LDR-50 District heating reactor & LDR lite benchmark

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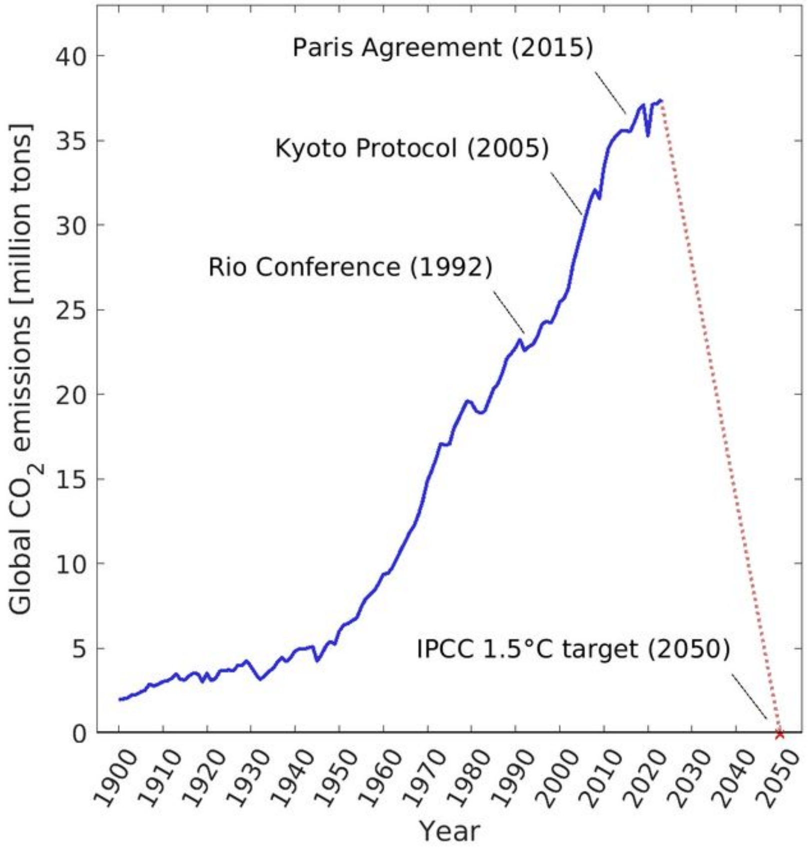
Kraken workshop @ PHYSOR-2024

