the final answer to this question will only be received in the course of decommissioning the facility.

Secondary waste generated during the management of radioactive waste

Secondary waste is generated in the course of management works at Paldiski object and in the course of decommissioning Tammiku object. This is primarily protective clothing, protective equipment (masks) and tools used (hoses, plastic, paper, rags). In addition, the dust gathered when cleaning the waste treatment centre. Protective clothing, masks and other tools can be decompressed into a 200 l barrel. Approximately 0.1 m^3 of soft decompressed waste is generated from them per year. The dust gathered in the course of cleaning the waste treatment centre located on Paldiski object must be fixed by concreting to prevent the distribution of pollution. About a 20 l plastic bag's worth of dust is generated in a year, which needs concreting. In addition to solid waste, liquid waste, which is collected into containers, is generated as a result of washing the protective clothing, management works and floors at Paldiski object. On average 10 m^3 of liquid waste is generated per year. So far, the specific activity of waste generated has been below clearance levels and these have been possible to be cleared after analyses. Considering the predictions of waste generation and the nature of radiation works, it can be presumed, that the same approach will also continue in the future. Considering the nature of the waste managed, it can be presumed that the secondary waste generated is low- and intermediate-level short-lived waste by type.

4.6.4. Liquid waste

As a rule, liquid waste is not generated in Estonia. It is rather a case of radioactively contaminated objects used in research institutions, as unsealed radiation sources (liquid in an ampule, etc.) are used up during tests. Research laboratories used short-lived (half-life less than 100 days) as well as long-lived radionuclides.

The holder of a licence may store short-lived radionuclides in a storage room, if such radionuclides radioactively decompose below the clearance level within five years. Pursuant to the Radiation Act, clearance must be requested. If, for instance, the clearance methodology is submitted alongside a radiation practice licence, conditions for clearance may be stipulated in the radiation practice licence and the person shall provide annual inventory on the cleared waste. This is especially important in terms of short-term waste as these radionuclides decompose quickly. Liquid waste requiring long-term storing is primarily of historic origin (waste has been generated in the course of decommissioning works of Paldiski and Tammiku objects) and it appears when removing historical warehouses. Therefore, such waste flows must be taken into account in the future as well. It is estimated that the stream of such waste is up to 100 ml per year and by type, this is low- and intermediate-level long-lived waste.

4.6.5. NORM residue and waste

Processing of niobium and tantalum ore

The only company in Estonia engaged in this area collects and packages the NORM waste generated in the process of processing niobium and tantalum ore and stores it on its territory in a warehouse temporarily, about which an environmental impact assessment has been carried out. Due to the specific character of the production process and demand, the waste stream is irregular. Furthermore, the amount of NORM residue generated varies depending on the raw material used. NORM residue amounted to 463.33 t as at the end of 2017 (generated since 2004). The estimated amount to be generated in 2018 is 72 t. The company has applied for the generation of up to 150 t of NORM residue for the years 2019–2024, provided they shall commence with the safe inclusion of existing residue during the same period and that all of the residue will have undergone safe inclusion by the end of 2024.

Groundwater treatment plants (Cambrian-Vendian water intake)

The studies carried out in 2014–2015 established generation of NORM material in approximately 65% of the studied water treatment plants that consume Cm-V water. It was revealed that occurrence of NORM material in water treatment plants of the Cm-V water complex is rather a rule than an exception. According to the estimates made, approximately 30–60 t of NORM material may be generated in Estonia each year. This is a proportional estimate which is primarily dependent on the frequency with which the material of the filter body is replaced.

Cement industry and maintenance of clinker furnaces

The 2017 study “Study for the preparations for transposing requirements of Directive 2013/59/Euratom on natural radiation substances (NORM) into national legislation” by the Physics Institute of the University of Tartu identified NORM material in a cement company for the first time. The clinker dust containing radionuclide Pb-210 (and likely also Po-210) generated during the production process of the company requires further characterisation. The preparation of radiation safety assessments concerning the management of clinker dust is also necessary; in the event of its disposal to landfills and in cases where the clinker dust is used in other areas of activity.

One furnace accumulates around 20,000 t of clinker dust, 3,000–5,000 t of which are used as stabilisation material in road construction. The remaining clinker dust is dumped at the industrial waste storage facility of cement industry. The amount of dumped ash is directly dependent of the number of clinker furnaces that are in operation, which is, in turn, designated by the market need for cement. The amount of dumped ash is also affected by opportunities for reuse.

The company will continue redirecting clinker dust into the clinker production process and sees at least two opportunities for reducing waste generation:

- a) use of clinker dust in the production of road cement (road binder);
- b) use of clinker dust instead of limestone in the grinding of cement.

In terms of other management methods, the company sees an opportunity in using clinker dust for the liming of acidic soil and as a soil improver. The use of clinker dust has thus far been most restricted by its properties regarding quality indicators. The company is constantly working on developing new solutions, as the occurrence of clinker dust is an inevitable material stream in cement production.

The researchers of the University of Tartu determined clearly increased concentrations of Pb-210 in the clinker dust generated during cement production and caught in electrostatic precipitators. The values

measured exceed the exemption levels established by the Directive, therefore the material generated is classified as a radioactive material containing natural radionuclides (NORM). Such enrichment is likely caused by the combustion technical specifics.

Pb-210 originates from the U-238 decomposition line and can only get into clinker dust from a material that contains this naturally occurring decomposition line. Based on the Pb-210 concentrations identified, the Environmental Board has asked the company to prepare a radiation safety assessment concerning the management of clinker dust in the production process in the event of its dumping into a landfill, as well as in cases where the clinker dust is used in other areas of activity.

4.6.6. Short-lived radioactive waste generated in medical institutions

Radioactive waste is generated in medical institutions as a result of the use of unsealed and sealed sources.

On the basis of the available information, radionuclides ^{131}I , $^{99\text{m}}\text{Tc}$, ^{18}F , ^{123}I , ^{90}Y , ^{89}Sr , ^{153}Sm , ^{57}Co , and ^{177}Lu are mainly used. The estimated total activity used per year is 4.23 TBq and volume approximately 6 l. The decay of short-lived nuclides used to below the clearance levels happens very quickly (minutes, hours) and usually takes place already inside the patient and thereafter, these isotopes are released into sewerage. Nuclides with a slightly longer half-life (a few days) are gathered into a separate container and released after the decay of the nuclides to below the clearance levels.

In terms of sealed radiation sources, isotopes ^{133}Ba (total activity 47.2 MBq), ^{152}Eu (18.5 kBq), ^{68}Ge (188 MBq), ^{125}I (185 MBq), ^{192}Ir (988 GBq), ^{106}Ru (108 MBq), ^{90}Sr

(156 MBq) are used in medical institutions. Sealed radiation sources are delivered to a handler of radioactive waste after the end of the time of use or cleared, if the activity level has dropped to below the clearance levels.

4.6.7. Summary of the radioactive waste generated in Estonia in the future

The stream of radiation sources in Estonia is decreasing and the annual waste stream is estimated at 0.1 m³. The average stream of metal waste of the last five years has been 1.4 m³. By year, the streams have been exponential due to the waste collection campaigns organised by the state. For instance, a total of 117 radiation sources were collected during a campaign in 2009; 214 sources and 1.5 m³ of radioactively contaminated metal in 2010; 199 sources and 2.5 m³ of radioactively contaminated scrap metal in 2012, and during the last campaign in 2015, 38 sources and approximately 1 m³ of contaminated scrap metal were collected. The volume of waste is likely to decrease in the future as the waste collected during the campaigns are of historic origin and the majority have most likely been collected over the years. The average expected metal waste stream is 0.5 m³/pa in the future. This is mainly metal waste contaminated by natural (0.4 m³) and to a lesser extent by artificial nuclides (0.1 m³).

The NORM residue generated during the process of processing niobium and tantalum ore amounted to 463.33 t as at the end of 2017 (generated since 2004). Based on the valid radiation practice licence of the company, they are allowed to generate up to 72 t of residue over the course of 2018. The company has applied for the generation of up to 150 t of NORM residue for the years 2019–2024, provided they shall commence with the safe inclusion of existing residue during the same period and that all of the residue will have undergone safe inclusion by the end of 2024.

According to the studies conducted in 2014–2015, Estonian groundwater treatment plants (Cambrian-Vendian water intake) may generate an estimated amount of 30–60 t of NORM material each year.

Up to 28 m³ of concrete scrap is expected in the course of the decommissioning of Tammiku facility. The

waste is generated from 2015–2022.

The waste generated during the decommissioning of the Tammiku waste storage facility are low-level.

Annual waste streams of 0.1 m³ (soft decompressed waste) and 0.02 m³ (waste requiring concreting) can be expected from Paldiski object. This is secondary waste generated in the management of radioactive waste.

The foreseeable streams of liquid waste are up to 100 ml of low- and medium-level waste per year. It is estimated that by waste type in the future:

1. 0.27 m³ low- and intermediate-level short-lived waste;
2. 0.06 m³ low- and intermediate-level long-lived waste;
3. 10 m³ cleared liquid waste;
4. 0.4 m³ (contaminated metal) NORM waste;
5. approximately 30–60 t of potential NORM waste may be annually generated in groundwater treatment plants (Cambrian-Vendian water intake);
6. 0.1 l low- and intermediate-level liquid waste will be generated.

4.7. Human resources

So far, the specialists of the Environmental Board and radioactive waste handlers have been trained primarily in the course of the technical cooperation with the International Atomic Energy Agency. At the same time, the focus of the IAEA cooperation in the European region is concentrating more and more on countries, which need more help than Estonia. People can be trained through the IAEA in Estonia to a certain extent in the future as well, but regular and consistent training cannot be ensured by this.

The University of Tartu and Tallinn University of Technology started the preparation of a joint master's curriculum in the field of nuclear energy and nuclear safety in 2010. The curriculum were ready in the universities, however, these were not implemented. The universities mentioned a lack of financial resources and changed priorities in the state's energy economy development plan as the main reasons. Modification of this curriculum would enable to develop a plan for further training on radiation safety with the existence of necessary financial means. Training must allow covering the needs of those bodies, which are involved in ensuring radiation protection and safety when issuing radiation practice licences and carrying out monitoring. Knowledge on radiation protection is also needed by the users of a radiation source and other interested persons (checking of goods on the border and discovering goods containing a radioactive substance, responding to an accident and emergency caused by a radioactive substance). This would allow to train employees in the field of radiation safety, including radioactive waste management, and to satisfy the need for the preparation of new specialists and periodic further training. However, further training, especially obtaining practical skills, is therefore still problematic. It is important to ensure the level of the further training, technical equipment of practice work, training providers and the consistency of training. To realise all this, appropriate requirements need to be added to the legislation considering radiation safety. If possible, foreign experts can be and, of course, should be used as training providers. In case of this option, as well as local training, various information technology solutions need to be used more widely (for example, Skype or e-learning environments). At the same time, attention must definitely be drawn to the training of the local training providers themselves. In addition to gathering knowledge, regular training allows to ensure more professional relationships of the competent body and the holders

of radiation practice licences, including bodies active in radioactive waste management.

Research and development in the field of radioactive waste management has not been developed in Estonia. This can be alleviated by participating in international projects, working groups, reporting meetings of conventions, etc. and developing cooperation between national participants.

5. Plans and technical solutions from waste generation to final storage

The planning of radioactive waste management is particularly based on existing types of waste, amounts of waste, and the level of activity. Given that nuclear fuel has been cleared from the reactor sections, existing waste in Estonia can be considered short-lived low- and intermediate-level waste and long-lived low- and intermediate-level waste according to Regulation No. 34 of 4 October 2016 of the Minister of the Environment “Requirements for the classification, registration, management, and delivery of radioactive waste and the compliance indicators of radioactive waste packaging”.

Short- and long-lived low- and intermediate-level waste will also be generated in the future.

In addition to the previously created characterisation system of sealed radiation sources, in 2014–2017, the waste management operator A.L.A.R.A AS also created a gamma measuring system for characterising waste, prepared the necessary characterisation methods for waste packaging, and trained personnel. A.L.A.R.A AS began characterising waste in 2017. Initially, the characterisation involves gamma spectrometric measurements, which will be followed by alpha and beta radiation measurement in the future, if relevant.

5.1. Reactor sections

According to the 50-year strategy for the storage of sections, the decommissioning of the reactor sections of the nuclear object of the former nuclear submarine training centre in Paldiski results in 900–1000 m³ of waste in the future. The preliminary studies conducted in 2014–2015 significantly specified the amounts and activity of the waste generated. Among other things, the amount of waste generated, type of waste, and recommended management method were specified as well. Additionally, the studies also evaluated the amounts of waste to be potentially cleared or taken to the final storage site and specified the radionuclides and their activity in the reactor sections.

5.2. Metal containers

The concreted waste generated in the course of the decommissioning works at the Paldiski object is stored in metal containers. On the basis of the character of concreted waste (particularly contaminated materials) and the dose rates of packaging, it can be assumed that this is short- and long-lived low-level waste. The waste stored in containers is in a conditioned (concreted) form and its further management is not foreseen. Since it is low-level waste, it is important to assess whether it is practical to store the waste in the final storage site in the future or wait until the activity of waste falls below the clearance levels as a result of radioactive decay, enabling to clear the waste. To this end, it is necessary to characterise the waste in detail. Since the characterisation process starts with gamma spectrometry, then further activities can be evaluated on the basis of its results. Essentially, two options are possible:

1. if gamma spectrometry reveals that it is not possible to clear the waste in the future due to the activity of waste and/or the presence of long-lived radionuclides, it is no longer necessary to further characterise waste in great detail (determination of alpha and beta emitting radionuclides) and the waste will be permanently stored in the final storage site;
2. if gamma spectrometry reveals that it is possible to clear the waste in the future due to the activity of waste and/or the presence of long-lived radionuclides, it is necessary to determine alpha and beta emitting radionuclides. It will probably be necessary to take samples from the waste packaging by a destructive method (drilling) and analyse them. Based on the analysis, it can be determined whether it is possible to clear the packaging or not. In the event of clearance, it is possible to store the packaging in non-

hazardous waste landfill, for example.

5.3. Concrete containers

In concrete containers, waste is stored in a conditioned (concreted) form, in lead shielding containers, and also in other packaging (if the sources do not require any shielding, for example, the sources of smoke detectors, the sources of ice detector). The waste is the result of the decommissioning works of Paldiski object (1995–2008), Tammiku radioactive waste storage facility, and institutions and undertakings of Estonia. Further activities are also dependent on the type of waste and storage method.

5.3.1. Concrete containers with conditioned waste

Similarly to conditioned waste stored in metal containers, conditioned waste in concrete containers must firstly be characterised and possible further activities include either their clearance or final storage (see Clause 5.2). During the characterisation of conditioned waste originating from the Tammiku storage facility, the determination of radionuclides contained in waste is facilitated by the radiological characterisation of the floors and walls of the storage facility in 2012–2015. This process included taking concrete samples and determining the occurring radionuclides.

5.3.2. Concrete containers with sealed radiation sources containing ^{137}Cs , ^{90}Sr , ^{239}Pu , ^{241}Am , ^{238}U , ^{60}Co , and Pu-Be

Since these are characterised sources, they first and foremost need to be conditioned before they are taken to the place of final storage. Suitable method is concreting. It is currently still unclear whether the sealed sources will be conditioned along with a shielding container or the sources must first be removed from them. Concreting with a shielding container is certainly more appropriate and safer in terms of management, since in this case, management is limited only to concreting. However, if the concentration of heavy metals in waste packaging will be limited in the compliance indicators of waste packaging stored in the final storage site to such an extent that the concreting in lead shielding containers is not possible, the sources must be removed from the shielding container prior to concreting, placed into a concrete container with an additional shielding, and then concreted. In this case, the sources must be taken out of the shielding container in a special shielded chamber, or hot cell prior to concreting in order to ensure radiation safety. Currently, Estonia does not have a hot cell and its acquisition should be considered, or alternatives should be sought (rental).

A concrete container with additional shielding is a standard concrete container, which has an iron or plastic pipe of 200–400 mm diameter placed in the middle and the free external space surrounding the pipe has been filled with concrete. The pipe is filled from the inside by layers of concrete and sources so that the last layer is concrete.

5.3.3. Concrete container with control sources

The concrete container brings together control sources with different isotopes. The sources in the container must be further sorted and separated by isotope. Then, the sources will be already placed by isotopes in separate concrete containers, which include other sources containing the same isotope. This is followed by the waste conditioning already described in Clause 5.3.2.

5.3.4. Concrete container with sealed radiation sources containing radionuclide ^{226}Ra

Such waste includes long-lived low-level waste, which will be stored in the final storage site. International recommendations on the final storage packaging of such waste have not been developed yet. There are only recommendations for intermediate storage and pursuant to these, waste must be stored in stainless steel hermetic storage containers. In the near future, A.L.A.R.A AS plans to package all such sources into

stainless steel containers surrounded by a reinforced stainless steel framework which will, in turn, be placed into a concrete container. The container has been equipped with a manometer and manually opened valve (to lower the pressure caused by helium resulting from the decomposition of ^{226}Ra , if relevant). Waste packed in such a way is stored in the intermediate storage site until a suitable method for final storage has been determined. Similarly, it is planned to also store the scales that glow in the dark and are covered with ^{226}Ra -containing paint (particularly aircraft watches, compasses, etc.), which are currently placed in a 200-litre metal barrel.

5.3.5. Sealed sources containing radionuclides ^{85}Kr , ^3H , ^{152}Eu , ^{106}Ru , ^{133}Ba

Such sources are kept in one container in the intermediate storage facility and are subject to the waiting tactics of radioactive decay. After the radioactive decay of the sources below the clearance levels, the waste will be cleared. As a final result, the waste will be stored in the non-hazardous waste landfill or reused as scrap metal.

5.3.6. Concrete containers with uncharacterised sources originating from the Tammiku radioactive waste storage facility

Each concrete container contains only one unshielded source. Some containers include a built-in additional shielding (for example, the source is located in the metal pipe in the middle of the container and it is surrounded by sand). Based on the dose rates of the sources, these are probably particularly the sources of ^{137}Cs , or in some other cases, the sources of ^{60}Co that need to be stored in the final storage site. The sources of ^{60}Co with their relatively short half-life would also be suitable candidates for waiting radioactive decay below the clearance levels and the subsequent clearance. However, given the relatively high dose rate of the sources and therefore, the activity, their decay below the clearance levels may take more than 300 years. Final decisions on the storage of such sources can be made after they have been characterised.

In case of the intermediate storage (waiting for radioactive decay below the clearance levels), it is practical to place the characterised sources in a concrete container together with other similar radionuclide sources. In the event of final storage, the sources must be gathered into a concrete container with an additional shielding by radionuclides, and then concreted.

5.3.7. Concrete containers with unidentified sealed sources originating from the Tammiku radioactive waste storage facility

The unknown sealed sources originating from Tammiku are probably ^{137}Cs and ^{60}Co sources located in shielding containers. This waste must be characterised and then, it can be decided whether the waste should be taken to the intermediate storage site and later cleared, or taken to the final storage site. Similar sealed ^{137}Cs sources, which are used for industrial purposes, are so active that the time for their radioactive decay below the clearance levels is 700–1,000 years and therefore, it is not practical to take these sources to the final storage site. The source of ^{60}Co need 100–200 years to reach the clearance level and it is justified to take them to the intermediate site and later clear them.

