District heating reactors and the development at VTT

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Contents of the presentation

- Why nuclear district heating reactor?
- Background on VTT's internal reactor design project
- Heat module concept and some preliminary analyses performed

Work presented has been performed by and supported by a large number of VTT's researchers

- More detailed technical presentations at ICONE 28 conference this August

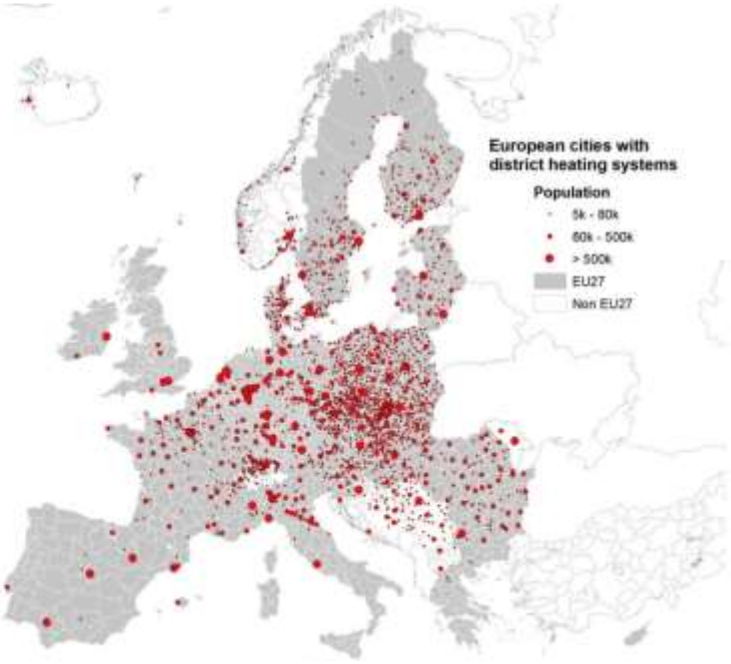
Motivation
Why nuclear district heating reactor?

Heat supply to the built environment a key pillar in EU climate strategy

Heating and cooling accounts for circa 50% of the energy consumption in the EU

District heating represents circa 12% of the heat energy consumed in the EU at present

Circa 3500 district heating systems in EU, serving circa 60M people, 75% powered fossil-fuel based Combined Heat and Power (CHP) plants.



Source: JRC Technical Report *Decarbonising the EU heating sector* (European Commission, 2019)

Need for clean dispatchable heat generation

CHP plants to be retired as electricity generation switches to a low-carbon grid

Why not also shift heating to direct electricity or heat pumps?

- Solar is dependent on the season. Solar and wind are dependent on the weather.
- Adding DH load to EU grid would increase requirements for storage, distribution grid upgrades, flexibility services
- Does not take advantage of existing district heating and cooling infrastructure

Overall DH is more suited to consistent dispatchable energy generation

- **Limited stocks of sustainable fuels**

→ Nuclear district heating reactor

- **Currently no nuclear district heating SMRs in size range well suited for Europe**
  - **Chinese projects ongoing, with ~400 MW plants**

Idea in itself not a new one

- Ågestaverket
  - Production of heat to district heat network as well as electricity
  - In use between 1964 – 1974
- VTT’s heat reactor design work in 1974
  - Conceptual design of a heat only reactor mostly manufactured in Finland
  - According to economic studies competitive when peat bogs far away from heat need
- ASEA ATOM’s SECURE district heating reactor
  - Offered to Helsinki but other competing solutions won
- But perhaps time is now right

VTT's district heating reactor project

Goals of the project – first phase

The project was started in February 2020

The goal was to create a pre-conceptual design of a small nuclear reactor module for district heating applications:

- Design covers the reactor unit and main components of the heating pant
- Thermal power 50 MW (reference design)
- Supplied temperature high enough for most of the year
  - Peak demand supply at other dedicated plants
- Pre-conceptual design by the end of 2020


Fossiilisille kyytiä! VTT kehittää pienreaktoria kaukolämpökäyttöön

Design boundary conditions 1/2

- Based on existing technology:
  - No unconventional features, materials or manufacturing techniques
  - Design using VTT's in-house computational tools
  - No additional effort or new expertise required from the regulator*
  - Compatible with the Finnish final disposal concept

Mitigation of technology risks related to later stages of the project by relying on well-established solutions.

