LDR-50 District heating reactor

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Rakenteiden mekaniikan seuran teemailta 17.11.2023

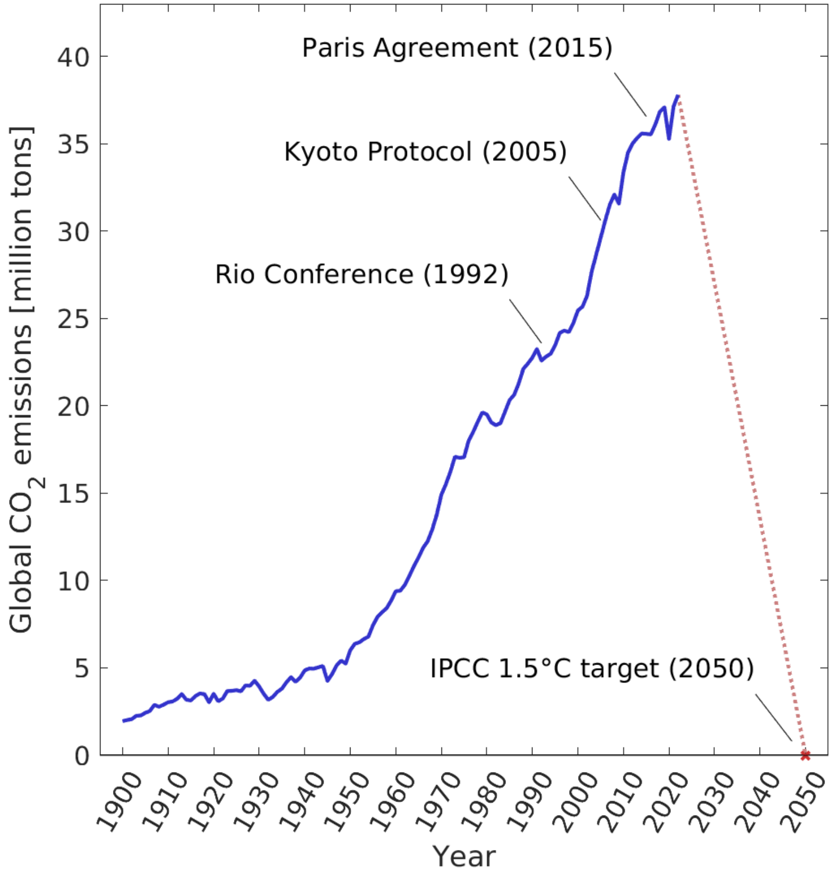
LDR

Outline

- Background – why use nuclear reactors for district heating?
- VTT’s district heating reactor project
- LDR reactor technology

Climate crisis

- IPCC: Limiting the adverse effects of climate change requires stopping global warming to 1.5°C
- This can be accomplished only by reducing global net CO_2 emission to zero by 2050
- Energy sector is a major source of carbon emissions
- Achieving the goal requires a comprehensive overhaul of the entire energy system
- Long way to go – emissions are still on the rise, despite political agreements and significant investments in renewable energy!



Carbon emissions from the energy sector

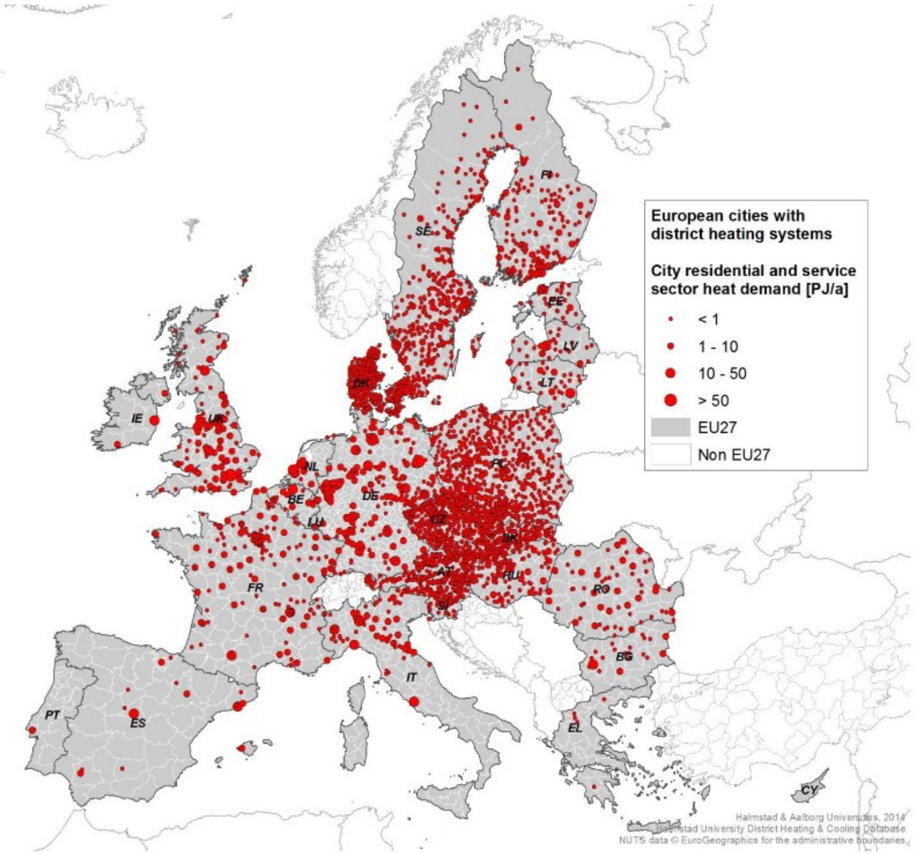
- Climate action is strongly focused on electricity production, but fossil fuels are the main source of energy also in transportation, industry and heating
- Electrification provides solutions, but also increases the demand for low-carbon electricity
- Long-term plans rely on hydrogen economy

Major challenges especially in applications where fossil energy is consumed in some other form than electricity

Electrification of the energy system leads to competition between different segments

