APPROVED
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 RADON ACTION PLAN

TALLINN 2019

ANNOTATION

Preparation of the National Radon Action Plan

The need to prepare the National Radon Action Plan arose from the European Union Directive 2013/59/Euratom (hereinafter “Directive”), which became effective in 2013, laying down the basic safety standards for protection against the dangers arising from exposure to ionising radiation. The Directive establishes requirements for the preparation of a national radon action plan. In application of Article 100 (1) of the Directive, Member States shall establish a national action plan addressing long-term risks from radon exposures in dwellings, buildings with public access and workplaces for any source of radon ingress, whether from soil, building materials or water. The action plan will take into account the issues addressed in Annex XVIII to the Directive.

The National Radon Action Plan is one of the Annexes to the National Radiation Safety Development Plan for 2018–2027 (hereinafter “KORAK”), as is the National Action Plan for Radioactive Waste Management and the Implementation Programme of the 2018–2021 KORAK. One of the sub-objectives of KORAK is to reduce the risks caused by natural radiation sources (including radon).

In addition to KORAK, 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 was also initiated with 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 National Radon Action Plan is reviewed in the course of the work and updated as needed.

The coordinator of the preparation of the action plan was Krista Saarik, Senior Officer of the Ambient Air and Radiation Department at the Ministry of the Environment. Also involved in the work as experts were Monika Lepasson, Manager of the Radiation Monitoring Bureau of the Environmental Board, and Alar Polt, Chief Radiation Monitoring Specialist. The plan has been coordinated with the Ministry of Economic Affairs and Communications, the Ministry of Social Affairs, the Ministry of Education and Research, 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.

After the completion of the action plan, a relevant press release will be published and a free information seminar will be organised. 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

ANNOTATION 2
Introduction 4
1. Radon related legislation in Estonia 5
2. Radon concentration in Estonian soil and determining radon risk areas 7
2.1. Sources of radon and radon risk areas in Estonia 7
2.2. Determining administrative units in radon risk areas 8
3. Indoor air radon concentration studies in Estonia 11
4. Measuring radon 13
4.1 Relationship between the radon concentration of soil air and indoor air 15
5. Reference levels of radon concentration 16
5.1 Reference levels in buildings 16
5.2 Radon concentration in workrooms 17
6. Reducing radon concentration in buildings 18
6.1. Standard of design of radon-safe buildings 18
7. Radon in groundwater 20
8. Radon from building materials 21
9. Long-term objectives of reducing health risks 23
10. Awareness 25
11. Research and development 28
11. Implementation Programme of the National Radon Action Plan 29
Summary 30
References 32

Introduction

Radon is a colourless, odourless and tasteless radioactive gas. It occurs naturally as a result of radioactive decay of uranium (U) and thorium (Th), and mainly consist of three isotopes: radon-222 (Rn-222), i.e. radon; radon-220 (Rn-220), i.e. thoron; and radon-219 (Rn-219), i.e. actinon. In terms of effect on human health, the most significant is Rn-222 – the direct decay product of radium (Ra-226) that occurs in the radioactive decay chain of the uranium isotope U-238; this is because the half-life of Rn-222 is sufficiently long for it to accumulate in indoor air in significant concentration. Rn-222 is an inert gas, the radioactive decay chain of which includes the occurrence of 7 radioactive isotopes until the formation of stable lead isotope (Pb-206). Hereinafter Rn-222 will be conditionally treated as radon (Rn).

Rn is almost 7.7 times heavier than air. Radon diffuses from the soil mostly due to pressure differences, but also with geogases (He-, N- and C-compounds) and from the composition of water. Rn-concentration becomes stable at about 2 metres below the ground and deeper. The closer to the ground, the more intense is the aeration of soil air and migration of Rn into the air. In the composition of indoor air, Rn concentrates in basements and first floors of buildings, especially in vacuum conditions resulting from ventilation.

From the modern medicine point of view, Rn that enters a human body through respiration is in the second place as a factor that increases the risk of lung cancer, immediately after smoking, which is in the first place. In an Rn-rich environment, Rn progeny elements start accumulating in the body, where the progeny elements will continue to decay. Although the half-life on Rn itself is only 3.82 days, the longest half-life of its isotopes, that of the daughter isotope Pb-210 is about 22 years. Therefore, the inhaled Rn elements will form a long-term radiation source, to which doses incurred throughout the person's life will be added.

Estonia is among those EU countries that exhibit an above average radon risk. In general, the concentration of radon in the indoor air of buildings located in areas with a high risk of radon, where no radon protection measures have been implemented, is high. The main reason for this is the high concentration of radon risk in the subsoil below the buildings, which is caused by uranium-rich subsoil rocks – dictyonema shale, obulus phosphorite, some varieties of Devonian sedimentary rocks, etc. Additional radon may originate from groundwater, building materials and sailing stones in the sedimentary cover.

Based on results from Rn-risk studies conducted in Sweden and Estonia (Petersell et al., 2004), the soil in Estonia can be distributed into four levels of Rn-risk:

1. Soils with low Rn-content. These are soils, the Rn-content of which does not exceed 10 kBq/m^3 (kilobecquerel per cubic metre; becquerel is a unit of radioactivity). These soils are virtually Rn-safe.
2. Soils with normal (background) Rn-concentration, which in soil air does not exceed the limit of 50 kBq/m^3.
3. Soils with high Rn-concentration, which in soil air remains in the range of 50–250 kBq/m^3. These soils are characterised by Rn-hazard and measures that minimise the Rn-hazard have to be implemented concerning buildings.
4. Soils with extremely high Rn-concentration, the U concentration of which exceeds 16 mg/kg and the Rn-concentration of which in soil air exceeds the limit of 250 kBq/m^3. These soils are characterised by Rn-hazard and measures that minimise the Rn-hazard have to be implemented.

The Rn-risk level and its variations in the indoor air of dwellings in Estonia are directly dependent on geological structure and U- and Th-concentration, which is why it is necessary, when characterising Rn-risk, to also pay attention to the geology of the region.

1. Radon related legislation in Estonia

The Radiation Act regulates radiation practices, activities upon which the presence of natural radiation sources may lead to a significant increase in the exposure of workers and members of the public, and intervention in cases of radiological emergencies or in cases of lasting exposure. The Radiation Act does not apply to exposure to radon in dwellings, to cosmic radiation prevailing at ground level and to aboveground exposure to radionuclides present in the undisturbed earth's crust caused by human activity.

In Estonian legislation, radon and natural radiation have been covered in the following valid regulations:

1) Regulation No 61 of the Minister of Social Affairs of 24 September 2019 "Drinking water quality and control requirements and methods of analysis" establishes requirements for the quality and control of drinking water and methods of analysis of drinking water samples in order to protect human health from the harmful effects of drinking water contamination. The Regulation establishes radiological quality indicators for tritium, radon and indicative dose.
2) Regulation No 28 of the Minister of the Environment of 30 July 2018 "Reference levels for indoor radon concentrations in workrooms, the procedure for radon measurements and obligations of employers at workplaces with increased radon risk" stipulates the reference levels for indoor radon concentrations in workrooms, the procedure for radon measurements and obligations of employers to decrease the health risks of employees that are caused by indoor radon concentrations in workrooms. The objective of the Regulation is to ensure the protection of employees in a situation in which a natural radiation source of radon can cause increased (compared to regular levels) exposure incurred by employees. In order to meet this objective, the Regulation stipulates that the reference level for indoor radon concentrations in workrooms must not be higher than 300 Bq/m^3, also required are the measurement of radon concentration in indoor air in workrooms with an increased radon risk and notification of workrooms where, despite the adoption of measures for decreasing the radon risk, the radon risk still exceeds the national reference level.
3) Regulation No 84 of the Government of the Republic of 30 May 2013 "Requirements of health protection for schools" establishes health protection requirements for schools, the territory, buildings, rooms, furnishings, indoor climate and maintenance thereof. The Regulation is applied to basic schools and upper secondary schools (hereinafter collectively as "schools") within the meaning of the Basic Schools and Upper Secondary Schools Act. The Regulation stipulates that the annual average indoor radon concentration of a school room has to remain below 200 becquerels per cubic metre (Bq/m^3) and the dose rate of gamma radiation has to be below 0.5 microsieverts per hour (µSv/h).
4) Regulation No 131 of the Government of the Republic of 6 October 2011 "Requirements of health protection for the territory, buildings, rooms, furnishings, indoor climate and maintenance of preschool childcare facilities" stipulates health protection requirements that apply to the territory of a preschool childcare facility (hereinafter "childcare facility"), the buildings, rooms, furnishings, indoor climate and maintenance thereof. The Regulation is also applied to private childcare facilities and to the childcare facility of an establishment that functions both as a childcare facility and a basic school. The Regulation stipulates that the annual average indoor radon concentration has to remain below 200 becquerels per cubic metre (Bq/m^3) and the dose rate of gamma radiation has to be below 0.5 microsieverts per hour (µSv/h).
5) Regulation No 19 of the Minister of Entrepreneurship and Information Technology of 28 February 2019 "Reference level for the radon content of the indoor air of a building and the effective dose of gamma radiation emitted from the building materials of a