* Apart from common SMR challenges related to urban siting, EPZs, etc.

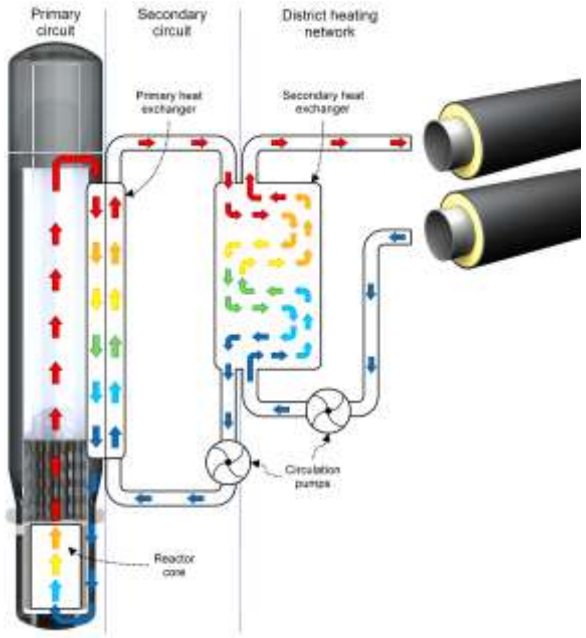
Design boundary conditions 2/2

- Passive safety:
  - High level of safety achieved without complicated active multiply-redundant systems
  - Simple operating principle, in which safety relies on physical phenomena (gravity, buoyancy, etc.)
- Business opportunities for the Finnish industry:
  - Apart from fuel, all key components can be manufactured in Finland
  - Design work relies on Finnish experience and expertise
- Parallel in-house tools and competence development

District heating reactor

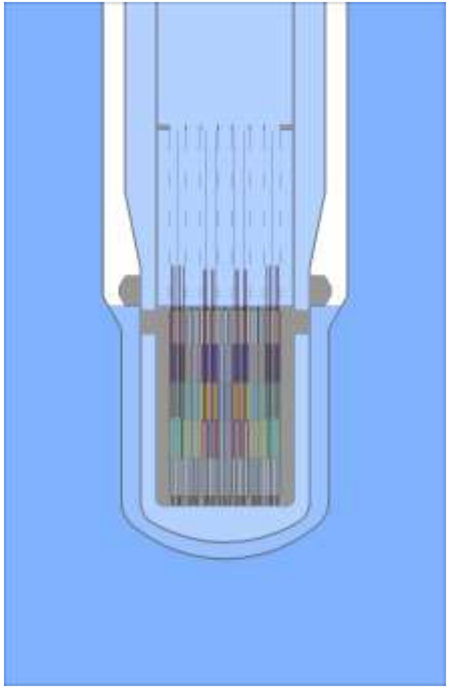
Reactor module – general description

- Reactor is separated from the district heating network by heat exchangers and an intermediate circuit
- Primary circuit:
  - All components integrated inside the pressure vessel
  - Natural circulation from reactor core to heat exchangers
  - Operating pressure ~ 5 bar, self-pressurizing with nitrogen bubble in pressurizer
  - Core outlet temperature 120°C, but scalable



