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UNDERGROUND SMALL MODULAR REACTORS FOR DISTRICT HEATING

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Abstract: Underground space is a resource for those functions that do not need to be on the surface. From the point of sustainability there are several benefits of locating technical maintenance systems underground such as expenses are shared by several users, land is released for other construction purposes, the city's appearance and image are improved.

Electricity and heat differ from each other in terms of energy distribution. Electricity can be transmitted through extensive distribution networks over thousands of kilometres across national borders. Heat, on the other hand, is both produced and consumed in connection with the local or regional district heating network. Centralised heat production is represented by district heating, where heat is distributed to customers through hot water or steam flowing in underground pipes. Distribution networks typically cover individual cities and multiple industrial sites.

District heating is commonly used throughout Europe, with around 3 500 networks serving 60 million people. 75 % of production is covered by fossil fuels, so the need to reduce emissions is considerable. Existing large networks are located in the Nordic and Baltic countries and Eastern and Central Europe.

There are just a few Small Modular Reactor (SMR) projects in the world designed for heat production only. The Low-temperature District heating Reactor (LDR-50) technology by a Finnish technology company is based on well-known light water reactor technology. The goal is to commission the first underground plant based on small nuclear reactor technology to be connected to the district heating network in 2030. So far, several cities in Finland, Poland and Baltic countries have been investigated as possible locations for underground SMR plants.

Keywords: Cut and Cover, district heating, Drill and Blast, Small Modular Reactor, sustainability

1. INTRODUCTION

Half of the energy we consume is used for heating and cooling and most of that energy still comes from fossil fuels. Heating alone accounts for up to 12 gigatons of CO2 emissions annually. Transitioning to carbon-free nuclear has enormous potential to make an enormous impact. The Finnish designed Low-temperature District heating Reactor LDR-50, with its small modular design, offers unmatched efficiency, making it ideal for dense urban environments. Each unit generates 50 MW of zero-carbon thermal power. A few units can warm an entire medium sized city, whatever the weather (Steady Energy, 2025).

The LDR-50 is small, in fact so small that, it can be built underground. No need for chimneys, mountains of coal, colossal fuel tanks, or large supporting superstructures. This invisible, yet impactful solution is the answer to urban heating headaches. No polluted air, water, or skylines - just clean, reliable warmth.

Water scarcity is a growing crisis, propelled by climate change and overconsumption. Desalination has the potential to generate theoretically unlimited fresh water but that comes at a high environmental cost due to its current reliance on fossil fuels.

Acceptability for the use of nuclear energy has increased significantly, and it is assumed that acceptability will be even higher when the plant is placed underground. There are also many other advantages of underground solutions over terrestrial alternatives. Table 1 presents some main advantages of underground solutions (Vähäaho, 2016).

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Table 1. Advantages of underground solutions over terrestrial alternatives.

1	Reliability of energy distribution through a looped tunnel network
2	Optimisation of energy production in the transmission network
3	Costs are shared between multiple users
4	The land is released for other construction
5	The appearance of the city is improved when technical facilities and wires are placed in tunnels and streets/plots do not need to be opened
6	Tunnel construction works have significantly fewer disadvantages
7	Quarry from tunnel construction can be utilised
8	Equipment in tunnels requires less maintenance and is easier to maintain
9	Failure of technical systems does not pose a great danger to the public
10	Tunnels are a safe option in a crisis

2. LOW-TEMPERATURE DISTRICT HEATING REACTOR

The Low-temperature District heating Reactor (LDR-50) is a small-scale nuclear reactor for district heating. LDR-50 operates at a temperature of less than 160 °C. The designation LDR-50 refers to a reactor with a thermal power of up to 50 MW and 300 GWh/reactor/year. There is no external cooling water circulation. Coolant circulates between the core and the main heat exchangers by natural convection. Heat is transferred to the district heating network via the secondary circuit. Spent nuclear fuel can primarily be stored at the plant for several years, at least two years, after which it is safely transferred to dedicated intermediate storage or final repository.

