LDR-50 District Heating Reactor Technology

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Scope of this presentation

Finnish firm launches SMR district heating project

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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.

VTT has been developing a district heating SMR for 2.5 years. Finnish Public Service Media Company YLE asked ten questions about the technology:

1. What does it produce and how much?
2. How large is it?
3. How does it work?
4. Is it safe?
5. What about external threats?
6. When is the first reactor on-line?
7. How long does it take to construct?
8. How much does it cost?
9. What is it using for fuel?
10. Does it produce nuclear waste?

Short answers in Finnish – https://yle.fi/uutiset/74-20002478; long(er) answers – this presentation

What does it produce and how much?

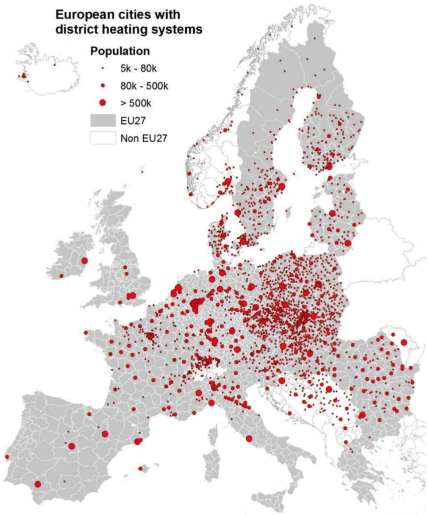
The heat market is divided between hundreds of independent networks:

- District heating is the most common heating form in Finland (used in 166 municipalities)
- Widely used in Eastern and Central Europe
- No nationwide / international distribution network, heat is both produced and consumed locally

Reactor operating parameters:

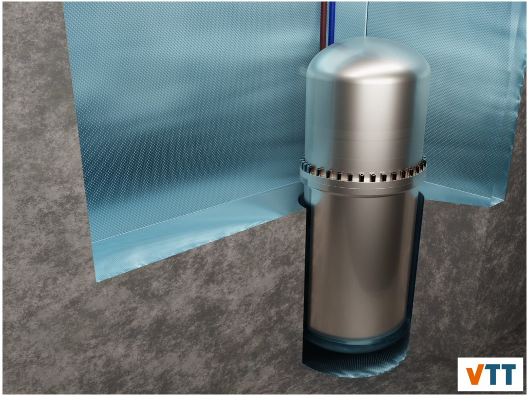
- Supply temperature up to 120°C (peak temperature in Finnish DH grids)
- Unit size 50 MW, no turbine cycle[1]

Scalability by modular design – the heating plant may consist of one or multiple reactor units.



[1] For comparison: thermal power of OL3 is 4300 MW; The DH demand in Helsinki varies between 200–2500 MW, depending on season.

How large is it?



Physical characteristics and dimensions of a single LDR-50 reactor unit:

