LUT
University

Nuclear energy research activities at LUT

Juhani Hyvärinen

SMR Seminar and MOTEL inauguration

Lappeenranta, October 17, 2019

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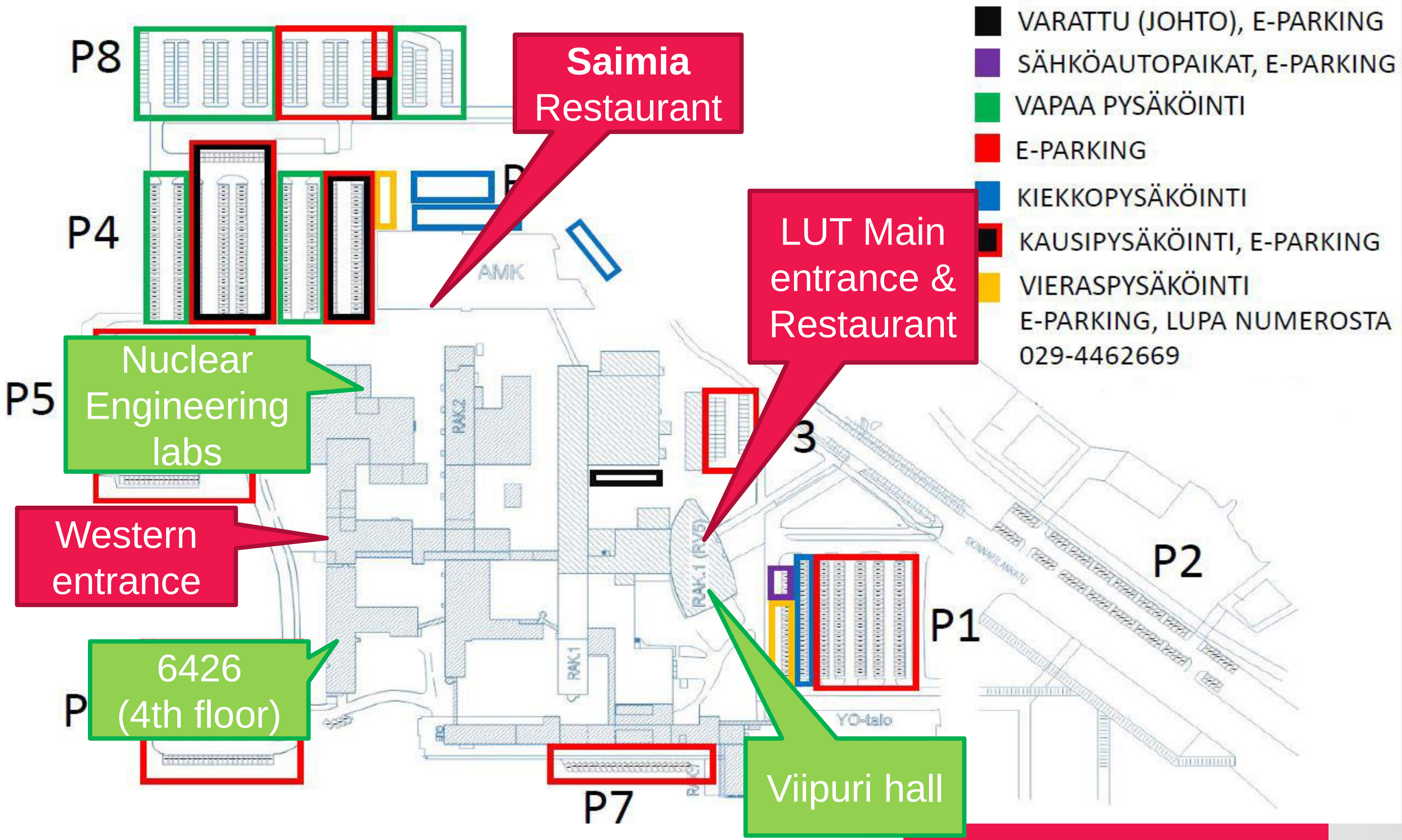
Plan of the day

When	Where
10.00	6426
~11.00	Laboratory tour
12.00	Lunch at **Saimia** Restaurant
13.00	Viipuri hall
15.50	Adjourn