LDR is based on well-known light water reactor technology. Figure 1 shows LDR-50 operating principle and an illustration of an underground LDR-50 heating plant.

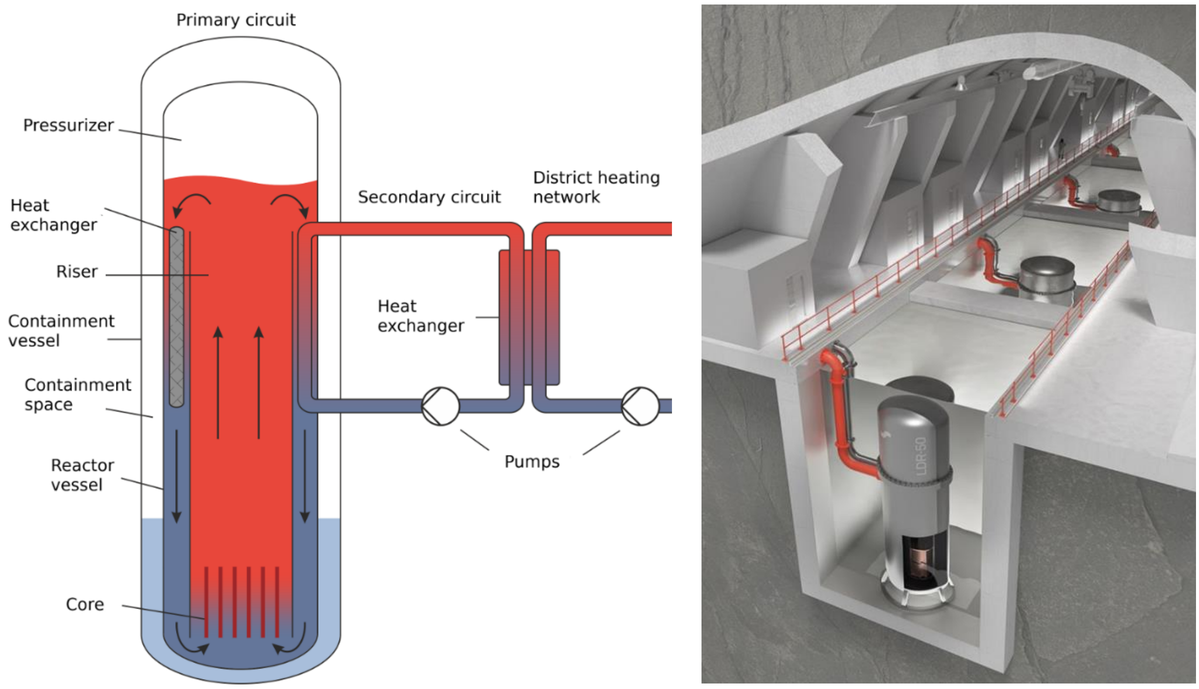


Figure 1. *LDR-50 operating principle and illustration of an underground LDR-50 heating plant.*

3. PRELIMINARY SKETCH OF AN UNDERGROUND FOUR-REACTOR LDR-50 HEATING PLANT

The size of the hall of the four reactors is approximately 35 metres wide, 33 metres high and 200 metres long, length depending on the number of reactors (Figure 2). The reactor vessel is about 11 metres high, i.e. about 20 metres from floor to ground.