building structure indoors” establishes reference levels for the radon content of the indoor air of a building and the effective dose of gamma radiation emitted from the building materials of the building structure to the interior.

2. Radon concentration in Estonian soil and determining radon risk areas

Estonia is among those EU countries that exhibit an above average radon risk. Based on measurements, the Rn-concentration in soil air varies from 5–600 kBq/m³, reaching 2,000 kBq/m³ in rare cases. In Estonia, the main source of radon in the soil is the radium (Ra, i.e. eU) that has been and is produced as a result of radioactive decay of uranium. The changeable content of eU, which is increased or high in many areas (eU > 3.5–4 mg/kg), and its positive correlation with Rn-concentration is the indoor air of buildings have caused the need to map Rn-concentration in the soil air and the natural radiation of soil of Estonia. The first map was drawn up based on methodology developed by the Geological Survey of Estonia (GSE), the Swedish Radiation Protection Institute and the Geological Survey of Sweden, and adopted to the conditions in Estonia, during 2001–2004, based on data from 566 field study observation points (Petersell et al., 2004). As a result of compiling said map, it became evident that nearly 1/3 of Estonian land territory has high Rn-risk (> 50 kBq/m³) or extremely high Rn-risk (> 250 kBq/m³) (Petersell et al., 2005). These are areas where U-concentration is high (> 3.5–5 mg/kg) in the soil or bedrock, or both in soil and bedrock. Based on data from 2,000 soil air and 5,500 indoor air observation points, the new Atlas of Radon Risk and Natural Radiation in Estonian Soil was completed in 2017. It was determined that the radon concentration in soil air on the Estonian territory is usually in the range of 23–75 kBq/m^3, but can sometimes exceed the limit of 500 kB/m^3. The information compiled in the atlas is comprehensive and indicative, however, it is necessary to continue radon studies.

2.1. Sources of radon and radon risk areas in Estonia

The main sources of radon are crystalline bedrocks (both in the lower deposits and the composition of clastic tills carried here by a glacier), Lower-Ordovician Obolus sandstone in the Cambrian border zone, its variety phosphorite and the Dictyonema shale on top of those.

The high Rn-concentration is predominantly related to the U-rich comminuted Dictyonema shale, phosphorite and granitoid material spreading in the soil, as well as zircon, xenotime and other minerals. All these high radiation and increased radiation varieties of Quaternary sediments form extensive ranges or are displayed as forms of various sizes and shapes, representing the lithotypes of Quaternary sediments. During the period between 2001 and 2016, the Geological Survey of Estonia determined Rn-concentrations in more than 2,000 soil air observation points in the ranges of important lithotypes.

The surface area level of radon risk is displayed on the corresponding Rn-risk thematic map (Figure 1). The Rn-risk thematic map has been compiled using the direct measurement of radon concentration (RnM) and the calculation method (RnG) of maximum concentration in soil air.

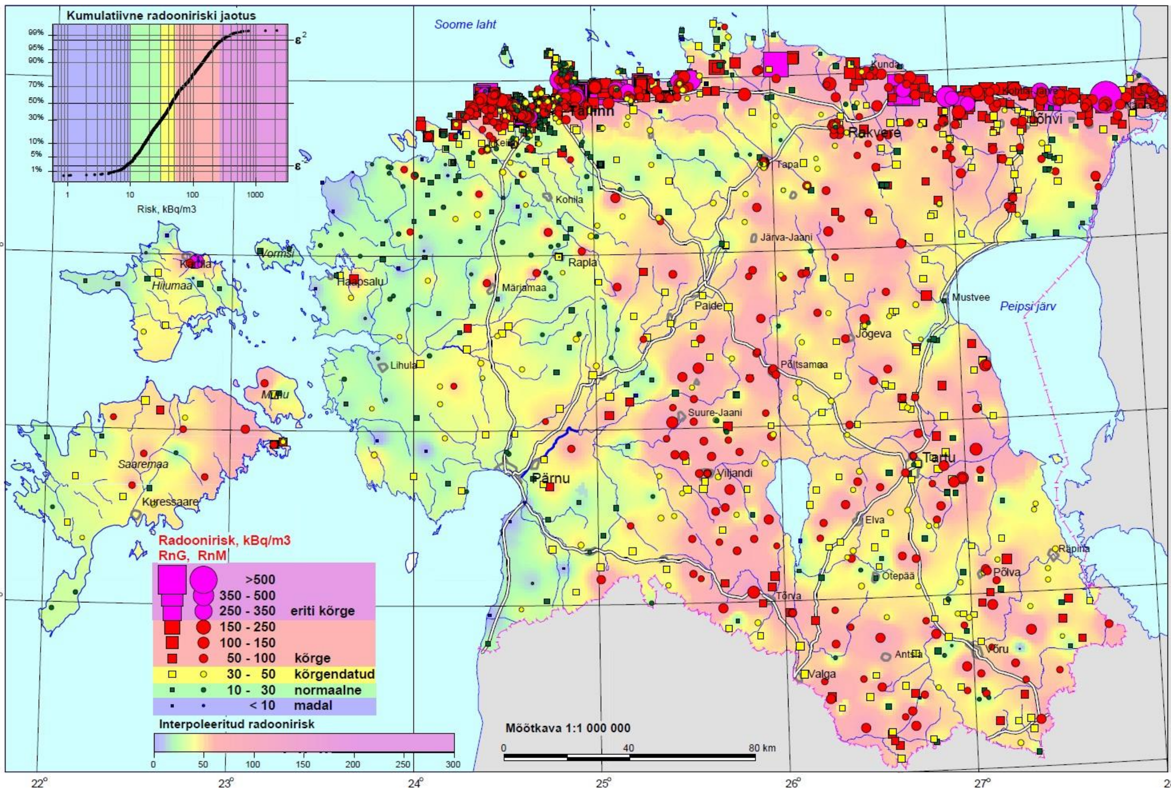

Figure 1. Radon-222 risk map of Estonian soil. Maximum concentration of radon-222 in soil air.

2.2. Determining administrative units in radon risk areas

The need to map radon risk areas arises from a requirement set out in Directive 2013/59/Euratom, stipulating that Member States shall identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level (300 Bq/m^3 in Estonia).

Based on a study compiled by the Geological Survey of Estonia (currently: Estonian Geological Service) in 2016, the territory of Estonia can be conditionally divided into three: administrative units with increased radon risk, administrative units with low or average radon risk, and administrative units with additional research needs. As at 2018, a total of 2/3 of the territory of Estonia has been mapped and based on the data available, it can be said that 36 administrative units are located on areas with increased radon risk and 24 administrative units are located on areas with low or average radon risk. No measurements have been conducted on areas with addition research needs (19), or the number of measurements conducted has been insufficient for assessing the radon risk. Additional mapping will be carried out from 2019–2024, with the plan of mapping about four administrative units per year.