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Ohjelma

10.00 Avaus ja LUTin ydinvoimatoimintojen esittely, **Juhani Hyvärinen**
11.00 Laboratoriovierailu ja MOTEL-juhlistus
12.00 Lounas Saimian ruokalassa
13.00 Seminaariesitykset jatkuvat

- Yliopistoyhteistyö konepajan näkökulmasta – **Refinec Oy**
- Fortum SMR-tutkimuksista - **Eero Vesaoja, Fortum**
- EU-projekti ELSMOR - **Ville Tulkki, VTT**
- EcoSMR -ekosysteemi - **Ville Sahlberg, VTT**
- Keskustelua yritysyhteistyöstä SMRien alalla

15.50 Päätös

LUT in Figures 2018

1969 founded in 1969, combining technology and business from the start

920 scientific publications

5000 Bachelor's and Master's students

524 doctoral students

80 M funding €80 M: Ministry of Education and Culture €48 M, supplementary funding €32 M

1000 staff

81 different nationalities on two campuses

⅓ of incoming students are international

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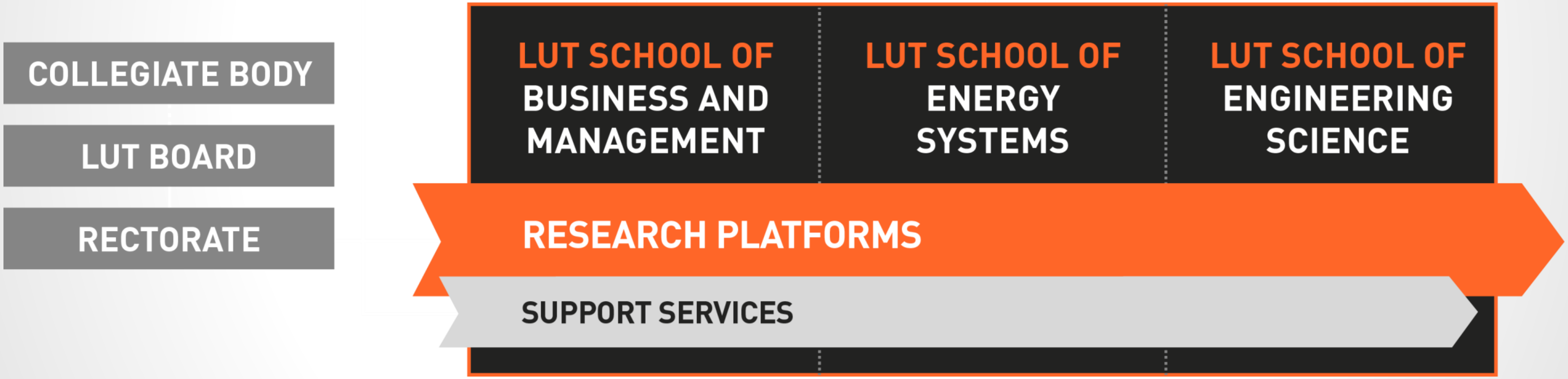
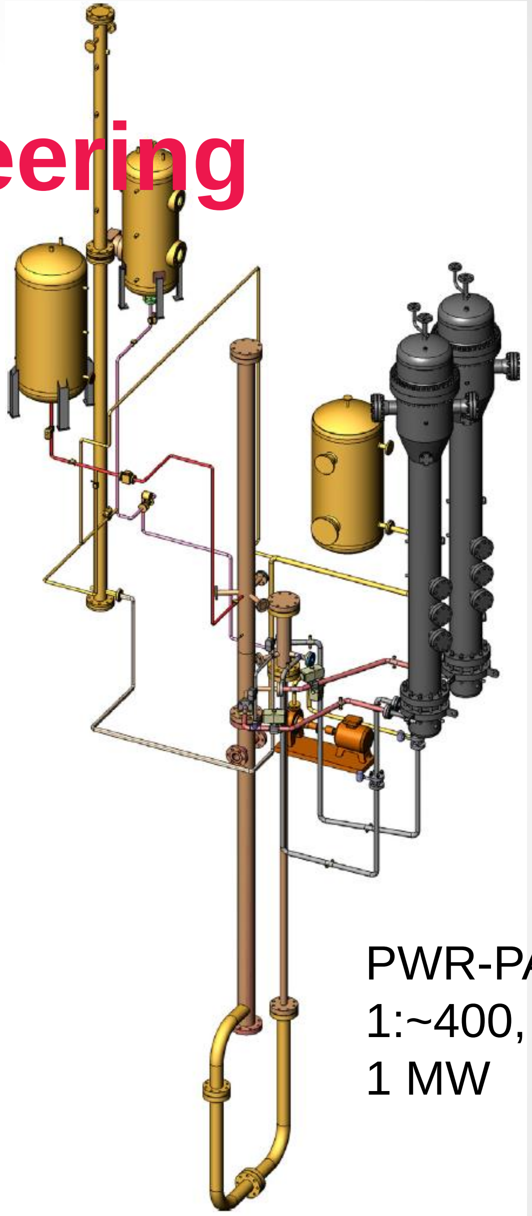
Solution-focused organisation