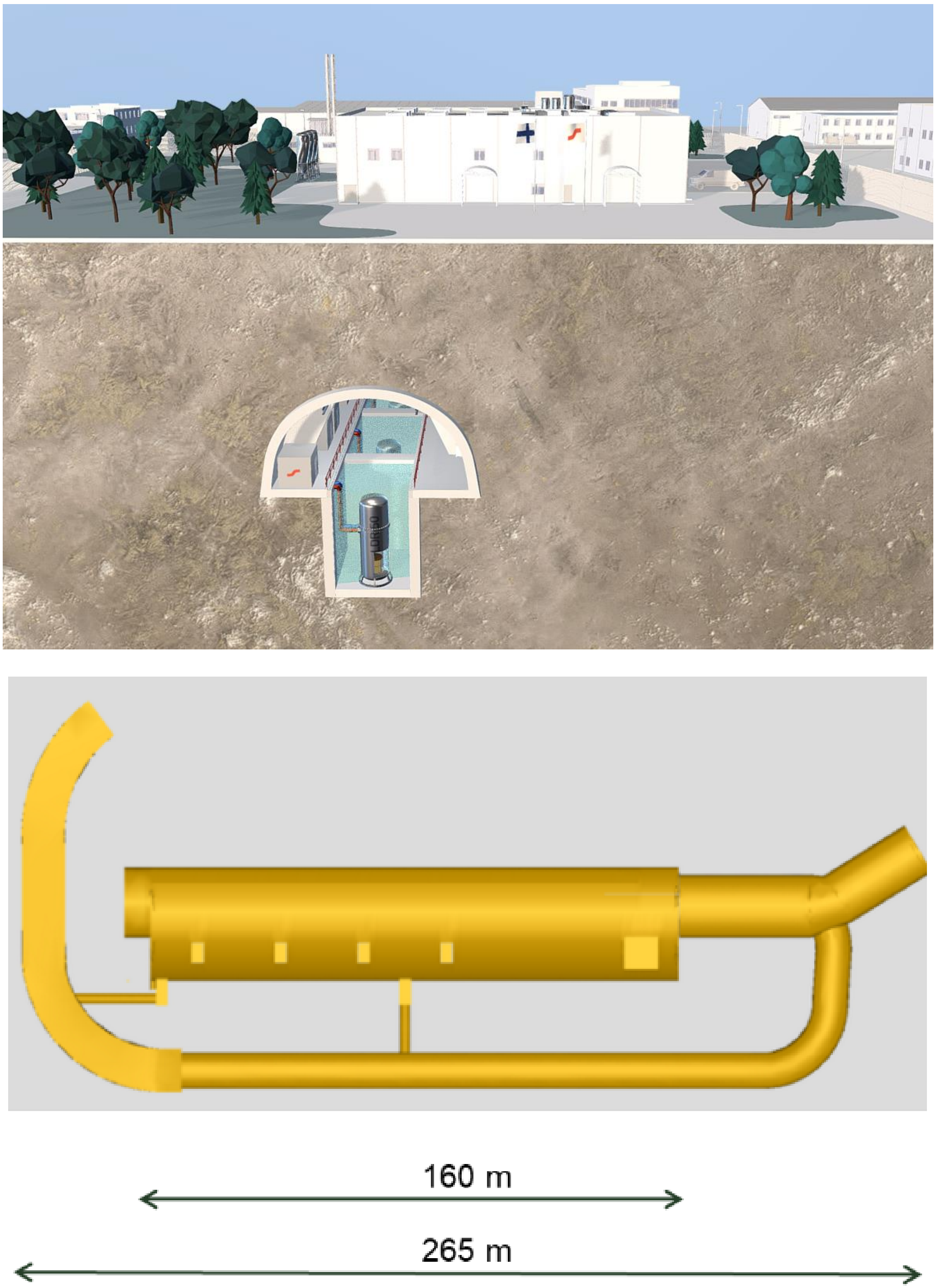


Figure 2. *Preliminary sketch of an underground four-reactor LDR-50 plant.*

4. WHO IS THIS NEW TECHNOLOGY FOR?

Heating of residential buildings and other premises consumes a lot of energy in countries with cold winter climate. In Europe, the homes of 60 million people are kept warm by 3,500 local district heating networks (VTT, 2025).

The principle of LDR technology is to provide carbon-free energy to existing energy companies. Our project has started with research and development work. The next step is to build a pilot reactor and then start operations and expand to full-scale heat production at an underground plant by 2030. In addition to Finland, locations have so far been explored in Poland and Baltic countries, Estonia as an example.