The waste to be stored in the intermediate storage site will be characterised and then stored in their existing form (in a shielding container) according to the radionuclide in a concrete container.

In the event of sources needed to be taken to the final storage site, the issue that has already been discussed in Clause 6.3.2 should be taken into account – whether concreting takes place with a shielding container or not – and on the basis of this, it is decided whether the waste packaging must be a standard concrete container or a concrete container with an additional shielding.

5.3.8. Concrete containers with beta radiation sources

Containers with beta radiation sources contain unknown sources particularly from Tammiku waste storage facility. The sources need to be characterised (determination of radionuclide and activity). It may be possible to visually identify some sources by catalogues, however, some of them can be identified only by radiochemical analysis. After the characterisation, it is possible to place identified sources into a concrete container by radionuclides and either take them to the intermediate storage site and clear them or take them to the final storage site and manage them as described in Clause 5.3.2.

5.3.9. Concrete containers with high-level boxes and S-pipe of Tammiku waste storage facility

The metal boxes removed from the Tammiku storage facility which contain highly active metal boxes are located in concrete containers of two different dimensions. This waste must be first characterised and then, it can be decided whether the waste needs to be taken to the intermediate storage site and released, or to the final storage site. A special shielded chamber, or hot cell is needed in order to open the boxes and sort the sources from a distance. Then, it is possible to characterise the sources in more detail and based on the results, the sources will be separated according to radionuclides and placed in concrete containers with an additional shielding and taken to the intermediate storage site and cleared, or concreted in order to take them to the final storage site.

If it is not possible to use the shielded chamber for any reason, their characterisation should be limited to using gamma spectrometry and modelling techniques. In such a case, the characterisation process is followed by a test and filling in the void surrounding the boxes with concrete mixture, and final storage. In doing so, problems may arise due to high dose rate on the surface of the containers, which may not meet the compliance indicators of the packaging taken to the final storage site that are subject to be established in the future. In this case, the metal boxes should be repacked into a concrete container with a bigger shielding.

5.3.10. Concrete container with a NORM increment core

The NORM increment core originating from the conservation works of Sillamäe waste storage facility must be characterised by means of gamma spectrometry and based on the obtained results, waste must be either cleared or concreted together with other materials contaminated with alpha-emitting radionuclides and disposed, since the waste contains long-term radionuclides (^{232}Th and ^{238}U -series).

5.3.11. Concrete container with contaminated metal of ^{226}Ra

A concrete container containing metal, which has contaminated with alpha-active isotopes, accommodates metal waste originating from Tammiku and at least ^{226}Ra has been identified. Since such waste is managed similarly to other metal waste, this issue has been addressed more in detail in Clause 5.4.1.

5.4. Sea containers

The sea containers located in the control area of the main building of Paldiski object accommodate contaminated metal and low-level concrete fracture. Additionally, these also include 200-litre metal barrels with concreted, soft compressible, etc. waste, the management of which is described more in detail in Clause 5.5.

5.4.1. Contaminated metal waste

The metal waste stored in the control area of Paldiski is located in the sea containers (part of the waste

has been placed in 200-litre metal barrels before placing them in the sea container) and concrete container, and their pollution level during the measurements carried out in 2012 was 0.6–40 Bq/cm². As at 2017, there was a total of 168 tonnes and 185 m³ of metal waste stored in the Paldiski management facility, and one alternative for the management thereof is to remelt them in the melting facility of Studsvik in Sweden (Studsvik Nuklear AB). During the melting of contaminated metal, most of the pollution will end up in the upper slag layer of the molten metal and it is possible to remove it from the rest of the materials. The metal that has been purified during melting will be recovered as a raw material and the remaining slag and possible metal that is not suitable for melting (estimated volume of 2 m³) will be sent back to Estonia. It is estimated that approximately 13 m³ of slag and secondary waste is returned to Estonia and this waste needs to be taken to the final storage site. Before final conditioning it is necessary to determine the average activity of waste. The radionuclide composition of contaminated metal is determined prior to the melting of material. For the purposes of final storage, the waste will be concreted in a concrete container.

5.4.2. Contaminated concrete fracture

Concrete fracture has been placed in 30-litre plastic bags, which, in turn, has been placed in big bags and after that in the sea containers. This material needs to be characterised before any further management related decisions. Since the radionuclide-based clearance levels had not been adopted during the early years of the deactivation of Paldiski object, the removal of pollution from the surfaces was based on very conservative clearance levels, namely 0.4 (β, γ) and 0.04 (α) Bq/cm². Therefore, it may be assumed that it is possible to clear part of the materials stored in bags immediately after the characterisation process or short intermediate storage. The rest of the material will be concreted into a concrete container and taken to the place of final storage.

5.5. 200-litre metal barrels

The 200-litre metal barrels accommodate low-level waste, which does not lead to a higher dose rate on the waste packaging surface than 50 µSv/h. The metal stored in metal barrels has been discussed in Clause 5.4.1 and the screens and scales that glow in the dark and are covered with ²²⁶Ra-containing paint in Clause 5.3.4.

5.5.1. Soft compressible waste

For the purposes of reducing the volume, such waste has been compressed after being placed in the barrel. This waste needs to be characterised. After this, a small part of waste may probably be cleared. However, a majority of waste must be conditioned prior to taking them to the place of final storage. There are three possible ways for further handling:

- a) the barrels are pressed together with a mobile machine press (volume reduction of up to six times) and then concreted in a concrete container;
- b) the barrels are concreted in their existing form in a concrete container;
- c) the waste stored in the barrels will be sent to be incinerated in some foreign country on the basis of a re-admission agreement, and the remaining ash will be sent back to Estonia, where it is concreted before final storage.

In case of alpha contaminated soft waste, only options b) and c) apply as solutions.

5.5.2. Wood and sawdust

Wood is biodegradable waste, which produces gases and may destabilise waste packaging. Since this is low-level waste, such waste must be first characterised in order to estimate the time when the activity of

waste drops below clearance levels. If it is possible to clear waste in the future, it is reasonable to implement the waiting tactics. If the decomposition time is still too long, it should be considered to incinerate the waste in a foreign country, and concrete and take the returned ash to the final storage site. There are no alternatives for burning wood that has been contaminated with alpha-emitting radionuclides.

5.5.3. Concreted waste, rust scrap and dust

It is no longer possible to decrease the volume of concreted waste. The waste must be characterised and then either released or placed in a concrete container for final disposal. In the event of such waste, it may be practical to develop a separate container for final storage, which would accommodate four to six 200-litre barrels. The existing 1 m³ standard concrete container can hold only one barrel. If it is possible to fill the surroundings of the barrel with other concreted waste (contaminated fracture, contaminated dust, contaminated iron rust, etc.), it may be practical to also use existing concrete containers.

In the event of rust scrap and dust that has not been concreted and stored in 200-litre barrel, after the characterisation process, it will be practical to clear it or concrete it into a concrete container for final storage.

5.5.4. Beta radiation sources

Beta radiation sources are soft sources on a foil base. These must be characterised and after that it is possible to make decisions on intermediate storage and clearance or final storage. In the event of intermediate storage, it is possible to store the sources in their existing form, however, in case of final storage, it is necessary to compress the sources together in the barrel and then they need to be concreted.

5.5.5. Contaminated asbestos

This kind of waste must be thoroughly characterised in order to identify the pollution levels. Then, it must be assessed whether the activity of waste has decreased or will decrease below the levels of release after which the waste will be released. If the radionuclide composition and/or activity of waste does not permit its release, the waste must be concreted in a concrete container and taken to the place of final storage. It is definitely worth to also wait the results of the decommissioning work of the reactor sections before the management of the mentioned waste in order to simultaneously manage the possible asbestos waste that may occur during the decommissioning of the sections.

5.6. Liquid waste

It consists of the waste found during the sorting of the waste of the Tammiku radioactive waste storage facility and amounts to around 30 litres. The waste management operator A.L.A.R.A AS is planning to characterise liquid waste, which will reveal whether these will be concreted or released.

5.7. Bulky waste located at the Paldiski object

Bulky waste means waste that includes 4 cylindrical concrete containers with the steering rods of the reactors and 8 steam generators stored on Paldiski object. Additionally, a total of 55 HEPA filters are stored here, which have also occurred during the operation of Paldiski object.

The steering rods of the reactors have been packed in suitable concrete containers for final storage and these do not probably need further management.

Steam generators contain the radionuclide of ⁶⁰Co and therefore, it is not possible to melt them again. It

is planned to cut up the equipment, determine their levels of activity, and place them into a concrete container. Depending on the activity of the activated metal, the containers are either taken to the intermediate storage site and cleared afterwards or taken to the final storage site.

The filter elements are to be placed in a concrete container, since the wooden box surrounding the element is not a durable solution in terms of time. Wherever possible, the filter will be previously dismantled as much as possible in order to accommodate as many filters as possible in a single container. Then, the surroundings of the filters will be filled with concrete and another layer of concrete will be casted upon it, and the container will be taken to the final storage site.

5.8. NORM residue and waste

The management methods of NORM residue and waste can be broadly divided into two: reuse and management as waste. The conditions for the reuse of NORM residue depend on the specific industry, the character of the generated material, applicable legislation, and state policy. Reuse is strongly recommended, especially in the light of sustainable and economic aspects.

Since the generation of NORM residue or waste is directly related to the production technology and the raw material used, the options for the prevention, as well as reduction of the generation of NORM residue and waste are limited. In addition, the NORM residue or waste of all industries consist of low value mineral material.

Groundwater treatment plants (Cambrian-Vendian water intake)

The studies carried out in 2014–2015 established generation of NORM material in approximately 65% of the studied water treatment plants that consume Cm-V water. An estimated 30–60 t of NORM material may be generated in Estonia each year.

In the case of water treatment plants, one option for preventing the generation of NORM waste is to establish monitoring conditions of filter materials and plan replacement of filter materials, if possible, in order to ensure that it takes place before exceeding the exemption levels established by the Radiation Act. This will ensure that there is no need for additional assessments under the Radiation Act for further management of filter material. However, the environmental, economic and social aspects accompanied by filter replacement must be taken into account. In practice, it cannot be considered very realistic for all water companies, as in the event of strong absorbents, the filter material is enriched very quickly. Thus, amendment of technology may prove more cost-efficient in the long run than constant replacement of filters.

The final storage of the NORM waste generated in the Estonian water industry using Cambrian-Vendian (hereinafter “Cm-V”) water intake in regular or hazardous waste storage facilities is becoming increasingly topical, as it has been revealed that the generation of NORM waste in Cm-V water complex water treatment plants is rather a rule than an exception, especially since there is no sustainable re-usage solution for the filter material generated in water companies yet. However, considering the national objective to reduce the generation of NORM waste and the rapid development of the NORM residue management technology, it is not feasible to establish a storage site for NORM waste in Estonia. The low value of the NORMs generated in water treatment companies is one of the reasons they end up in landfills. Countries where NORMs have been dealt with extensively mostly dump these in hazardous or regular waste landfills as part of their moderate mineral material management method. In this case, the maximum activity concentration and amount of NORM waste are limited. Dumping in landfills relies on radiation safety assessments.

If NORM waste can be dumped in regular or hazardous waste landfills, the landfill must prepare a radiation safety assessment to evaluate the need for applying for a radiation practice licence. The dumping of NORM waste into landfills is not subject to the requirements of the Radiation Act, provided the radiation safety assessment proves that the dose to which the landfill employee is exposed does not exceed the bases of exemption and the activity can be excluded from implementation of the requirements of the Radiation Act if exemption is the best solution considering economic, social and environmental factors. Currently, one waste reuse company has prepared a radiation safety assessment and based on this, there is no need for a radiation practice licence for the dumping of NORM waste generated in the water industry in a landfill. The landfill must have a relevant environmental permit. The aforementioned company that is engaged in the reuse of waste has requested an amendment of the hazardous waste management licence in 2017 to, inter alia, dump NORM waste at a landfill.

One option would be to reduce the generation of NORM waste by adopting new technologies for the disposal of radionuclides, e.g. hydrous manganese oxide suspension (HMO) technology which makes it easier to remove accumulating radionuclides from filters – this prevents the concentration of radionuclides in filters from getting too high. At the same time, the testing of the technology in industrial production has not been completed.

The shaping of the future practices of Cm-V water intake water treatment plants will be revealed once the studies regarding the use of the new radium disposal technology in the industrial production of water are completed.

There are likely no market-based reuse options for NORMs generated in the water industry. The material could potentially be used as filling material, but there are no preliminary studies, radiation safety assessments or potentially interested parties, as there are many waste generators, the quantities are small, and material types vary.

However, one thing is sure – proven technologies that enable to minimise and/or avoid generation of NORM residue must be preferred when constructing a new water treatment plant in order to reduce the likelihood of generating NORM waste in the future.

Processing of niobium and tantalum ore

The only company in Estonia engaged in this area collects and packages the NORM waste generated in the process of processing niobium and tantalum ore and stores it on its territory in a warehouse temporarily, about which an environmental impact assessment has been carried out. Due to the specific character of the production process and demand, the waste stream is irregular. Furthermore, the amount of NORM residue generated varies depending on the raw material used. NORM residue amounted to 463.33 t as at the end of 2017 (generated since 2004). The estimated amount to be generated in 2018 is 72 t. The company has applied for the generation of up to 150 t of NORM residue for the years 2019–2024, provided they shall commence with the safe inclusion of existing residue during the same period and that all of the residue will have undergone safe inclusion by the end of 2024.

The company has analysed the technical solutions for the safe inclusion of NORM residue on-site and a safe inclusion plan for NORM residue has been prepared. The aim is to exempt NORM residue from the application of the requirements of the Radiation Act in order to recycle it as filler material in the construction of a local port. For this, NORM residue are mixed with oil shale ash in order to reduce the activity concentration of radionuclides contained in the NORM residue to an extent that it corresponds with the clearance levels of radionuclides, and secondly, reduce the content of heavy metals contained in NORM residue to an extent that the resulting material could be used as filler material at the port. For the

safe inclusion of NORM residue in such a manner, the company needs to build additional facilities for the mixing of oil shale ash and obtain and amend licences regarding environmental use. The company must prove the use of NORM residue diluted with oil shale ash in the construction of the port for the safe inclusion of the NORM residue. The safe inclusion plan of NORM residue set out in the company's 2018 application for a radiation practice licence is to be implemented during the period 2019–2024, which includes the safe inclusion of all NORM residue. Although the removal of NORM residue from Estonia during the updating of the action plan is not currently on the agenda, the company will still continue to work on finding export opportunities for the safe inclusion of NORM residue. In the event of problems during the realisation of the safe inclusion plan of NORM residue, the alternative solution for the safe inclusion of NORM residue – removal of NORM residue – reduces the chance for sustainable collection of NORM residue which, in turn, must help to reduce the likelihood of NORM residue generation and therefore the issues regarding the management, including final storage, of NORM waste.

Cement industry and maintenance of clinker furnaces

Waste from the cement industry has long been used as a road binder in road construction. The company also sees the liming of acidic soil as one possible application. Although clinker dust was already used as lime fertiliser in the 1960s, its use for field fertilisation was prohibited in 2005 by a Regulation of the Minister of Agriculture after it was found that the concentration of the heavy metal lead in the clinker dust generated during the use of alternative fuel in cement production exceeded the applicable limit value (100 mg/kg). In the light of this new knowledge on Pb-210 contained in clinker dust, the final product must undergo radiological measurement before the fertiliser can enter the market, in order to ensure that the Pb-210 contained in the fertiliser mixture does not exceed the exemption value or clearance level.

The Environmental Board has asked the company to prepare a radiation safety assessment concerning the management of clinker dust in the production process and its dumping into a landfill, as well as in cases where the clinker dust is used in other areas of activity. The concentrations of Po-210 in clinker dust must also be determined.

5.9. Short-lived radioactive waste generated in medical institutions

Short-lived radionuclides, which are used in medical institutions, decompose below the clearance levels in a very quick manner (minutes, hours) and this process usually takes place already inside the patient, and then, these isotopes are released into sewerage. Longer-lived radionuclides (days) are collected in a separate container and released after the decomposition below the clearance levels. At the end of their lifetime, the sealed radiation sources used in hospitals will be handed over to the radioactive waste handler, A.L.A.R.A. AS, who will then practice intermediate storage and clearance or final storage, depending on the radionuclide and activity.

5.10. Final storage of waste

The preliminary studies carried out in 2014–2015 identified the possible decommissioning scenarios of the reactor sections of the Paldiski object, the quantities and types of waste that require final storage, suitable types of final storage sites and the construction cost thereof.

Considering existing radioactive waste at the intermediate storage site and control area of the Paldiski object, the waste generated during the decommissioning of the reactor sections and the waste generated in Estonian industries, medicine and research institutions up to the year 2040, approximately 3,000 m³ of low- and intermediate-level waste require final storage. The preliminary studies revealed that the most suitable final storage solution for Estonia is a combination of underground shaft-type final storage sites

and final storage sites established near the ground.

5.10.1. Underground final storage site

As the activity of existing and generated intermediate-level waste in Estonia is high enough, such waste must be stored in underground storage sites. Such waste include sealed radiation sources, intermediate-level waste and waste with a long half-life, as well as the reactor vessels disassembled during the decommissioning of the reactor sections. The quantity of waste that require final storage is relatively small and thus a shaft-type final storage site should be most suitable. The depth of the planned shaft is approximately 50 m and its outer diameter is 10.4 m (inner diameter 9.4 m). The waste is planned to be stored at the depth of 30–50 m. The lining of the shaft may be constructed from prefabricated reinforced concrete details (segments) or from concrete cast on-site. The outer walls will be additionally covered by a high-quality impermeable concrete layer (minimum thickness of the layer is 0.5 m), which will form a concrete barrier. The ground plane is made from the same concrete. The shaft that is filled with waste packaging shall be refilled with concrete. The backfilling and the construction material of the cover plate is advised to consist of porous gas-permeable concrete, on which a compressed sand/bentonite mixture will be used as a gas-permeable cover. The thickness of the sand/bentonite layer may not be less than 5 metres. The capacity of the shaft will be approximately 1,400 m³. Such capacity is sufficient for the final storage of all conditioned waste in the shaft (around 900 m³ with 70 m³ of spare space). The cross-section of the sealed shaft-type final storage site is set out in Figure 3.