Carbon emissions from the energy sector

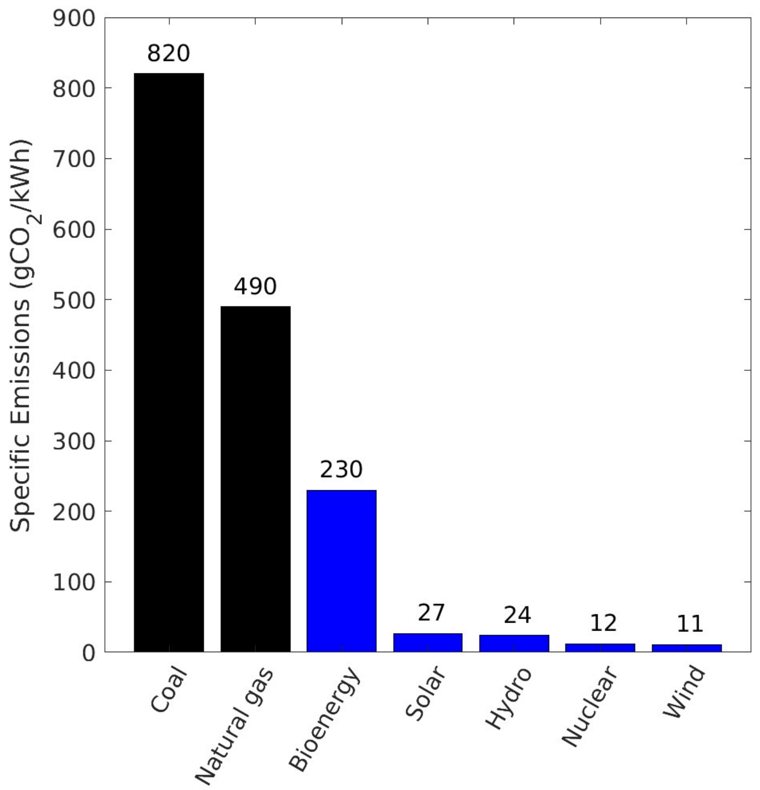
- Heating is a major source of carbon emissions in countries with cold winter climate
- Alternatives to fossil fuels (bioenergy, geothermal, heat pumps) have their limitations
- District heating is a popular heating form in Europe (3500 networks, 60 million people)
- Much of the production is co-generation using fossil fuels – decarbonization with wind, solar or conventional nuclear energy de-couples heat from electricity
- Natural gas is no longer considered a viable interim solution



What about nuclear?

- Energy in nuclear fission is released as heat – could this be applied to district heating?*
- Nuclear certainly has some advantages:
  - Low carbon footprint (comparable to wind power)
  - Production not dependent on weather conditions or market price of electricity
  - Capable of base-load and load follow operation
  - Security of supply (fuel for several years of operation can be stored on site)
- But unlike electricity, heat cannot be transported over long distances – are we ready for urban reactors?

* The idea is not completely new. Nuclear power plants have been used for co-generation in Bulgaria, China, Hungary, Russia, Sweden, Switzerland, Slovakia and Ukraine.



IPCC life-cycle estimates of specific CO_2 emissions for different energy sources (electricity production)

VTT's district heating reactor project

- VTT's district heating reactor project was launched in 2020:
  - District heating covers almost 50% of the Finnish heat market
  - Phase-out of coal in energy production by 2029
  - Peat and natural gas not viable options, biomass considered only an interim solution
- Preliminary market studies at VTT in 2019:
  - Nuclear energy is an economically viable heating option in the 2030's
  - However, none of the developed SMR concepts provides an ideal solution for the Finnish case

Finnish firm launches SMR district heating project

24 February 2020

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VTT Technical Research Centre in Finland has today announced the launch of a project to develop a small modular reactor for district heating. Most of the country's district heating is currently produced by burning coal, natural gas, wood fuels and peat, but it aims to phase out its use of coal in energy production by 2029.

Helsinki (Image: Pixabay)

VTT noted that decarbonising the district heat production system is "one of the most significant climate challenges faced by many cities". The objective of the project is to create a new Finnish industrial sector around the technology that would be capable of manufacturing most of the components needed for the plant, the company said. Designing the district heating reactor will require expertise from a wide range of Finnish organisations, it added.

"The schedule is challenging, and the low-cost alternatives are few," said Ville Tulkki, research team leader at VTT. "To reach the target, new innovations and the introduction of new technologies are required. Nuclear district heating could provide major emission reductions."

VTT - which has about 200 researchers working with nuclear energy and related applications - said it will rely on in-house calculation tools and use its multidisciplinary competence to develop the SMR. "For example, in the modelling of the reactor core, we are able to apply high-fidelity numerical simulation methods that have become feasible by the advances in high-performance parallel computing," said Jaakko Leppänen, research professor for reactor safety at VTT.

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What's so special about district heating?

	Coal	Waste	Natural gas	Wood and peat	Industrial wood based	Oil	Large heat pumps	Other	Plant count
200+ MW_{DH}	2	0	6	2	0	3	0	0	13
100-200 MW_{DH}	8	2	7	15	4	9	0	0	45
50-100 MW_{DH}	1	2	10	12	4	22	1	0	52
20-50 MW_{DH}	1	5	33	34	8	73	2	3	159
0-20 MW_{DH}	0	10	109	240	46	310	9	19	743
Plant count	12	19	165	303	62	417	12	22	1012
Sum MW_{DH}	2160	614	5232	5480	1258	7902	172	133	23000

- The total capacity of current heating plants in Finland is more than 20 GW, but the consumption is divided into 166 municipal district heating networks
- Conventional SMRs could replace large co-generation units in the capital region, but most networks cannot utilize the full capacity of a typical reactor designed primarily for electricity production
- Heat-only reactors are developed in China, but they are designed for the local needs (cities with millions of inhabitants)
- SMR-scale HTGRs designed to produce industrial heat could be used for co-generation, but applications for high-temperature heat do not exist in every network

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What's so special about district heating?

- Electricity production at high thermal efficiency requires ~300 °C steam, but district heating networks operate at 65–120 °C
- The operating pressure of the reactor can be reduced from 15 MPa to less than 1 MPa (closer to an espresso machine than a traditional PWR)
- Modest operating conditions simplify manufacturing of pressure components and design of passive safety systems
- When the reactor is designed for production heat, there is no need for turbine or generator

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LDR district heating reactor technology

- The developed technology was named LDR (Low-temperature District heating Reactor)*
- Conceptual design 2020-2022 (self-funded project)
- In January 2023 VTT announced a two-year 5M€ investment to advance and commercialize the technology
- Currently involves 30–40 technical experts from VTT, external partners involved through contract work
- Spin-off company Steady Energy founded in June – technical development continues at VTT as contract work
- Milestones: large-scale electrically heated test facility (2027), Pilot plant (2030), commercial technology (2030’s)

* In some contexts also referred to as “Low-temperature District heating and *Desalination* Reactor.

VTT haluaa saada Suomeen ensimmäisen kaukolämpöreaktorin vuonna 2030

Hanke on yksi VTT:n tänään julkistamista viidestä investointikohteesta.