Existing data was taken into account when compiling the radon risk map of administrative units (Figure 2). Based on the existing radon measurements from soil air, administrative units were divided into three groups based on the following conditional criteria: 1) number of the measurements; 2) measured values;
3) 3) geological situation.

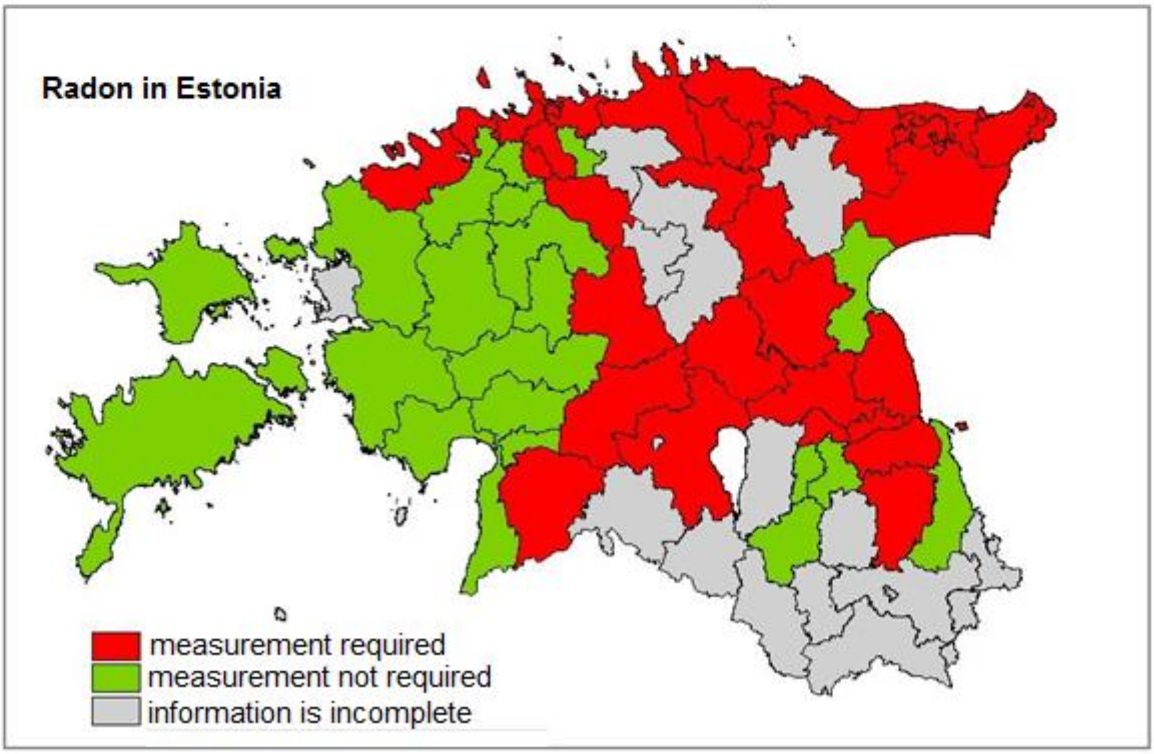

Figure 2. Map of prioritised radon risk areas of Estonian administrative units (as at 2018)

Administrative units with increased radon risk

When mapping increased radon risk areas, measurements made by the GSE, which confirmed the higher radon concentration of soil specifically on areas of Dictyonema shale, as well as on distributional ranges of Devonian sedimentary rocks in central Estonia and southern Estonia, were the determining factor.

The Rn-concentration in the soil air of high Rn-risk klint zone often exceeds the limit of 50 kBq/m³ and can reach 600 kBq/m³, rarely more than that. Dictyonema shale and phosphorite with high U-concentration that crop out under the sedimentary cover at the klint and on the slopes of ancient valleys cutting it, as well as the clastic fragments of those rocks and granitoid material with increased U-concentration originating from Finland. The outcrops of Dictyonema shale and phosphorite in the klint zone deepen by about 3 m/km in the southern direction. The radon in these rocks reaches the soil air primarily through fractures in carbonate rocks of the ground surface; mostly from the depth of 100 m, in rarer cases, from the depth of 200 m.

The zone is characterised by high (50–250 kBq/m³) and extremely high (> 250 up to 600 kBq/m³, and even higher in rare cases) Rn-concentration areas, which come about due to radon forming in the upper layer (about 2 m) of soil air, as well as radon migrating from deeper.

The range of Devonian sedimentary rocks in central and southern Estonia is characterised by relatively frequent areas with high Rn-concentration (>50 kBq/m³) in soil air. The cause for the high Rn-concentration (50–250 kBq/m³) is often the migration of radon from deep in the ground (>2m). Rn-sources are unclear. These may include sediment varieties of Devonian terrigenous material, enriched with U-rich zircon, U-rich clay and silt layers (lenses) or sources currently unidentified.

Administrative units with low or average radon risk

When selecting low or average radon risk areas, the geology of and measurements, which enabled to conclude that the radon risk is average or low, from the areas were taken into account.

Local authorities, the measurements and geological situation of which allows to conclude that the radon risk is low or average, are represented among the administrative units with low or average radon risk. The aforementioned areas are mostly in western Estonia and on the islands. West-Estonian soil air is characterised mainly by normal Rn- concentration. Isolated high concentrations in low or medium radon risk areas are likely to be associated with karstic areas and fracture zones. High concentrations (up to 264 kBq/m^3) at the Kärdla ring structure in the Pühalepa Rural Municipality are an exception.

Administrative units with additional research needs

Administrative units with additional research needs are areas on which there is insufficient data to draw conclusions with regard to radon risk (there is no measurement data or the amount of measurements conducted has been insufficient).

In administrative units where measurements are insufficient or not made, additional measurements must be made to identify the radon risk in the area, i.e. areas where radon levels in soil air often exceed 75 kBq/m^3 and where radon levels (annual average) are expected to exceed the national reference level in a significant number of buildings (300 Bq/m^3). As at 2018, there is insufficient data on 19 administrative units. Additional mapping will be carried out from 2019–2024, with the plan of mapping about four administrative units per year.

Radon measurements from soil air will be continued to specify the location of areas with increased radon risk; the correlation of radon concentrations in soil air and indoor air will be studied as the amount of measurement data of radon concentration in indoor air increases in volume.

3. Indoor air radon concentration studies in Estonia

Studies of indoor radon concentration in Estonia began at the end of the 1980s.

It was determined, with a study conducted by the Department of Building Physics of the Institute for Scientific Research of Construction from 1989–1991, that the main course of indoor radon concentration is the soil below buildings. Increased indoor radon concentrations have not been detected in cases that might be caused by tap water or building materials.

From 1994–1998, an Estonian-Swedish radon studies programme was conducted with the goal of creating radon measurement capability in Estonia, training specialists in this field, and determining Rn-risk areas and types of buildings that are characterised by an above-average indoor radon concentration. It was determined that regions with potentially high indoor Rn-concentration are Toila and Kunda, the radon level of one-family dwellings is higher than that of apartments, and if a building has a basement, the radon level in the rooms of the first floor is lower than in buildings without a basement.

In 1999, the Estonian design standard EPN 12.2 “Indoor climate” established the rated value of Rn-concentration in dwellings, rest areas and workrooms at 200 Bq/m^3.

From 1998–2001, a national study was conducted in Estonia, by way of cooperation of the Estonian Radiation Protection Centre and the Swedish Radiation Protection Institute, as a result of which the first radiation map of average radiation levels of rural municipalities was compiled, the average effective dose to a person caused by radon was determined to be 1 millisievert (mSv) and it was estimated that radon causes about 90 new lung cancer cases in Estonia every year (about 10 of those among non-smokers).