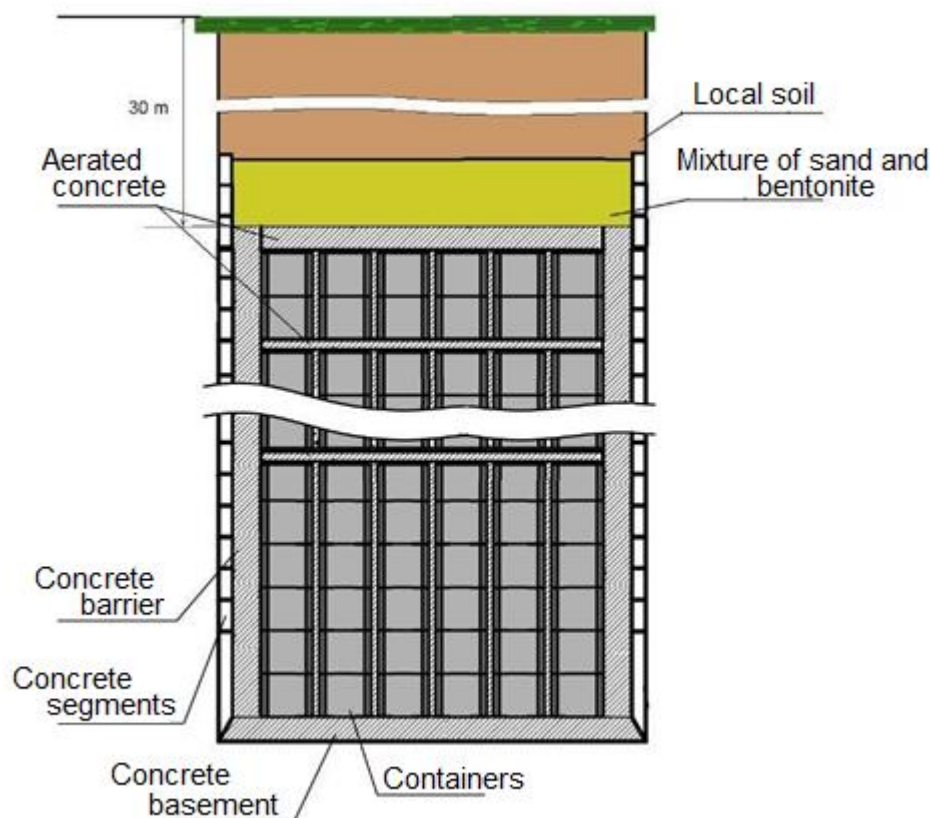


Figure 3. Cross-section of the sealed shaft-type final storage site

5.10.2. Final storage site close to the ground

For the final storage of low-level waste and waste with a short half-life in Estonia, it is sound to establish a final storage site close to the ground, composed of two reinforced concrete sections, located on the

ground or in low-humidity soil. The planned internal dimensions of the sections are $15 \times 12.5 \times 6$ m (the capacity of one section is approximately $1,125 \text{ m}^3$). It is sufficient for the storage of all conditioned waste that are suitable for storage at such a storage site (approximately $2,100 \text{ m}^3$ with 60 m^3 of spare space). The best geological environment for such a storage site is low-humidity soil with great absorption properties which enable efficient water drainage without radionuclide spreading to the environment. The cross-section of a sealed final storage site close to the ground is set out in Figure 4.

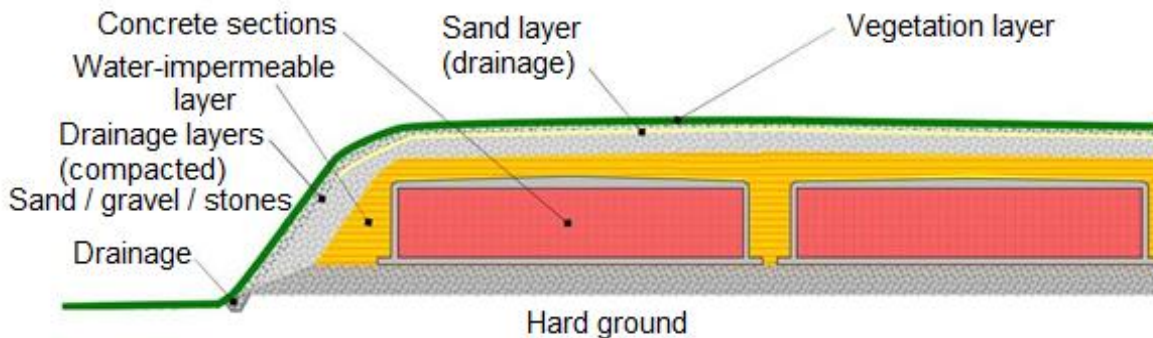


Figure 4. Cross-section of a sealed final storage site close to the ground

Various types of waste packaging are suited for final storage: standard concrete or metal containers, large concrete containers and barrels containing compressed or concreted waste. During the operation period, the final storage site is equipped with a crane and covered with a temporary cover structure. The objective of the cover is to protect the waste packaging located in the unsealed section from weather conditions and thus avoid possible leakage.

The waste will be placed into the section of the storage site through the upper part. Packaging can be placed vertically or horizontally. The gaps between packaging and the openings are filled with concrete. A concrete plate will be installed/cast onto the section once the section has been filled.

The design of the final storage sites of radioactive waste is based on a three-level protection concept. The waste packaging will provide initial protection against radioactive waste reaching the environment. The second protective level consists of reinforced concrete walls and the third protective level is based on geology (e.g. clay layer). Observation tunnels have been constructed under the sections for regular monitoring in order to discover possible leaks quickly.

During the placement of waste into the section, it is protected by a protective structure. However, a small amount of water may enter the sections. Therefore, a water collection system must be built, if necessary. The seeping water will flow through the pipes located in the observation tunnels into a special stainless steel container. The water collected in the container is pumped out regularly and monitored. The water can be collected and monitored until the instalment of the final cover of the final storage site or until the end of the active institutional control period (follow-up monitoring). After this, the container will have to be filled with concrete and the observation tunnels and the pipe must be properly sealed with concrete or bentonite.

6. Post-closure plans for the radioactive waste storage site

The Radiation Act establishes that upon applying for a radiation practice licence, the applicant shall submit information regarding the methods of management and final closure of the storage site for the management and intermediate and final storage of radioactive waste. Closure of the storage site means termination of all activity after the used nuclear fuel or radioactive waste have been placed into the facility intended for final storage, including final engineering and technical or other works for the facility to reach long-term safe status. Final disposal means the placing of radioactive waste in waste disposal sites which conform to certain requirements or locations which are adapted for such purposes, without the intent to retrieve the waste later. Therefore, the final storage site of radioactive waste is a facility where the radioactive waste that are stored in it are not taken out. The final storage site will be closed after it is filled with radioactive waste. Closure of the storage site is a radiation practice and requires application of a radiation practice licence where the conditions for closure shall be determined. In addition to the application for a radiation practice licence for the closure of a storage site, the following shall be submitted among other things:

- 1) closure plan;
- 2) data on the total activity of planned radioactive waste;
- 3) planned number of waste packaging units and specification of waste packaging;
- 4) descriptions of post-closure access restriction measures;
- 5) prognosis for the need and extent of post-closure radiation monitoring;
- 6) description of measures planned for limiting the discharge of radionuclides into the environment;
- 7) plans for storing design plans of management facilities and other relevant plans;
- 8) radiation safety assessment of the closure of a final disposal facility.

The Radiation Act also establishes that after the closure of the radioactive waste management site, the Environmental Board shall preserve the documents on the location of the radioactive waste storage site, its planning and the inventory of radioactive waste without a term; it also shall organise radiation monitoring and the control of access restriction as appropriate and shall carry out intervention if based on the monitoring data or upon inspection it is identified that radioactive substances have entered the environment. So far, there has not been any need to formulate the post-closure conditions in a more specific manner, since Estonia does not have a final storage site and already only its establishment necessarily requires updating the valid legislation.

The preliminary studies carried out in 2014–2015 identified the possible decommissioning scenarios of the reactor sections, the quantities and types of waste that require final storage, suitable types of final storage sites and the construction cost thereof. The preliminary studies revealed that the most suitable final storage solution for Estonia is a combination of underground shaft-type final storage sites and final storage sites established near the ground. The final storage site of radioactive waste in Estonia must be completed in 2040. Although final storage sites close to the ground are used in several countries, there is little experience regarding their closure. Based on the IAEA guide, closure activity may take up to 20 years. The planning and design of the final storage site must also include the preparation of an initial closure plan. Its aim is to reduce the costs of closure. In the light of the aforementioned, it is necessary to simultaneously work on amending and developing legislation in regard to the establishment, as well as closure of final storage sites.

The intermediate storage site of radioactive waste is demolished simultaneously with the decommissioning of the reactor sections located in the same head building of the former Paldiski nuclear object. The waste stored in the intermediate storage site have been placed into the final storage site by then. The conditions on the site during and after decommissioning, including monitoring, shall be

appointed in practice licences, which are issued by 2040 at the latest. The input therefor shall be provided by studies to be completed in 2023.

The lifetime and active institutional control period (follow-up monitoring) of the final storage site completed by 2040 will be determined in practice licences which are issued in 2027 at the latest. The input therefor will be provided by studies to be completed in 2023, after which the costs of closure of the final storage site can be assessed.

7. Research and development

7.1. Sources

In accordance with clause 13 (1) 1) of the Organisation of Research and Development Act, the functions of all ministries in the field of research and development include the organisation of the required research and development in their areas of government and the financing thereof, taking into account the results of evaluation and the related assessments and recommendations. According to clause 2 of the same section, the ministries are responsible for the development and organisation of research and development programmes both in the state and in their area of government.

The Estonian research and development and innovation strategy 2014–2020 “Knowledge-based Estonia” determines the directions for the development of research and development and innovation, on the basis of which this field of activity can be managed, public financial resources can be applied and the competitiveness of the state and the welfare of the population can be increased.

The overall aim of the development of RDI is to create favourable conditions for an increase in productivity and in the standard of living, for good-quality education and culture, and for the sustainable development of Estonia.

“Knowledge-based Estonia” establishes four significant sub-objectives for Estonia:

- research in Estonia is of a high level and diverse;
- research and development (RD) functions in the interests of the Estonian society and economy;
- RD makes the structure of the economy more knowledge-intensive;
- Estonia is active and visible in international RDI cooperation.

7.2. Organisation of R&D in the Ministry of the Environment

The role of ministries in determining the needs of society has increased, as has the share of coordination activities within and outside the ministry in regard to ordering the necessary R&D for the state. The research and development and innovation (RDI) policy should be addressed as a means to achieve economic, social and environmental objectives. The SWOT analysis of the Estonian RDI strategy

”Knowledge-based Estonia 2014–2020” brings out that the problem in Estonia lies in “uneven capacity in the management and coordination of field-specific research and development and the minor role of ministries in determining societal needs”.

In terms of weaknesses, for resolution of which the Ministry of the Environment could contribute also include coordination problems, lack of unity [in studies], RD financing statistics do not support field-specific management, very dominant project-basis, not output- or quality-basis, concentration on national topics, little outward orientation, inability to agree on big issues (strategic choices).

The amount and complexity of upcoming problems and challenges in the field of environment has increased in Estonia, as well as the rest of the world, therefore, investment into RDI has proven a successful practice, facilitating the impact of research in ensuring national interests and adoption of decisions. The aim of the RDI activities of the Ministry of the Environment is to ensure a clean environment and sustainable use of natural resources by developing better solutions, technologies and processes through RD and spreading and facilitating their adoption.

Therefore, the Ministry of the Environment mainly focuses on three activities that support the research system and research development, which involves funding and coordination of the research and development activity of the ministry:

1. sectoral applied research that is necessary for providing a scientific input for the shaping of policy and legislative drafting.

The aim of the activity is to increase the role of the Ministry of the Environment and strengthen its capability to guide and organise research in the area of the environment by ordering (applied) research and guiding funding instruments. Thanks to the implementation of this activity, the Ministry of the Environment has the necessary scientific input for making science-led decisions, shaping the policy, legislative drafting and national surveillance.

There is need for studies that support the protection of people and the natural environment from the damaging effect of ionising radiation. Research and development activities in the field of radiation safety has been briefly reflected in the national development plan of radiation safety. Given the small size of the Republic of Estonia and the fact that Estonia does not have any nuclear installations and the waste stream generated in the future is moderate, Estonia lacks a separate document, which would establish research and development issues in the field of radioactive waste management. While taking into account the implementation plan of the national development plan of radiation safety, it can be argued that the main related issues in the field of research and development are the following:

- the development of procedures for determining alpha and beta emitters necessary for the characterisation of waste;
- the development of the procedures necessary for the release of waste;
- supporting the research and development of the field of new technology of NORM residue and/or waste.

2. Coordination and funding of participation in international research collaboration projects, including joint programming initiatives (JPI), ERA-Net projects and other international research collaboration projects.

The aim of the activity is to facilitate international RDI collaboration to bring added value to local research and development activity and to participate in solving common environmental problems. The implementation of the activity resulted in increasing the capability of Estonian research and development institutions for international collaboration, which is illustrated in the number of international collaboration projects with participation of Estonian researchers and scientific publications published on the basis thereof. Participation of Estonian researchers in international research collaboration networks enables to gain experience and new knowledge, and contribute to developing relevant areas of research in Estonia through participation in international research groups. It is important for environmental researchers to increase their participation in international research collaboration, because participation in international networks provides researchers (in a broader sense, also manufacturers, processors, consultants, policy-makers) with the experience and knowledge necessary for professional development, and help ensure the quality of research activities under limited resources.

Horizon 2020 includes the radiation and nuclear safety related work programme “Euratom Research and Training Programme (2014–2018)”. The research and innovation framework programme for 2021–2027 Horizon Europe includes the Research and Training Programme of the European Atomic Energy

Community for the period 2021–2025. The new programme continues the main research activities of the current programme and expands research for using ionising radiation in areas other than energy (e.g. areas of healthcare and medical equipment). The programme also includes other just as important tasks: improving opportunities for the management and final storage of used nuclear fuel and radioactive waste and supporting readiness for a radiation-related emergency.

The programme enables nuclear scientists to participate in education and training plans, supporting their mobility from the Marie Skłodowska-Curie measures.

3. Ensuring the sustainability of sectoral research and development and development of human resources.

The state is currently in a situation where there are no underlying studies on many topics or there are so few relevant researchers, that the state is unable to get quality scientific data due to overload. However, research facilities are unaware of national priorities and interests and they do not know where to direct the next generation of researchers. Having recognised their RDI needs, the Ministry of the Environment can use RDI policy (e.g. funding principles, legal bases, procurements, etc.) to direct the behavioural routine and priorities of RD institutions and companies, so they are actually interested and capable of contributing to RD objectives of the Ministry of the Environment (analytical capability, collaboration, etc.).

Research and development in the field of radioactive waste management has not been developed in Estonia. In order to solve this problem, it would be necessary to grow the capability of world-class radiation-related research and development by implementing it in the interest of the Estonian society and economy. The activity focuses on developing RD human resources in the field to ensure a sufficient number of specialists, high-level management of the field and correspondence of RD activities with the needs of companies and the public sector. Firstly, it would be necessary to work together with relevant Estonian universities to add a course on radiation safety in environment-related curricula which would offer all first year students an overview of the current situation in the field, ongoing research projects, research methods, etc. This teaches all graduates with essential scientific literacy and offers cleverer students an option to continue their studies in the relevant field.

7.3. Funding instruments

Research and development activities are based on potential funding sources, which, in turn, can be divided into three groups:

- national research funding;
- international funding options (incl. structural funds);
- participant funding.

7.3.1. National research funding

The funding of research and innovation in Estonia is mainly horizontal (i.e. without sectoral preferences) and based on competition. The aim of the competitiveness plan “Estonia 2020” is to ensure that the level of national funding of research and development is 1% of GDP. Although the level of national funding was far behind the planned amount in 2018, amounting to only 0.66% of GDP, the Government of the Republic and other participants have taken steps and concluded further agreements for the funding to reach the level planned.

- The decisions of the state must be science-led and that is why the Estonian Research Council funds research and development through the programme “Strengthening of sectoral R&D”, the aim of which

is to increase the role of the state in strategic guidance of research and the capability of research and development institutions to conduct socially significant studies. The Estonian Research Council uses the programme to fund applied research with socio-economic objectives based on the needs of the state. The programme lasts up to 2022.

- In addition, applied research is funded from the budget of the Environmental Investment Centre (hereinafter “EIC”). The EIC is a financial institution which funds environmental projects from four sources: environmental fees of the Republic of Estonia, EU structural funds, loan given to Estonia by the European Investment Bank, and CO₂ quota sales of Estonia. The funding of main activities has changed over the years – during the first years of operation, support was mainly provided from the resources of the Estonian state, whereas in recent years, the volume of foreign support projects has significantly exceeded the first.

In the last few years, projects carried out regarding NORM residue and waste have received funding from the EIC. For instance, several scientific studies have been completed on NORM residue and waste by the Physics Institute of the University of Tartu thanks to funding from the Environmental Investment Centre, including

- 1) the 2015 project “Generation of radioactive waste in water treatment plants using Cambrian-Vendian water intake”. The completed work covers the first ever results evaluating the quantities of low-level radioactive waste generated in water treatment plants with Cm-V water intake. The aim of the study was to provide a quantitative assessment on the quantities of radioactive material generated in Cm-V water treatment plants, as well as to characterise the radioactive material generated.
 - 2) In 2017, the study “A study on the preparation of the adoption of the requirements regarding natural radioactive materials (NORM) set out in Directive 2013/59/Euratom into national legislation” was completed. The resulting work covers results on assessing the radiation risks and generation of NORM material as a by-product of production in the oil shale industry, cement industry, central boiler plants and combined plants, and groundwater treatment plants in Estonia. The radon risks of underground mines and the radioactivity of construction materials and the raw materials used therein were assessed as well.
- The Ministry of the Environment funds research and participation in international collaboration from public resources (foreign resources will be discussed in the next chapter). In 2018, the Ministry of the Environment provided funding for studies from public resources in the total amount of 1,077,306 euros. Studies are ordered pursuant to an overview of studies and study plan.

7.3.2. International funding options

One of important options for funding research and development activities is the European Union funding programme for research and innovation “Horizon 2020”. The aim of this programme is to create new ideas and jobs and to promote growth. The programme includes all the current European Union research and innovation funding instruments: the activities of the Research Framework Programme, the Competitiveness and Innovation Framework Programme, and the European Institute of Innovation and Technology.

The three priorities of the programme:

- Excellent research. The aim is to raise the quality of the European research activities and to ensure the continuation of the world-class research in order to ensure the long-term competitiveness of

Europe.

- Leadership in the industry. The aim is to make Europe a more attractive place for investment in research and innovation by promoting business-related activities.
- Problems of society. The aim is to stimulate achievement of the necessary critical mass of research and innovation for achieving EU policy goals. This priority covers the strategic goals of “Europe 2020” and problems before society, which are largely connected to the area of agriculture, food, and fishing science. The priority includes innovational partnership. The focus is on the following:
 - healthcare, demographic changes and welfare;
 - food security, sustainable agriculture, marine studies and bioeconomy;
 - safe, clean and efficient energy;
 - smart, environmentally friendly and integrated transportation;
 - climate measures, resource-efficiency and raw materials;
 - inclusive, innovative and secure society.

This is already the eighth framework programme. Taking into account the experience of the previous programming periods, it has been concluded that the programme “Horizon 2020” should be attractive to top researchers and innovative companies. This, in turn, requires the simplification of rules and procedures. The simplification of the programme “Horizon 2020” has three main objectives:

- to reduce the administrative costs of the participants;
- to speed up all the procedures relating to applications and grant agreements;
- reduce the rate of financial errors.