JAA

VTT:n toimitusjohtaja Antti Vasara VTT:n tiedotustilaisuudessa tiistaina. KUVA: MARKKU ULANDER / LEHTIKUVA

STT
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TEKNOLOGIAN tutkimuskeskus VTT asettaa tavoitteeksi, että Suomeen rakennetaan ensimmäinen kotimainen kaukolämpöreaktori vuonna 2030. Hanke on yksi VTT:n tänään julkistamista viidestä investointikohteesta, joilla pyritään edistämään kestävää teollista kasvua ja vihreää siirtymää sekä kiihdyttämään yritysten uudistumista ja kilpailukykyä.

VTT on kehittänyt kaukolämmön tuotantoon tarkoitettua LDR-50-pienydinreaktoria vuodesta 2020. Tavoite on kaupallistaa teknologia tämän vuosikymmenen loppuun mennessä. VTT investoi kaukolämpöreaktorin jatkokehitykseen viisi miljoonaa euroa vuosina 2023–2024.

Energiayhtiöt toivovat valtiota mukaan Suomen ensimmäiseen pienydinvoimalaan – haaveena sarjatuotanto ja miljardiluokan vientituote

Energiayhtiöiden kaavailema laitos tuottaisi lämpöä, mutta ei sähköä. Selvityksen mukaan pelkästään kaukolämpöä tuottava reaktori olisi edullisempi ja nopeampi toteuttaa.

Yksi pienydinvoiman pilottihanketta penäävän lausuman allekirjoittaneista yhtiöistä on Tampereen Sähkölaitos. Video: kuvaus ja toimittaja Juha Kokkala, editointi Marko Melto / Yle

ANTTI PALOMAA

18.1. 8:00 · Päivitetty 18.1. 10:37

Jaa

Suomalaiset energiayhtiöt kehottavat valtiota nopeisiin toimiin ensimmäisen pienydinvoimalan saamiseksi Suomeen. Viisi yhtiötä ja Lappeenrannan kaupunki ovat laatineet asiasta julkilausuman. Ne toivovat tulevalta hallitukselta päätöstä pienydinvoiman pilottihankkeen edistämisestä ja rahoituksesta.

Lausuman allekirjoittaneet energiayhtiöt ovat Imatran Lämpö, Kuopion Energia, Lappeenrannan Energia, Pori Energia ja Tampereen Sähkölaitos.

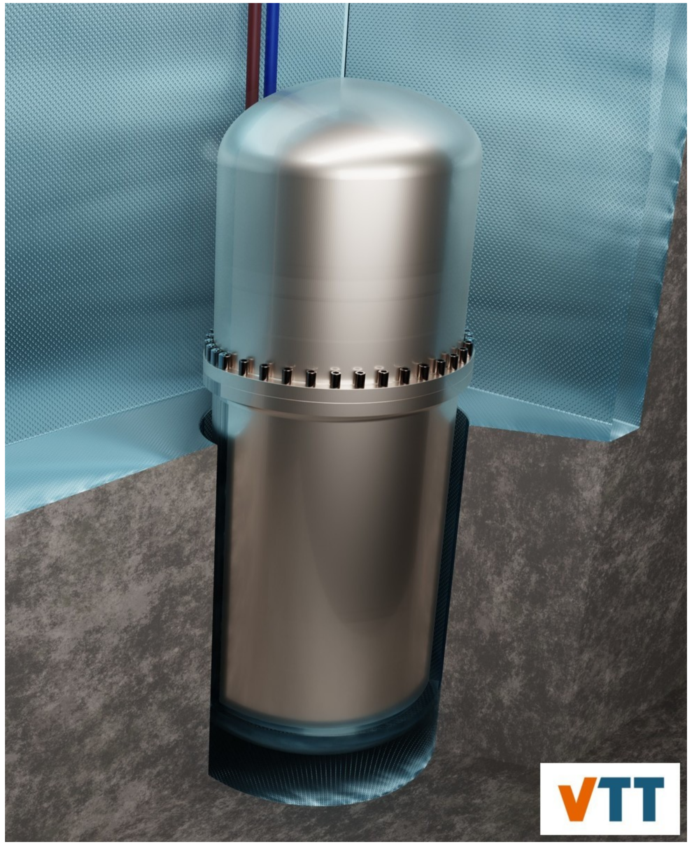
UUTINEN / 3.10.2023

Helen ja Steady Energy tähtäävät ydinlämpötuotannon käynnistämiseen Suomessa

Helen ja Steady Energy ovat solmineet pienydinvoimaa koskevan aiesopimuksen, jonka tavoitteena on mahdollistaa investointi pieneen lämpöä tuottavaan ydinvoimalaitokseen. Pienydinvoima on yksi lupaavimmista ratkaisuista, jolla energiantuotannon päästöjä saadaan vähennettyä nopeasti ja kustannustehokkaasti sekä sähkön että lämmön tuotannossa, mutta sen rakentaminen edellyttää vielä muun muassa lainsäädännön uudistamista.

Aiesopimuksen mukaan Helen ja Steady Energy käynnistävät suunnittelun, jonka tavoitteena on saavuttaa ydinlämpötuotantoa koskeva ennakkoinvestointisopimus seuraavan puolen vuoden aikana. Vuosille 2024–2027 sijoittuva sopimus kattaisi muun muassa ydinenergialain uudistamisen edistämisen, sijoituspaikka- ja teknologialuvan hakemisen sekä laitoksen kauppahinnan kiinnittämisen. Lisäksi se mahdollistaisi Helenille jopa kymmenen teholtaan 50 megawatin reaktoriyksikön hankkimisen Steady Energyltä. Helen on ensimmäinen Steady Energyn kanssa yhteistyöhön ryhtyvä energiayhtiö.