Outline

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

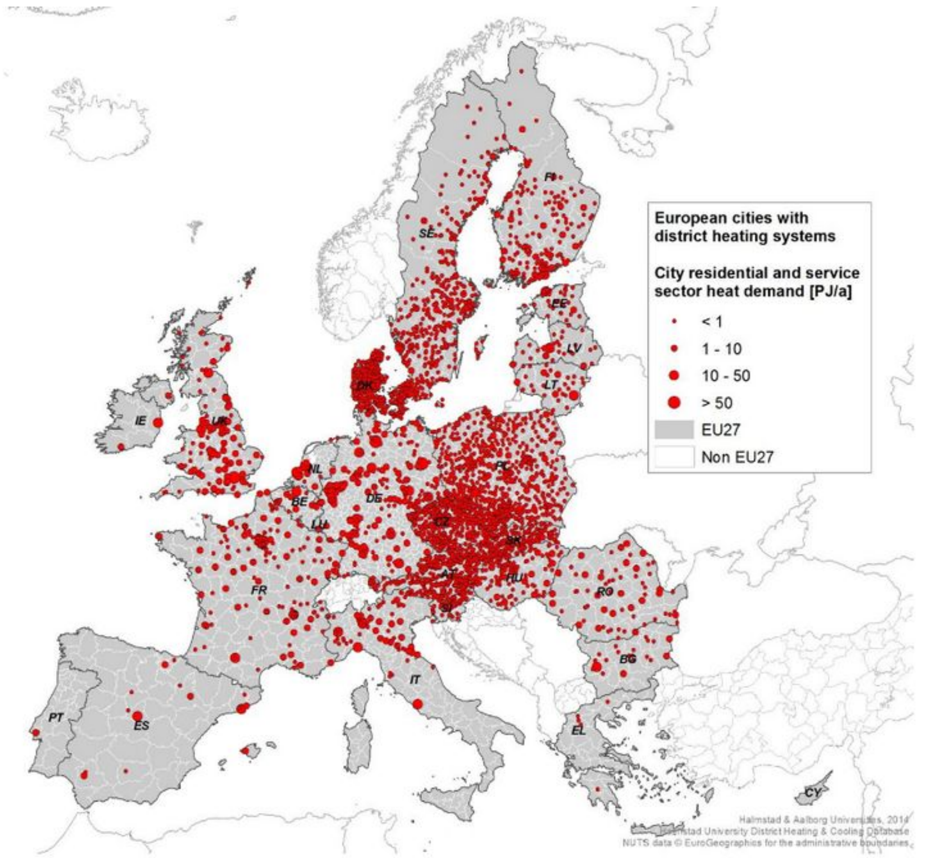
Climate crisis

- Limiting the adverse effects of climate change requires a complete overhaul of the entire energy system.
- Public discussion is focused on electricity, but the other segments of the energy sector are even mode difficult to de-carbonize:
  - Transportation
  - Industry
  - Heating
- Electrification (short-term) and hydrogen economy (long-term) provide new solutions, but also lead to competition between end users.



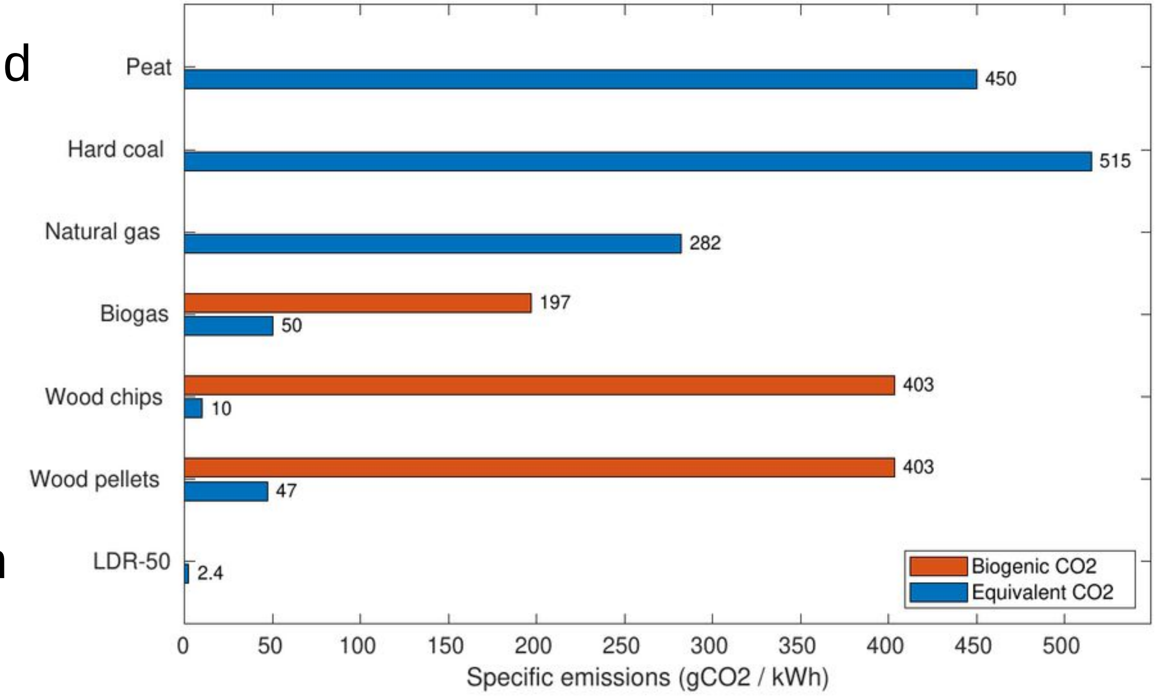
Carbon emissions from the heating sector

- 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 current production relies on co-generation using fossil fuels – decarbonization with wind or solar 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
  - 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?



Life-cycle estimates of specific CO_2 emissions for LDR-50 compared to different heating fuels (VTT, 2023)

*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.

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.

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

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
- Usage can be optimized for heat production
- No need for turbine cycle

LDR district heating reactor technology

- The developed technology was named LDR (Low-temperature District heating Reactor)
- Conceptual design 2020-2022 (small self-funded project)
- In January 2023 VTT announced a two-year 5M€ investment to advance and commercialize the technology
- Project staff grew to 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
- More about LDR technology: https://www.ldr-reactor.fi/en/

Steady Energy company

← All News

Steady Energy raises 2 million euros to decarbonise residential heating with small modular nuclear reactors

Published on June 27, 2023

External news

The VTT spin-out will build a heating plant powered by a small nuclear reactor, designed to produce heat efficiently, safely and carbon-neutrally, at considerably lower temperature and pressure than traditional nuclear reactors.