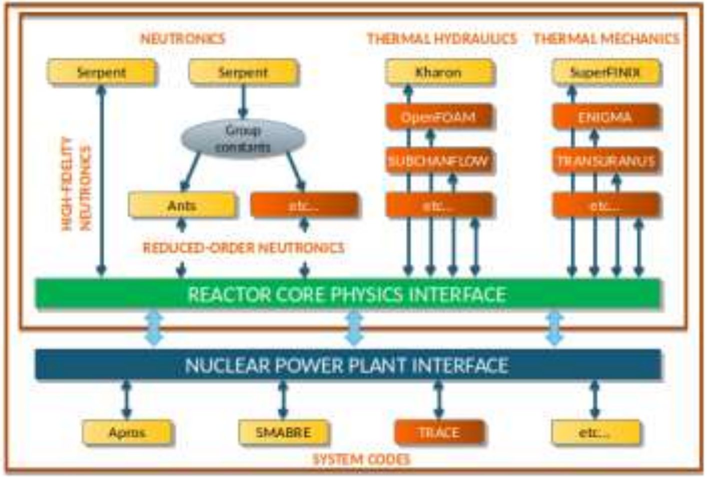
Containment and passive heat transfer

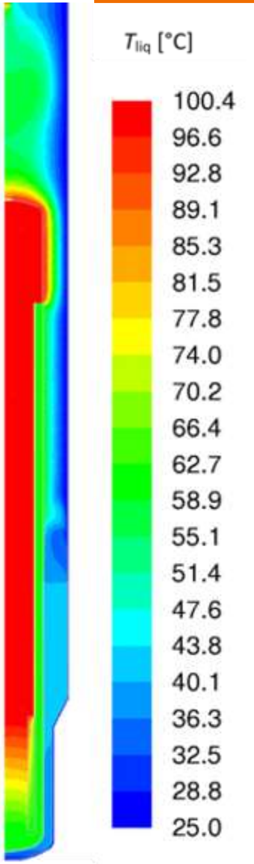
- Double shell containment immersed in water pool
  - Intermediate space partially filled with water
- Decay heat removal is based on natural circulation:
  - In normal operating state, water in the downcomer cools the pressure vessel wall.
  - Water temperature inside the containment remains below boiling point, reducing heat losses to the pool.
  - When heat transfer through the heat exchangers is compromised, temperature in the downcomer begins to rise.
  - Boiling inside the containment opens an effective heat transfer path to the pool.



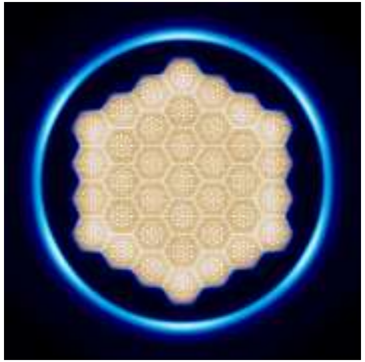
Deterministic analysis

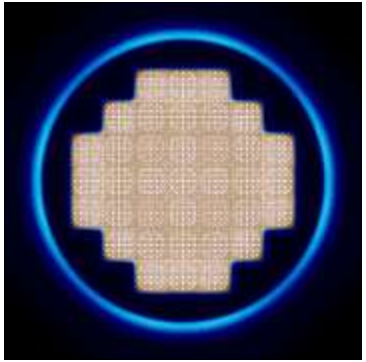
- Aim to demonstrate the basic functioning of the concept
- Functioning of the passive decay heat system with CFD
- Basic behaviour of the module with Apros
  - Reactor startup and shutdown, station blackout, pipe break
- Reactor core design with Kraken
  - Serpent Monte Carlo code used for reactor physics investigations