The programme includes a separate work programme for radiation and nuclear safety (Euratom Research and Training Programme), which serves as the basis for competitions to obtain funding. The most up-to-date version of the work programme is from 2018.

In addition to studies on nuclear safety, management of radioactive waste, and radiation protection, the 2018 work programme also supports studies related to the decommissioning of nuclear structures, innovation, and facilitation of education and trainings. Therefore, all projects similar to the Research and Innovation Action (RIA) must contribute at least 5% of their total budget to doctoral students, post-doctoral students, and interns.

In terms of activities, collaboration with third countries and international organisations engaged in radiation safety is welcomed. As is use of the project results in scientific publications.

Estonia may not be ready to lead some consortium and organise the preparation of the application, but it certainly has the ability to participate in joint projects.

- Environmental applied research is supported from the INTERREG programme. INTERREG programmes facilitate cooperation between Member States. One of the main goals is to reduce the impact of state borders in order to facilitate more equal economic, social and cultural development throughout the territory of the European Union. The programmes are divided into programmes of cross-border cooperation (Estonia-Latvia, Estonia-Russia, Central-Baltic Sea), cross-regional cooperation (INTERACT III, Interreg Europe, ESPON 2020, and URBACT III), and transnational cooperation (Baltic Sea region).

- The programme of the European Economic Area entails support by Liechtenstein, Iceland and Norway to reduce economic and social inequality in the European Economic Area and strengthen bilateral relations between donor and beneficiary countries. There are six support programmes in Estonia for the period 2014–2021: in the area of competitiveness, cyber security, environment and climate, healthcare, research, education, social protection, cultural heritage, and civil society.
- Structural funds. The European Union wishes to balance and harmonise the development of Member States in order to increase the overall competitiveness of the Union as a unified economic area on the world market. Therefore, structural funds are allocated to Member States by the European Regional Development Fund, European Social Fund and the Cohesion Fund.
- LIFE programme is a financial instrument of the European Commission that has been used to fund environmental projects throughout the EU for over 25 years. It is the only directly environment-oriented funding instrument which facilitates the development and implementation of the environmental policy in the Union. The LIFE programme contributes to sustainable development, achievement of goals and targets of the strategy “Europe 2020”, and relevant EU environmental and climate strategies and plans. Estonia is currently involved in the science project “LIFE Alchemia – Toward a smart & integral treatment of natural radioactivity in water provision services” which lasts up to the end of 2020. It is a cooperation project between Spain and Estonia where Estonian partners include the University of Tartu, AS Viimsi Vesi and the Tallinn University of Technology, while Spanish partners involve two research centre and one local government. The primary aim of the project is to develop a water treatment technology which results in a minimum amount of NORM waste. The project involves one pilot station of a water treatment plant on the Estonian side and three on the Spanish side. Studying adoption of technology also includes the conduct of cost-benefit analyses, assessment of social impacts, lifecycle analysis, as well as CO₂ savings. It is planned to develop a so-called guidance document under the project in order to share the knowledge acquired during the work to other countries as well.

7.3.3. Participant funding

In addition to funding options described above, it is necessary to also include the financial instruments meant for research and development activities in the budgets of the organisations engaged in the radioactive waste management. This ensures the continuity of knowledge and the development of the organisations.

8. Obligations and responsibility, performance indicators

8.1. Participants and their obligations

Pursuant to the Radiation Act, the radiation safety activities are organised by the Ministry of the Environment through the Environmental Inspectorate and the Environmental Board. The Ministry of the Environment develops radiation policies and legislative drafting. The Environmental Board reviews the applications of the radiation practice licences and the qualified expert licences, provides services ensuring radiation safety and advises the Environmental Inspectorate, which carries out monitoring and coordinates and controls the use of the environment and natural resources by applying the coercive measures of the state in the cases determined by law.

Additionally, several ministries and ministerial agencies have been involved in the radioactive waste management and related activities:

- The Ministry of the Interior is responsible for the preparation of emergency plans (including radiological emergency) managed by the authorities in its area of government. The governmental authorities within the area of government of the Ministry of the Interior – the Rescue Board, the Police and Border Guard Board, and in cases relating to nuclear material also the Estonian Internal Security Service – participate in liquidation of emergencies within their competence.
- The Ministry of Economic Affairs and Communications coordinates the development of the energy field and organises the intermediate and final storage of radioactive waste. There is the public limited company A.L.A.R.A which organises the management and storage of radioactive waste under the administrative field of the ministry.
- The Ministry of Finance organises the allocation of national funds and the Estonian Tax and Customs Board, which belongs in the administrative field of the Ministry of Finance, monitors the transport of goods across the border crossing points and manages the network of radiation monitors on the border crossing points.

8.2. Environmental Board

Pursuant to the statutes of the Environmental Board, it shall, inter alia:

- in the cases and to the extent provided by law issues environmental permits, permits for the use of natural resources, radiation practice licences, and other permits and licences within its competence;
- if necessary and within the limits of its competence, participates in environmental legislative drafting, also in the preparation of strategies, programmes, and plans thereof, and shall be responsible for their implementation to the extent established by legislation;
- in the cases provided by law, organises the collection, reporting, and forwarding of the environmental and natural resource utilisation data;
- in the cases provided by law, keeps databases related to its area of activity;
- in the cases provided by law, participates in the environmental impact assessment and the strategic environmental impact assessment;
- organises the monitoring of the radioactivity of air, soil, water, and food;
- organises the assessment of the doses arising from the radiation activities of the residents and the reference groups of the residents;
- conducts radiation laboratory analysis;
- ensures the operation of the system for early warning of transboundary radiation hazard pursuant to the procedures provided for in legislation and the terms and conditions of international

- conventions and agreements;
- acts as a contact point between the Euratom and the IAEA;
- acts as a national data centre in mediating information with the international data centre on the basis of the Comprehensive Nuclear-Test-Ban Treaty;
- organises public inclusion, environmental education and related awareness-raising;
- participates in international cooperation, prepares international projects and participates in them within its competence;
- informs the Ministry of the Interior, the Ministry of the Environment, and the Environmental Inspectorate and the public in the cases determined by legislation about accidents and emergency situations which could result in significant damage to the environment;
- participates in the preparation of emergency plans, their testing and resolving possible emergency situations;
- organises environmental communication and education activities.

8.3. Environmental Inspectorate

Pursuant to the statutes of the Environmental Inspectorate, it shall, inter alia:

- carries out national supervision and applies enforcement powers of a state on the grounds and to the extent provided by law;
- acts as an extrajudicial body conducting proceedings of misdemeanours in the cases provided by law;
- keeps record of financial resources of the state received through the inspectorate;
- organises environmental protection guarding service;
- participates in the liquidation of the consequences of an accident threatening the environment in cooperation with other governmental authorities and local governments to the extent and in the manner established by law;
- participates in the management of emergencies in cases and to the extent provided by the crisis management plan of the Ministry of the Environment;
- develops cooperation with natural and legal persons, the state and local government agencies, and the organisations of foreign countries as well as international organisations within the limits of its respective powers;
- resolves issues related to memoranda and statements in its area of activity;
- performs an obligation to disclose information and inform the general public on the basis of and to the extent provided by legislation;
- collects environmental monitoring data, analyses the effects of the legislation in its field of activity and makes suggestions for improvements, participates in the preparation and coordination of new draft legislation;
- participates in the preparation of national programmes, development plans, and financial plans in their field of activity;
- organises training on environmental supervision;
- performs other tasks that have been assigned to it by law.

8.4. A.L.A.R.A. AS

The establishment of A.L.A.R.A. AS in 1995 was driven by the need to manage and decontaminate the nuclear object of the former nuclear submarine training centre in Paldiski, which was taken over from the Russian Federation on

26. September 1995. On 1 November in the same year, also Tammiku radioactive waste storage facility

was taken over from Tallinna Eriautoaas, which contained radioactive waste had been generated in the industrial companies, research and medical institutions of Estonia since the beginning of the 1960s. The radiation practice of A.L.A.R.A. AS covers the decommissioning of the objects of Paldiski and Tammiku, as well as the transport, handling, and storing of radioactive waste.

A.L.A.R.A. AS is a 100% state-owned company that belongs under the administration of the Ministry of Economic Affairs and Communications with its main activities including the following:

- The management and decommissioning of the Paldiski former nuclear site and Tammiku radioactive waste storage facility;
- The management and storage of radioactive waste generated in Estonia;
- the development and implementation of radioactive waste management projects;
- the provision of services in the fields of radioactivity and radioactive contamination measurement and radioactive contamination deactivation;
- The development and implementation of plans for the conservation and safe dismantling of unnecessary and/or hazardous establishments of Paldiski former nuclear site.

A.L.A.R.A. AS manages liquid and solid and stores low and medium active short-term and long-term radioactive waste in the intermediate storage facility. High-level radioactive waste is not handled or stored. A.L.A.R.A. AS is responsible for the maintenance of Paldiski object and Tammiku radioactive waste storage facility (with its radioactive waste taken to the radioactive waste management centre in Paldiski for further management). In addition to the management centre, the main building of Paldiski object also accommodates a place of intermediate storage (used since 1997) and two sarcophagus containing reactor sections that have not been decommissioned.

8.5. Radiation practice licence holders

There are approximately 600 radiation practice licences in Estonia of which issued licences related to the practice of radioactive substance amount to approximately 10%. The rights and obligations of the licence holder have been established by the Radiation Act and regulations issued on the basis of this Act. Taking into account the legal framework related to radiation practice licences, the issuing authority, or the Environmental Board has the right and option to establish additional terms and conditions in the corresponding radiation practice licence.

8.6. Qualified radiation expert

The Radiation Act established the definition of the qualified radiation expert as follows: a qualified radiation expert is a person having the knowledge and training needed to carry out tests enabling doses to be assessed, and to give advice to individuals in order to ensure the effective protection of the individuals and the correct operation of protective equipment. The qualified radiation expert advises the holder of the radiation practice licence in ensuring radiation safety and protecting the health of radiation workers. Pursuant to the Radiation Act, only a legal person holding a corresponding licence may operate as a qualified radiation expert.

8.7. Division of responsibility

The current legislation does not provide for the exact division of responsibility in the management of radioactive waste and this may cause confusion. The obligations and responsibilities of the participants need to be specified. Additionally, several legislative acts have come into force in the European Union, which, in turn, place additional obligations on the Republic of Estonia and it is also necessary to specify the obligations in order to meet them. The development of relevant procedures and guidelines also

facilitates the process of ensuring radiation safety and safe management of radioactive waste. For example, in order to ensure the safety of orphan sources, guidelines have been provided in “Notification of radiation sources found”.

It is foreseen that in relation to radioactive waste management, there will be an additional burden in Estonia – preparations are made to establish a final storage site, as well as to characterise and clear radioactive waste. Taking into account the burden that has been placed on the Ministry of the Environment, the Environmental Board Radiation Safety Department, as well as A.L.A.R.A. AS, as well as the complexity of the issues related to the management of radioactive waste, it is expedient to train already experienced employees to have a higher number of specialists. This leads to the need for additional workers. For example, the Environmental Board Radiation Safety Department needs at least two specialists, who would be mostly engaged in topics related to the management of radioactive waste. To this end, however, the Radiation Safety Department needs more people, who would take over other duties of employment of the mentioned employees.

8.8. Performance indicators

Primary performance indicators and deadlines on implementing the action plan in chronological order are as follows:

Seq · no.	Performance indicator	Deadline , year
1.	The preparation of a project for the establishment of a final storage site for radioactive waste and a strategic environmental assessment has commenced.	2019
2.	The environmental assessment on the decommissioning of the reactor sections of the former Paldiski nuclear site.	2019
3.	Amendment of legislation on NORM residue and waste.	2020
4.	The safe inclusion of the Tammiku radioactive waste storage facility has been carried out in the depository – waste has been removed from the depository, it has been decontaminated, demolished, and cleared for general use.	2022
5.	The environmental studies necessary for the construction of the final storage site for radioactive waste have been completed.	2023
6.	The environmental studies necessary for the decommissioning of the reactor sections of the former Paldiski nuclear site.	2023
7.	Practice licences for the construction of the final storage site have been issued.	2027
8.	The complex of the final storage site has been completed, including also the facilities for the processing and packaging as well as temporary storage of waste.	2040
9.	Authorisation for use of the final storage site has been issued.	2040
10.	Practice licences for the decommissioning of the reactor sections has been issued.	2040
11.	The reactor sections have been liquidated, the generated radioactive waste has been processed and packaged and stored in the place of final storage. The existing intermediate storage site has been demolished as well.	2050

Table 6 sets out planned activities, the results along with responsible bodies, executors, time of implementation, and costs, including labour costs and the time profile of the distribution of costs up to the year 2050. The operational costs will be ensured from the funds of the state budget, if possible, and from the external funding sources, if necessary.

Table 6. Planned activities and results together with responsible bodies, executors, periods of implementation, and costs, including labour costs and the time profile of the distribution of costs (ME – Ministry of the Environment; MEAC – Ministry of Economic Affairs and Communications; MER – Ministry of Education and Research; MI – Ministry of the Interior; EB – Environmental Board; EI – Environmental Inspectorate; RB – Rescue Board; PBGB – Police and Border Guard Board; ETCB – Estonian Tax and Customs Board; UT – University of Tartu)

No.	Activities	Expected result	Primary responsible body	Executor(s)	The beginning and end of implementation	Cost (in thousands of euros) 2018–2021	Cost (in thousands of euros) 2022–2030	Cost (in thousands of euros) 2031–2040	Cost (in thousands of euros) 2041–2050	EA type
1.	The long-term safe radioactive waste management									
1.1	State capacity building as a result of specialisation and training of staff	Continuous training of the staff of the Environmental Board, Environmental Inspectorate, and A.L.A.R.A. AS	ME; EB	ME; EB; EI; A.L.A.R.A. AS	2020–2050	40	360	400	400	SB
1.2.	Analysis of legislative drafting and improvement of legislation	Adding new important requirements to legislation, incl. for the introduction of the storage site, the development of the requirements of the import/export and transit of radioactive waste, the requirements of the waste management responsibility and the environmental monitoring of management sites, minimum security requirements, specification of the requirements of physical protection, and the development of the principles for classifying radiation sources, as well as adding and amending provisions on NORM materials, residues, and waste	ME; MEAC	MEAC; A. L.A.R.A. AS; ME; EB;	2015–2050	0	0	0	0	SB
1.3.	Development of the waste management quality management system	Constant improvement of the management system takes place to ensure the safe management of radioactive waste.	A.L.A.R.A. AS	A.L.A.R.A. AS	2018–2050 (continuous)	22	70	91	105	SB
1.4.	Management of an intermediate storage site	The place of intermediate storage has been maintained and protected against unwanted attack, which may result in the contamination of the surrounding environment. The implementation of monitoring programmes and the preparation and implementation of action plans based on the monitoring results, if necessary.	MEAC	MEAC; A. L.A.R.A. AS	2018–2050 (continuous)	1,510	4,189	5,342	6,165	SB
1.5	Initiating a project and SEA procedure for the establishment of a final storage site for radioactive waste	The project and SEA have been initiated.	MF	MF, ME, MEAC, EB, A.L.A.R.A. AS	2019	10	0	0	0	SB

No.	Activities	Expected result	Primary responsible body	Executor(s)	The beginning and end of implementation	Cost (in thousands of euros) 2018–2021	Cost (in thousands of euros) 2022–2030	Cost (in thousands of euros) 2031–2040	Cost (in thousands of euros) 2041–2050	EA type
1.6.	Ordering environmental studies necessary for the establishment of a final storage site	Location selection studies are carried out, such as mapping of tectonic specificities, seismic analysis, analysis of the geological-lithological composition of earth, terrain analysis and geodetic studies, analysis of hydrogeological conditions, study on climate conditions, environmental study (flora, fauna, habitats of species, habits, etc.), study on the social situation (significant communities, purpose of use of the land, ownership of land, economic aspects, aspects of cultural history, etc.), road and infrastructure analysis, etc.	MF	MF, ME (EB), A.L.A.R.A. AS	2019–2023	1,658	1,006	0	0	RE / external funding
1.7.	Applying for licenses for the establishment of the place of final storage	The operating licenses have been issued for the design and construction of the place of final storage.	MEAC	MEAC; A. L.A.R.A. AS	2023–2027	0	596	0	0	SB
1.8.	The design and construction of the place of final storage	Based on the results of the EIA, the complex of the final storage site has been designed and constructed, including also the facilities for the processing and packaging as well as temporary storage of waste.	MEAC	MEAC; A. L.A.R.A. AS	2027–2040	0	11,167	27,857	0	RE / external funding
1.9.	Application for authorisation for use to introduce the place of final storage	Applying for and issuing an authorisation for use, implementation of the monitoring programme and adoption of the final storage facility.	MEAC	MEAC; A. L.A.R.A. AS	2039–2040	0	0	1,846	0	SB
1.10.	The management of the established place of final storage	The place of final storage has been maintained and protected against unwanted attack, which may result in the contamination of the surrounding environment. The implementation of monitoring programmes and the preparation and implementation of action plans based on the monitoring results, if necessary.	MEAC	MEAC; A. L.A.R.A. AS	2041–... (continuous)	0	0	0	3,630	SB
1.11	Initiating the EIA for the decommissioning of the reactor sections of the former Paldiski nuclear site	EIA has commenced.	ME	ME; MEAC; A.L.A.R.A. AS	2019	10	0	0	0	SB
1.12.	Ordering the environmental studies necessary for the decommissioning of the reactor sections of the former Paldiski	Studies such as engineering and technical study on the condition of the main building of the Paldiski site, radiological study of the reactor sections, study on the construction of the reactor sarcophagi and reactor sections, etc.	MEAC	MEAC, ME, A.L.A.R.A. AS	2019–2023	2,408	1,008	0	0	RE / external funding

	nuclear site									
1.13.	Applying for authorisations for use for decommissioning of the reactor sections	The authorisations for use have been issued to liquidate the reactor sections Preparation work for the demolition of the sections will take place during this as well, including the fact that the equipment necessary for the demolition have been purchased.	MEAC	MEAC; A. L.A.R.A. AS	2027–2040	0	3,523	8,746	0	SB