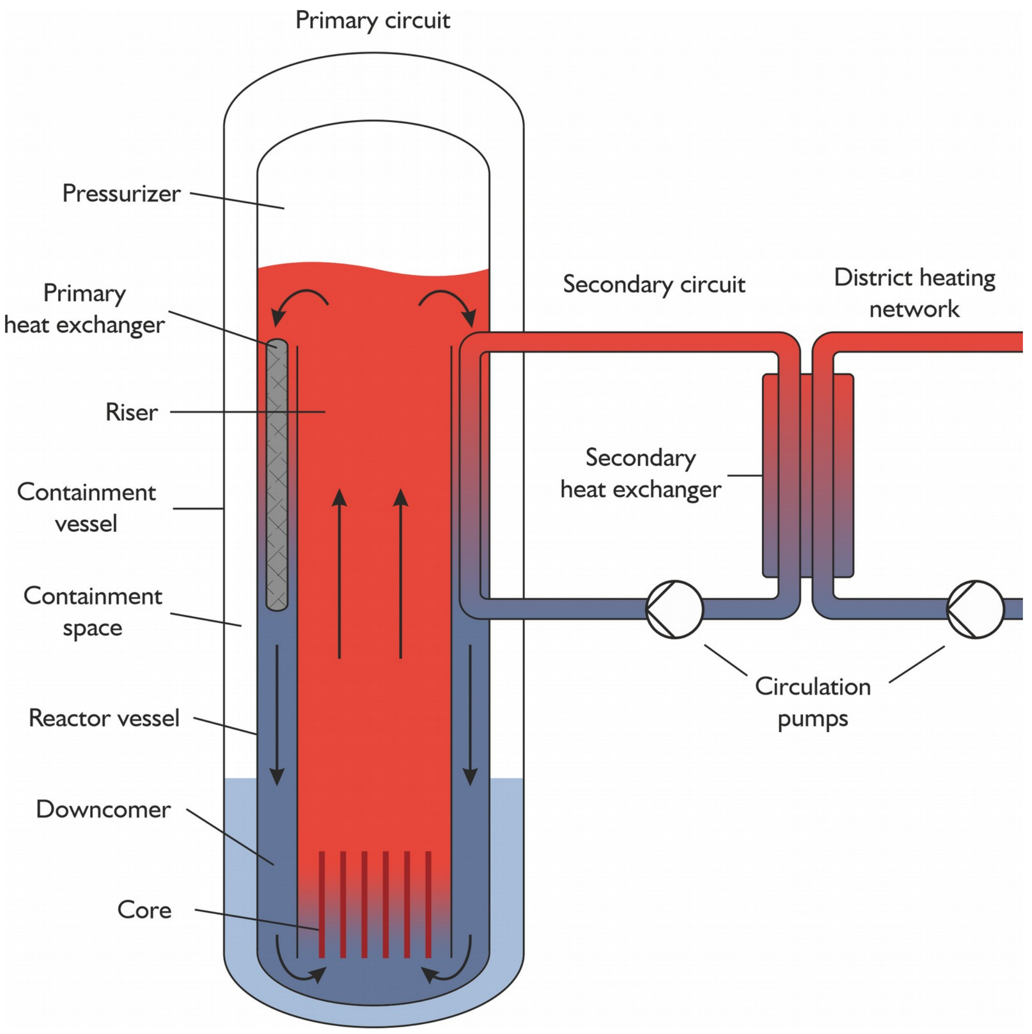
LDR district heating reactor technology



- Design goals:
  - Basic solutions relying on well-known light water reactor technology (more than 70 years of industrial experience)
  - Passive safety features taking advantage of low operating temperature and pressure
  - Serial-produced components using conventional manufacturing techniques
  - Compatibility with the Finnish nuclear waste disposal concept (deep geological disposal)
- No “moonshots”, no “quantum leaps”, no reliance on exotic technology that has not been invented yet!

LDR-50 reactor module

- A single LDR-50 reactor module produces 50 MW of heat:
  - Essentially a PWR-type SMR
  - Reactor operates at 150 °C temperature and 0.8 MPa pressure
  - Primary coolant circulation by natural convection (no pumps)
  - Connection to district heating network via intermediate water loop and heat exchangers
- Heating plant may consist of one or multiple independent LDR-50 units
- Both above- and underground siting options considered



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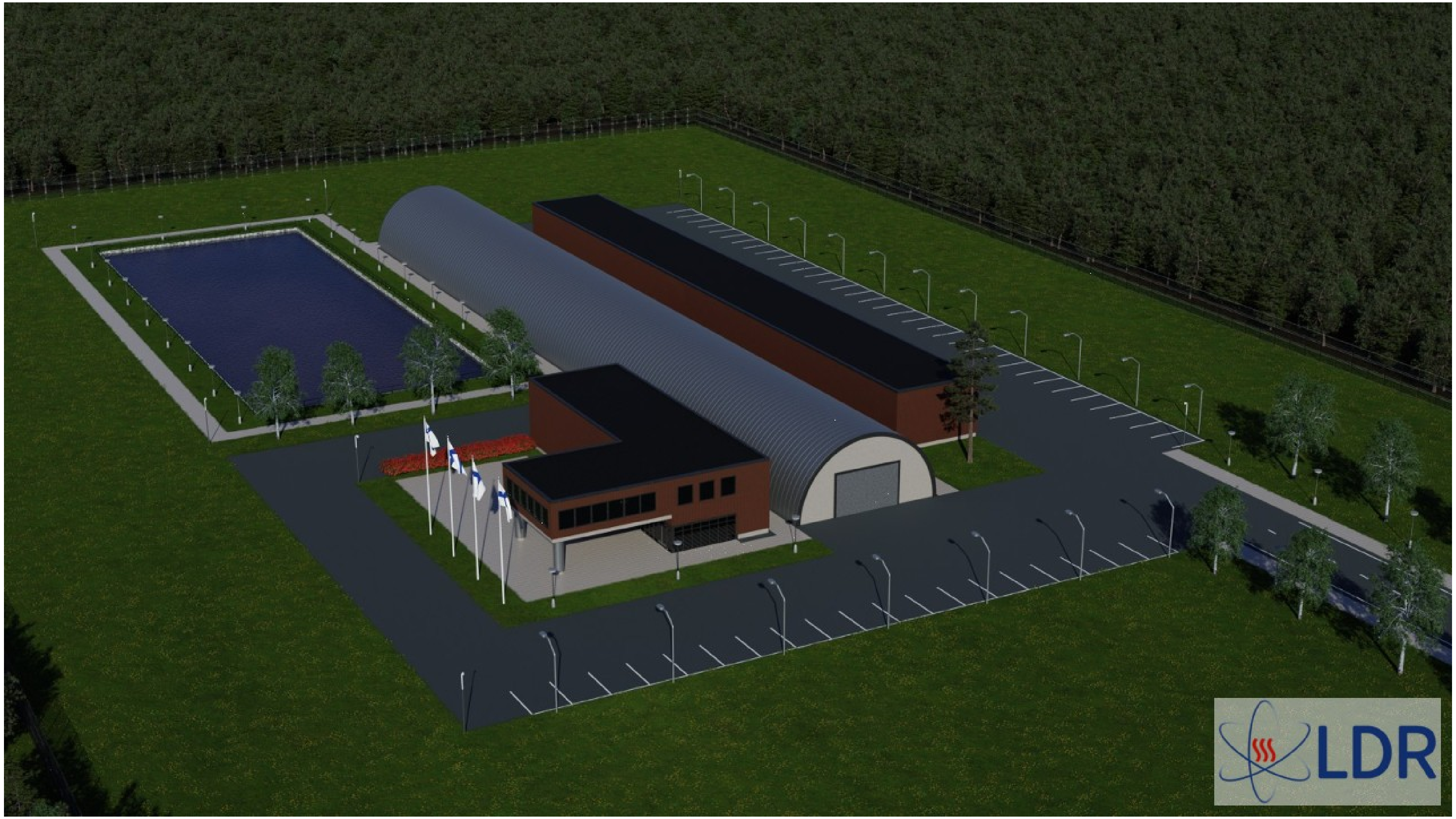
Example layout: 4-unit LDR heating plant