Location of existing district heating networks in EU countries can be viewed using the Halmstad University District Heating and Cooling database (Persson et al., 2012). The dataset was created by extracting all hectare grid cells from the Heat Roadmap Europe 4 heat demand density raster with values of 500 GJ/ha and above, converting this raster data subset into a polygon layer, and adding various attributes from other sources, mainly data on current district heating systems from the Halmstad University District Heating and Cooling database.

Figure 3 shows European cities with district heating systems (district heating areas by red colour). Figure 4 shows an example of locations of existing district heating networks in Southern Finland.

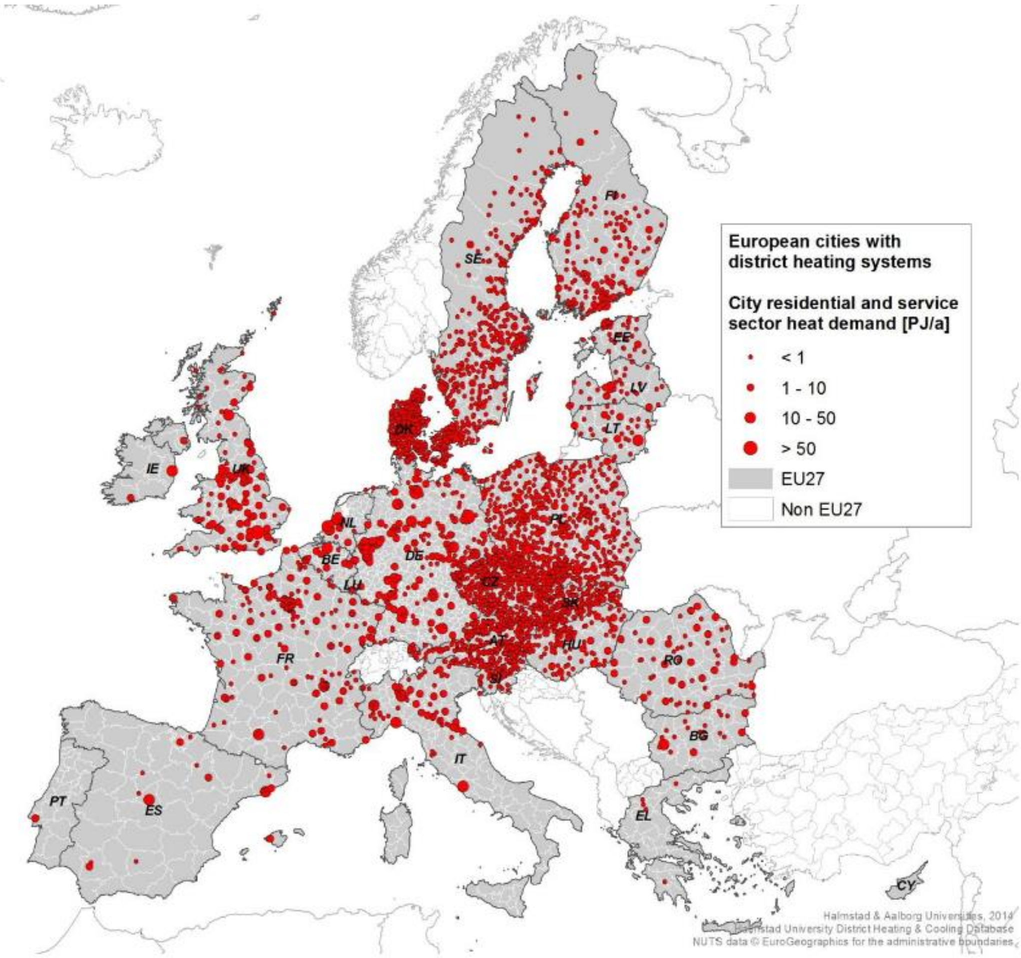


Figure 3. *European cities with district heating systems.*

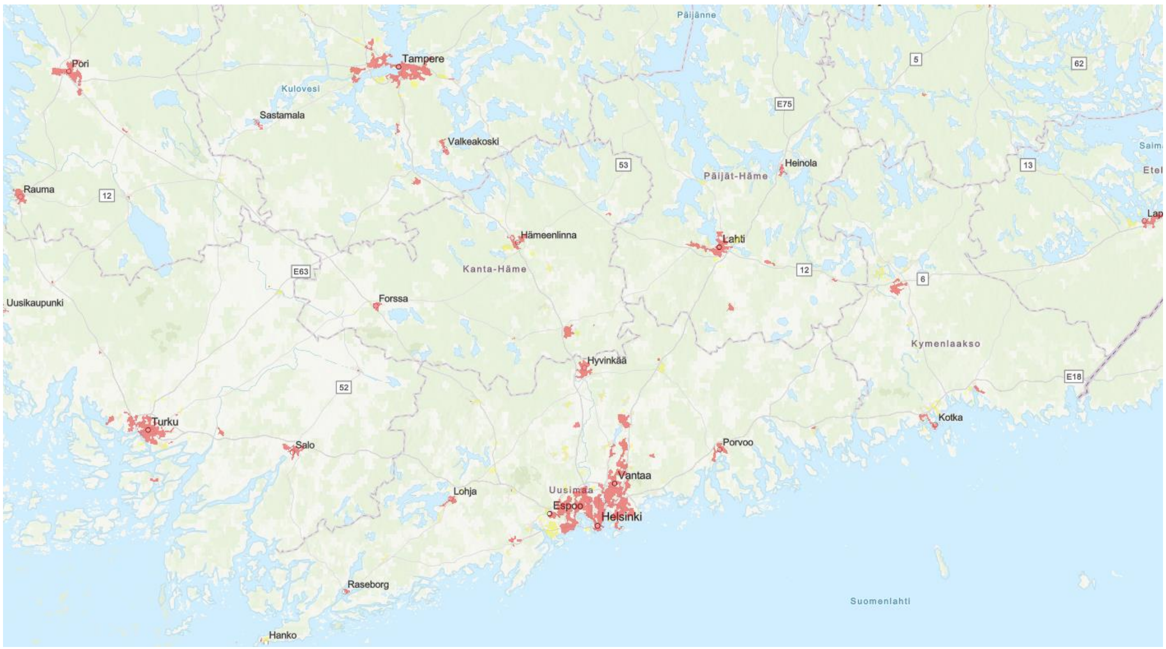


Figure 4. *An example of locations of existing district heating networks in Southern Finland.*