A project titled “Radon in buildings” and supported by the Environmental Investments Centre was conducted from 2002–2004. Data collected during this study and previous studies were used, in addition to geological and soil air radon measurements, for compiling the Estonian radon map. Information material titled “Radon-safe building” was completed.

From 2005–2006, a research project titled “Radon in childcare facilities on radon risk areas”, in the framework of which 208 childcare facilities were inspected in 30 rural municipalities and cities. As a result of the study, it was determined that the Rn-level in childcare facilities is usually lower than that of residential buildings, although problematic rooms were found in 49% of buildings.

Collection of data for updating the radon map of rural municipalities was continued from 2007–2008. A measurement system of radiation detectors from the Hungarian company Radosys was purchased for the Estonian Radiation Protection Centre; this system is used to this day, although, it needs to be replaced over the next years due to depreciation. An updated map of average radon levels of rural municipalities was completed. The Estonian Radiation Protection Centre issued guidance material titled “Consideration of radon risk in construction design and existing buildings” to the employees of local authorities. An electronic database of indoor radon measurements was adopted by the Estonian Radiation Protection Centre.

From 2008–2010, radon level was inspected at various workplaces – mines, water parks, water treatment establishments and childcare facilities. In parallel, radon measurements were continued in residential buildings on the basis of the submitted orders.

From 2011–2012, a total of 101 pre-school childcare facilities were inspected in Tallinn, most of which were compliant with the radon level requirements established in Regulation No 131 of the Government of the Republic of 6 October 2011. The average radon level exceeded 200 Bq/m^3 in 6 childcare facilities and in 7 buildings; this level was exceeded in a few individual rooms.

By this time, according to data of the Radiation Department of the Environmental Board, the distribution of radon concentrations in indoor air in about 2,500 buildings where measurements have been conducted is the following:

- below 100 Bq/m^3 – ~62%;
- below 200 Bq/m^3 – ~83%;
- over 300 Bq/m^3 – ~10%;
- over 600 Bq/m^3 – ~3%;
- over 1,000 Bq/m^3 – ~1%.

It has to be taken into account that most measurements have been conducted in regions which, based on geological data, have higher concentrations of uranium in the soil, which is why it can be assumed that the radon concentration of indoor air in buildings in Estonia as a whole is somewhat lower than the statistics of previous measurements indicate.

In order to get a more comprehensive overview, it is necessary to conduct a national radon study. In European Union countries, radon studies are conducted on the basis of a 10 x 10 km grid, where samples are taken from at least 30 randomly selected buildings in each square of the grid. In case of measurements at the aforementioned density, the necessary number of buildings where measurements are conducted would be about 15,000 in Estonia. As at 2018, radon measurements have been conducted in about 2,500 buildings (indoor air measurements).

A new development is needed for the database of measurements of indoor air, because statistical processing of data is difficult with the current database. A vision document and business analysis have already been prepared for the development of this database, which will allow for improved management and analysis of radon measurement data in the future. Development works of the database are scheduled to begin in 2019. The database is managed by the Environmental Board.

4. Measuring radon

The first radon concentration measurements in Estonia were conducted in the air of basements or first floors of buildings from 1985–1990. Scheduled studies were started by the Estonian Radiation Protection Centre independently and in cooperation with the Swedish Radiation Protection Institute in 1994. Measurements of radon concentration in the first individual observation points in Estonia were conducted in cooperation with researchers (and their equipment) from the Swedish Radiation Protection Institute in 1995.

The use of a suitable measuring method is important during the measurement of radon concentration in both soil air and indoor air. All parties, including the contracting entity of the measurements, the executor and the persons conducting monitoring have to understand the measurement process and its results in a uniform manner. Pursuant to the Measurement Act, the traceability have to be ensured at least during national monitoring, if a precept is issued on the basis of measurement results. In order to ensure the traceability of measurement results, the measurements have to be conducted by a competent person who uses a calibrated measuring instrument or an instrument that has been calibrated in a monitored manner, in compliance with the relevant measurement methodology.

Guidance material titled "Measurement of radon activity concentration (RAM 2016)", financed by the Foundation Environmental Investments Centre and compiled by the Ministry of the Environment, was completed in 2016. The guidance material is accessible on the website of the Ministry of the Environment: https://www.envir.ee/sites/default/files/radooni_mootmise_juhend.pdf.

The guidance material describes such measurement methods for measuring radon activity concentration in soil and indoor air, which, when implemented, provide results that can be used in construction activities or, if necessary, for decreasing the radon concentration in indoor air of existing buildings. The guidance material has been compiled with the goal of providing instructions for persons conducting measurements of Rn activity concentration in soil air and indoor air and for presenting results in a way that ensures a sufficient overview of radon level at the measured object both for contracting entities and for monitoring purposes. The requirements concerning the form, protocol and report of measurement are also provided. The guidance material helps select a suitable measurement method according to the objective of measurement. Although the guidance material is indicative, the long-term measurement of indoor radon activity concentration is the only suitable way of assessing annual average value of radon concentration. The only suitable measurement method for assessing radon concentration in soil air is direct measurement of soil with the calculated determining of radon through radium-226.

When compiling the guidance material, the Environmental Board also cooperated with the Finnish Centre for Radiation and Nuclear Safety, by asking their opinion and amendment proposals for the guidance material. In cooperation with the Finnish Centre for Radiation and Nuclear Safety, a training event titled "Measurement of radon activity concentration" was organised for the persons conducting radon measurements in Estonia in May 2016.

Under the guidance of the Ministry of the Environment, as at 2018, five parts of the International Organisation for Standardisation (ISO) standard series ISO 11665 "Measurement of radioactivity in the environment – Air: radon-222", which cover all the most important fields of radon measurements both in terms of indoor air of buildings and soil air, have been translated into Estonian.

The aforementioned standards are the Estonian-language versions of international ISO, the translations of which have been published by the Estonian Centre for Standardisation and which have the same status as the standard versions in official languages.

A competent person conducting measurements shall measure radon concentration in the air within the meaning of the Measurement Act and the measurement results have to be traceable incompliance to the procedure established in the Measurement Act. In accordance with the Measurement Act, the competence of a person conducting measurements is assessed and attestation by way of accreditation or assessment of professional competence and attestation. In Estonia, the accreditation as well as assessment and attestation of the professional competence of a person conducting measurements is conducted by the Estonian Accreditation Centre.

4.1 Relationship between the radon concentration of soil air and indoor air

In Estonia, research on the relationship between Rn concentration in soil air and indoor air has been conducted only to a modest extent. Studies conducted in Sweden have shown that soil is harmless in regard with Rn, if the Rn concentration in soil air does not exceed 10 kBq/m^3. Sandy and silty soils are hazardous with regard to Rn, when Rn concentration in soil air exceeds 50–60 kBq/m^3 (Clavensjö, Åkerblom, 1994). Soils, the Rn-concentration of which in soil air exceeds 50 kBq/m^3, are considered to be hazardous with regard to Rn. In such cases, when no measures have been implemented to stop the migration Rn, the Rn-concentration in the indoor air of dwellings can very likely increase above the limit of 200 Bq/m^3.

If radon has not been taken into account during construction, there is a clear, traceable positive correlation between the Rn-concentration in the soil air and in the indoor spaces of the building. It has been observed that, depending on the quality of buildings, in a few individual cases the Rn-concentration of indoor air of buildings exceeds the limit of 200 Bq/m^3 on areas where the Rn-concentration in soil air is nearly 50 kB/m^3. Similarly, Rn-concentration in indoor air may exceed the limit of 300 Bq/m^3 on areas, where the Rn-concentration in soil air is nearly 75 kBq/m^3.

5. Reference levels of radon concentration

5.1 Reference levels in buildings

The radon activity concentration in ambient air is generally low, as radon disperses in ambient air and does not pose a threat to health. However, the radon that is released to indoor spaces from the subsoil, can increase the radon concentration to a level that can be detrimental to health in the long term.