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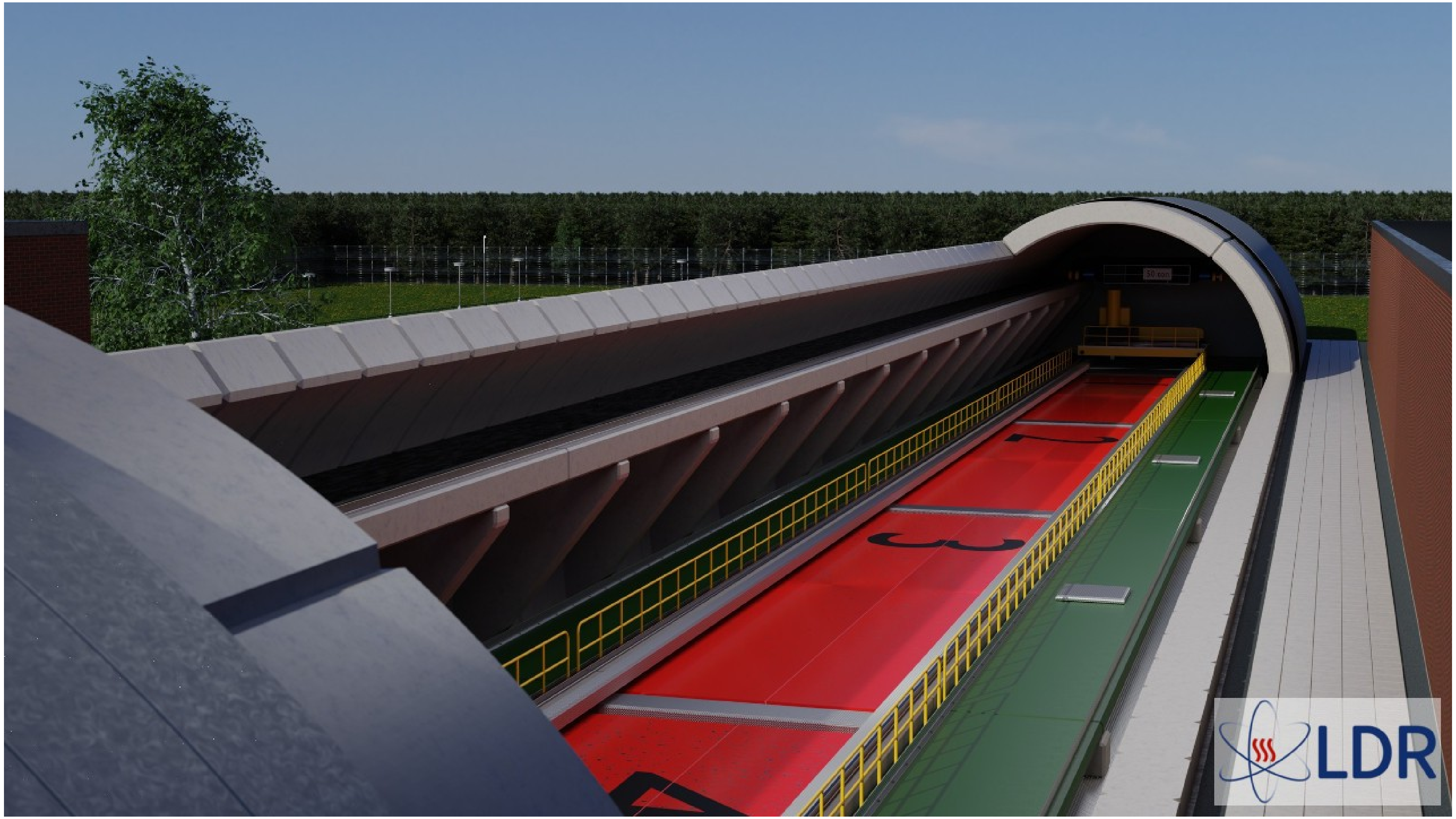
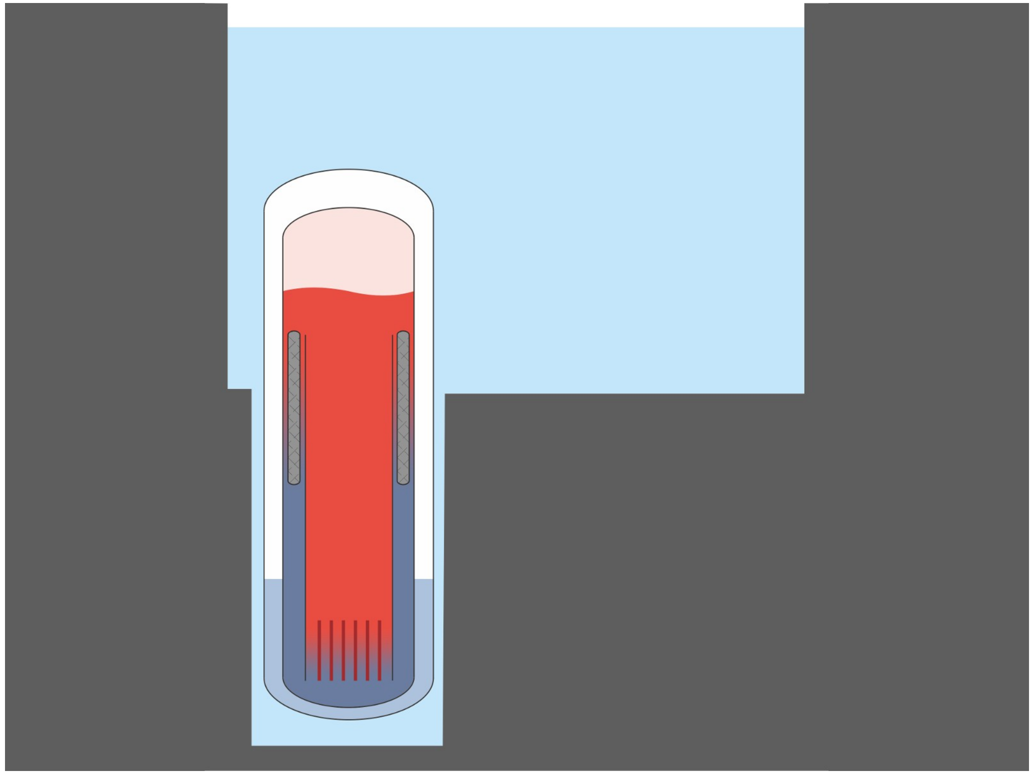
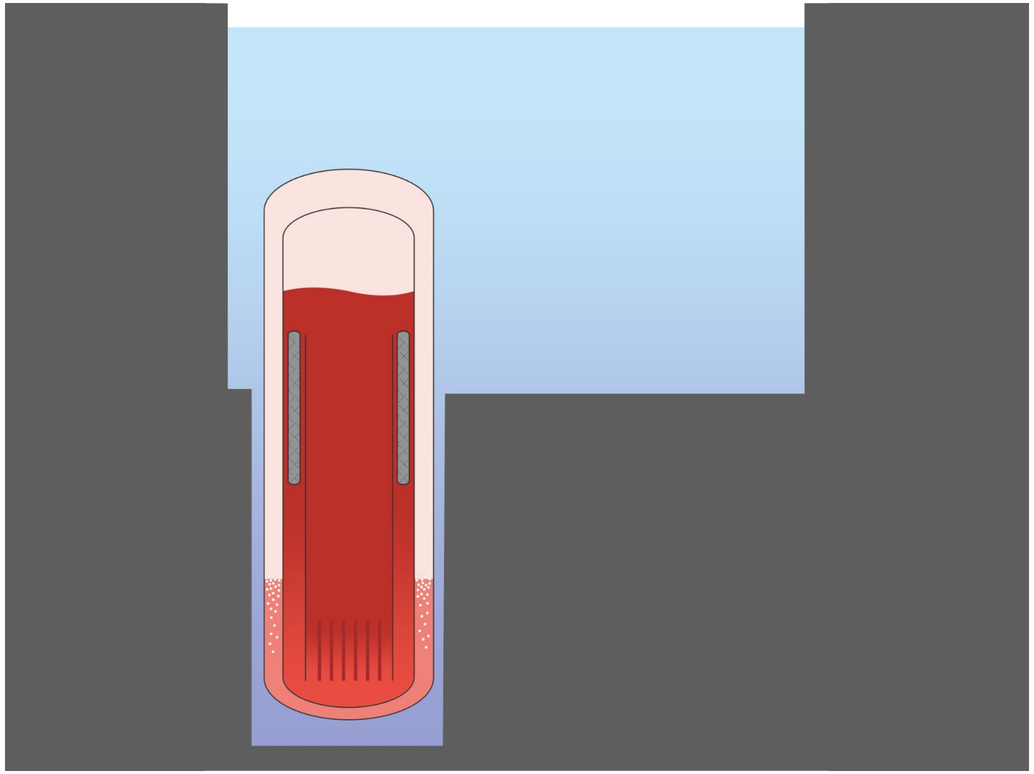