No.	Activities	Expected result	Primary responsible body	Executor(s)	The beginning and end of implementation	Cost (in thousands of euros) 2018–2021	Cost (in thousands of euros) 2022–2030	Cost (in thousands of euros) 2031–2040	Cost (in thousands of euros) 2041–2050	EA type
1.14.	Decommissioning of the reactor sections	The reactor sections have been liquidated, the generated radioactive waste has been processed and packaged and stored in the place of final storage. The existing intermediate storage site has been demolished as well.	MEAC	MEAC, A.L.A.R.A. AS	2040–2050	0	0	0	31,219	RE / external funding
1.15.	Safe inclusion of the Tammiku radioactive waste storage facility	Safe inclusion has been carried out in the depository — waste has been removed from the depository, it has been decontaminated, demolished, and cleared for general use.	MEAC	MEAC, A.L.A.R.A. AS	2006–2022	170	0	0	0	SB
1.16.	The preparation and implementation of the communication strategy on the establishment of the place of final storage and the decommissioning of the reactor sections	The strategy provides for the objectives of communication and identifies target groups. The strategy includes a plan for further activities. In future, communication will be based on a strategy that is reviewed on a regular basis and updated, if necessary.	MF, ME, MEAC	MF, ME, MEAC, EB, A.L.A.R.A. AS	2019–2040	70	297	300	0	SB
Total cost (in thousands of euros)						5,898	22,216	44,582	41,519	114,215
						114,215				
2.	Reducing the generation of radioactive waste									
2.1.	Development of the waste characterisation system for determining alpha and beta emitters	Acquisition of measuring devices enabling to determine alpha and beta radiation sources, preparation of measuring methods, and staff training.	MEAC	MEAC, A.L.A.R.A. AS	2019–2029	42	144	0	0	RE / external funding
2.2.	Development of the procedures necessary for the release of radioactive waste	The main procedures have been drawn up and approved.	MEAC	MEAC, A.L.A.R.A. AS	2016–2019	8	0	0	0	SB
2.3.	The development of the radioactive waste management equipment park and the purchasing of the packages necessary for storing waste	The park of the management equipment of radioactive waste is constantly developed, which enables to suitably manage waste for the final storage. Also, waste packaging necessary for final disposal has been purchased.	MEAC	MEAC, A.L.A.R.A. AS	2018–2050 (continuous)	48	1,500	1,500	2,000	SB

2.4.	Conditioning sealed radiation sources	The characterised waste has been properly processed and packaged to enable their subsequent storage in the place of intermediate or final storage.	MEAC	MEAC, A.L.A.R.A.	AS	2018–2050 (continuous)	16	56	72	86	SB
2.5.	Conditioning of soft compressible waste	The characterised waste has been properly processed and packaged to enable their subsequent storage in the place of intermediate or final storage.	MEAC	MEAC, A.L.A.R.A.	AS	2018–2050 (continuous)	12	51	64	76	SB

No.	Activities	Expected result	Primary responsible body	Executor(s)	The beginning and end of implementation	Cost (in thousands of euros) 2018–2021	Cost (in thousands of euros) 2022–2030	Cost (in thousands of euros) 2031–2040	Cost (in thousands of euros) 2041–2050	EA type
2.6.	Contaminated wood management	The characterised waste has been properly processed and packaged to enable their subsequent storage in the place of intermediate or final storage.	MEAC	MEAC; A. L.A.R.A. AS	2018–2050 (continuous)	8	24	31	0	SB
2.7.	The collection and melting of contaminated scrap metal	The collected contaminated metal is characterised and sent for melting. The concentrated waste that has been left over from melting has been properly processed and packaged to enable their subsequent storage in the place of intermediate or final storage.	MEAC/A. L.A.R.A. AS	A.L.A.R.A. AS	2019–2050 (continuous)	1,123	0	0	400	SB
2.8.	The development and operation of the management system of orphan sources	Safe collection of orphan sources and their constant handling have been ensured.	MEAC	MEAC, MI (RB), ME (EB), A.L.A.R.A AS	2018–2050 (continuous)	136	327	391	418	SB/EIC
Total cost (in thousands of euros)						1,393	2,102	2,058	2,980	
						8,533				
3.	Avoiding NORM residue and waste and ensuring safe management thereof									
3.1	Amendment of NORM-related legislation	Legislation has been amended in regard to the area of NORMs.	ME	ME, EEB	2019–2021	15	0	0	0	SB
3.2	Supporting the research and development of the field of new technology of NORM residue and/or waste.	The research and development of the field of new technology of NORM residue and/or waste has been supported.	ME	ME, companies	2015–2021	350	0	0	0	SB
3.5.	Conduct of a further study on the radioactivity of construction materials and development of specified monitoring conditions and requirements, if necessary.	The radioactivity of building materials has been studied further in order to prevent the use of materials with increased radioactivity and production of radioactive waste at a later time. Additional requirements have been established, if necessary.	ME/EB/MEAC	ME/EB/MEAC	2015–2021	50	0	0	0	SB
Total cost (in thousands of euros)						415	0	0	0	415
4.	Increasing the awareness of radioactive waste									

4.1	Timely preparation and submission of international reports	The reports are prepared and submitted in a timely manner	ME	ME; EB; MEAC; A.L.A.R.A. AS	2015–2050 (continuous)	0	0	0	0	SB
-----	--	---	----	-----------------------------	------------------------	---	---	---	---	----

No.	Activities	Expected result	Primary responsible body	Executor(s)	The beginning and end of implementation	Cost (in thousands of euros) 2018–2021	Cost (in thousands of euros) 2022–2030	Cost (in thousands of euros) 2031–2040	Cost (in thousands of euros) 2041–2050	EA type
4.2	Preparation of background materials and raising the awareness of the population	Disclosure of more thorough multilingual information on where and in which fields radioactive waste is generated, what are the options for its management depending on the types and characteristics of radioactive waste, what are the requirements for radioactive waste management, how such activities are regulated, what are the procedures of the choice/preparation of the final storage site, how the management of radioactive waste affects the surrounding residents, etc.	ME/MEAC/EB/A.L.A.R.A. AS	ME/MEAC/EB/A.L.A.R.A. AS	2018–2050 (continuous)	30	120	144	172	SB
4.3	Training of experts engaged in radioactive waste	The preparation of training materials and the organisation of further training sessions for the issuers and holders of the licence, as well as other experts. Separate attention should be paid on training the media in relation with the adoption of the decision of the place of storage	ME	MER; ME; EB; A.L.A.R.A. AS; research institutions, radiation practice licence holders, experts	2015–2050	10	15	20	20	SB
4.4	Training exercises for responding to radiation emergency situations related to radioactive waste	Responders are trained for being prepared to respond in an emergency situation in a consistent manner; these training sessions teach them to respond to situations related to radioactive waste	MI/ME	MI, ME, MEAC, RB, PBGB, EB, EI A.L.A.R.A. AS	2018–2050 (continuous)	15	50	50	50	SB
4.5	Development activities in the field of radioactive waste	Since such development work has not yet been done in a coordinated manner in Estonia, it is necessary to map the participants and their interests. Based on the vision of the participants, it is possible to map common interest and this serves as a good ground to plan further research or the preparation of projects, for example. Meetings should be held regularly. This would ensure constant development in the area of research and development and facilitate information exchange.	ME	ME; MER; EB; A.L.A.R.A. AS; research institutions, radiation practice licence holders, experts	2015–2050	60	60	60	60	SB
Total cost (in thousands of euros)						115	245	274	302	
						936				
						7,821	24,563	46,914	44,801	

Total cost of all activities (in thousands of euros)	124,099	
--	---------	--

9. Cost estimate

The cost estimate particularly highlights the higher costs for obtaining equipment or ordering service work. The assessment does not take into account the costs of waste handler A.L.A.R.A. in relation to daily workforce and outsourced materials and services with regard to the maintenance and decommissioning of the Paldiski and Tammiku objects, using the funds of budgetary grant in the amount of approximately 0.45 million euros per year. Additionally, A.L.A.R.A. AS provides the safe inclusion of orphan sources and preparedness assurance service, which is financed by the funds of budgetary support (preparedness) and the Environmental Investment Centre (safe inclusion) in the amount of approximately 35,000 euros in a year.

The higher costs of the characterisation, management, and final storage of waste are particularly related to the following works:

- the development of the waste characterisation system;
- the decommissioning of reactor sections and the management of generated waste;
- the establishment of the place of final storage;
- the melting of contaminated metal;
- the acquisition of a concrete knot to condition waste;
- the acquisition of concrete containers for final storage.

Additional cost leads to possible use of mobile machine press and hot cell (equipment rental) and the incineration of part of the waste service work.

Since the amount of waste generated during the decommissioning of the reactor section is of the same size as already existing amounts of waste, it is not possible to propose the best final solution for certain types of waste (soft compressible waste, contaminated wood). There are several alternatives available in the event of compressible waste:

- a) the rental of a mobile machine press and the subsequent concreting of the so-called tablets gained from the compression of 200-litre metal barrels;
- b) the subscription of waste incineration service and the subsequent concreting of combustion residues;
- c) waste volumes are not reduced, but the waste is packed in concrete containers to be concreted.

The waste stream coming from the reactor section is very important in choosing a suitable solution, since it provides a general overview of the volumes and types of waste, which are not significantly affected by the amounts of radioactive waste generated in Estonia in the future (this on the assumption that Estonia will not start to develop nuclear energy or develop any other waste producing industries).

In addition, the cost assessment presumes that a company engaged in the processing of niobium and tantalum ore will perform the safe inclusion of their NORM residue on their own, and that they will not be managed as waste or provided final storage in Estonia.

9.1. The development of the waste characterisation system

A majority of waste in the intermediate storage site located on the nuclear object of Paldiski originates from the waste generated during the management and decommissioning of Paldiski former nuclear site and Tammiku radioactive waste storage facility. This partially consists of conditioned waste packaging, however, unconditioned waste also forms a fairly large part of it – in particular, various contaminated construction residues generated during the cleaning and demolition of contaminated facilities and establishments – concrete fracture, but also wood, asbestos, and other waste, used polythene film, special

clothing, etc. Institutional (received from other institutions and organisations) waste of which a majority includes sealed sources represent a modest share in terms of volume, however, these account for a larger part of the stored activity. As a separate group, contaminated scrap metal taken over from metal management undertakings can be observed among institutional waste, characterised by large volume and small specific activity similarly to deactivation waste. There is mostly sufficient basic information (certificates of sources or other similar documents) available on sealed radiation sources, therefore, it can be said that these have been described in sufficient detail and the data can be used as input data in designing the final storage site of radioactive waste and in preparing safety assessments. However, there are still problems with existing decommissioning waste, which amount to at least 90% of the volume of existing waste, as well as the liquidation of Tammiku radioactive waste storage facility and the characterisation of (the so-called historic) waste to be generated in the future during the decommissioning of the reactor sections of Paldiski object. The situation is complicated by the fact that part of the information concerning the waste composition of radionuclides and their activity is missing. As it is often the case with historic waste, reliable describing data on the previous stages of the life cycle of waste is also missing here. The situation is made even more complicated by the fact that at times, the existing decommissioning waste includes already conditioned and previously prepared waste packaging, which is much more difficult to describe than waste that has not been completely conditioned. The analysis “Overview of the Characterisation Options of Radioactive Waste Located in Paldiski Intermediate Storage Facility”, which was carried out in 2012, found that given the limited resources and main radionuclides found in radioactive waste, it is justified to start with the development of the methodology of waste characterisation from, in situ, gamma spectrometry. As a result of the development of the waste management system, a gamma measuring system was purchased in 2014–2017, which enables to characterise – for example, determine the radionuclides and special activities (Bq/g) of waste – historic waste, which serves as a prerequisite for a later release, or disposal of the waste. Also, employees were trained to use the equipment and measuring methods were prepared and tested for the assessment of waste packaging with different configuration and of the activity of radioactive waste still not packaged, including the assessment of measurement uncertainty, with the aim of a subsequent clearance of waste or final storage. The total cost of the purchase of the characterisation system was 0.26 million euros. The gamma spectrometric characterisation of waste commenced in 2017.

If appropriate, in the next stage, it is planned to continue with the characterisation of alpha and beta emitters in the waste packaging (from 2019–2029), the cost of which is significantly higher than gamma spectrometry. Additionally, it must be noted that this field has experienced a significant technical development over the past years and some important changes in measuring systems and methodologies, including their cost, may come over the next few years. Therefore, the forecast of costs for the Characterisation of alpha and beta radiation sources is not reliable at the moment.

9.2. Reactor sections

Only the estimate prepared by Technicatome-BNFL over ten years ago (2001) is available on the cost estimate of the reactor sections. With regard to costs, this assessment discusses only such scenario in detail according to which the sections will be completely demolished, however, in the course of demolition, only essential cuttings are carried out and waste / waste packaging generated are relatively large. As at 2001, the cost of such a strategy was 14.1 million euros. The strategy recommended by the same working group and chosen by Estonia was to completely demolish the sections after they had been preserved for 50 years and to minimise the amounts of waste to be disposed, however, an additional cost estimate was not carried out with regard to this strategy.

The preliminary studies of the decommissioning of the reactor sections carried out from 2014–2015 revealed the approximate cost of the decommissioning work. The preliminary studies focused on the scenario of full demolition of the section selected in 2001 and the minimisation of waste.

The preliminary studies were fully financed from the European Union structural funds in a total amount of approximately 1.14 million euros (the studies also covered the establishment of the place of final storage). The preliminary studies form a basis for further activities.

- A plan shall be prepared in 2017–2025 along with a strategic environmental assessment with the aim to find the best location for the final storage site. The environmental impact will be assessed in parallel in order to find the best option for the demolition of the reactor sections.
- The practice licence for the design and construction of the final storage site shall be requested and obtained in 2025–2027.
- The design and construction of the place of final storage in 2027–2040. Based on the results of the plan and impact assessment, the complex of the final storage site has been designed and constructed, including also the facilities for the processing and packaging, as well as for the temporary storage of waste. In addition, existing radioactive waste have been processed and packaged and are ready for storage at the final storage site.
- Applying for and acquisition of authorisations of use for the demolition of the reactor sections in 2027–2040. Preparation work for the demolition of the sections will take place during this as well, including the fact that the equipment necessary for the demolition have been purchased.
- Applying for and issuing the authorisation for use, implementation of the monitoring programme and adoption of the final storage site in 2039–2040.
- Demolition of the reactor sections in 2040–2050. In addition to the demolition of the reactor sections, the radioactive waste generated will have been managed and packaged, and stored in the final storage site.

The preliminary studies estimated the cost of these works to amount to around 89,095 million euros, for which foreign resources and support from the state budget are planned to be used.

9.3. Melting of contaminated metal

The profitability of melting contaminated metal was discussed in “Methodology of the management of metal waste containing natural and artificial radionuclides”, issued in 2012, which revealed that melting is six times more cost-effective management method than long-term intermediate storage for waiting for radioactive decay and thereafter clearing the waste. The price calculation considered previous consultations with the handlers, waste pollution measurements, waste transport, melting in Swedish company Studsvik Nuclear AB, and the management of returned slag. The total cost of the melting of the existing contaminated metal is 2.51 million euros. The melting is scheduled for the period of 2018–2020.

9.4. Concrete mixer

Since concreting is the only used technical solution when conditioning waste (except for the management of contaminated wood and soft waste), then a semi- or fully automatic concrete mixer must be obtained in order to prepare waste for final storage. Such mixer ensures the stable quality of concrete and compared to hand mixing concrete method, also the levels of doses are slightly lower for the employees.

Modern semi- or fully automatic concrete mixer with performance of up to 12 m³/h costs 35,000–40,000 euros. Given the need for conditioning the waste that is returned after the melting of metal waste, it is necessary to acquire the concrete mixer in 2020. After the development of compliance indicators of packaging required for final storage (by the end of the EIA, or 2027), it is possible to start with the management of concreted waste concreted in the 200-litre barrel, concreted 200-litre barrels and high-level radiation sources for final storage, which is very much related to the concreting of waste.

9.5. Concrete containers

The assessment of the amount of concrete containers needed for final storage in the future was based on a conservative scenario, i.e. the service for compressing 200 l metal barrels by means of mobile machine press is not ordered and no other technology for minimising the volume of waste (incineration) will be used in addition to the melting of metal. Additionally, a new type of concrete containers storing 200 l concreted metal barrels and accommodating 4–6 barrels will not be acquired, instead, one barrel will be placed in one standard concrete container of 1 m³; sealed sources will be conditioned together with shielding containers (hot cell is not used); the entire concrete fracture will be concreted. The assessment was based only on existing waste and waste generated during the cleaning process of Tammiku object (approximately 28 m³ of contaminated concrete fracture will be generated from 2015–2022).

Given the above-mentioned circumstances, approximately 600 additional standard concrete containers of 1 m³ are needed to dispose existing waste (the preliminary studies carried out in 2014–2015 determined that the existing concrete container used for intermediate storage is also suitable for final storage). This is accompanied with 900–1,000 m³ unconditioned waste from the decommissioning of the reactor sections. Given that a majority of such waste can be cleared (metal through melting, etc.), the volume of waste to be generated will be reduced, however, later conditioning by means of concreting probably at least doubles the volume of disposed waste (1,800–2,000 m³) and about 2,000 standard containers of 1 m³ are further needed for their storage. The price of a single container is approximately 2,500 euros, meaning that approximately 5 million euros is needed to purchase the necessary amount of containers. It is reasonable to start obtaining an additional amount of containers by stages in order to avoid major one-off costs.

9.6. The establishment of the place of final storage

Considering radioactive waste at the intermediate storage site and control area of the Paldiski object, the waste generated during the decommissioning of the reactor sections and the waste generated in Estonian industries, medicine and research institutions up to the year 2040, approximately 3,000 m³ of low- and intermediate-level waste require final storage. The stages, time schedule, and cost of the establishment of the place of final storage has been described in point 9.2.

10. Financing scheme

Developed countries, which operate nuclear power stations, have special funds for the final storage of generated waste and the financing of the commissioning of the stations that collect funds as a part of the price of the electricity sold. In case of institutional radioactive waste, the polluter pays principle is generally recognised, meaning that the waste owner is financially responsible for the management and storage of this waste.

Estonia does not have any nuclear power plants and therefore, no waste management funds have been created. A total of 94.5 % of existing waste is of historic origin (Paldiski and Tammiku objects) and therefore, their safe inclusion is a national responsibility. In the future, their percentage of waste amounts to over 99%, since further waste streams originating from the holders (institutional waste) are small. In such a situation, it is not reasonable to establish a management fund, since the resources collected there are virtually non-existent and inadequate to solve the problems of waste.

Estonia has implemented the system of financial securities, ensuring that the resources needed for the safe inclusion of used radiation sources are available. Pursuant to the Radiation Act, upon applying for the radiation practice licence, the holder of the source shall be obliged to submit an assessment on the cost of safe inclusion of the source, which is prepared by the radioactive waste handler. Then, the Environmental Board considers the economic credibility of the applicant and, where applicable, the amount required to the safe inclusion of the source will be deposited in the bank. The estimation of the cost of the safe inclusion of the source made by the waste handler is based on a developed price methodology, which also takes into account the cost of taking waste to the place of final storage. This arrangement is sufficient to ensure that in case a company goes bankrupt, the state does not have to ensure safe inclusion from its resources. On the other hand, the proportion of such sources is small and this solution does not ensure the funding of final storage, but rather reduces public expenditure to a very small extent and ensures the equal treatment of the holders of radiation practice licence.

Paldiski and Tammiku objects are state-owned and belong under the area of government of the Ministry of Economic Affairs and Communications (Paldiski object) and the Ministry of the Environment (Tammiku object). For maintaining and decommissioning the objects, the Ministry of Economic Affairs and Communications orders services from radioactive waste handler A.L.A.R.A. In order to finance the service, the funds of budgetary grant are used in the amount of approximately 0.45 million euros in a year. Additionally, A.L.A.R.A. AS provides the safe inclusion of orphan sources and preparedness assurance service, which is financed by the funds of budgetary support (preparedness) and the Environmental Investment Centre (safe inclusion) in the amount of approximately 35,000 euros in a year. These funds are sufficient for the maintenance, decommissioning, and safe inclusion of orphan sources of the objects, however, these are insufficient to finance large-scale projects planned in the coming years, such as the decommissioning of the reactor sections and the establishment of the final storage site, the development of the characterisation and clearance systems of radioactive waste.