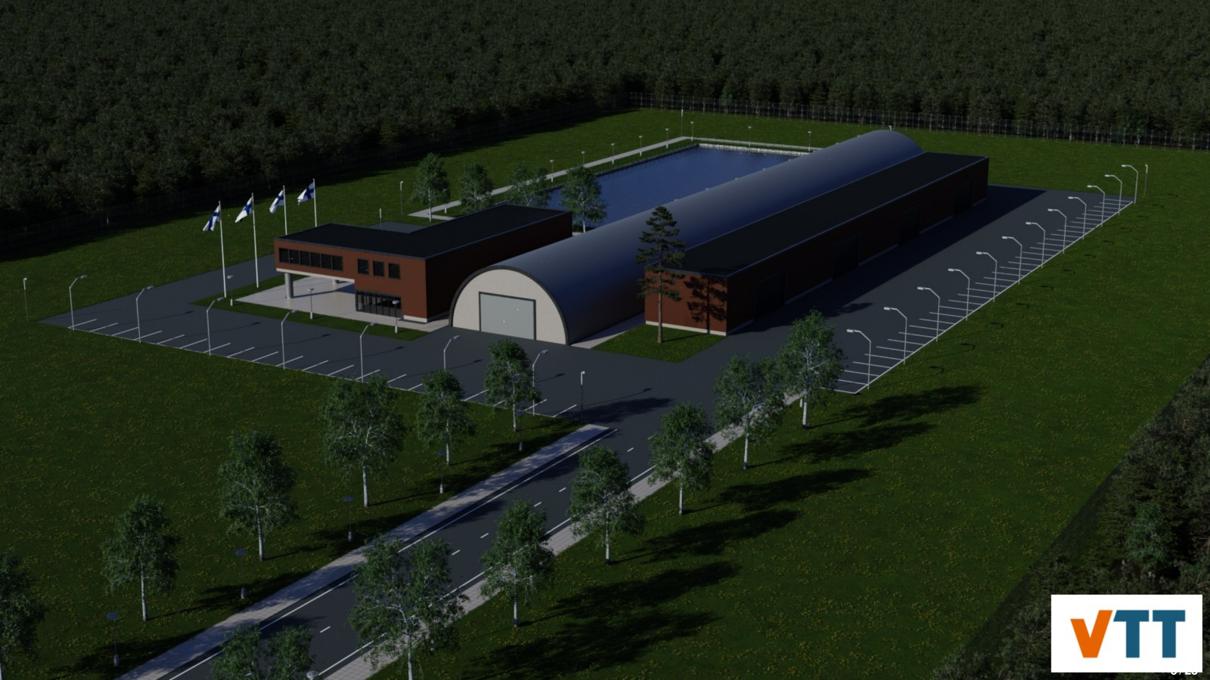
- 37 fuel assemblies, 4.7t of uranium in core[2]
- Module dimensions $\sim 4 \times 12$ meters (size of a bus)
- Reactor pool volume $\sim 1000\ m^2$

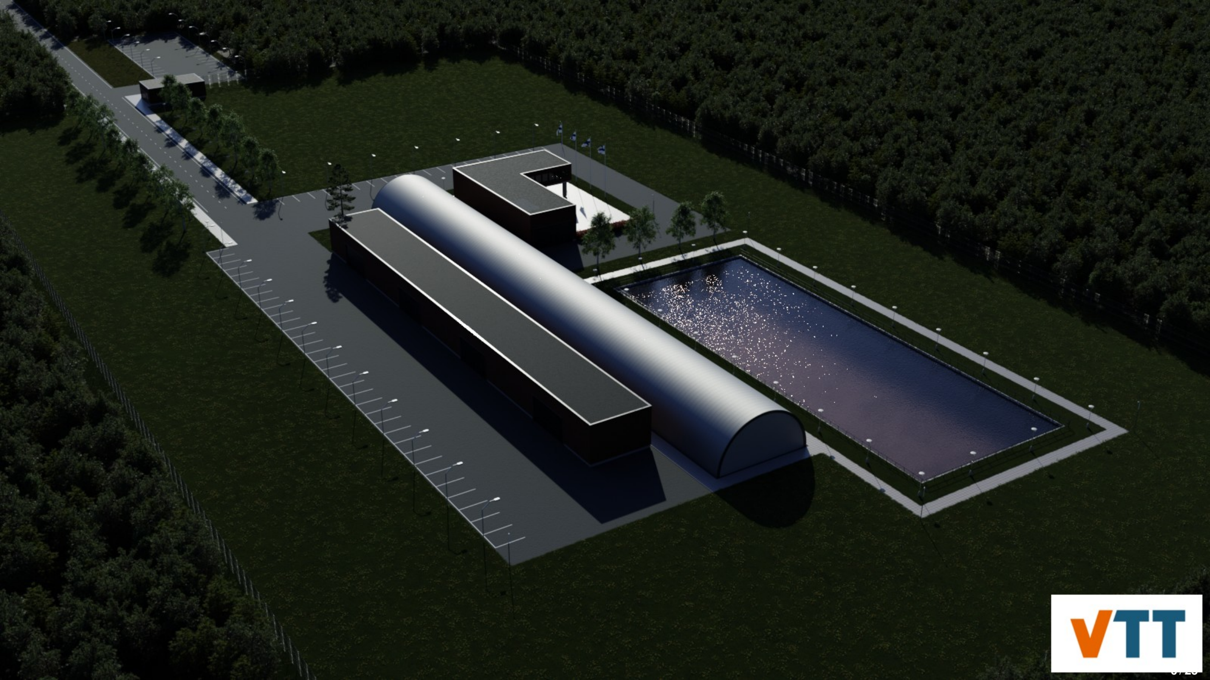
Size of the heating plant depends on number of units (most recent layout):