LDR-50 passive cooling function



- The reactor module is comprised of two nested pressure vessels:
  - Inner reactor vessel
  - Outer containment vessel
- Intermediate space between the vessel is partially filled with water
- In normal operation, heat is extracted through the main heat exchangers
- Temperature at the lower part of the module is low, and heat losses to the surrounding reactor pool remain small

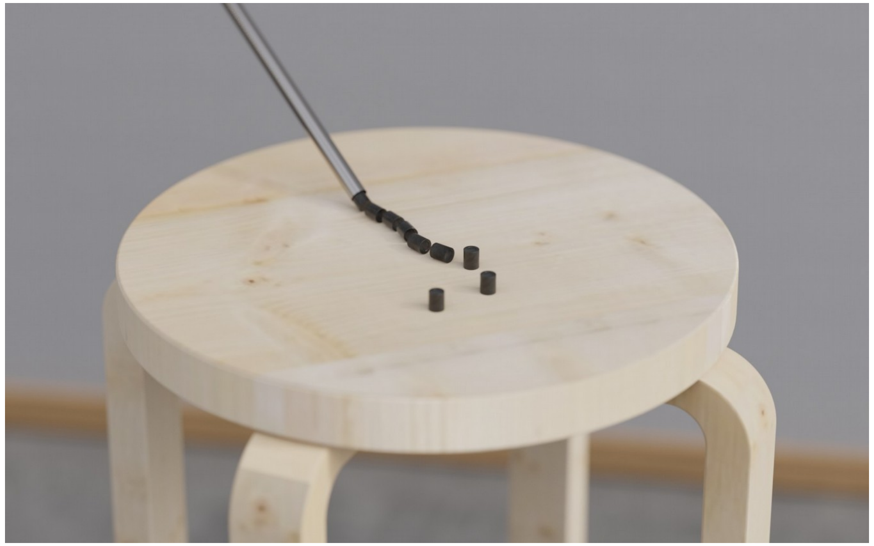
LDR-50 passive cooling function



- When the heat exchangers stop working, temperature at the lower part of the module begins to rise
- Water in the containment space starts to boil
- Top part of the containment vessel is filled with steam, which begins to condense on the cool outer wall
- This forms an effective passive heat transfer route into the pool, without any mechanical moving parts
- The pool can receive decay heat for several weeks without any cooling or operator action*