From additional public financing mechanisms, the Environmental Investment Centre (EIC) is the most appropriate establishment for the financing of waste management projects. The EIC was established as a foundation on the basis of the Act on the Funds Received from Environmental Use and amending Act in the area of government of the Ministry of Finance in May 2000. Their main activity is to finance environmental projects from the funds received from the Estonian environmental charges, the European Union Cohesion Fund (CF), the European Regional Development Fund (ERDF), and the European Social Fund (EFS) and to implement green investment scheme (CO₂ sales quotas and mediating subsidies).

One of the drawbacks of the EIC is definitely high-level competition in receiving the grant, since there are quite a lot of areas of concern in Estonia. Therefore, all issues should be addressed on the basis of

projects, and thus ensure their financing.

It is also possible to apply for support from the European Union Structural Funds to carry out projects. The period of 2007–2013 has ended and therefore, the funds of the period of 2014–2020 will be discussed further on. So far, the Structural Funds have supported projects to the extent of up to 85 % of their cost.

In addition to the EIC and the EU Structural Funds, third possible donor of waste management projects is the International Atomic Energy Agency (IAEA). Although the IAEA does not provide direct financial support for the activities, it offers expert assessments and organises expert missions in the country of location. The missions particularly represent an analysis of the situation and making recommendations on the basis of available information, as well as highlighting possible weaknesses. Therefore, the possible support from the IAEA is rather analytical than material.

11. Transparency policy or process

11.1. Involvement

The concept of involvement is based on the assumption that state-level decision-making processes and the drafting of legislation do not only centrally take place among politicians and officials, but more and more citizens and interest groups are also participating in the preparation of decisions and legislation. Involvement in the decision-making processes represents intensive work and it has several forms. Involvement acts as an umbrella, which covers notification, consultation, and participation. The first two are particularly important in terms of radioactive waste management:

- notification – one-sided relationship in which the state informs about its activities and decisions, but the feedback is not expected. At the same time, however, notification serves as a prerequisite to be able to speak about effective involvement and being informed. It is important that the issued information would be adequate, objective, reliable, relevant and easily understood;
- consultation – members of the community can express their opinion and make proposals.

There is a large number of legal acts in the field of the environment concerning involvement. One important way to ensure transparency policy is the process of the environmental impact assessment, which, in turn, serves as a part of the decision process that guides development. In addition to the process of the environmental impact assessment, the Radiation Act provides that in the case of certain radiation practices (including radioactive waste management), the provisions concerning open proceedings apply to the procedure for issue or amendment of radiation practice licences. Open procedure requires, inter alia, that prior to making a decision, the administrative authority must provide the participants in the proceedings an opportunity to express their opinion on the draft or application and submit appropriate objections, and to listen to them. The administrative authority shall determine a deadline for the submission of proposals and objections, which may not be less than two weeks from the beginning of the public display. The Radiation Act provides that the time and location of the public display of the application and draft of the radiation practice licence shall be communicated at least two weeks prior to the beginning of the public display in the official publication *Ametlikud Teadaanded*, in at least one national newspaper and on the website of the Environmental Board.

11.2. Environmental impact assessment and strategic environmental assessment

The aim of the environmental impact assessment (EIA) is to give decision makers information on the environmental impact of all real courses of action and to propose the most suitable option of solution. Environmental impact will be assessed if:

- Upon application for a development consent if the proposed activity, which is the basis for application for or amendment of the development consent, potentially results in significant environmental impact;
- upon application for amendment of a development consent if the proposed activity, which is the basis for application for or amendment of the development consent, potentially results in significant environmental impact;
- activities are proposed, which alone or in conjunction with other activities may potentially significantly affect a Natura 2000 site.

Pursuant to the Environmental Impact Assessment and Environmental Management System Act, the environmental impact is significant if it is likely to exceed the environmental capacity of the impact area, cause irreversible changes to the environment, or endanger human health and well-being, cultural heritage or property. An important part of the EIA process includes public discussions, which must be carried out

during the process of the assessment programme and the confirmation of the final report.

This means that prior to the approval of the decision maker, the developer must organise a public discussion and to this end, also all documents to be discussed must be made available to interested parties at an early stage. This enables interested parties to make proposals, which require to be also justified in the final environmental impact report if these are not taken into account. Information about the opportunities to participate in the public discussions and obtain access to documents shall be published in *Ametlikud Teadaanded*, however, the main interest groups are often also directly informed. Since many aspects of radioactive waste management have a significant impact on the environment, it is also necessary to pass the environmental impact assessment stage with regard to the application process of the radiation practice licences.

In addition to conventional environmental impact assessment, there is a separate strategic assessment available. The aim of the strategic environmental assessment (hereinafter “SEA”) is to take environmental considerations into account when preparing and adopting strategic documents. SEA facilitates high level environmental protection and the promotion of sustainable development. Taking into account environmental considerations must begin already at a time when the main trends of the field and regions are in the planning stage. SEA enables to prevent later problems by taking environmental issues into account already at a higher level of decision-making. In this case, the EIA serves as already a later specifying assessment at the project level.

SEA is organised during the preparation of strategic planning documents and plans, incl. during preparation of plans for the construction of the final storage site. Therefore, the general public can participate in the preparatory process of the national development plan for radiation safety or other activities through the SEA process. The organiser of the preparation of the strategic planning document, or the Ministry of the Environment initiates SEA and is responsible for it, as well as covers all the costs related to it.

11.3. Ensuring awareness

In order to ensure that public interests are better represented in decision-making, it is also important for the parties to be better informed about this issue. In order to improve the current situation, more attention must be paid to the development of various information materials and ensure better communication. Additionally, it is necessary to train people directly engaged in the media (both from the side of the operators and the media).

It is possible to find information about radioactive waste management on the websites of the Ministry of the Environment, the Environmental Board, and radioactive waste handler A.L.A.R.A AS. However, in all these cases, it is relatively static information, which typically includes a short description with references to the legislation. In general, the topic of radioactive waste management has been surprisingly little discussed in Estonia. However, taking into account the expectations of the public, there is a great need to demonstrate available radioactive waste management methods, and it is also important to show the feasibility and effectiveness of different technologies. In addition to theoretical background information, an overview of activities in Estonia in this regard should also be given. Therefore, the websites most certainly need to be upgraded and it is worth considering the use of social media. Such activities lead to additional time expenditure, however, if we base this, for example, on the website of tuumajaam.ee, which ensured a good overview of nuclear power station in Estonian during its short active operation, it could be observed that at least the younger generation developed a better attitude towards the issue. Various participants should also consider planning the upgrading of websites together and for example, divide the topics between themselves and then use mutual referencing on the websites.

The main objective should be raising the awareness of the Estonian population. It is also important to develop and implement a general communication strategy on radiation (including radioactive waste handlers) and more attention should also be paid to improving the awareness of school pupils. In doing so, it is possible to collaborate with various participants, for example, organisation of additional courses in cooperation with Teaduskool or Science Centre Ahhaa. Background materials introducing radiation and radioactive waste management would help people to understand the topic and reduce the fears of the population with regard to ionising radiation (including also the issue of radioactive waste). The preparation of background materials should consider as different target groups as possible – for example, school pupils, residents living near radioactive waste management facilities, etc. In addition to traditional printed material, it is also important to prepare background materials suitable for the web environment. The most important step to be taken first is to determine possible target groups and the most suitable ways to reach them. Only good information materials are not enough if there is no idea of their distribution. Here, the development of media plans for different participant could be helpful.

In recent years, little has been published to facilitate learning about ionising radiation. The first activity could be the organisation of an interesting exhibition in cooperation with the Ahhaa centre. One does not have to go far to obtain examples and ideas – it is possible to take a look at the visitor centre of Olkilouto Nuclear Power Plant. In order to ensure successful organisation of such event, the participants (the Ministry of the Environment, the Environmental Board, the radioactive waste handlers, etc.) could join their forces, and such endeavour could also ensure positive media coverage.

Based on the materials published in the media so far, it can be confidently said that there is also a need to train both journalists and potential producers-mediators of radiations news among the radiation protection staff. In order to stand out in today's world that is overloaded with information, the media staff must have as easy access to information as possible and an opportunity to consult with knowledgeable professionals. In this context, the communication strategy of competent authorities (the Ministry of the Environment, the Environmental Board) and radioactive waste handler A.L.A.R.A. AS is important, since it helps to ensure quick and objective exchange of information.

12. Agreements

The Republic of Estonia does not have any agreements with other Member States of the European Union and third parties in terms of radioactive waste management, including final storage. The possibility of sending metal contaminated with NORM materials to another Member State of the European Union for processing has been under discussion, since the quantities of metal are so small that the development of the opportunity to process them would be too expensive for Estonia. In the event of possibilities under discussion, concentrated waste is returned to Estonia after the materials have been processed in some other countries and their final management would take place in Estonia.

13. Steering document

13.1. Introduction

In 2011, Directive 2011/70/Euratom concerning reasonable and safe management of radioactive waste and spent fuel in the European Union came into force, which obliges each Member State to prepare and submit a national programme (activity plan) to the Council, describing the situation of waste management in the Member State and the measures taken from generation to final storage of waste. The action plan includes a description of the national radioactive waste policy, existing waste inventory, technical solutions for waste handling and (final) storage, time frame for the activities, resources, etc.

The general and more specific principles of radioactive waste management have been regulated both at the international level as well as in Estonian legislation. In order to learn and take part in the know-how on radioactive waste management developed at an international level and the international cooperation thereof, the Republic of Estonia has acceded to several international conventions and organisations. The accession to the International Atomic Energy Agency has been a very important step. According to the general principle, in most of the countries, the safe management of radioactive waste is the responsibility of a person who has generated the waste. However, this does not mean that the country itself does not have any obligations in ensuring safe radioactive waste management. In the Preamble of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the Contracting Parties reaffirm that the ultimate responsibility for ensuring the safety of spent fuel and radioactive waste management rests with the State. The State shall also ensure the control over the use of radioactive sources, including safe management of orphan sources.

The aim of this guidance document is to provide an overview of the national action plan of radioactive waste management and thus, to create a common broad understanding of the issues related to the topic of radioactive waste among the representatives of the interest groups.

The guidance document contains a summary of the following parts of the national action plan:

1. national policies;
2. stages and time schedules;
3. inventory;
4. plans and technical solutions from waste generation to final storage;
5. cost estimate;
6. financing scheme.

13.2. National policy

Basic principles

Radioactive waste management uses both the non-hazardous waste management practices (first two) and also specific procedures:

- concentration and isolation (used if the amounts of waste are large and activity average or great);
- dilution and separation (used for the low activity concentrations and small quantities);
- delay and radioactive decay.

During radioactive waste management it is very important to ensure the minimisation of the amounts of waste to be handled. To this end, it is necessary:

- to keep the amount of generated waste as low as it is possible when taking various factors into account;

- to keep the spread of radioactive contamination under control during radiation activities in order to reduce the possibility that as a result of contamination, the amount of radioactive waste that needs to be managed would increase;
- to optimise the opportunities for processing and recycling of components;
- to implement management technologies to minimise the amounts of waste.

Legislation

In Estonia, the issues of safe management of radioactive waste and emissions are addressed by the Radiation Act and it is complemented by the regulations of the Government of the Republic and the Minister of the Environment. Legislation provides that in case of a high-level radiation source, the applicant of the radiation practice licence shall be obliged to prefer a manufacturer during the acquisition of the radiation source, who agrees to add the requirement on returning the radiation source 15 years after the import of the radiation source to the sales agreement if the activity of the radiation source ten years after its import is higher than 10 MBq. Additionally, each applicant shall submit a plan on the safe inclusion of the radiation source after the termination of radiation source use, indicating the method according to which the safe inclusion of the source will take place in the future. In the event of moderate or high risk radiation practices, the plan shall be approved by a qualified radiation expert.

Transparency of decisions and involvement of the public

The concept of involvement is based on the assumption that state-level decision-making processes and the drafting of legislation do not only centrally take place among politicians and officials, but more and more citizens and interest groups are also participating in the preparation of decisions and legislation. The following are particularly important in terms of radioactive waste management:

1. notification – one-sided relationship in which the state informs about its activities and decisions, but the feedback is not expected. Notification serves as a prerequisite to be able to speak about effective involvement and being informed. It is important that the issued information would be adequate, objective, reliable, relevant and easily understood.
2. consultation – members of the community can express their opinion and make proposals.

There is a large number of legal acts in the field of the environment concerning also involvement. One important way to ensure transparency policy is the process of the environmental impact assessment (EIA), which, in turn, serves as a part of the decision process that guides development. The aim of the EIA is to give decision makers information on the environmental impact of all real courses of action and to propose the most suitable option of solution. An important part of the EIA process includes public discussions, which must be carried out during the process of the assessment programme and the confirmation of the final report. This means that prior to the approval of the decision maker, the developer must organise a public discussion and to this end, also all documents to be discussed must be previously made available to interested parties. This enables interested parties to make proposals, which require to be also justified in the final EIA report if these are not taken into account. Information about the opportunities to participate in the public discussions and obtain access to documents shall be published in *Ametlikud Teadaanded*, however, the main interest groups are often also directly informed. Since many aspects of radioactive waste management have a significant impact on the environment, it is also necessary to pass the EIA stage with regard to the application process of the radiation practice licences.

Agreements

Estonia has acceded to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which establishes that if the safety of management enables it, then radioactive waste should be taken to the final storage site in a country in which they have been generated.

The Republic of Estonia does not have any agreements with other Member States of the European Union and third parties in terms of radioactive waste management, including final storage. The possibility of sending contaminated metal to another Member State of the European Union for processing has been under discussion, since the quantities of metal are so small that the development of the opportunity to process them would be too expensive for Estonia. In the event of possibilities under discussion, concentrated waste is returned to Estonia after the materials have been processed in some other countries and their final management would take place in the Republic of Estonia.

Classification of waste

The legislation of Estonia establishes the classification and the requirements for the registration, management, and delivery of waste, as well as compliance indicators of radioactive waste. Types of radioactive waste are the following:

- cleared waste – waste generated during radiation practices with its activity, specific activity or surface-specific activity being smaller than the clearance levels established in the Radiation Act;
- NORM (Naturally Occurring Radioactive Material) waste – radioactive waste generated as a result of processing raw materials with naturally occurring radionuclides (Th-232 and U-238 and radionuclides which belong to their decay chain), the special activity of which is than the clearance levels specified in the Radiation Act;
- short-lived radioactive waste – radioactive waste containing less than 100-day half-life radionuclides, which decompose below the clearance levels established in the Radiation Act within five years;
- short-lived low- and intermediate-level radioactive waste – radioactive waste containing less than 30-year half-life beta and gamma emitters and a limited amount of long-lived alpha emitters (not more than 4,000 Bq/g in one waste packaging and not more than an average of 400 Bq/g per total amount of waste);
- long-lived low- and intermediate-level radioactive waste – radioactive waste containing greater than 30-year half-life radionuclides with their specific activity being higher than that of short-lived low- and intermediate-level radioactive waste and for which the amount of heat generated by the radioactive decay is less than 2 kW/m³;
- high-level radioactive waste – radioactive waste for which the amount of heat generated by the radioactive decay is greater than 2 kW/m³.

13.3. Stages and time schedules

In view of the character of the existing waste in Estonia, the decisions adopted so far, and also the economic state of the country, it is likely that the most time and capital consuming activities will be carried out from 2035–2045 (the decommissioning of the reactor sections and the establishment of the final storage site). Necessary preparations should be started already in the near future in order to divide the costs more evenly and take into account that part of the preparatory work is extremely time consuming (preliminary studies, the environmental impact assessment, the application of activity licences, the planning of the final storage site, etc.).

Major milestones in the radioactive waste management in Estonia are:

1. the characterisation of existing waste. The gamma measuring system for the characterisation of waste was purchased, measuring methods for waste packaging were prepared and staff training was carried out in 2014–2017. The gamma spectrometric characterisation of waste commenced in 2017. This is followed by the preparation of release procedures. It will be followed by the next stage of the development of the waste characterisation and clearance systems, which includes the purchase of measuring devices needed for

identifying the existence of alpha and beta emitters, the preparation of the methodology for measurements and waste clearance, and staff training. It is planned to be carried out from 2019–2029;

2. the decommissioning of reactor section and the establishment of the place of final storage. The preliminary studies for the decommissioning of the reactor sections and the construction of the final storage site took place in 2014–2015 and provided important input for assessing the environmental impact of the decommissioning of the reactor sections, preparing the plan for the construction of the final storage site and strategic environmental assessment. International experience shows that the impact assessment of such a sensitive topic may last up to ten years. The assessments are scheduled to be completed by 2027. The final storage site will be completed by 2040. Then, it is possible to start with the decommissioning of the reactor sections, since the waste generated during this process cannot be placed in the existing intermediate storage facility due to its activity and volume, and after the characterisation process, it should be managed and stored in the final storage site;
3. management of contaminated waste metal. Contaminated waste metal is planned to be melted over the period 2018–2020. The management of concentrated and secondary returnable waste generated during this process is planned to be completed by 2022. Given the decommissioning of the reactor sections and a relatively large amount of metal waste requiring melting, the next larger amount of metal must be probably melted from 2045–2050. Henceforth, melting takes place by one sea container (30 m^3) and considering the foreseeable generated metal waste streams in the future, the interval of melting is 60 years.

13.4. Inventory

The amount of existing radioactive waste in Estonia is estimated to be $2,127 \text{ m}^3$ as at 31 August 2018. The waste is located in the main building of the former nuclear submarine training centre in Paldiski, which is maintained by A.L.A.R.A. AS. Existing waste also cover the waste removed from Tammiku radioactive waste storage facility and transported to Paldiski object for further management from 2008–2011.

The conserved reactor sections in the main building have yet to be demolished. The amount of waste to be generated during the demolition thereof were estimated to be $900\text{--}1,000 \text{ m}^3$ in the study carried out in 2001, based on the 50-year strategy for the storage of sections. As at 31 December 2015, the estimated activity of the reactor sections was 351 TBq.

Existing waste packagings are located in the main building in the intermediate storage facility and control area. The waste is stored in metal and concrete containers (external dimensions $1.2 \times 1.2 \times 1.2 \text{ m}$), in full and half high sea containers, and in 200 l barrels.

While selecting suitable options for further waste management or intermediate storage / final storage, it is necessary to know the isotopes and their activity in the waste, meaning that the waste must be characterised. Since existing waste in Estonia is mainly of historic origin and existing information on waste is still insufficient, it can be said that the majority of existing waste still requires characterisation. Currently, approximately 11.7% of the volume of waste has been characterised. It mostly consists of sealed radiation sources received from other institutions and undertakings.

Since a large part of the activity of waste to be stored is mainly located in sealed sources, which has been transferred to A.L.A.R.A. AS along with detailed documentation, it can be estimated that together with the waste originating from the reactor sections, approximately 40% of the total activity of waste has been characterised. As at 31 December 2013, the activity of the characterised waste was approximately 730 TBq.