Reactor and fuel

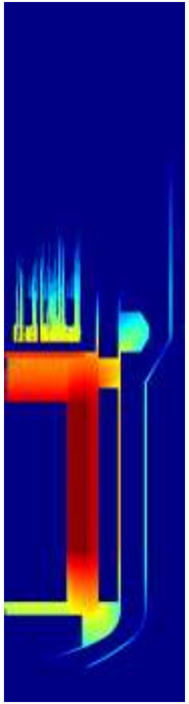




- The reactor is essentially a small conventional PWR:
  - 37 fuel assemblies, low enriched fuel (1.8 - 3.0%)
  - Commercial assembly type (PWR / VVER-1000), truncated to 120-150 cm active length
  - Reactivity control by control rods and burnable absorbers
  - No soluble boron control
  - Cycle length ~ 3 years
- Conservative analysis aimed to demonstrate
  - Negative feedback coefficients through the cycle, sufficient shutdown margins, exclusion of fast reactivity transients, flat power profile

Structural materials

- Preliminary design reference the requirement of district heating network – 16 bar pressure
  - In accident analysis performed the primary circuit pressure stays below 6 bars
- Water on both sides of the wall so austenitic steel proposed
  - Just using pressure equipment directive standards the required wall thickness would be approx 18 mm
- Austenitic steel susceptible to irradiation assisted stress corrosion cracking at low temperatures
  - However fluence to load bearing structures should stay low enough for IASCC not to be an issue



Preliminary results: station blackout 1/2

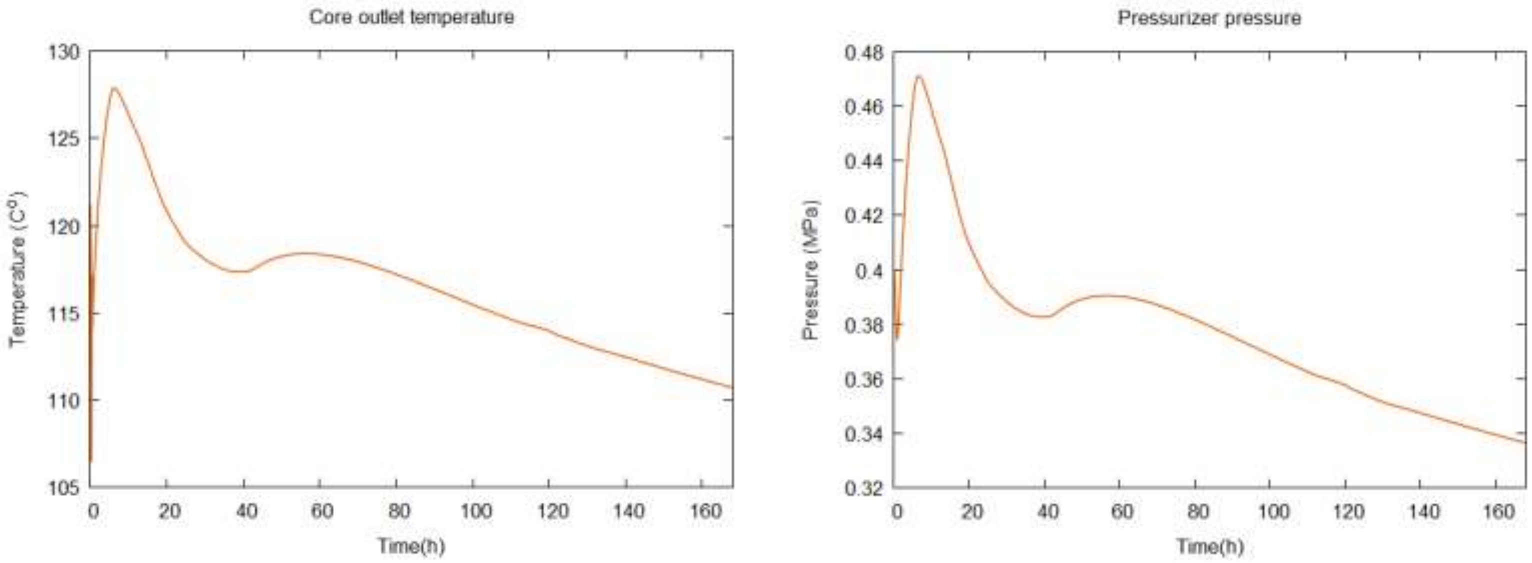


Figure 1: Core outlet temperature and pressurizer pressure inside reactor module during station blackout. Heat exchangers stop functioning and the reactor scrams due to loss of offsite power at t=0. Decay heat starts to conduct to intermediate space and from there to the water pool acting as a heat sink.