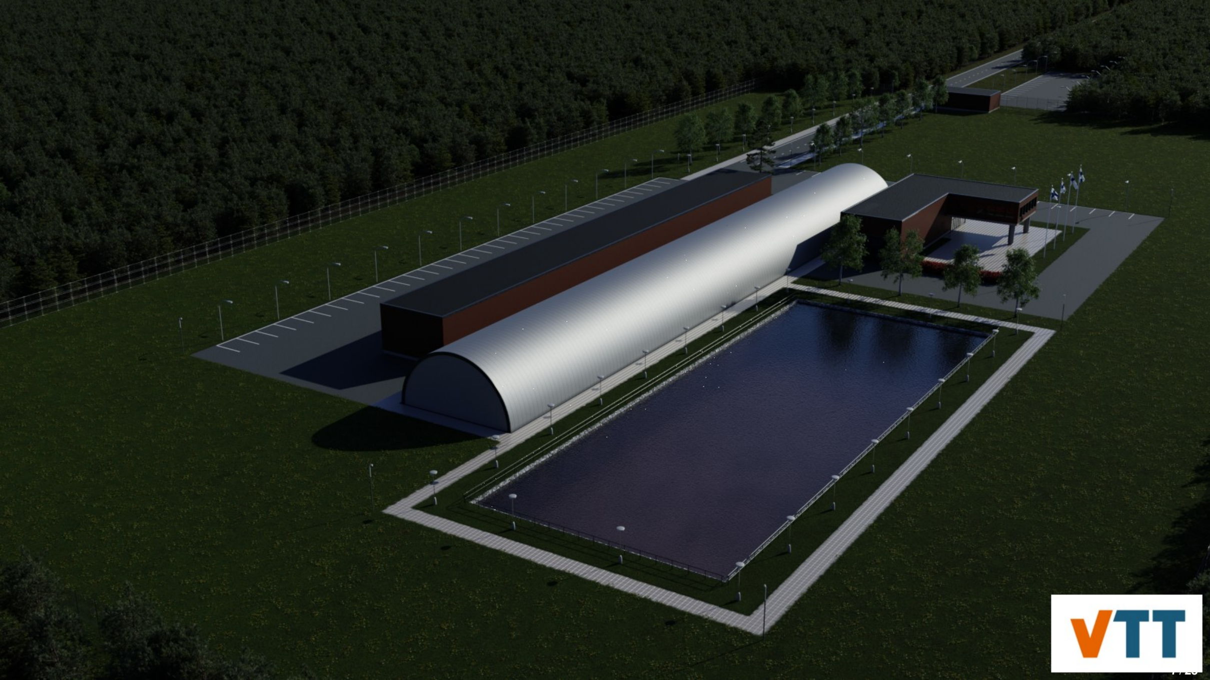
- Height of reactor building $\sim$ 10 meters (partially underground)
- Overall size comparable to a small or medium-size industrial site