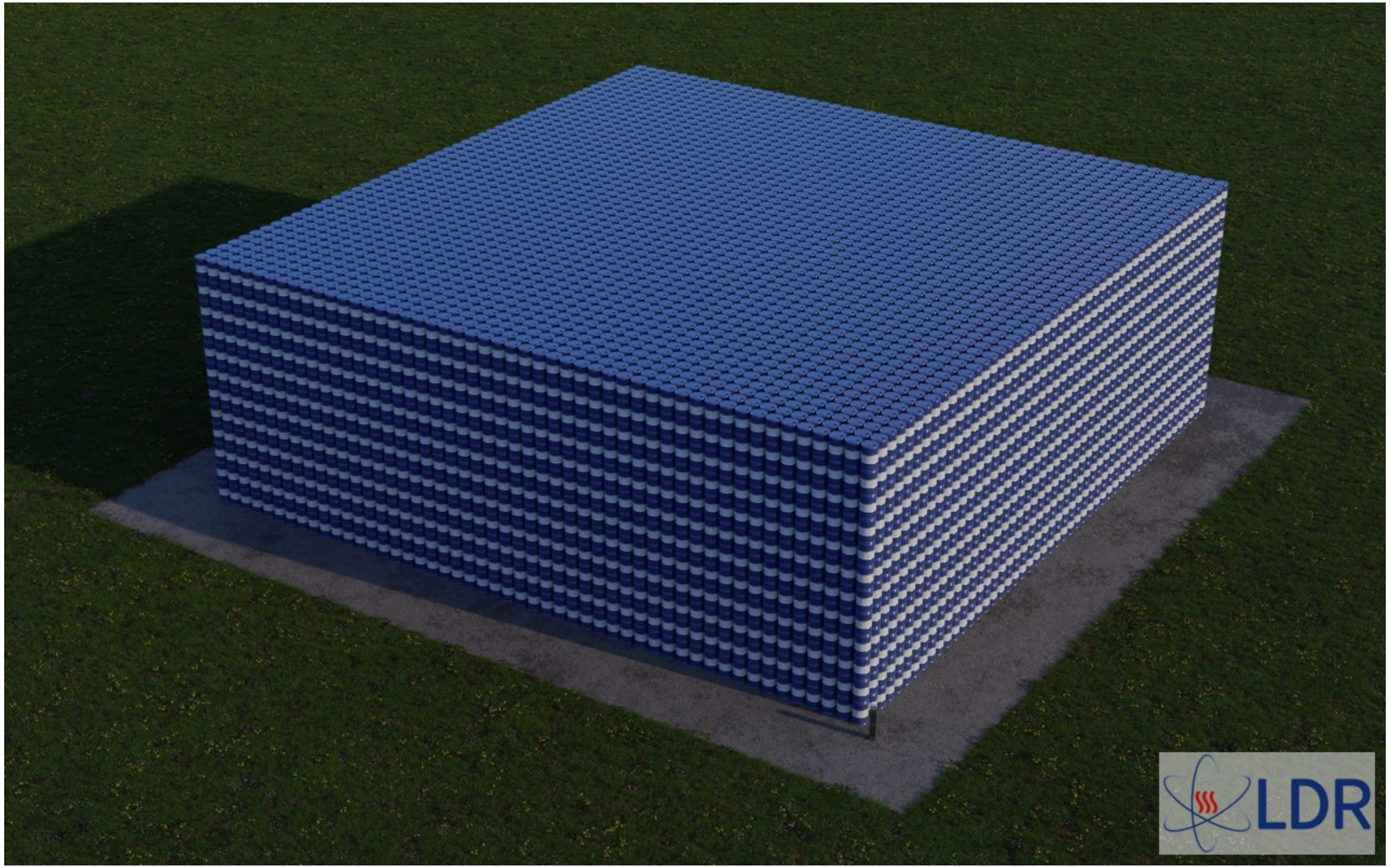
* The pool is also equipped with an emergency water injection line (defence-in-depth requirements)

LDR-50 reactor and fuel cycle



- LDR-50 is based on conventional light water reactor technology
- Commercial low-enriched uranium oxide fuel (~2.5% U235)
- Standard 17x17 PWR fuel assembly truncated to 100 cm active length
- Energy density of uranium is very high – a single LDR-50 fuel assembly can produce as much heat as 6 million liters of heating oil