5. PLACEMENTS OF UNDERGROUND SMALL MODULAR REACTORS IN POLAND, ESTONIA AND FINLAND

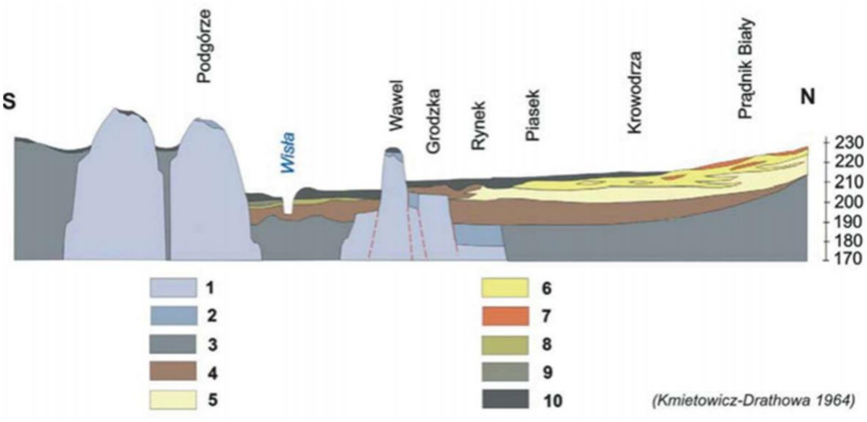
From the point of view of the placement of an underground small modular reactor (SMR) plant, the following are the starting points for each country and region:

- district heating market
- legislation and regulations
- zoning situation
- earthquake risk
- geology
- groundwater
- soil contamination

Following a preliminary evaluation of the above points, an in-depth analysis of alternative locations is expected to be carried out in accordance with the IAEA (International Atomic Energy Agency) Safety standards. In the following, we will focus only on the effects of geology on the placements of underground SMR plants. The feasibility of the following methods was investigated: Drill and Blast (D&B) Method, New Austrian tunnelling Method (NATM), Tunnel Boring Method (TBM) and Cut and Cover Method.