Preliminary results: station blackout 2/2

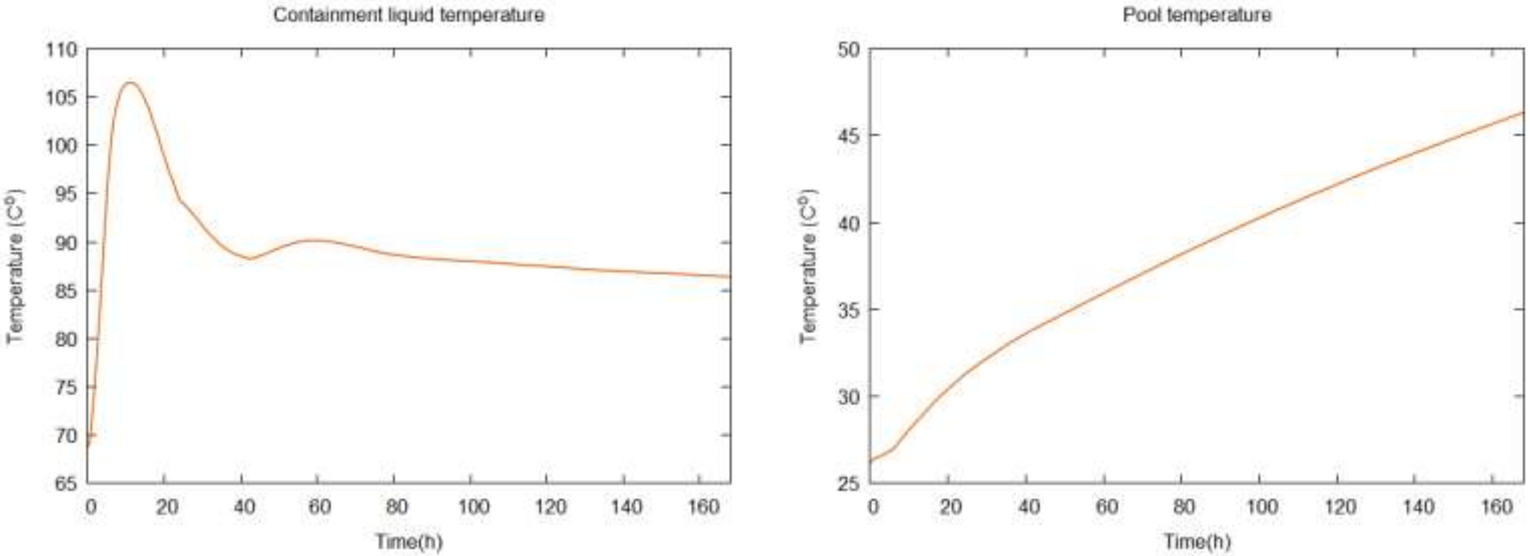


Figure 2: Temperature in the intermediate space and in the water pool. Rate of heat conduction to the pool is increased when the water in the intermediate space starts to boil and the resulting steam condenses to the cool containment wall.

To Conclude

- Decarbonizing district heating supply a challenge
  - Nuclear district heating reactors one potential alternative
- VTT’s design work initiated in February 2020
  - Aiming for proof of concept type design demonstrating a low temperature reactor intended for district heat production
  - Demonstration of in-house simulation framework in parallel
- Can be designed with well-established technologies and materials
  - Low temperatures and pressures enable simpler lighter solutions

Parallel Finnish SMR ecosystem creation project

www.ecosmr.fi Open Business Day 22.3.2021

EcoSMR

beyond

the obvious

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