Read more here

- Staff 13+
- In-house expertise specialized in licensing and commercialization
- Subcontractors: VTT, SWECO, TVO Nuclear Services, …
- Letter of intent with Helen (Helsinki city energy company) for 10 reactor units and Kuopion energia for 5 units
- For more information, see: https://www.steadyenergy.com/

2024	2025	2026	2027	2028	2029	2030
						By 2030
Decision on R&D pilot plant investment	Safety demonstration experiments with R&D pilot plant		LDR-50 plant ready for technology assessment	Decision on the first commercial plant investment	Preparation for submitting the construction license	First commercial plant in operation

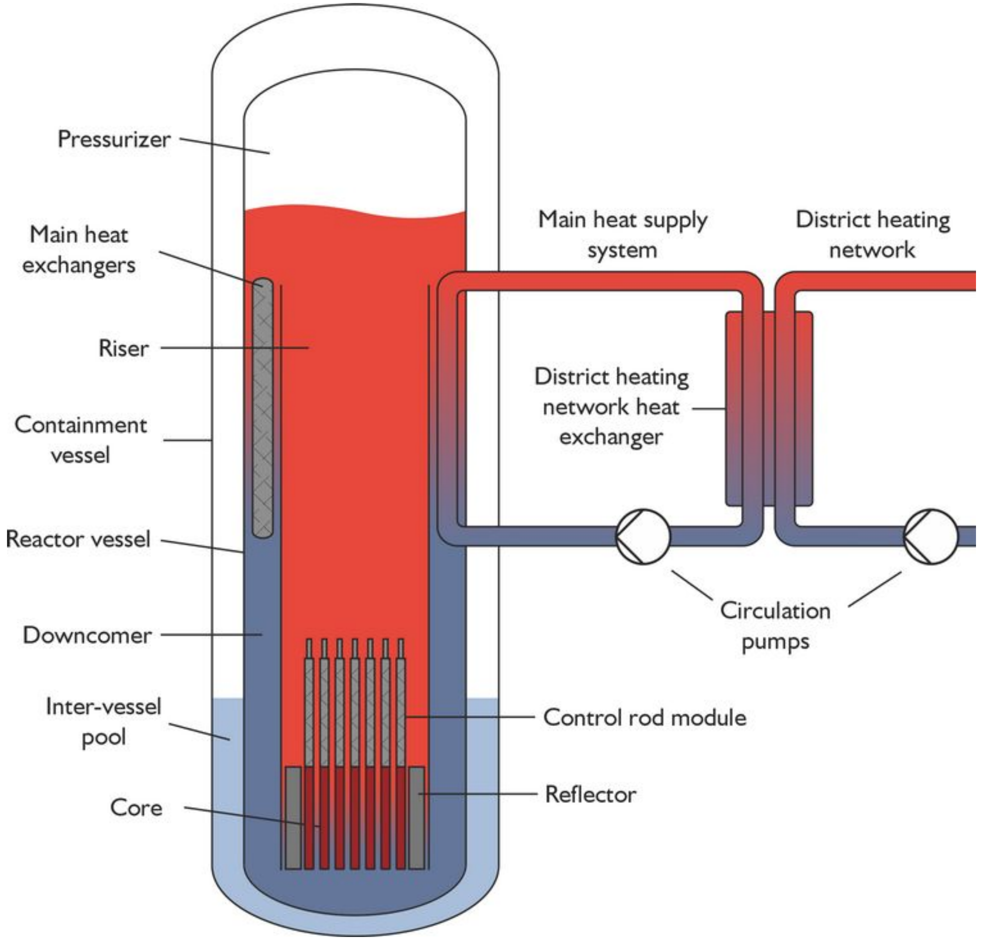
LDR district heating reactor technology

- 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
  - Compatibility with the Finnish nuclear waste disposal concept (deep geological disposal)
- Support for nuclear energy in Finland is very high,* but there is skepticism related to new projects because of OL3
- No “moonshots”, no “quantum leaps”, no reliance on exotic technology that does not exist yet!