In Estonia, the regulation of radon concentration in indoor air began in 2011 with the enforcement of Regulation No 131 of the Government of the Republic of 6
6. October 2011 "Requirements of health protection for the territory, buildings, rooms, furnishings, indoor climate and maintenance of preschool childcare facilities", which set the annual average indoor radon concentration of 200 Bq/m³ (becquerel per cubic metre) as a limit value. Regulation No 84 of the Government of the Republic of 30 May 2013 "Requirements of health protection for schools" stipulates that the annual average radon concentration in the indoor air of schools has to be below 200 Bq/m³. This requirement originated from the standard EVS 840 "Design of radon-safe buildings", which was valid at that time, and according to which the radon concentration in buildings has to be lower than 200 becquerel per cubic metre (Bq/m³).

In 2016, the Ministry of Economic Affairs and Communications began preparing a draft for the Regulation titled "Requirements of indoor climate of buildings" (hereinafter "Regulation of indoor climate"), with which it is planned to, inter alia, regulate the reference level of indoor radon concentration of dwellings. Until the establishment of the indoor climate regulation, Regulation No 19 of Minister of Entrepreneurship and Information Technology of 28 February 2019
"Reference level for the radon content of the indoor air of a building and the effective dose of gamma radiation emitted from the building materials of a building structure indoors" applies.

Directive 2013/59/Euratom stipulates the reference level of radon activity concentration in indoor air at 300 Bq/m³, which is also set as the national reference level of Estonia.

It is planned to establish separate exceptions for the general reference level of the annual average value of radon activity concentration to be established under the Regulation of indoor climate. The reference level of the annual average value of radon activity concentration for the building of a pre-school childcare facility (creche, nursery school, daycare, nursery-primary school), basic school, secondary school, vocational educational institution, children's home, youth home, general care home, or a special care home is set at 200 Bq/m³. Compared to the generally established reference level of the annual average value of radon activity concentration, a stricter requirement is set for such buildings the intended purpose of which includes long-term stay by members of vulnerable target groups, first and foremost, children.

National studies should also include radon studies in the indoor spaces of establishments that have been assigned a lower reference level of the annual average value of radon activity concentration, 200 Bq/m³, as an exception.

Consideration should also be given to and opportunities determined for taking radon into account in support programmes of reconstructing small private houses and apartment buildings. The objective would be to ensure that the radon concentration of indoor air would be taken into account, inter alia, when applying for support for reconstructing small private houses or apartment buildings.

5.2 Radon concentration in workrooms

Directive 2013/59/Euratom stipulates that Member States shall establish national reference levels for indoor radon concentrations in workplaces, which shall not be higher than 300 Bq/m^3, requiring radon concentration measurements to be conducted in workspaces, located on areas with increased radon risk,

that are situated on the first floor or basement floor. When exceeding the reference level of 300 Bq/m^3 , the employer is required to implement justified and optimal radon protection measures. If, despite the implementation of constructional measures, it is not possible to achieve the reference level, the monitoring of radiation doses of employees and notification of a competent establishment has to be ensured.

In order to transpose the aforementioned provisions into national legislation, Regulation No 28 of the Minister of the Environment “Reference levels for indoor radon concentration in workrooms, the procedure for radon measurements and obligations of employers at workplaces with an increased radon risk” (hereinafter “Regulation of radon concentration in the air of workrooms”) was adopted on 30 July 2018 based on the Radiation Act. The Regulation stipulates the procedure reference level of radon concentration in the air of workrooms and the procedure for measuring radon concentration in the air and for assessing compliance with the reference level; the employers’ obligations in decreasing the long-term health risks arising from radon concentration in the air of workrooms; the employers’ obligation to ensure monitoring of radon exposure doses incurred by employees, if the radon concentration in the air of the workroom during work hours exceeds the reference level; and the employers’ obligation to notify the Environmental Board of workplaces where, despite implementing measures for decreasing the long-term health risk, the radon concentration in the air of the workroom continues to exceed the reference level.

The Regulation of radon concentration in the air of workrooms stipulates the reference level of radon concentration in the air of workrooms as 300 Bq/m^3. The reference level is set for annual average value, which can be measured or assessed based on measurements the duration of which was less than a year. The radon concentration is considered to correspond to the reference level if the results of a continuous measurement for one year do not exceed the reference level or if the results of a continuous measurement for at least two months within the period from 1 November to 30 April do not exceed the reference level more than 20%. The assessment methodology complies with that in use in our neighbouring countries and the measurement methodology complies with the international standards transposed to the Estonian standard system. In the Estonian climate, radon becomes problematic during winter, when the ground is frozen and the free movement of radon into the atmosphere is therefore impeded. This is when radon starts to accumulate in the soil below buildings, in search of a way out, as the ground is not frozen under buildings, and will migrate into the indoor air of buildings.

6. Reducing radon concentration in buildings

One of the measures of reducing radon concentration indoors is to determine whether or not the radon activity concentration in the soil below the building could cause problems in the future already before the design stage of the building. Although several maps of radon risk areas have been compiled concerning the soil in Estonia (including the Atlas of Radon Risk, radon risk maps of Harju County and Ida-Viru County), it is better to measure the radon activity concentration at the planned location of the building to be constructed. Namely, the radon concentration of soil varies a lot on relatively limited areas, as it is affected by a lot of different factors.

If no soil air radon concentration measurements are conducted or it is determined as a result of measurements that the radon activity concentration in the soil exceeds 50,000 Bq/m^3 (or the radium activity concentration exceeds 45 Bq/kg), measures that minimise radon danger have to be implemented in order to avoid radon danger. It is strongly recommended to measure the radon concentration in soil and plan the implementation of measures for decreasing radon concentration on areas with high radon risk. If the radon activity concentration in the soil is in the range of 10,000–50,000 Bq/m^3, radon-safe solutions for structures have to be ensured. If the soil below the building has low radon concentration (radon activity concentration < 10,000 Bq/m^3), good construction quality has to be ensured during the construction/designing of the building. (RAM 2016)

Main sources of radon in indoor air are (EVS 840:2017):

1) air leak from the soil through structures and insufficient density at the connections of structures. The most critical spots are connections of the floor (on the soil) and external/partition/basement walls, shrinkage fractures in concrete floors;
2) air leak from the soil through penetrations (electricity, water, sewerage, etc.) and through unfilled (not filled with concrete) precast concrete masonry, through the vertical vacuity between layers of different materials (e.g. insulation and foundation wall);
3) diffusion or air leak through the surface-exposed structures (e.g. basement walls made from materials that conduct air well (e.g. exclay block, especially if it has been fitted with unfilled vertical joints), materials with low diffusion resistance);
4) radon emanating from building materials;
5) use of domestic water that is hazardous in terms of radon.

Among the aforementioned radon sources, in Estonia, the greatest proportion of indoor radon originates from radon migrating indoors from the soil via air leaks. The prerequisite for the movement of air through barrier structures, insufficient densities, connections and penetrations is ensuring barometric pressure differences of indoor spaces and the soil between. Barometric pressure differences of indoor spaces and the soil can be caused by differences in airflow amounts caused by ventilation, differences in air density and wind. Air density differences caused by wind and different temperatures are not dependent on human factors; whereas, the functioning of ventilation is dependent on the designer, the builder and user of the building. Therefore, barometric pressure difference caused by ventilation is the most significant human activity factor that can affect the migration of radon from the soil to indoor spaces.

6.1. Standard of design of radon-safe buildings

An updated design standard for radon-safe buildings EVS 840:2017
“Guidance for radon-protective measures for new and existing buildings” was completed in 2017. In this standard, designers and builders are given instructions on how to build a radon-safe building, in order to avoid exceeding the reference level of radon that damages health in rooms where people spend longer periods of time. The standard includes a selection of measures for decreasing radon risk in existing buildings and new buildings. It must be taken into account that neither the list nor solutions are definitive and radon safety can be ensured with other

measures as well, the efficiency of which has been studies and confirmed in a documented manner.