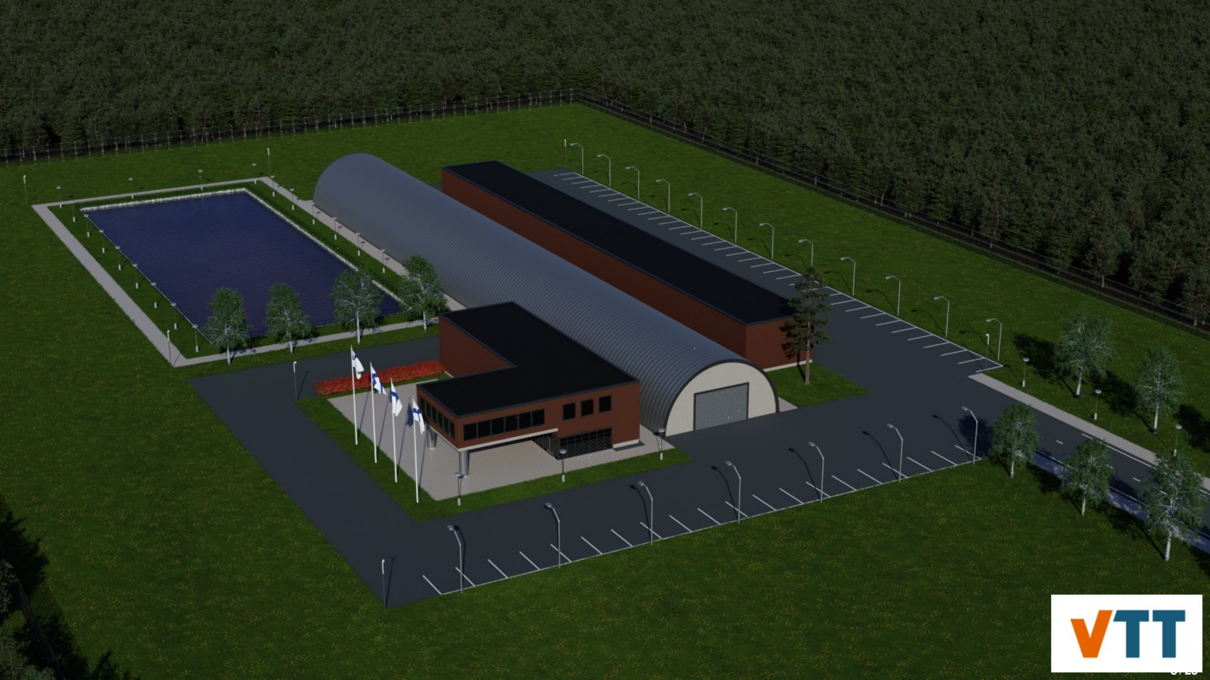
Various siting options still under consideration.

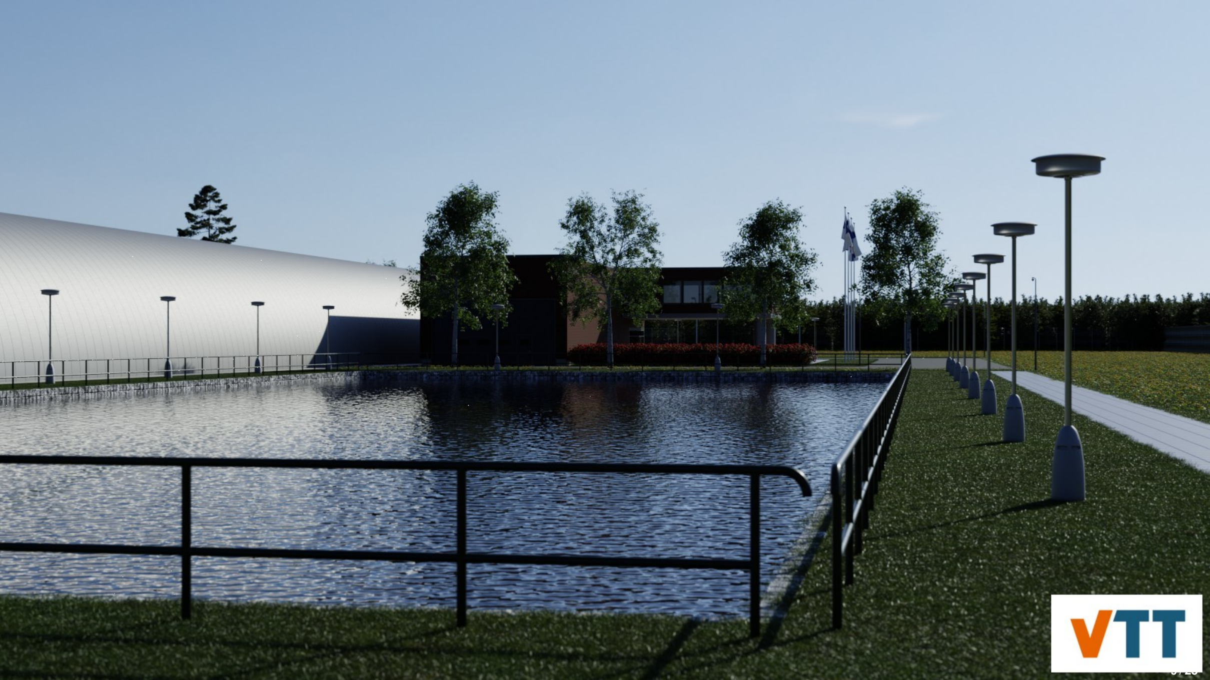
2 For comparison: 241 assemblies and 128t of uranium in OL3