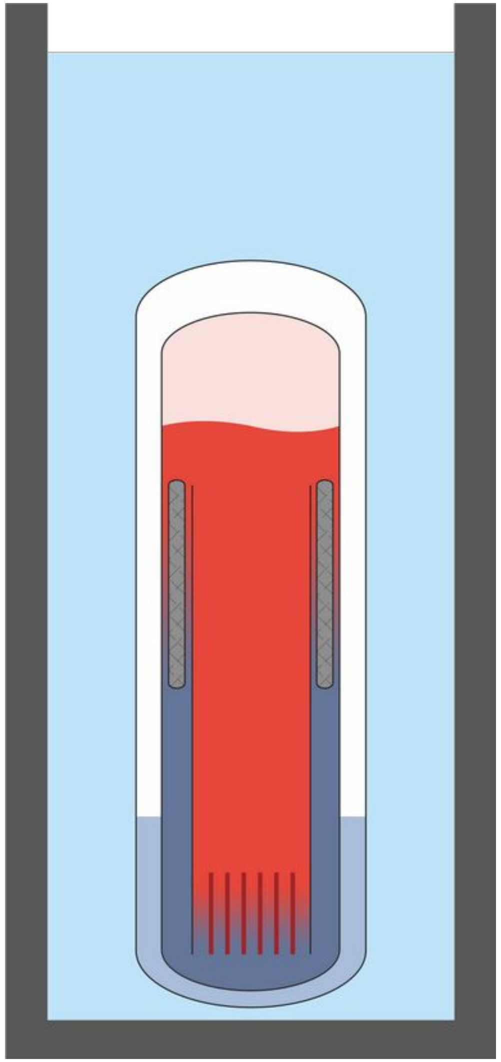
*A poll from November 2023: 68% responses fully / mainly positive towads nuclear, and only 6% fully / mainly negative. As a heating option, nuclear was considered more favourable than fossil fuels, peat, bioenergy, waste incineration, electric heating and heat pumps.

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
- Reactor units and associated main systems located in an underground rock cavern