In particular, low- and very low-level waste need to be characterised, since its proportion of volume is high compared to other waste. These are particularly contaminated metal, contaminated concrete fracture, contaminated soft waste, and low-level concreted waste.

More detailed information about different types of waste and amounts thereof has been provided in Chapter 5.

The waste located in the object of Paldiski is low- and intermediate-level radioactive waste, which is usually stored in either a ground-level final storage site (established either on the ground or a few meters below the ground) or in an underground final storage site (usually a tunnel located up to 100 metres below the ground). The preliminary studies carried out in 2014–2015 identified the possible decommissioning scenarios of the reactor sections of the Paldiski object, the quantities and types of waste that require final storage, suitable types of final storage sites and the construction cost thereof.

Considering existing radioactive waste at the intermediate storage site and control area of the Paldiski object, the waste generated during the decommissioning of the reactor sections and the waste generated in Estonian industries, medicine and research institutions up to the year 2040, approximately 3,000 m³ of low- and intermediate-level waste require final storage. The preliminary studies revealed that the most suitable final storage solution for Estonia is a combination of underground shaft-type final storage sites and final storage sites established near the ground.

In the future, the flows of radioactive waste generated in Estonia are very small and generally described in great detail. Significant quantities originate from the decommissioning of the Tammiku storage facility, i.e. contaminated concrete fracture generated during decontamination of surfaces (around 28 m³). Predictable stream of metal waste received from other establishments and undertakings will be approximately 0.5 m³ of waste in a year in the future. It should be additionally mentioned the company engaged in the processing of niobium and tantalum ore has NORM waste which must undergo safe inclusion by 2024.

Short-lived nuclides, which are used in medical institutions, decompose below the clearance levels in a very quick manner (minutes, hours) and this process usually takes place already inside the patient, and then, these isotopes are channelled. Slightly longer-lived (days) nuclides are collected in a separate container and released after the decomposition of the nuclides below the clearance levels.

The volume of the sealed radiation sources that will be given to A.L.A.R.A. AS by other establishments and undertakings is 0.1 m³ in a year. The rest of the waste flows and their activity, including orphan sources, are insignificant.

No significant development is expected in terms of waste clearance until waste is characterised. This commenced in 2017. Previously characterised waste includes specifically the sealed sources of ⁹⁰Sr, ⁶⁰Co and ¹³⁷Cs, which have a high level of activity. Their radioactive decay below the clearance levels typically takes 100–1000 years and therefore, it is appropriate to take this waste to the place of final storage.

13.5. Plans and technical solutions from waste generation to final storage

When speaking about the technical solutions of waste management, it should be noted that the existing and future amounts of waste generated in Estonia compared to countries using nuclear energy are so small that the price of the majority of the new technological solutions per one unit of waste is significantly higher than in countries using nuclear energy. Additionally, the capacity of the devices is so high, that in most cases, it is possible to handle the waste amounts of Estonia within a week or a month. In such a situation, it is not practical to acquire new technology but, if possible, one should focus on the effective

implementation of existing technologies and, where appropriate, seek for particularly mobile (rentable) waste management solutions (super-press, hot cell). The selection of a suitable technology and its later implementation should by all means take into account that in addition to the waste in the waste packaging, the decommissioning of the reactor sections generate at least as much waste as there is now. This may change the use of some new technological solution in a more perspective way.

The most inexpensive, accessible, and suitable conditioning technology that applies to a majority of the existing and future amounts of waste generated in Estonia is concreting. In most cases, concreting is the final stage of waste management before storage. However, more work needs to be done before, starting with the characterisation of waste and ending with the preparation of compliance indicators of the waste packaging of the place of final storage.

In volume, a large part of the waste are partly or fully uncharacterised. Therefore, in 2014–2017, A.L.A.R.A AS purchased a gamma measuring system for the characterisation of waste, developed the necessary measuring methods for waste packaging and provided staff training. The gamma spectrometric characterisation commenced in 2017 and its aim is later clearance or final storage of waste. This is followed by the preparation of release procedures.

From the selection of mobile rentable management solutions, Estonia is particularly interested in machine press and a special shielded chamber, or hot cell. Another option is to take waste to a foreign country to be handled (incinerator, super-press) and bring back already handled waste and carry out conditioning (concreting) in Estonia. Prior to final decision, it is needed to carry out an economic analysis – this, however, requires the preparation of compliance indicators of the waste packaging of the place of final storage.

Table 7 shows the possible solutions for waste management, including intermediate storage and clearance or final storage, of all waste (excl. NORM waste) generated or to be generated in Estonia by type. NORM waste are not reflected in the Table since it requires a case-by-case approach, as they have different chemical and physical characteristics depending on their origin.

Table 7. The possible solutions for waste management, including intermediate storage and clearance or final storage, of waste generated or to be generated in Estonia (excl. NORM waste) by type

Type of waste	Waste packaging	Waste origin	Type of waste	The need for characterisation	Possibility of clearance	Suitable treatment method	Alternative treatment method	Storage method
Low- and medium activity <30 y	Reactor section No. 1	Paldiski	concreted	yes	no	dismantling and packaging into standard size (1.2 m × 1.2 m × 1.2 m) containers. The reactor vessel goes fully into a special container.	dismantling and packaging large special containers	final storage
	Reactor section No. 2	Paldiski	concreted	yes	no	dismantling and packaging into standard size (1.2 m × 1.2 m × 1.2 m) containers. The reactor vessel goes fully into a special container.	dismantling and packaging large special containers	final storage
	Metal containers	Paldiski	concreted	yes	yes/no	handled	-	intermediate storage/ final storage
	Concrete containers	Paldiski	concreted	yes	yes/no	handled	-	intermediate storage/ final storage
		Tammiku	concreted	yes	yes/no	handled	-	intermediate storage/ final storage
		Estonia	sealed sources	no	yes/no	dismantling, placement into a collection vessel used as special shielding and concreting	concreting	intermediate storage/ final storage
	Sea containers	Paldiski	metal	yes	yes	melting	concreting	final storage

Type of waste	Waste packaging	Waste origin	Type of waste	The need for characterisation	Possibility of clearance	Suitable treatment method	Alternative treatment method	Storage method
			concrete fracture	yes	yes/no	concreting	-	intermediate storage/ final storage
	200 l barrel	Paldiski and Tammiku	compressible	yes	yes/no	pressing and concreting	concreting	intermediate storage/ final storage
			wood	yes	yes/no	incineration	waiting for the fall of the activity below the clearance levels	intermediate storage/ final storage
			metal	yes	yes/no	melting	concreting	intermediate storage/ final storage
			concreted	yes	yes/no	handled	-	intermediate storage/ final storage
			stainless steel scrap, dust	yes	yes/no	concreting	-	intermediate storage/final storage
	Liquid waste	Tammiku	organic liquid	yes	yes	incineration	chemical treatment	-
	Bulky waste	Paldiski	metal	yes	yes/no	cutting-up	-	intermediate storage/final storage
	Waste generated in medical institutions	Estonia	chemicals	no	yes	waiting for the fall of the activity below clearance levels	-	-

Low and intermediate level waste >30 y	Reactor section No. 1	Paldiski	concreted	yes	no	dismantling and packaging into standard size (1.2 m × 1.2 m × 1.2 m) containers. The reactor vessel	dismantling and packaging large special containers	final storage
--	-----------------------	----------	-----------	-----	----	---	--	---------------

Type of waste	Waste packaging	Waste origin	Type of waste	The need for characterisation	Possibility of clearance	Suitable treatment method	Alternative treatment method	Storage method
						goes fully into a special container		
	Reactor section No. 2	Paldiski	concreted	yes	no	dismantling and packaging into standard size (1. 2 m × 1.2 m × 1.2 m) containers. Whole reactor vessel into a special container	dismantling and packaging large special containers	final storage
	200 l barrel	Paldiski and Tammiku	alpha-contaminated ompressible	yes	no	pressing and concreting	concreting	final storage
			alpha-contaminated metal	yes	no	melting	concreting	final storage
			alpha-contaminated wood	yes	no	incineration	-	final storage
			²²⁶ Ra indicators	yes	no	intermediate storage in a hermetic container until the development of suitable packaging	-	final storage

13.6. Cost estimate

The cost estimate particularly highlights the higher known costs for obtaining equipment or ordering services. Higher costs for the characterisation, management and final storage of waste are:

- development of the waste characterisation system – acquisition of measuring devices enabling to determine alpha and beta radiation sources, preparation of measuring methods and staff training – up to 0.8 million euros from 2019–2029;
- the decommissioning of reactor sections and the management of generated waste amounting to a total of 89.095 million euros:
 - a plan shall be prepared in 2018–2027 along with a strategic environmental assessment with the aim to find the best location for the final storage site. The environmental impact will be assessed in parallel in order to find the best option for the demolition of the reactor sections. Costs amount to a total of 5.584 million euros.
 - The practice licence for the design and construction of the final storage site shall be requested and obtained in 2025–2027, the estimated cost is 0.396 million euros.
 - The design and construction of the place of final storage in 2027–2040 with an estimated cost of 38.384 million euros. Based on the results of the impact assessment, the complex of the final storage site has been designed and constructed, including also the facilities for the processing and packaging as well as temporary storage of waste. In addition, existing radioactive waste have been processed and packaged and are ready for storage at the final storage site.
 - Applying for and acquisition of authorisations of use for the demolition of the reactor sections in 2027–2040 with an estimated cost of 11.629 million euros. Preparation work for the demolition of the sections will take place during this as well, and the equipment necessary for the demolition have been purchased.
 - Applying for and issuing the authorisation for use, implementation of the monitoring programme and adoption of the final storage site in 2039–2040 with a cost of 1.716 million euros.
 - Demolition of the reactor sections in 2040–2050, which will cost 30.739 million euros. In addition to the demolition of the reactor sections, the radioactive waste generated will have been managed and packaged, and stored in the final storage site.
 - The communication strategy for the construction of the final storage site and the removal of the reactor sections is prepared and implemented from 2017–2040, establishing the goals of communication and identifying target groups. The activity is necessary since the area of ionising radiation is often a difficult to comprehend and sensitive topic for regular citizens. Costs amount to a total of 0.647 million euros;
- the establishment of the place of final storage – see previous point;
- the melting of contaminated metal – 2.51 million euros in 2019;
- the acquisition of a concrete knot to condition waste – 40,000 euros in 2020;
- The purchase of concrete containers for the final storage of waste – 5 million euros from 2018–2040.

13.7. Financing scheme

Developed countries, which operate nuclear power stations, have special funds for the final storage of generated waste and the financing of the commissioning of the stations that collect funds as a part of the price of the electricity sold. In case of institutional radioactive waste, the polluter pays principle is generally recognised, meaning that the waste owner is financially responsible for the management and storage of this waste.

Estonia is in a situation in which there are no nuclear power plants and no waste management funds have been established. Additionally, a total of 94.5% of existing waste is of historic origin (objects of Paldiski and Tammiku) and the proportion in the future waste amount increases over 99%, since waste streams that will arise from the source holders (institutional waste) are small. It is not reasonable to establish a management fund in such a situation as the resources accumulated are insufficient for resolving the problems concerning waste.

Estonia has implemented the system of financial securities, ensuring that the resources needed for the safe inclusion of used radiation sources are available. Pursuant to section 98 of the Radiation Act, upon applying for the radiation practice licence, the holder of the source shall be obliged to submit an assessment on the safe inclusion of the source, which is prepared by the radioactive waste handler. Then, the Environmental Board considers the economic credibility of the applicant and, where applicable, the amount required to the safe inclusion of the source will be deposited in the bank. The estimation of the cost of the safe inclusion of the source prepared by A.L.A.R.A. AS is based on a price methodology, which also takes into account the cost of taking waste to the place of final storage. This arrangement entered into force on 10 November 2011 and is sufficient to ensure that in case a company goes bankrupt, the state does not have to ensure safe inclusion from its resources. On the other hand, the proportion of such sources is small and this solution does not ensure the funding of final storage, but rather reduces public expenditure to a very small extent and ensures the equal treatment of the holders of radiation practice licence.

Paldiski and Tammiku objects are state-owned and belong under the area of government of the Ministry of Economic Affairs and Communications (Paldiski object) and the Ministry of the Environment (Tammiku object). The Ministry of Economic Affairs and Communications orders services from A.L.A.R.A. AS to maintain and decommission the objects. In order to finance the service, the funds of budgetary grant are used in the amount of approximately 0.45 million euros in a year. Additionally, A.L.A.R.A. AS provides the safe inclusion of orphan sources and preparedness assurance service, which is financed by the funds of budgetary support (preparedness) and the EIC (safe inclusion) in the amount of approximately

35,000 euros in a year. These funds are sufficient for the maintenance, decommissioning, and safe inclusion of orphan sources of the objects, however, these are insufficient to finance large-scale projects planned in the coming years, such as the decommissioning of the reactor sections and the establishment of the final storage site, the development of the characterisation and clearance systems of radioactive waste.

From additional public funding mechanisms, the EIC (www.kik.ee) is the most appropriate establishment for the financing of waste management projects. The EIC was established as a foundation on the basis of the Act on the Funds Received from Environmental Use and amending Act in the area of government of the Ministry of Finance in May 2000. Its main activity is to finance various environmental projects from the funds received from the Estonian environmental charges, the European Union Cohesion Fund (CF), the European Regional Development Fund (ERDF), and the European Social Fund (EFS) and to implement green investment scheme (CO₂ sales quotas and mediating subsidies).

One of the drawbacks of the EIC is definitely high-level competition in receiving the grant, since there are quite a lot of environmental areas of concern in Estonia. Therefore, all issues should be addressed on a project basis, and thus ensure their financing.

It is also possible to apply for support from the European Union Structural Funds to carry out projects. So far, the Structural Funds have supported projects to the extent of up to 85%.

In addition to the EIC and the EU Structural Funds, another possible donor of waste management projects is the International Atomic Energy Agency (IAEA). Although the IAEA does not provide direct financial support, it offers expert assessments and organises expert missions in the country of location. The missions particularly represent an analysis of the situation and making decisions on the basis of available information, as well as highlighting possible weaknesses. Therefore, the possible support of the IAEA is rather analytical than material.

14. References

- Radiation Act (RT I 2018, RT I, 26.06.2018, 9);
- Clearance Levels of Radioactive Substances Generated during Radiation Activity or Objects Contaminated by Radioactive Substances and the Conditions of Their Clearance, Recycling and Reuse, Regulation No. 43 of the Minister of the Environment (RT I, 29.10.2016, 1);
- The classification and the requirements for the registration, management, and delivery of radioactive waste, as well as compliance indicators of radioactive waste packaging, Regulation No. 34 of the Minister of the Environment (RT I, 05.10.2016, 6);
- Bases for calculation of exemption levels of radionuclides and the exemption levels below which no radiation practice licence is required, Regulation No. 96 of the Government (RT I, 20.09.2016, 8);
- Waste Act (RT I 2004, 9, 52);
- Water Act (RT I 1994, 40, 655);
- Draft of the National Radiation Safety Development Plan 2018–2027;
- Estonian National Development Plan of the Energy Sector until 2030;
- IAEA Safety Series No. 111-G-1.1, *Classification of Radioactive Waste*, 1994;
- IAEA Safety Guide RS-G-1.7, *Application of the Concepts of Exclusion, Exemption and Clearance*, 2004;
- IAEA Safety Reports Series No 44, *Derivation of Activity Concentration Values for Exclusion, Exemption and Clearance*, 2005;
- IAEA Safety Fundamentals, No 111-F, *The principles of radioactive waste management*, 1995;
- IAEA Safety Series, No 111-S-1, *Establishing a national system for radioactive waste management*, 1995;
- IAEA Safety Series 103, *International Basic Safety Standards for Protection Against Ionising Radiation and for the Safety of Radiation Sources*, 2007;
- IAEA TS-R-1, *Regulations of Safe Transport of Radioactive Material*, 2005;
- IAEA TECDOC 1145, *Handling, conditioning and storage of spent sealed radioactive sources*, 2000;
- IAEA-TECDOC-1260, *Procedures and techniques for closure of near surface disposal facilities for radioactive waste*, 2011;
- Contract B7-5350/99/6141/MAR/C2, *Evaluation of Management Routs for the Paldiski Sarcophagi, Final Report*, 2001;
- The reports of Estonia submitted at the reporting meetings of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management in 2015 and 2018;
- Radioactive waste database prepared on the basis of contract for services No. 18-19/276 of 4 November 2009, 2009;
- The assessment of radioactive waste streams prepared on the basis of contract of employment No. 4-11/141 of 1 June 2010, 2010;
- The management options of materials containing natural radionuclides and being contaminated with natural radionuclides prepared on the basis of contract of employment No. 4-1.2/231 , 2010;
- An overview of the radioactive waste management technologies and the economics of their implementation, Eesti Energia, 2010;
- Guidance material of the European Commission “*Guidelines for the establishment and notification of National Programmes under the Council Directive 2011/70/Euratom of 19 July 2011 on the responsible and safe management of spent fuel and radioactive waste*”, 2013;
- European 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;
- Council Directive 2013/59/Euratom, 5 December 2013, laying down basic safety standards for

- protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom;
- European Council Directive 2014/87/Euratom, 8 July 2014, amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations;
 - Final report of the preliminary studies on the decommissioning the reactor sections of the Paldiski nuclear site at the former military area and the establishment of a final storage site for radioactive waste, A.L.A.R.A AS, 2015.
 - Report of project No. 9888 of the Environmental Investment Centre: Study on the preparation of the adoption of the requirements regarding natural radioactive materials (NORM) set out in Directive 2013/59/Euratom into national legislation, Madis Kiisk, Taavi Vaasma, 2017.
 - Analysis of the management solutions of materials containing naturally occurring radionuclides (NORMs) generated in Estonia, Madis Kiisk, Taavi Vaasma, Maria Leier, 2018.
 - Project No. 11759 of the EIC, Development of a methodology for assessment of health risks arising from the content of radionuclides in drinking water and studies on the feasibility of NORM-free water treatment, Maria Leier, Siiri Suursoo, Madis Kiisk, 2017.

Annex 1. General principles of radioactive waste management

Rules for the management of radioactive waste

General principles for radioactive waste management that have been established by the IAEA are the following:

- radioactive waste is managed in a manner that ensures the protection of human health and the environment to an acceptable level;
- radioactive waste is managed in a manner, which ensures that potential cross-border effects are taken into account with regard to human health and the environment of the neighbouring countries;
- radioactive waste is managed in a manner that does not cause an excessive burden on future generations, and with predictable effects on human health that would not be greater than today's acceptable level;
- radioactive waste is handled pursuant to the provisions of the legislation. Legislation must, inter alia, ensure the existence of an independent regulatory authority and a clear division of areas of responsibility;
- the generation volumes of radioactive waste are kept as low as possible;
- while generating and managing radioactive waste, any interdependence between the generation of radioactive waste and the stages of its management should be taken into account;
- the safety of the waste management facility is ensured throughout their lifetime.