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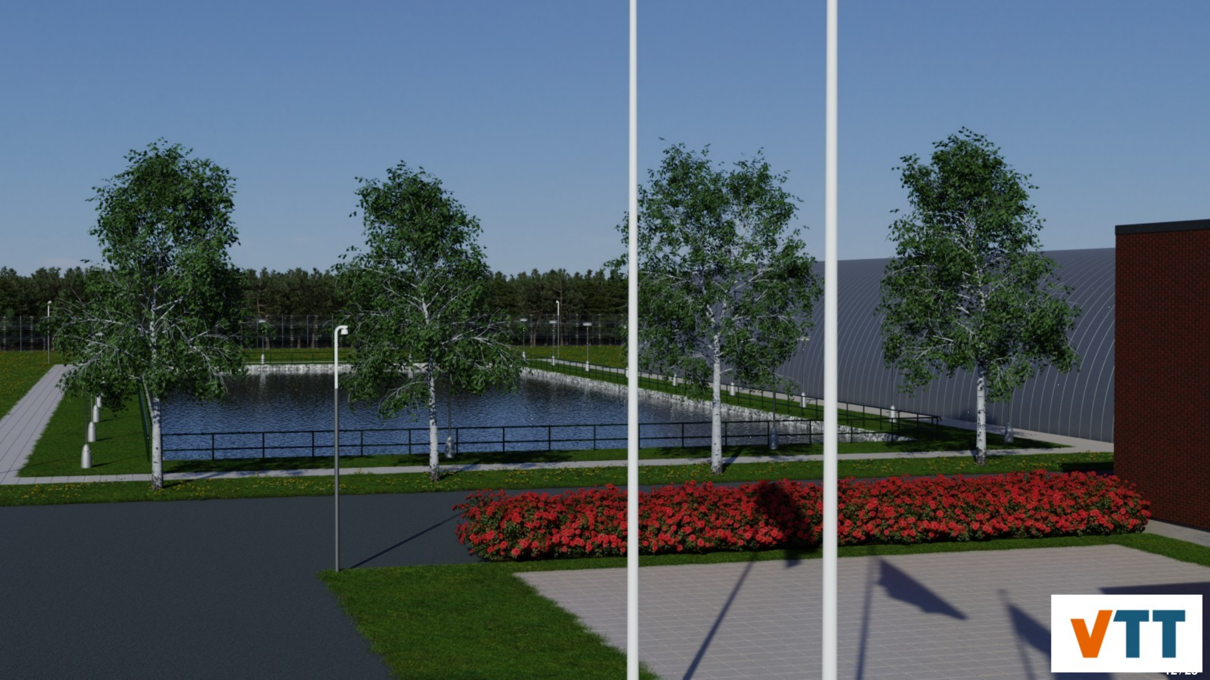