LDR-50 reactor and fuel cycle

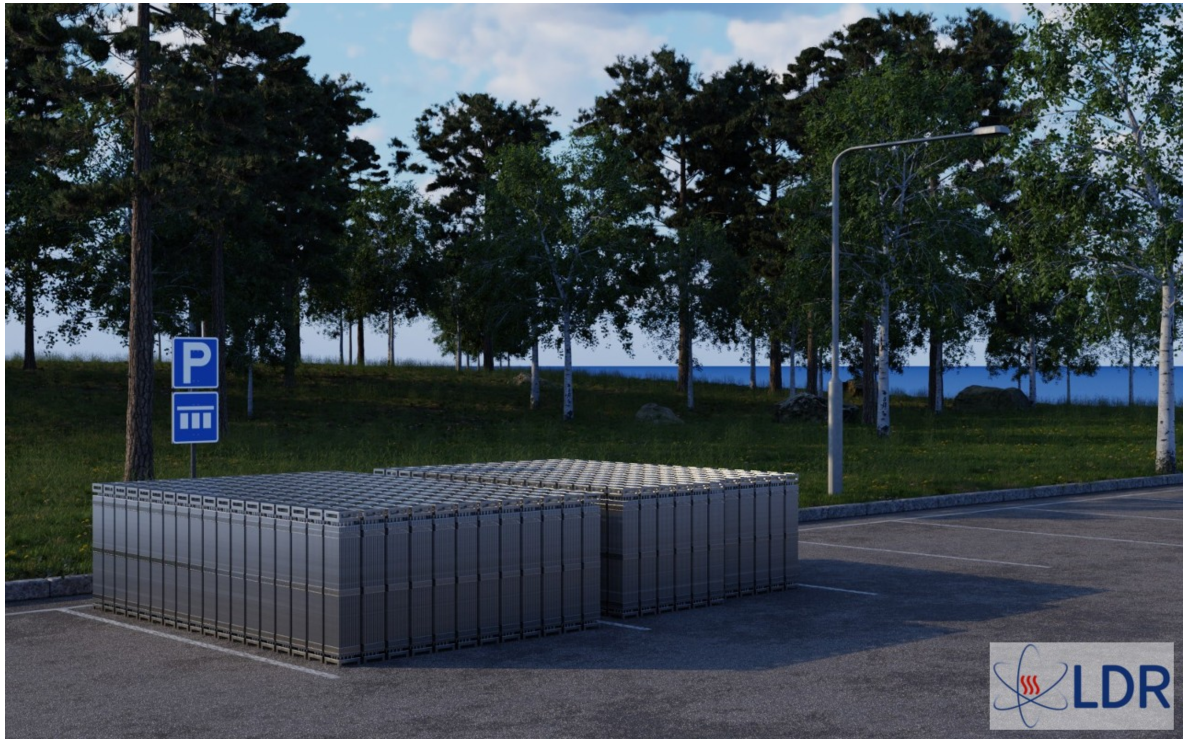


LDR-50 reactor and fuel cycle

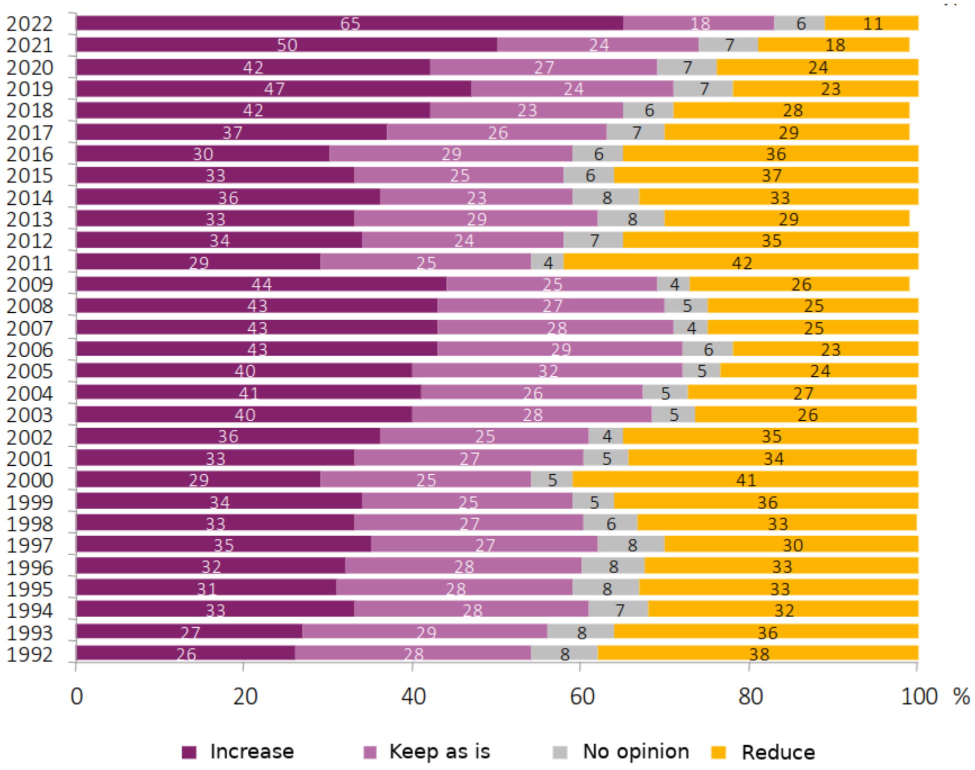
- The core is comprised of 37 fuel assemblies
- The reactor operates two years with a single fuel loading
- 13 oldest assemblies are replaced after each cycle
- Fabrication of new fuel batch requires 7.5 tons of natural uranium
- For comparison, the estimated annual uranium production capacity of the Sotkamo mine in Finland is around 200 tons

LDR-50 reactor and fuel cycle

- Spent fuel assemblies become high-active radioactive waste:
  - Cooling in reactor pool for 4–6 years
  - Centralized interim storage
  - Geological final disposal
- LDR heating plants are designed for 60 years of operation
- Fuel consumed by a single reactor over its entire lifetime would fit inside two parking spaces



LDR Heating solution for the 2030's

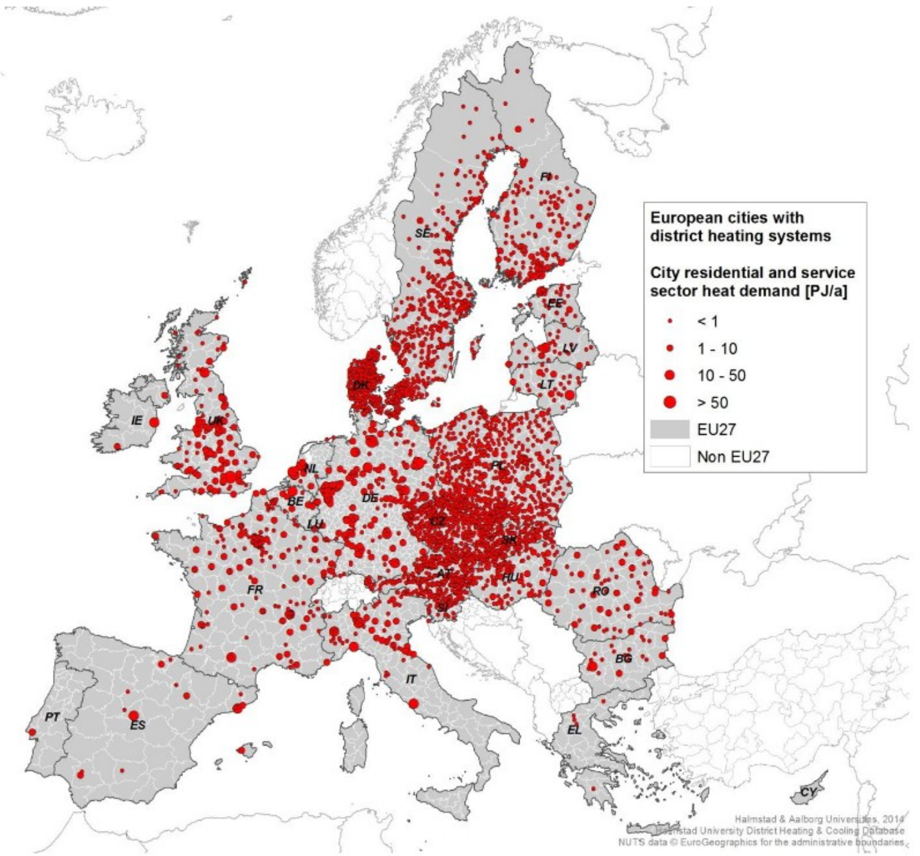


Survey on Finnish energy attitudes – Should reliance on nuclear energy be increased, kept as-is or reduced? Source: Energiateollisuus ry

- Several municipal energy companies see nuclear district heating as a promising option for the 2030's
- But there are also challenges:
  - The current licensing procedures were drafted for large NPP units
  - Reactors have to be built close to consumption, which puts even more emphasis on safety
  - Small unit size and passive safety features are a major advantage
- Nuclear energy has strong political and public support in Finland, but urban reactors will be an entirely new discussion!

Heating solution for the 2030's

- The first LDR units are planned to be built in Finland
- Potential market covers European countries with existing district heating networks and public support for nuclear
- New business model needed for fleet operation:
  - Heat as a service for municipal energy companies
  - Owner / operator responsible of safety and nuclear waste
  - Centralized maintenance, fuel and waste management
- Alternative uses for LDR technology: desalination, low-temperature industrial heat, direct air capture of CO_2



Thank you for your attention!

Questions – Jaakko.Leppanen@vtt.fi

LDR website – https://ldr-reactor.fi (Finnish and English versions)