In **Poland**, four cities were studied in terms of the feasibility of the SMR plant. The recommendation for the basic solution for underground SMR plant in all the cities studied is the Cut and Cover Method and its implementation with Diaphragm Wall Construction. This recommendation is especially meant for tentative economic analyses.

Poland is covered with deposits of different genesis: alluvial, eolian, lacustrine, glacial, fluvioglacial and sea deposits. Most of the rocks found on Poland’s area are sedimentary rocks (detrital, chemical, organogenic); in southern area within mountain ranges we can find igneous and metamorphic rocks. For example, near the centre of Warsaw the thickness of quaternary deposits is more than 100 metres. Figure 5 shows an example of the geological conditions of the city of Krakow in southern Poland (Gaszyńska-Freiwald and Truty, 2024).



. Schematic geological cross section through subsoil of Krakow: 1 – Jurasic limestones, 2 – Cretaceous marls, 3 – Miocene clays, 4 – Carpathian gravels, 5 – limestone gravels of Prądnik Stream, 6 – Pleistocen sands, 7 – less, 8 – Holocene sands, 9 – Holocene loam, 10 – anthropogenic fill

Figure 5. *Schematical geological cross section through subsoil of Krakow in Poland.*

In **Estonia**, three cities were studied in terms of the feasibility of the SMR plant. Cut and Cover method is the most suitable method for all studied cities.

Buried valleys is a speciality in Estonia. Special attention should also be paid to groundwater protection during the construction and operation phase. In terms of the construction of underground spaces and tunnels, buried valleys are the most difficult and expensive sites from a geological point of view, and their location is the most important initial information in the planning and constructing underground. Fortunately, the public register of Estonian underground data (Geological Survey of Estonia, 2025) is the best that has come across in SMR investigations so far. Figure 6 shows an example of a buried valley in Tallinn, Estonia (Vaher et al., 2012).

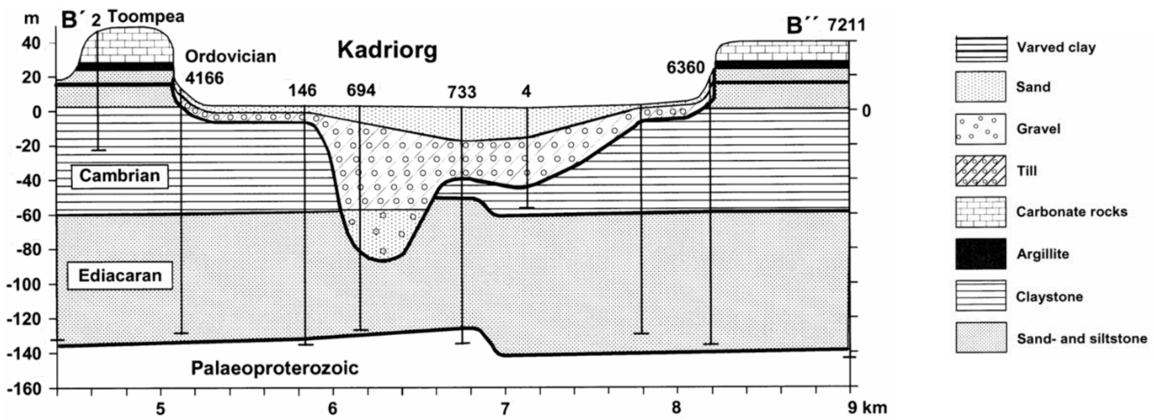


Figure 6. *An example of buried valley cross section in Kadriorg branch of the Tallinn incision*.