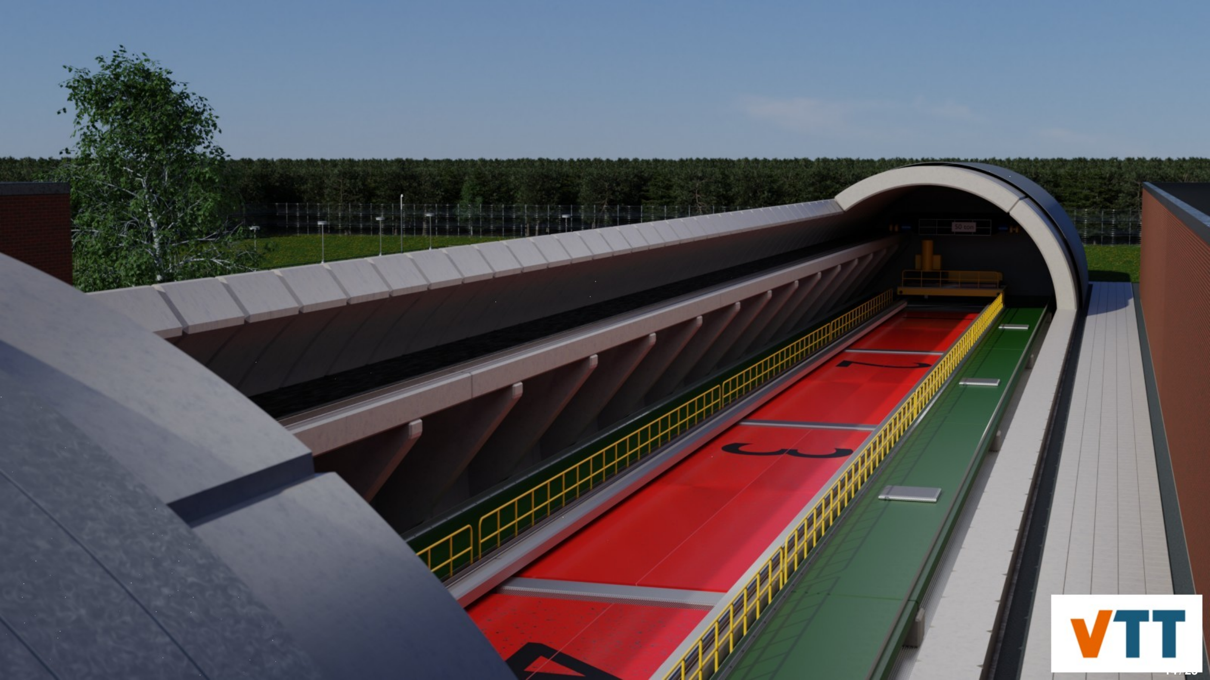
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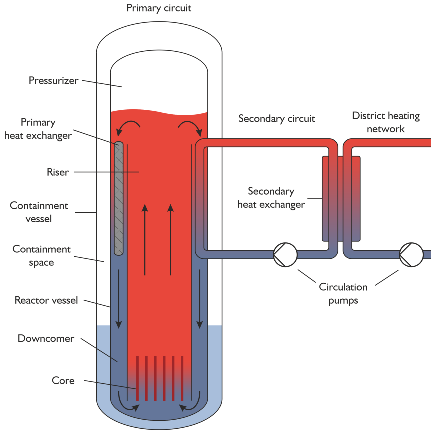
How does it work?

Key features:

- Boron-free core, low-enriched PWR fuel (17×17 assembly)
- Integrated dual pressure vessel design
- Natural circulation in primary loop
- Connection to district heating network via an intermediate circuit and heat exchangers
- Reactor vessel pre-pressurized with inert gas, operating pressure depends on temperature (max 0.8 MPa @ 155°C)
- Base-load and load-follow operation

Conceptual design based on computational models:

- Kraken framework for core physics calculations
- Apros for system-scale simulations and safety analyses



Is it safe?

The safety philosophy of LDR-50 relies on passive cooling and elimination of severe initiating events:

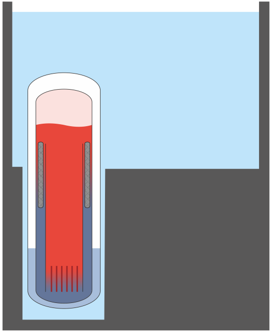
- Primary circuit integrated inside reactor vessel – no large-break LOCA from pipe rupture
- Low operating pressure ensures that core coolability is unlikely to be compromised due to failure of the pressure boundary (even complete break-down of the reactor vessel)
- Other favorable features: low temperature, low power density, low burnup, low radioactive inventory

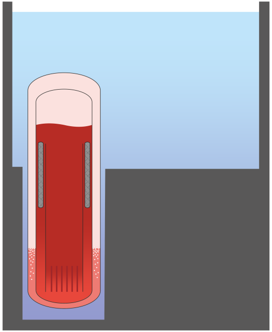
All heat produced in the reactor core and spent fuel storage rack is passively deposited into the reactor pool (mechanism presented on next slide):

- Large heat capacity provides long grace period (> 1 week)
- Pool integrity is ensured by physical protection against external threats
- Loss of water by evaporation is prevented by passive cooling and diversified arrangements for water injection

From technical aspect, the LDR-50 reactor resembles a pool-type research reactor or a spent nuclear fuel storage pool.

Is it safe?