The new standard EVS 840:2017 differs from the previous standard by providing instructions on how to design a radon-safe building as well as how to make an existing building radon-safe. The new standard also covers the measures for decreasing radon risk more thoroughly, starting from the principles of radon-safe construction and ending with specific solutions for old buildings with basements. The standard has also been updated with text and visual material, in order to support the effective implementation of radon control measures.

Pursuant to Council Directive 2013/59/Euratom, the reference level of radon concentration in indoor air is set at 300 Bq/m^3 in Estonia (an exception is made for a building of a pre-school childcare facility, basic school, secondary school, vocational educational institution, children's home, youth home, general care home, or a special care home, where the reference level is set at 200 Bq/m^3). In cases where the reference level is exceeded, measures for decreasing radon concentration have to be considered and implemented, if necessary. Taking into account that the standard presents instructions and best practices for implementing radon protection measures, and the fact that a design standard has been enforced in Estonia for a long time, the objective set in the standard is achieving the level of 200 Bq/m^3. In that case, it is very likely that, when implementing the measures described in the standard, the national reference level of 300 Bq/m^3 will not be exceeded in the future.

7. Radon in groundwater

So far, in the course of studies conducted concerning water for human consumption, no additional increased radon concentration has been found in the water for human consumption taken from aquifers.

In Estonia, radon concentration studies have been conducted on water for human consumption taken from aquifers. According to the research article of research fellows of the Institute of Physics of the University of Tartu “Relevant radionuclides in Estonian drinking and ground waters – measurement techniques and activity concentrations”, from 2011, the radon concentration in water for human consumption originating from aquifers has been measured, during various studies, on 135 instances. The results showed that the average radon concentration was in the range of 9.0–19.4 Bq/l, which is significantly lower than the control value stipulated on the basis of Council Directive 2013/51/Euratom, which is 100 Bq/l.

Regulation No 61 of the Minister of Social Affairs of 24 September 2019 “Drinking water quality and control requirements and methods of analysis” establishes requirements for the quality and control of drinking water and methods of analysis of drinking water samples in order to protect human health from the harmful effects of drinking water contamination. The Regulation establishes radiological quality indicators for tritium, radon and indicative dose. The Regulation stipulates that radon content in water has to be determined in case, based on scientific research or other reliable information, the Health Board has reason to assume that the control value may have been exceeded.

8. Radon from building materials

Radiological safety of construction products is assessed pursuant to the activity concentration index and it must be below 1. In Estonia, the radioactivity of building materials is regulated by two Regulations:

1) Regulation No 49 of the Minister of Economic Affairs and Communications of 26 July 2013 "Requirements to the building materials and construction products, and procedure for attestation of conformity", which stipulates the requirements set on gamma radiation originating from construction products. Pursuant to the Regulation, the activity concentration index of the construction product must be less than 1, except if the Environmental Board has approved the use of a product with a higher emission on account of the intended usage purpose 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, there have been no problems with the content of natural radionuclides in construction materials of Estonian origin. In the framework of a University of Tartu study conducted in 2012 by M. Lust and E. Realo "Assessment of natural radiation exposure from building materials in Estonia" the content on natural radionuclides was determined in 53 samples of (different) building materials used in Estonia. High resolution HPGe gamma spectrometry analysis method was used for the analysis. It was found that the activity concentrations of natural radionuclides ^{40}K, ^{226}Ra and ^{232}Th, in the studied building materials, vary in the following ranges: according to the 7–747 Bq/kg, 4.4–69 Bq/kg and 0.8–86 Bq/kg, respectively. The activity index values of building materials assessed on the basis of activity concentration are in the range of 0.02–0.74. The dose assessments for the most common building materials were taken indoors and doses to members of the public based on those assessments were in the range of 0.16–0.44 mSv.

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 conduct an additional study of the radioactivity (gamma radiation and radiation exhalation) of building materials in order to prevent the use of materials with increased radioactivity.

In order to decrease the radon risk of indoor spaces caused by building materials, on which there is no attested or study-based information concerning radon danger, it is important to conduct the corresponding studies already before allowing the product on the construction market. When determining activity concentration I, one of the radionuclides taken into consideration is Ra-226, the decay of which results in the formation of Rn-222. Further research is necessary to determine whether the condition $I<1$ is always sufficient for concluding that the radon emanating from that building material does not increase a significant portion of the radon concentration in the indoor air.

A necessity has become evident for conducting an additional study of the radioactivity (gamma radiation and radiation exhalation) of building materials, in order to prevent the use of materials with increased radioactivity and avoid producing radioactive waste at a later time (NORM).

9. Long-term objectives of reducing health risks

The World Health Organization drew attention to the effects on health of radon concentration in the air of dwellings in 1979. In 1988, radon was classified as a carcinogen. According to the WHO, radon is the second most prevalent cause of lung cancer. Only smoking precedes radon exposure as a cause for lung cancer. The lung cancer risk of a smoker is 25 times greater than that of a non-smoker. The synergy of smoking and radon also has a significant role. A study conducted among non-smokers in Sweden showed that there is a synergistic relationship between radon and second-hand smoke. Inhaling air with smoke in it results in more Rn daughter isotopes getting into the lungs, thereby causing an additional radiation dose to the mucous membranes.

Scientific studies indicate that 3–14% of lung cancer cases are caused by radon concentration in the inhaled indoor air. It is estimated that indoor radon causes 70,000–170,000 new lung cancer cases every year. According to data of the National Institute for Health Development, 650–700 new cases of lung cancer are registered in Estonia every year. The Estonian Radiation Protection Centre and the Swedish Radiation Protection Institute estimate that about 90 of those cases can be linked with radon. So far, no epidemiologic study has been conducted in Estonia to determine the connection between incidence of lung cancer and radon exposure. Consideration should be given to the conducting such a study.

Based on an omnibus survey of European settlements, conducted in 2005 and 2006, and scientific research conducted elsewhere in the world, the WHO (WHO, 2009) and the International Commission on Radiological Protection (ICRP, 2010) have compiled estimates for the probability of incidence of lung cancer among life-long non-smokers and smokers by the time they turn 75 years old, depending on the radon concentration of their place of residence and spending 25–30 years in an environment with radon concentration in the air (Table *1*).

Table 1. Probability of incidence of lung cancer among life-long non-smokers and smokers by the time they turn 75 years old, depending on the radon concentration of their place of residence and spending 25–30 years in an environment with radon concentration in the air

Radon concentration		0 Bq/m^3 *	100 Bq/m^3	400 Bq/m^3	800 Bq/m^3
Risk of cancer by 75 years of age	non-smoker	0.4%	0.5	0.7	1%
	smoker	10%	12%	16%	22%
Ratio of cancer risk of smokers/non-smokers (times)		25	24	23	22

* 0 Bq/m^3 is a theoretically radon-free situation; in practice, the radon concentration rarely falls below 5 Bq/m^3 even in ambient air.

To this day, no scientific evidence has been provided of radon causing any other health detriment in addition to lung cancer.

Long-term goals have to be set in order to reduce the risk of lung cancer linked with radon exposure. Activities that contribute to achieving the objective are, for example, conducting radon studies, updating legislation concerning radon, informing the public, persons conducting radon measurements and other people involved in this field. The aforementioned activities have been covered throughout the action plan.

In order to mitigate the lung cancer health risks of smokers, in addition to activities related to radon risks, the most significant impact is made by way of restricting the use of tobacco on a national level.

In its activities, the Estonian Institute for Health Development is guided by the following three principles of limiting the spread of tobacco use:

- prevention;
- developing programmes for giving up tobacco use;
- shaping an environment free of tobacco smoke.