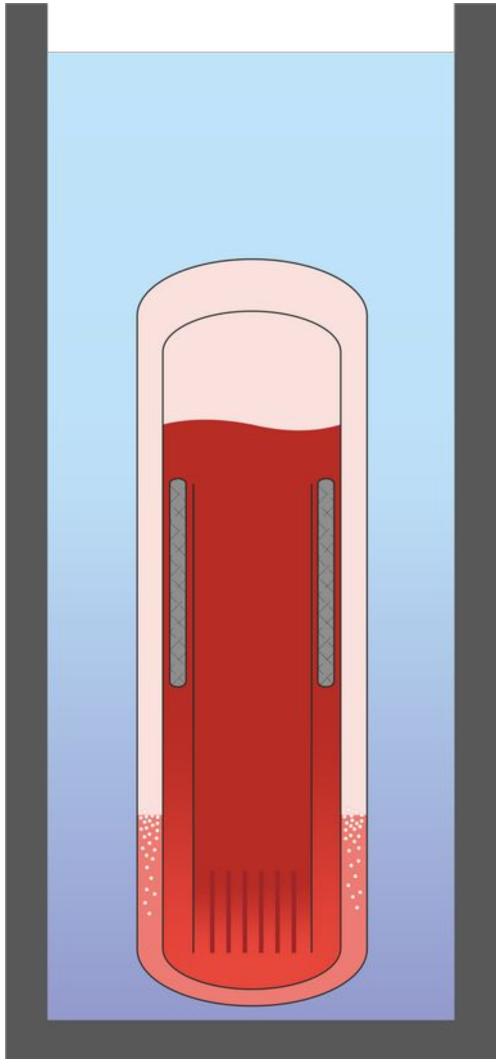


LDR-50 passive cooling function



- 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

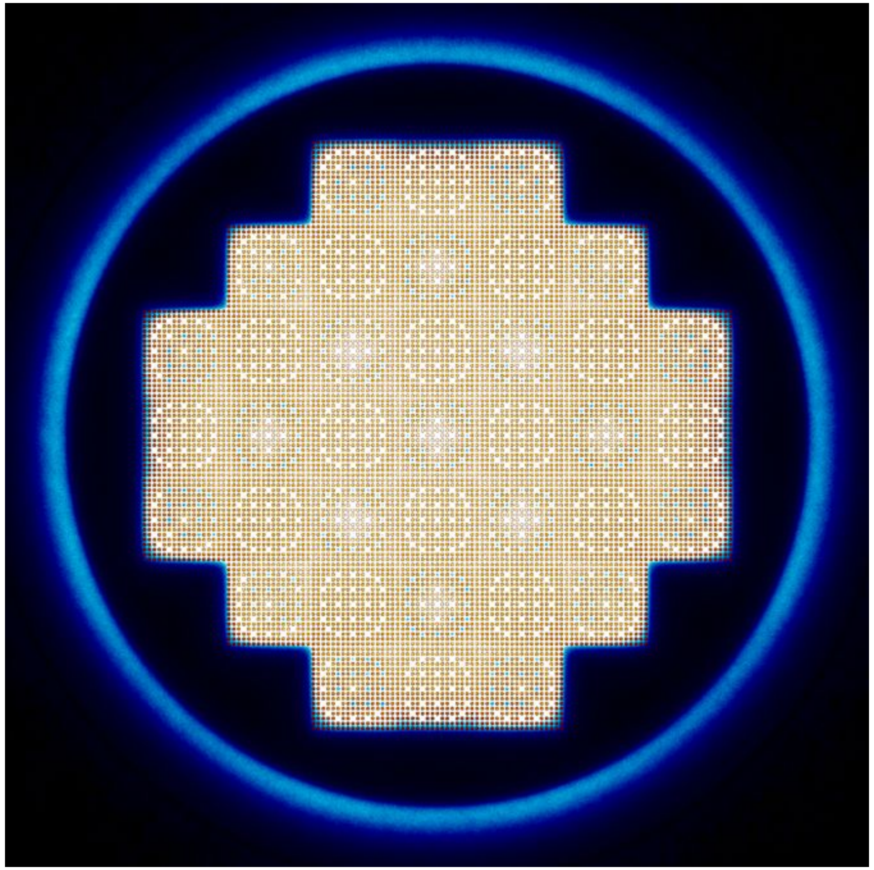
LDR-50 passive cooling function



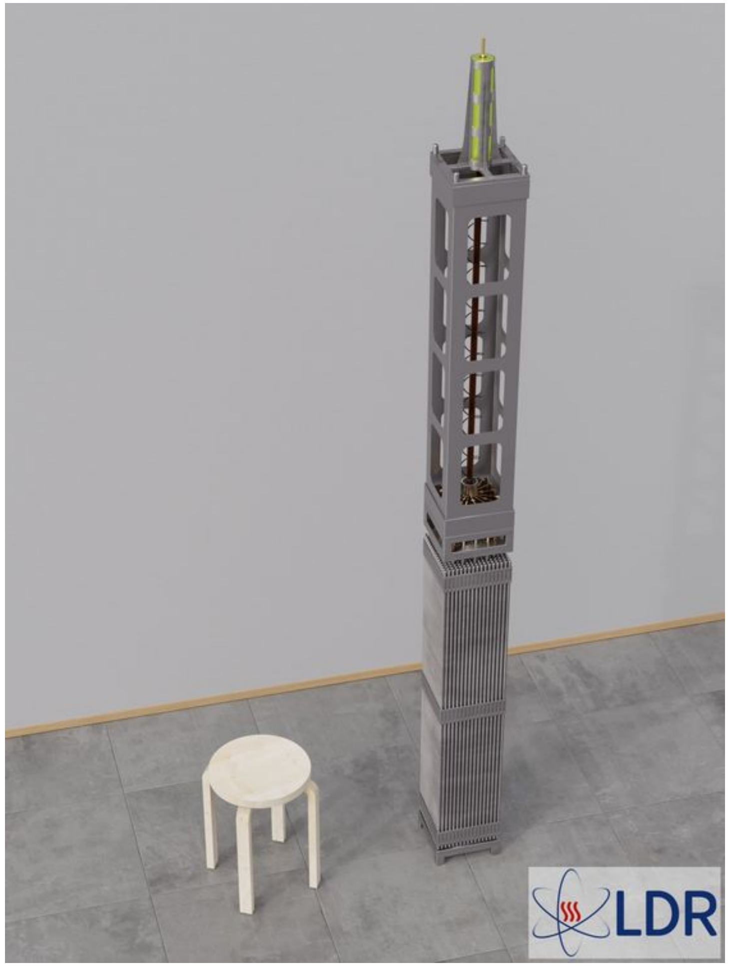
- When the heat exchangers stop working, temperature at the lower part of the module begins to rise
- Water in the containment space starts to boil
- Top part of the containment vessel is filled with steam, which begins to condense on the cool outer wall
- This forms an effective passive heat transfer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