Normal operation:

- Heat is removed from the reactor via primary heat exchangers
- Water temperature at the bottom of the reactor vessel is below 100°C
- Reactor remains thermally isolated from the pool (heat losses < 1%)

Passive heat removal mode:

- When the active heat removal route is compromised, temperature begins to rise
- Water inside the containment vessel begins to boil
- Steam is condensed on the cool outer wall of the containment vessel, forming an efficient cooling path into the pool

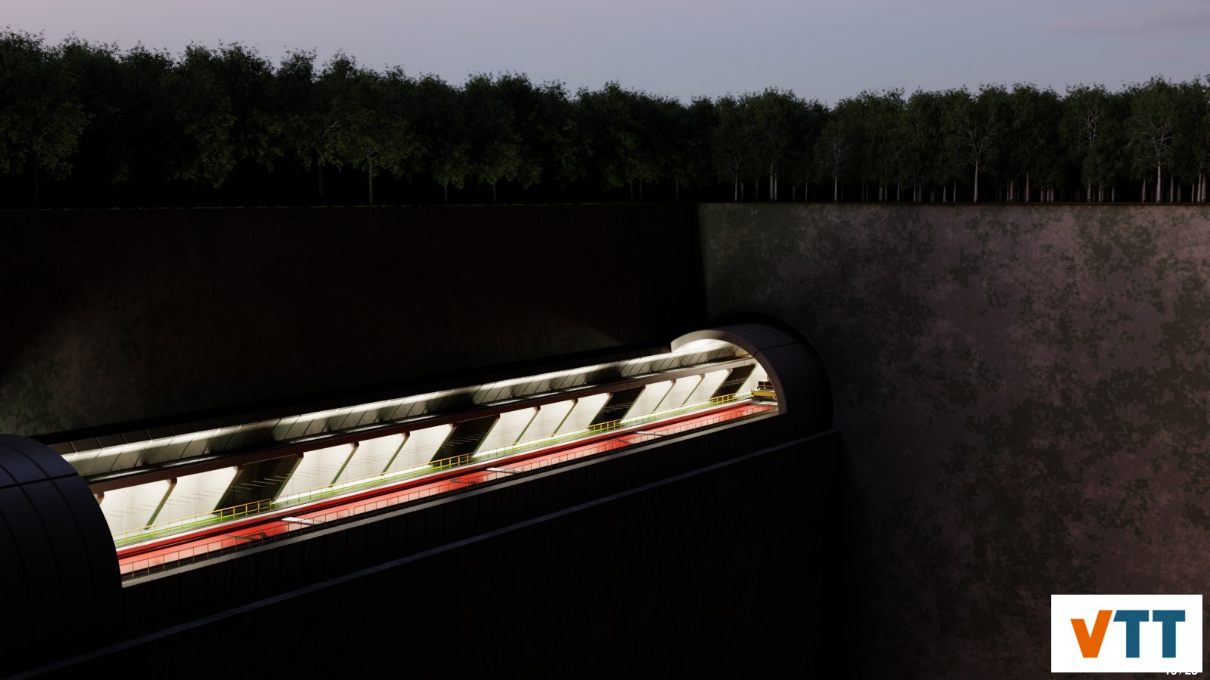
What about external threats?

Several events during the past decades have raised concerns about the vulnerability of NPP:s against external threats:

- Aircraft crash (9/11)
- Natural phenomena (Fukushima)
- War (Ukraine)

Specific issues for SMR's:

- Passive safety provides some additional protection against loss of auxiliary systems
- Questions related to urban siting
- Cyber security challenges with remote operation
- Pros and cons of constructing underground