Buried valleys are ancient river or subglacial (beneath a glacier) drainage networks that are now abandoned and have become either partly or completely buried by more recent sediment. As such, buried valleys often exhibit little or no surface expression within the modern landscape. The concealed occurrence of buried valleys can have significant and often unexpected implications for groundwater and hydrocarbon or geothermal resources. Buried valleys can also be significant stores of sand and gravel mineral resources, which can act as traps for contaminants as well as pathways into groundwater aquifers (British Geological Survey, 2025).

In **Finland**, five cities, in a total of 10 different locations, were studied in terms of the feasibility of the SMR plant. In all cases, placement has been sought in hard pre-Cambrian bedrock. In Finland, a self-supporting rock space is an inexpensive alternative by far. The construction method is invariably D&B method.

Helsinki is a forerunner in the utilisation of underground space both in Finland and internationally. Helsinki makes use of the underground opportunities in a variety of ways. As far as is known, Helsinki has the world's only underground master plan that covers the entire city. The underground master plan is the city's strategic land use plan, which reserves underground spaces for the city's vital functions and traffic in the long term. The underground master plan supports and enables the densification of the urban structure and a pleasant environment above ground. In Helsinki, there is a practice according to which the property above cannot restrict the use of the underground space if it does not cause any harm and the property above does not lose anything. For decades, the City of Helsinki's practice has been that the right of use of an above-ground property extends six metres from the lowest corner point of the plot, even if the right of ownership extends to the centre of the Earth. Helsinki's underground master plan 2021 includes several sites that have already been zoned for underground operations.

Helsinki's landscape is quite flat – the highest natural point is only 60 metres above sea level. One third of Helsinki's ground is clay with an average thickness of three metres and shear strength of around 10 kPa. The average depth of soil material upon bedrock is seven metres but varies from 0 to almost 70 metres. The bedrock quality in Finland is, for the most part, ideal for tunnelling and building underground spaces since the bedrock mainly consists of old pre-Cambrian rocks and there are only a few places where younger sedimentary rocks exist. There are no sedimentary rocks in the Helsinki area; however, there are several fracture zones formed by rock block movements that cross the bedrock in the city centre. It is important to identify the locations and properties of these zones in the planning and excavation of rock constructions. In the early stages of the Svecofennian Orogeny, rock deformations were ductile; later, the rock cooled down and the deformations at the topmost layers became brittle and formed faulted structures. The fault zones were subsequently fractured by weathering, hydrothermal alterations, recrystallisation and later movements. Being more fragmented than surrounding areas, the fractured zones have eroded more rapidly and are seen as depressions in the topography. The fractured zones have had a great impact in defining the shoreline of Helsinki's city centre. The fractured zones are usually under a thick layer of soil and therefore hard to examine. However, there are signs of movements on nearby rock surfaces which help to locate those zones (Vänskä and Raudasmaa, 2005).

Figure 7 gives an example of the public Map Service of the City of Helsinki with information on bedrock, soil and bedrock surveys and fracture zones of bedrock (Helsinki Map Service).