LDR-50 core and fuel

- Neutronics design of LDR-50 relies on conventional LWR technology:
  - Low-enriched PWR fuel (17 x 17 rods)
  - ~2.5% enrichment, Gd burnable absorber
  - 37 assemblies in core, cycle length ~ 550 EFPD, oldest 13 assemblies replaced after every cycle
  - Designed for base-load and load-follow operation
- With a few twists:
  - Boron-free core – control rods in every assembly position
  - In-vessel control rod drives
  - Weak absorber in regulating rods
  - Low power density, low temperature, low burnup

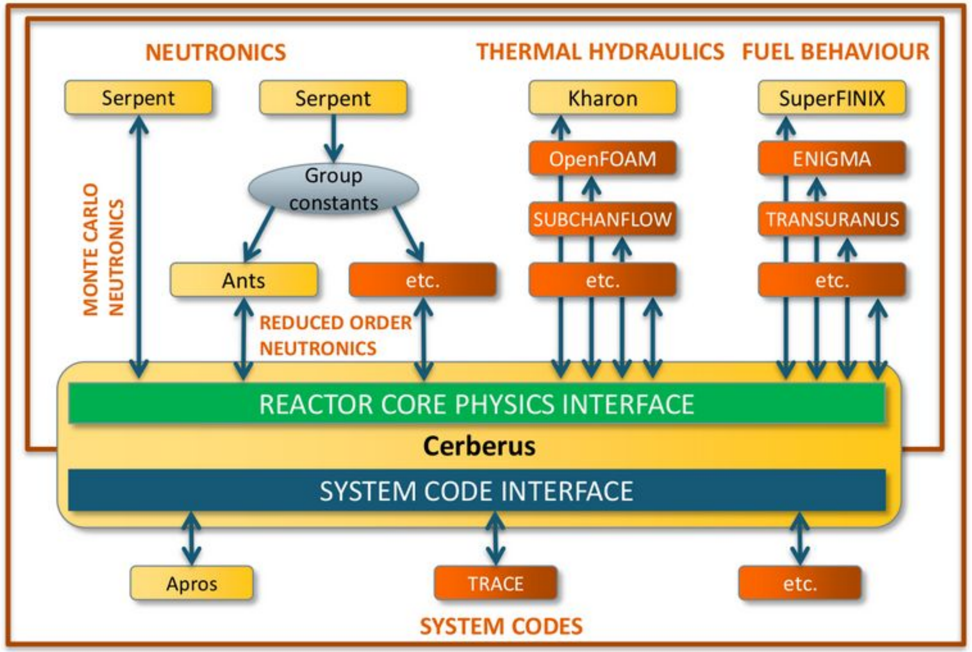


LDR-50 core and fuel



LDR lite

- Neutronics and TH design is currently carried out at VTT as contract work for Steady Energy:
  - System-scale TH design using Apros
  - Supporting CFD simulations with OpenFOAM
  - Core design and dynamics simulations using Kraken
  - Supporting Monte Carlo calculations with Serpent



- LDR lite benchmark:
  - Public “LDR-like” reactor concept, with similar features (low operating temperature and pressure, natural circulation, passive cooling, boron-free core)
  - For international collaboration, participation in public research projects (e.g. Euratom), thesis work, etc.
  - Specifications openly available, first participation from NRG

VIDEO

Thank you for your attention

- Questions – Jaakko.Leppanen@vtt.fi
- LDR website – https://www.ldr-reactor.fi/en/
- LDR lite benchmark – https://www.ldr-reactor.fi/en/ldr-lite-benchmark/
- Steady Energy website – https://www.steadyenergy.com/
- LDR lite presentations in this conference:
  - R. Tuominen, et al. *"LDR Lite Benchmark: Description of the Core Model."* Light-Water Reactors Design and Core Analysis: I, **Monday, April 22, 10:15 PDT**, Franciscan B.
  - R. Komu, et al. *"LDR Lite Benchmark: Coupled 3D Neutronics and Thermal-Hydraulics Analysis of a Control Rod Drop Transient."* Light-Water Reactors Design and Core Analysis: III, **Wednesday, April 24, 10:15 PDT**, Franciscan B