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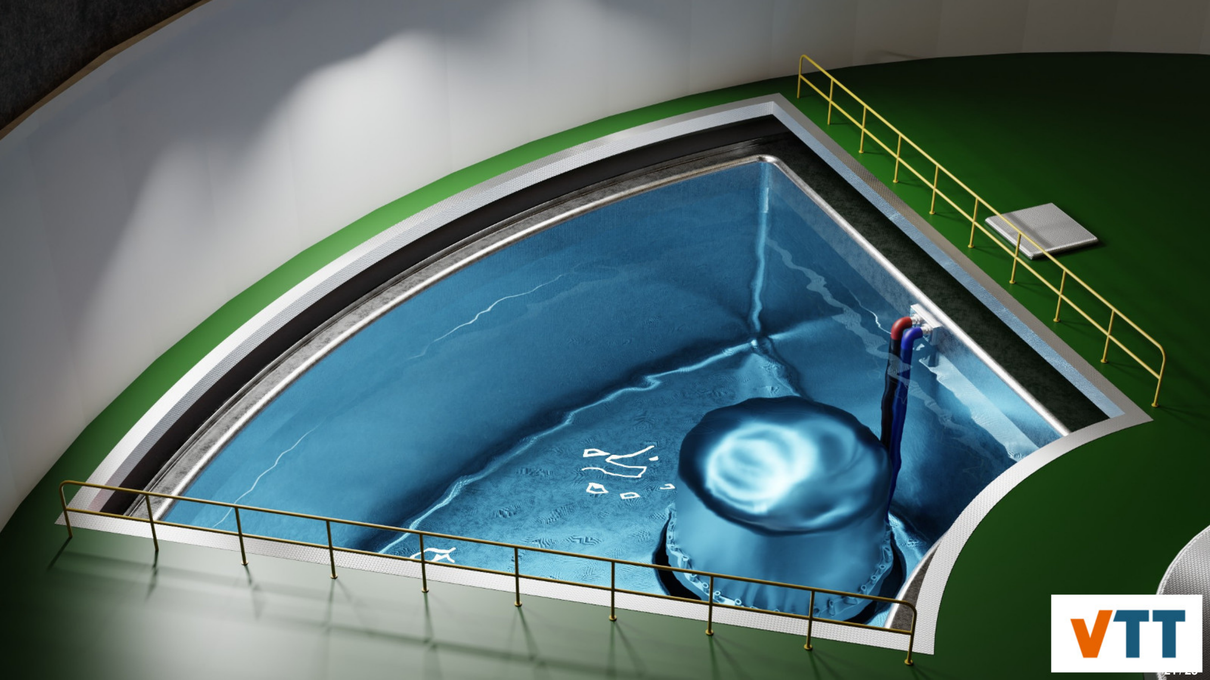

When is the first reactor on-line / how long does it take to construct?

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Boundary conditions from Finnish climate goals:

- Carbon-neutrality by 2035
- District heating is a major contributor to CO_2 emissions
- To make an impact, the technology should be in large-scale use in the 2030's
- Demonstration plant by the end of the decade, followed by commercialization

Features favoring early deployment and fast construction:

- Conservative technology – no major unconventional features, materials or manufacturing techniques
- Low operating pressure and temperature, simpler manufacturing techniques for pressure components
- Diverse supply chains

Still several open questions related to licensing, business model, political and public acceptance, etc.

How much does it cost?

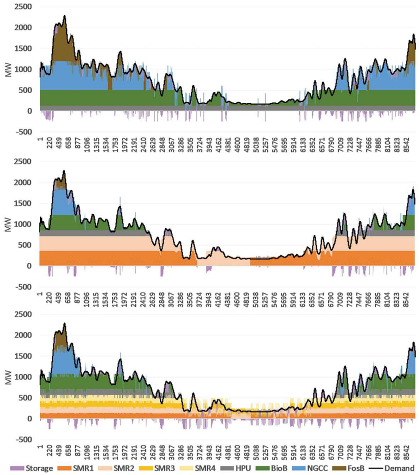
Techno-economic assessments suggest a strong business case for district heating reactors:

- Competition with bioenergy and heat pumps, which have their own issues
- Niche market for heat-only microreactors

Estimated limit for capital costs is around 1500€/ kW:

- Rough estimates for non-nuclear components
- Evaluation of nuclear components in collaboration with Fortum and MIT
- The project is still well "on budget"

More difficult questions arise form operating costs, especially personnel.



What is it using for fuel / does it produce nuclear waste

VTT

One of the main design criteria is that the fuel cycle relies on conservative technology, and is compatible with the Finnish final disposal concept:

- Low-enriched uranium fuel (2-3% ^{235}U)
- Truncated 17×17 PWR fuel assembly
- No domestic fuel production
- Spent fuel management in Finland relies on direct disposal
- Repository in Olkiluoto starts operating during this decade

Technical solution to waste management exists, but there are open questions related to the business and operational model.

Thank you for your attention! Questions? – Jaakko.Leppanen@vtt.fi

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