Activities of the National Institute for Health Development in limiting the spread of tobacco use are the following:

- preparing reports and analyses of the situation in Estonia;
- preparing and publishing guidance materials and informative printed publications;
- providing counselling services on the topic of smoking cessation;
- working on decreasing the spread of smoking in the Estonian Defence Forces and health care institutions;
- participating in international working groups;
- preparing and carrying out training courses, information days and conferences;
- conducting a prevention programme "Smoke-Free Class" aimed at school students.

Various specialists are involved in activities of the National Institute for Health Development, including health care workers, psychologists, social workers, teachers, youth workers, etc.

10. Awareness

Radon is an odourless, colourless and invisible gas, which is why people are notified of the dangers of this gas by way of sharing relevant information. The aim of the radon related notification strategy is to improve the public's awareness of hazards related to radon (including the connection to smoking), as well as the awareness of decision-makers on the local level, employers and employees. In order to notify the public and specialists in the radon field, information days are organised, websites updated with additional information, new informative materials are compiled, training events organised, information shared via media channels (television, radio, press).

In order to determine how effectively the objective of a notification activity has been fulfilled, a corresponding study should be organised. Based on the results of that study, it is possible to plan further notification activities.

Information days

The Ministry of the Environment regularly organises information days – the annual radiation day, which always includes the topic of radon as one of the topics. For example, at the information day of 2017, participants were informed on how to measure radon concentrations in dwellings and workrooms; an overview was given on the use of radon protection measures and the radon atlas of Estonian soil was presented. A press release about the seminar was published on the website of the Ministry of the Environment.

Websites

Information on radon and helpful instructions are available on the following

websites: https://www.envir.ee/ – the website of the Ministry of the Environment;

https://www.keskkonnaamet.ee/ – the website of the Environmental Board;

https://www.egt.ee/ – Estonian Geological Service;

https://www.evs.ee/ – Estonian Centre for Standardisation (radon measurement and radon safe building design standards);

http://www.eak.ee/ – Estonian Accreditation Centre (accredited bodies and competent people who conduct measurements)

In addition to the aforementioned authorities, the importance of radon is also reflected on the websites of private companies that provide radon measurements and construction measures against radon.

Training events

In addition to information days for the public and information available on websites, training events are organised based on specific needs and target groups. For example, the Ministry of the Environment, in cooperation with the Foundation Environmental Investments Centre, organised a training event titled "Measurement of radon activity concentration" from 3–4 May 2016. The training providers were specialists from the Ministry of the Environment, the Finnish Centre for Radiation and Nuclear Safety and the Geological Survey of Estonia. The training event was attended by 15 people who conduct radon measurements and 15 people who conduct monitoring. In the future, the state is planning to organise such a training event for inspection officials (of the Labour Inspectorate and the Environmental Inspectorate) as well.

In 2018, the Environmental Board, with support from the Environmental Investments Centre, carried out a training programme for the environment specialists of local governments, as part of which participants were given a two-hour lecture on the nature of radon, the health risks thereof, opportunities for decreasing radon in indoor air and legislative acts concerning radon. The lecture was held on three instances and with over a hundred environment specialists from local governments participating. In the future, it is planned to continue providing training events for officials of local governments, especially those located on increased radon risk areas.

Teaching radon-related topics is currently not included in the mandatory part of any official curricula, but the aim should be to include it in various curricula. Emphasis must be put on updating curricula related to design and construction with topics of natural radiation, especially concerning radon-induced hazards and measures for decreasing those hazards, in order to increase the knowledge of specialists in this field.

Instructions and information materials

The following is a list of the most important instructions and information materials published in recent years on the topic of radon.

Information on how to design a radon-safe building can be found in the standard EVS 840:2017 “Guidance for radon-protective measures for new and existing buildings” and in information material of the Estonian Radiation Protection Centre “Radon-safe building”. The information booklet
“Radon in existing buildings”, published by the Ministry of the Environment, provides practical tips on how to decrease radon concentration in the air of buildings with increased radon concentration.

The new standard EVS 840:2017, enforced in 2017, provides instructions on how to design a radon-safe building as well as how to make an existing building radon-safe. The new standard also covers the measures for decreasing radon risk more thoroughly, starting from the principles of radon-safe construction and ending with specific solutions for old buildings with basements. The standard was also updated with text and visual materials in order to support the effective implementation of radon control measures.

The main goal of the Atlas of Radon Risk and Natural Radiation in Estonian Soil, completed in 2017, is to improve the population’s knowledge of levels of radon and natural radiation in Estonia and of the potential negative impact thereof to people’s health. The Atlas is meant to be used for assessing the need to implement measures for decreasing radon concentration, when preparing detailed plans, compiling construction regulations of local governments, as well as in research and studies.

At the end of 2016, the guidance material for measuring radon activity concentration (RAM 2016) was completed under the coordination of the Ministry of the Environment. The material is used to harmonise the various methods of radon measurement of different authorities in Estonia. The guidance material can be found on the website of the Ministry of the Environment.

As the field of radiation (including radon) has undergone significant progress in recent years (establishing the reference level for indoor radon concentration, updating the standard EVS 840, completion of RAM 2016, etc.), information materials aimed at the public, which provide an overview of ionising radiation, radon, legislation, radon measurements and constructional measures of radon protection, should also be updated.

Media

In addition to the aforementioned, notifications (content marketing articles, advertisements of companies) are issued via the media (television, radio, press) by the Ministry of the Environment, as well as by private companies. The Ministry of the Environment shall organise media coverage when new information is received on the topic of radon (e.g. a brochure is completed on the topic of the Radon Atlas, or amendments are made to it) or an information day is coming up.

Smoking

As smokers are more likely than non-smokers to develop lung cancer due to radon exposure, it is important to notify the public of the dangers of smoking.

The National Institute for Health Development conducts the following activities in order to limit the spread of tobacco use and to improve awareness among the public:

- preparing and publishing guidance materials and informative printed publications;
- providing counselling services on the topic of smoking cessation;
- working on decreasing the spread of smoking in the Estonian Defence Forces and health care institutions;
- preparing and carrying out training courses, information days and conferences;
- conducting a prevention programme “Smoke-Free Class” aimed at school students.

Various specialists are involved in activities of the National Institute for Health Development, including health care workers, psychologists, social workers, teachers, youth workers, etc.

11. Research and development

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 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 R&D has proven a successful practice, facilitating the impact of research in ensuring national interests and adoption of decisions. The aim of the R&D 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 R&D and spreading and facilitating their adoption. In order to achieve the objectives and increase the impact of research and development, the most important R&D activities of the Ministry of the Environment are the following:

- 6.1.1. Sectoral applied research needed to provide science-based input to policy-making and legislation.
- 6.1.2. Coordination and funding of participation in international research collaboration projects, including joint programming initiatives (JPI), ERA-Net projects and other international research collaboration projects.
- 6.1.3. Ensuring the sustainability of sectoral research and development and human resource development.

Radiation research and development in Estonia is largely project-based and mostly funded from research institutions and universities outside the budget, from EU and EIC funds, as well as from the budget of the Ministry of the Environment.

In the field of radiation, research is needed to support the protection of humans and the natural environment from the harmful effects of ionising radiation. In the field of radiation research, UT and TalTech have a leading position in research on radioactivity in drinking water, NORMs, radon, construction materials and the environment. The main radiation topics in research and development that should be focused on in the future 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;
- the support of research and development in the field of free technology for NORM residues and/or waste;
- soil radon studies;
- additional radiological examinations of construction materials used in Estonia.

11. Implementation Programme of the National Radon Action Plan

The National Radon Action Plan is part of the National Radiation Safety Development Plan. Activities planned in the field of radon, the relevant results, persons responsible, executors, conducting periods, costs and distribution of costs over time are included in the implementation programme of 2018–2021. The following is a brief list of the radon-related activities in the implementation programme and activities that are not covered by the period of the implementation programme (i.e. activities that are to be conducted after 2021).