These principles are, one way or another, also reflected in the Estonian legislation. In Estonia, the principles for the radioactive waste management and the obligations related to management are established in the Radiation Act. Among other things, it provides that the radiation practice licence holder must guarantee the safe management of radioactive waste and emissions generated during radiation practice and ensure that:

- radioactive waste is managed in such a way that the estimated harmful effect on future generations would not be higher than permitted by the Radiation Act or legislation provided on the basis of this Act;
- the activity and amounts of the generated radioactive waste and emissions would be as small as possible;
- biological, chemical, and other dangers, as well as interaction between the stages of radioactive waste generation and its management would have taken into account;
- the transfer of radioactive waste to the radioactive waste management site would take place no later than within five years after their generation;
- the holder of the radiation practice licence, which has been issued for radioactive waste management, ensures that the safety of radioactive waste management site would be guaranteed throughout the period of use;
- the generator of radioactive waste must cover all costs related to the radioactive waste management.

Radioactive waste management techniques

Based on the recommendation of the IAEA, radioactive waste is managed by using methods known from the practice of non-hazardous waste management, such as concentration and isolation, as well as dilution and separation, and unique procedures, such as delay and radioactive decay.

The selection of procedures is particularly based on the amount of radioactive waste and its special activity. In the event of radioactive waste in smaller amounts and with higher special activity, it is often preferred to use concentration and isolation. In the event of larger amounts and smaller special activity, particularly dilution and dispersion are considered. However, in addition to above-mentioned general principles, radiation-related legislation also includes more specific provisions:

- different type of radioactive waste with different physio-chemical properties must be separately collected and stored;
- untreated radioactive waste must be collected and stored separately from conditioned waste;
- radioactive waste must be collected and stored separately from caustic, explosive and inflammable substances;
- biological radioactive waste must be collected and stored in a frozen state, placed in an appropriate solvent, or processed in some other appropriate manner;
- used sealed radiation sources must be collected and stored either in their own or any other suitable radiation shielding shell;
- sharp radioactive waste must be collected and stored separately, preferably in a metal container, which has been labelled as “Sharp radioactive objects”;
- unconditioned wet solid radioactive waste must be collected and stored in at least a double storage container in order to prevent the leakage of radioactively contaminated liquids;
- unconditioned liquid radioactive waste must be collected and stored in a container, which is surrounded by an absorbent material in an amount that ensures twice as high binding of the amount of liquid than that of the liquid in the container. The container may be placed inside of another container or reinforce it in some other appropriate manner.

When speaking about radioactive waste management, it is very important in the first stage to ensure the minimisation of the amounts of waste to be handled. In terms of the minimisation of waste streams, the principles of waste management can be formulated as follows:

- to keep the amount of generated waste as low as it is possible when taking various factors into account;
- to keep the spread of radioactive contamination under control during radiation activities in order to reduce the possibility that as a result of contamination, the amount of radioactive waste that needs to be managed would increase;
- to optimise the opportunities for processing and recycling of components;
- the implementation of management techniques to minimise the amounts of waste.

The aim of minimising the waste amount is to decrease the amount of generated and managed radioactive waste and reduce the spread of pollution. The objective of the overall activity is to ensure that the amount of managed radioactive waste (including waste to be taken to the place of final storage) would be minimum. The main activities related to the minimising of waste may be divided into four subgroups:

- reducing sources of radioactive waste;
- preventing/controlling the pollution of materials;
- processing and recycling of materials;
- optimising the radioactive waste management.

It possible to use various tools and techniques to control the generation of radioactive waste. In Estonia, the Radiation Act provides the principles of radiation safety based on which the planned activities must first be justified and proven that this is the best possible solution when considering economic, social, and other aspects. This means that if the radiation practice licence applicant or licence issuer finds that the planned radiation activity still has a better alternative, the radiation practice licence will not be issued for this activity. The implementation of the principle keeps the amounts of generated radioactive waste as small as it is possible when considering various aspects.

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management establishes that if the safety of management enables it, then radioactive waste should be taken to the final storage site in a country in which they have been generated. On the other hand, international radiation practice contributes to returning the used radiation sources to the manufacturer.

In general, it is possible to use several options to ensure the reduction of the amount of radioactive waste – starting with work culture and ending with different technological solutions. In the context of the reduction of the amount of waste, it is important to ensure clearly established division of responsibility and work tasks. This applies both to such an activity in the course of which radioactive waste is generated, as well as the activities of the waste handlers. Important parts of work culture are, inter alia, work procedures, which form a part of the quality system of radiation safety, the development of used techniques, the renewal of technologies, etc. Also, staff training and their awareness-building should not be underestimated. It is possible to decrease the waste to be generated by cleaning tools and materials that have been contaminated in the course of various activities. The selection of methods should always also consider economic, social, and environmental aspects, namely to assess the economic viability of the activities, taking into account the impact on humans and the environment. The control mechanisms can be divided into administrative and technical.

Administrative control mechanisms:

- continuous renewal of technical data and conversation measures;
- the organisational structure to ensure a clear division of responsibility;
- regular inventory of radiation sources and radioactive waste;
- the preparation of work processes also considers activities during which radioactive contamination may occur;
- the continuous development of operational procedures and the exchange of experiences;
- the regular training of radioactive waste handlers and the exchange of experience.

Technical factors, which may contribute to the minimisation or prevention of the generation of radioactive waste:

- the design of the establishment;
- the choice of materials;
- the use of the establishment and systems;
- cleanliness and the clearance of contamination.

In order to gain an overview of the implementation of administrative and technical factors, the radiation practice licence applicant must submit an overview of ensuring radiation safety, radiation work rules, and the description of the quality system of radiation safety in addition to the application materials.

Once radioactive waste has been generated, it is necessary to minimise the volume of handled waste in order to reduce the cost of their management. Naturally, the principle of optimisation should be monitored at the reduction of volumes, in other words, it is necessary to also take into account the cost of processes and to find the most optimal solution. Different countries use different methods for reducing the volumes of radioactive waste. These are mainly based on mechanical, physical, chemical, biological or thermal processes and the most suitable one is selected in a way that takes into account the properties of the generated radioactive waste and their volumes.

One aspect to be always considered is that it is possible to regulate and control the generated amounts of waste by means of recovery of materials. It is also important to separate different types of waste in order to reduce the amounts of generated waste and facilitate their management. The management of mixed waste is generally much more expensive and complicated than the management of separated waste.

Types of radioactive waste

Pursuant to international practices and also the Estonian legislation, radioactive waste is classified according to the following properties of the radionuclides contained therein:

- activity and specific activity;
- half-life;
- type of radiation;
- amount of heat arising from the radioactive decay.

Estonia has established the following types of radioactive waste:

- cleared waste – waste generated during radiation practices with its activity, specific activity or surface-specific activity being smaller than the clearance levels established in the Radiation Act;
- NORM (Naturally Occurring Radioactive Material) waste – radioactive waste generated as a result of processing raw materials with naturally occurring radionuclides (Th-232 and U-238 and radionuclides which belong to their decay chain), the specific activity of which is than the clearance levels specified in the Radiation Act;
- short-lived radioactive waste – radioactive waste containing less than 100-day half-life radionuclides, which decompose below the clearance levels established in the Radiation Act within five years;
- short-lived low- and intermediate-level radioactive waste – radioactive waste containing less than 30-year half-life beta and gamma emitters and a limited amount of long-lived alpha emitters (not more than 4,000 Bq/g in one waste packaging and not more than an average of 400 Bq/g per total amount of waste);
- long-lived low- and intermediate-level radioactive waste – radioactive waste containing greater than 30-year half-life radionuclides with their specific activity being higher than that of short-lived low- and intermediate-level radioactive waste and for which the amount of heat generated by the radioactive decay is less than 2 kW/m³;
- high-level radioactive waste – radioactive waste for which the amount of heat generated by the radioactive decay is greater than 2 kW/m³.

Types of radioactive waste generated in Estonia from their generation to final storage or clearance have been provided in the following figures: Figure 1.1 sets out the movement of short-lived low- and intermediate-level waste, Figure 1.2 sets out the movement of long-lived low- and intermediate-level waste, and Figure 1.3 sets out the movement of NORM residue from its generation to its clearance or storage as NORM waste.

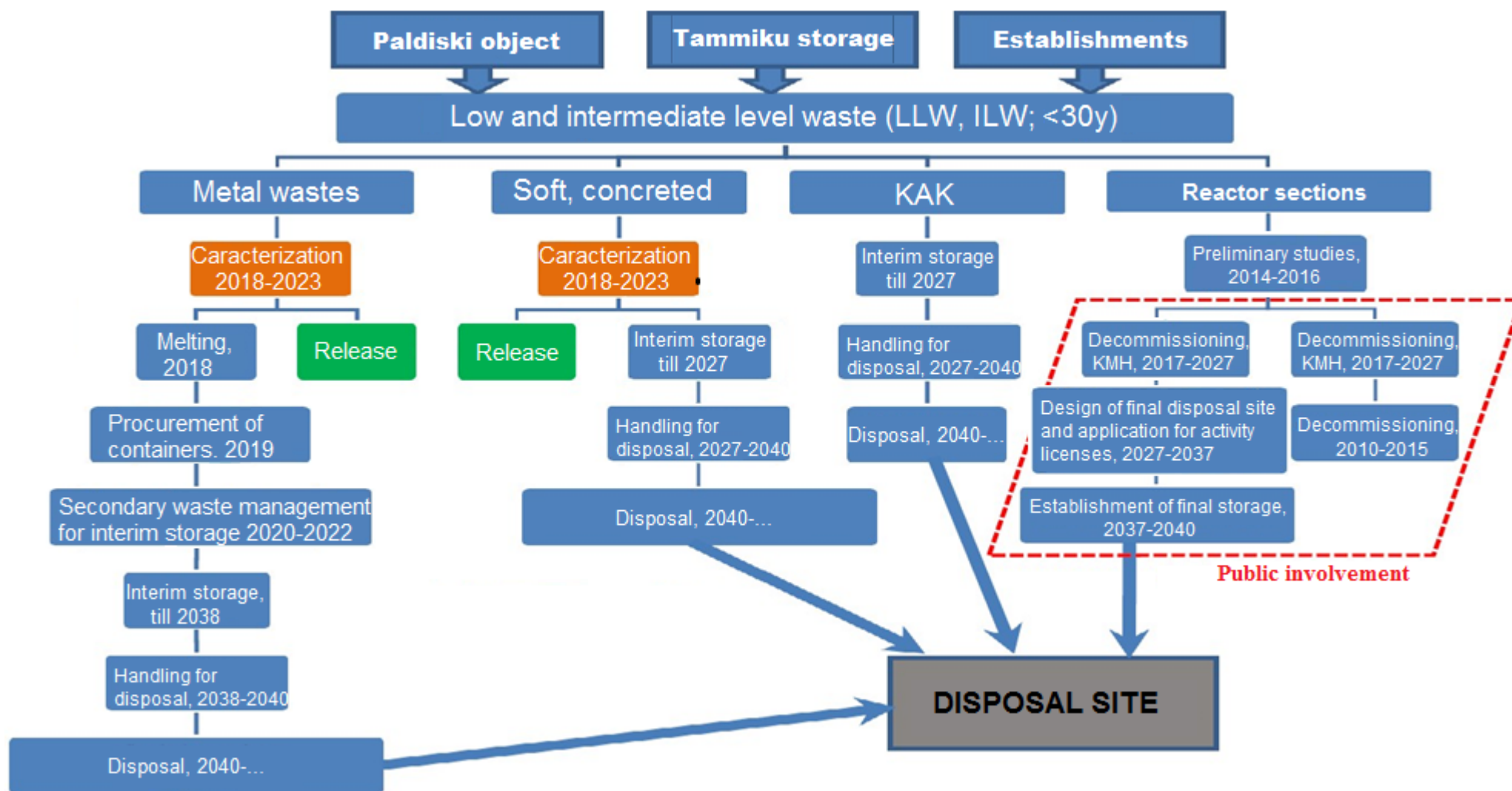


Figure 1.1. The movement of short-lived low- and intermediate-level waste from its generation to its final storage or clearance

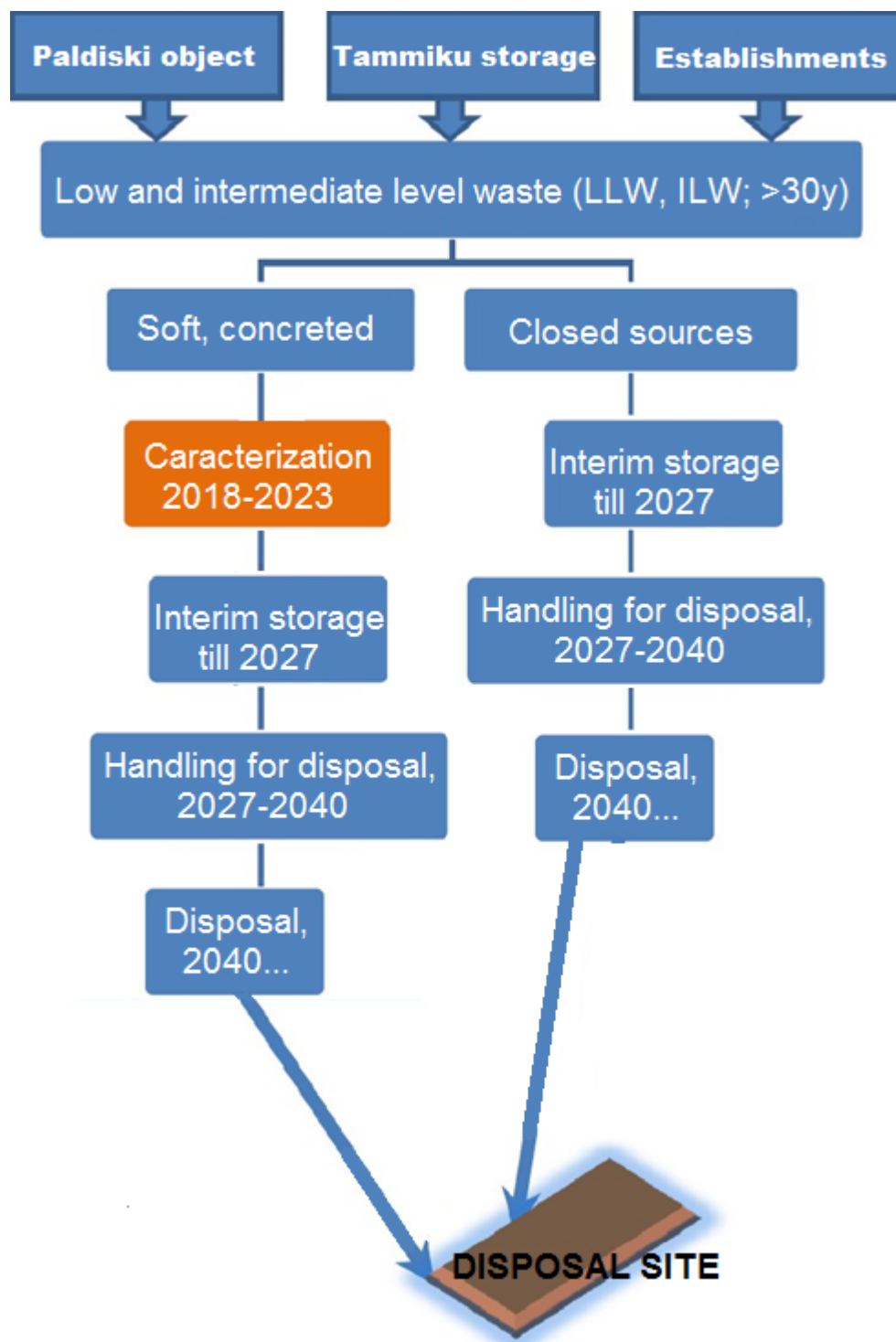


Figure 1.2. The movement of long-lived low- and intermediate-level waste from its generation to its final storage or clearance

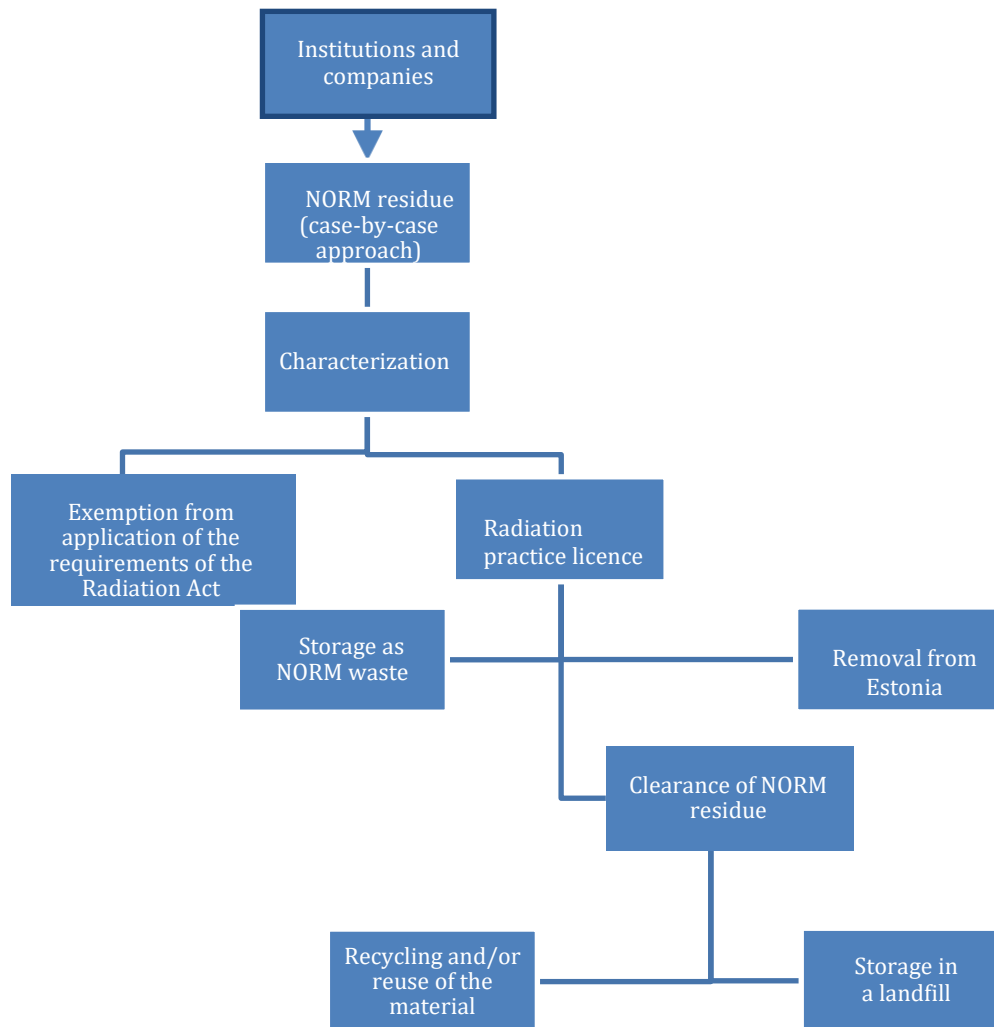


Figure 1.3. The movement of NORM residue from its generation to its clearance or storage as NORM waste.