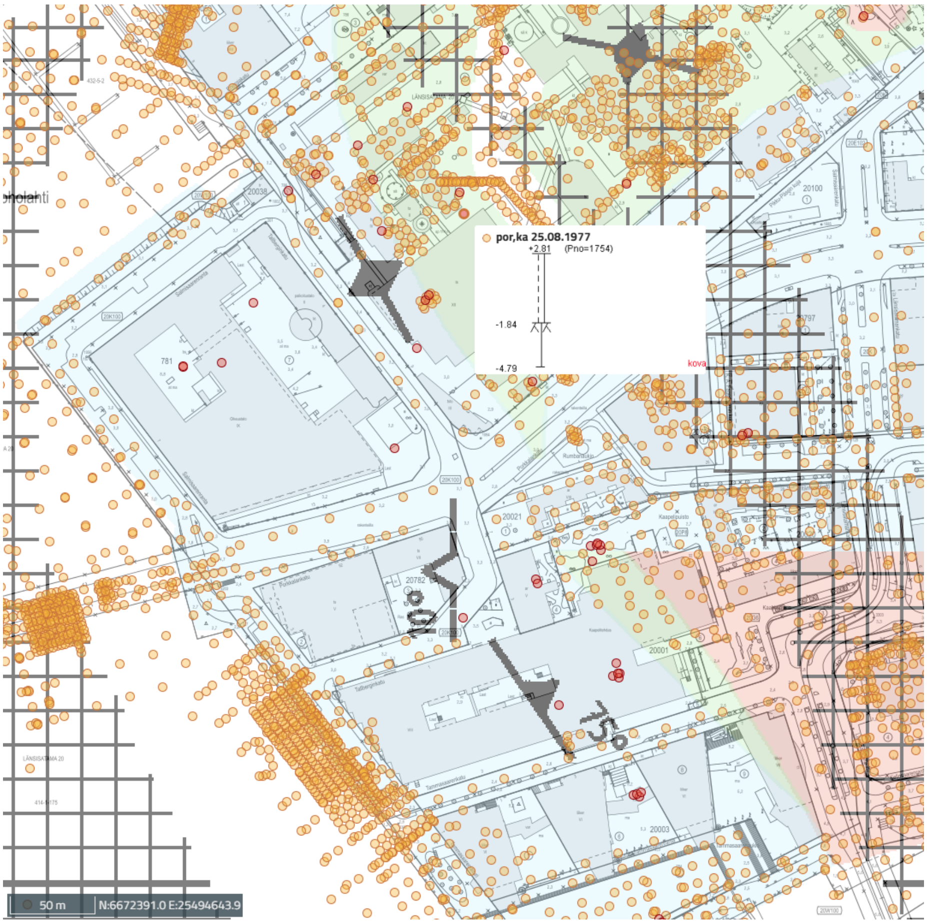


Figure 7. *An example of the public Map Service of the City of Helsinki with information on bedrock, soil and bedrock surveys and fracture zones of bedrock.*

6. CONCLUSIONS

Heating of residential buildings and other premises consumes a lot of energy in countries with cold winter climate. In Europe, the homes of 60 million people are kept warm by 3,500 local district heating networks.

Acceptability for the use of nuclear energy has increased significantly, and it is assumed that acceptability will be higher when the plant is placed underground. There are also many other advantages of underground solutions over terrestrial alternatives.

In this research only the effects of geology on the placement of an underground SMR plant have been studied, though the main arguments are district heating market, local legislation and regulations and zoning situation. The feasibility of the following methods was investigated: Drill and Blast (D&B) Method, New Austrian tunnelling Method (NATM), Tunnel Boring Method (TBM) and Cut and Cover Method.

Placements of underground small modular reactors have been studied so far in Poland, Estonia and Finland. Total number of studied cities is 12.

Poland is covered with deposits of different genesis: alluvial, eolian, lacustrine, glacial, fluvioglacial and sea deposits. Most of the rocks found on Poland’s area are sedimentary rocks; in southern area within mountain ranges we can find igneous and metamorphic rocks. For example, near the centre of Warsaw the thickness of quaternary deposits is more than 100 metres. In Poland the basic recommendation for underground SMR plants is the Cut and Cover Method and its implementation with Diaphragm Wall Construction.

Buried valleys is speciality in Estonia. In terms of the construction of underground spaces and tunnels, buried valleys are the most difficult and expensive sites from a geological point of view, and their location is the most important initial information in the planning and constructing underground. Fortunately, the public register of Estonian underground data is the best that has come across in SMR investigations so far. Cut and Cover method is the most suitable method for all studied cities in Estonia.

Helsinki is a forerunner in the utilisation of underground space both in Finland and internationally. Helsinki makes use of the underground opportunities in a variety of ways. Underground space is a resource for those functions that do not need to be on the surface. The underground master plan is the city's strategic land use plan, which reserves underground spaces for the city's vital functions in the long term. In Finland, five cities in a total of 10 different locations, were studied in terms of the feasibility of the SMR plant. In all cases, placement has been sought in hard pre-Cambrian bedrock. In Finland, a self-supporting rock space is an inexpensive alternative by far. The construction method is invariably D&B method.

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