Activities:

- Conducting additional radon studies in the soil air of administrative units that lack data for making conclusions concerning the potential increased radon risk (there are no measurement results or there have been insufficient measurements conducted).
- In order to get a more comprehensive overview, it is necessary to conduct a national indoor radon study.
- National studies should also include radon studies in the indoor spaces of establishments that have been assigned a lower reference level of the annual average value of radon activity concentration, 200 Bq/m³, as an exception.
- Studying the correlation between the radon concentration of soil air and indoor air, once the amount of measurement data of measurements conducted in indoor air and in the soil air of the same plot of land increases.
- Updating of the radon measuring equipment of the Environmental Board.
- Organising information days on the topic of radiation at least once a year.
- Developing the database for results of radon concentration measurements.
- Assessing the feasibility of and determining opportunities for taking radon into account in support programmes of reconstructing small private houses and apartment buildings.
- Conducting a study on the radioactivity (gamma radiation and radon exhalation) of building materials.
- Assessing the feasibility of conducting and epidemiologic study for identifying the link between radon and incidence of lung cancer.
- Adding courses on the principles of radiation protection (including radon) to various curricula.
- Organising radon-related training events for inspection officials.
- Determining people’s level of awareness concerning radon with a corresponding study.
- Compiling information materials aimed at the public concerning topics of radiation and radon.

Summary

Radon is the most significant radiation source among various natural sources of ionising radiation. Radon accounts for 1.26 mSv, i.e. about 52.1% of the annual effective dose (2.42 mSv/a) caused by natural radiation sources (UNSCEAR 2008). The main objective of the radon strategy of Estonia is to reduce the impact of radon on the population in workplaces and dwellings, thereby reducing the risk of lung cancer.

More general and specific principles of decreasing radon-related lung cancer risks have been regulated both at an international level as well as in legislation established in the Republic of Estonian. Legislation of the European Union 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. The most important legislative act in the field of radon is Council Directive 2013/59/Euratom, 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. The Directive requires the Member States to regulate radon-related issues in their legislation, including compiling a national radon action plan in order to contain the long-term risks arising from radon exposure. The aforementioned action plan provides, inter alia, compiling a strategy for conducting radon studies and the management of measurement data, notifying of radon, decreasing radon exposure in dwellings and workplaces, and decreasing the risk of lung cancer caused by radon exposure.

A brief overview of the Estonian radon strategy has been provided in this chapter. The strategy has been described in greater detail in chapters on corresponding topics.

The Estonian radon strategy is based on scientific studies and practice. Information on radon is distributed nationally based on both national and international (including the World Health Organization – WHO and the International Atomic Energy Agency – IAEA) studies, guidelines and experiences.

As radon migrates to the indoors spaces of workplaces from the ground and the prevalence of radon is largely unaffected by human activity at workplaces, it has to be deemed an existing exposure situation; however, as this kind of exposure is significant in some fields and some types of workplaces, relevant measures for decreasing radon exposure have to be implemented.

The national reference level of radon concentration in indoor workspaces has been set at 300 bq/m^3 and conducting radon concentration measurements is compulsory in workspaces, located on areas with increased radon risk, which are situated on the first floor or basement floor. The Environmental Board should also be notified of those workplaces where, despite the implementation of measures to decrease radon risk, radon concentration continues to exceed the national reference level. Employers are responsible for the protection of their employees in any exposure situation, including the protection of those employees who incur radon exposure on the job. Monitoring of radiation doses is required at workplaces with high radon level in indoor air, in some cases, medical surveillance and notification of employees is also necessary.

The radon strategy mostly focuses on the most significant pathway of radon – migration from the soil into buildings. The strategy covers the topic of radon in new and existing buildings, mostly in dwellings and workplaces. Other potential radon sources have also been included.

The most effective way to combat radon risk is to prevent it from getting inside buildings, instead of decreasing radon concentrations that are already indoors (i.e. fight with the consequences). When constructing new buildings, the strategic goal is to avoid high radon concentration in the buildings by implementing construction measures barring the release of radon into buildings. It is important to determine whether or not the radon activity concentration in the soil below the building could cause problems in the future already before the design stage of the building.

In case of existing buildings, the main aspects of the strategy are evaluation of risks and implementing measures for decreasing the radon risk.

When it comes to measurements, it is important that the measurements are conducted by a competent person who uses the appropriate measuring methodology and equipment and that the measurement results are traceable.

One part of the Estonian radon strategy is the mapping of radon risk areas. As at 2018, a total of 2/3 of the territory of Estonia has been mapped and based on the data available, it can be said that 36 administrative units are located on areas with increased radon risk and 24 administrative units are located on areas with low or average radon risk. No measurements have been conducted on areas with addition research needs (19 administrative units), or the number of measurements conducted has been insufficient for assessing the radon risk. Additional mapping will be conducted from 2019–2024.

The radon strategy also takes into account the synergism between radon exposure and smoking, which increases the risk of lung cancer. Namely, smokers are more likely to develop radon-induced lung cancer than non-smokers. A study conducted among non-smokers in Sweden showed that there is a synergistic relationship between radon and second-hand smoke as well. The strategy for reducing smoking is the main strategy in Estonia that is aimed at decreasing the population's risk of developing lung cancer.

The aim of the radon related notification strategy is to increase the public awareness of risks related to radon (including the connection to smoking), as well as the awareness of decisionmakers on the local level, employers and employees. In order to notify the public and specialists in the radon field, information days are organised, websites of state authorities updated with additional information, new informative materials are compiled, training events organised, information shared via media channels (television, radio, press).

References

Clavensjö, B., Åkerblom, G., 1994. The Radon book. Measures against radon, Swedish Council for Building Research, Stockholm, 129.

IAEA Safety Standards for protecting people and the environment. Protection of Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation. No. SSG-32. 2015. International Atomic Energy Agency, Vienna.

ICRP, 2010. Lung Cancer Risk from Radon and Progeny and Statement on Radon. ICRP Publication 115, Ann. ICRP 40(1).

Petersell, V., Åkerblom, G., Ek, B.-M., Enel, M., Mõttus, V., Täht., K., 2004. Radon risk map of Estonia. Explanatory note. Tallinn-Stockholm, 52.

Petersell, V., Åkerblom, G., Ek, B.-M., Enel, M., Mõttus, V., Täht, K., 2005. Radon Risk Map of Estonia: Explanatory text to the Radon Risk Map Set of Estonia at scale of 1 : 500 000 Report 2005:16. Swedish Radiation Protection Authority (SSI), Tallinn-Stockholm, 74.

Design of radon-safe buildings, 2003. Estonian Standard. (EVS 840:2003).

Design of radon-safe buildings, 2009. Estonian Standard. (EVS 840:2009).

Guidance for radon-protective measures for new and existing buildings, 2017. Estonian Standard. (EVS 840:2017).

RAM 2016 Radooni aktiivsuskontsentratsiooni mõõtmine [RAM 2016. Measurement of radon activity concentration] Ministry of the Environment.

Kiisk, M.; Suursoo, S.; Isakar, K.; Koch, R. 2011. Relevant radionuclides in Estonian drinking and ground waters – measurement techniques and activity concentrations. Radioprotection, 46 (6), 107−112.

Lagarde, F., Axelson, G., Damber, L., Mellander, H., Nyberg, F., Pershagen, G. 2001. Residential radon and lung cancer among never-smokers in Sweden. - Epidemiology, **12,** 4, 396–404

UNSCEAR 2008. Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly with Scientific Annexes. (Vol 1, Annex B: Exposures of The Public and Workers from Various Sources of Radiation, p. 404.) New York, 2010.

WHO Handbook of Indoor Radon, WHO 2009.

Zeeb, H., Shannoun, F. (Eds.). (2009). WHO handbook on indoor radon: a public health perspective. Switzerland, Geneva: WHO Press.