What we do at LUT Nuclear Engineering

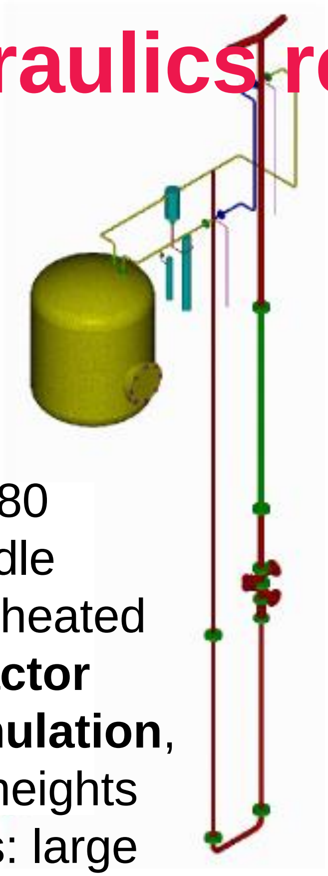
- **Teach** nuclear power plant engineering
  - MSc and DSc degrees
  - “National mission” to give MSc nuclear engineering education
- Thermal hydraulics **research**
  - Historical overview
  - Passive cooling system performance
  - OL3 licensing: keeping vibration damper viscomass from interfering with ECCS
  - SMRs and district heating reactors → MOTEL (and more)
- Reactor physics **research**
- Conclusions

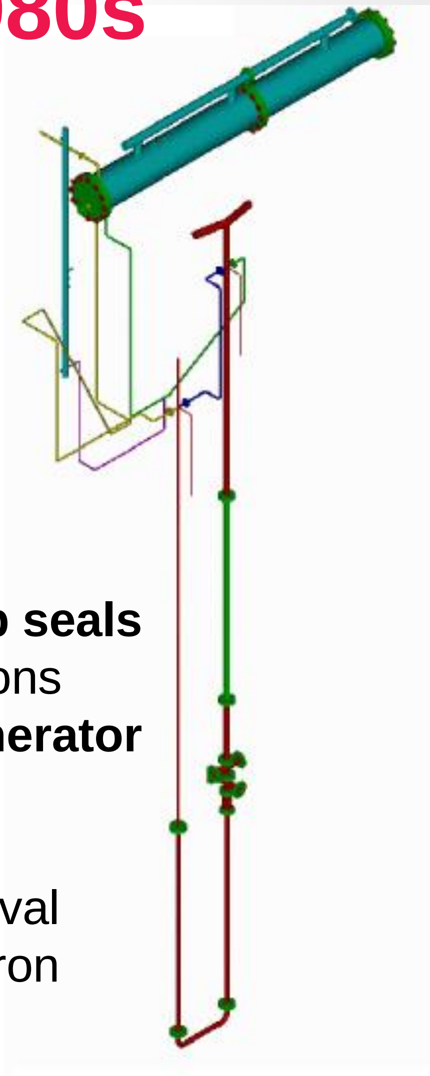


PWR-PACTEL
1:~400, 17 m high
1 MW

Thermal Hydraulics research

LUT thermal hydraulics research 1970-1980s





REWET-I, 1976

- **3 rod bundle**, electrically heated
- prototypic rod dimensions
- main topic: **large LOCA, reflood heat transfer** under forced flow

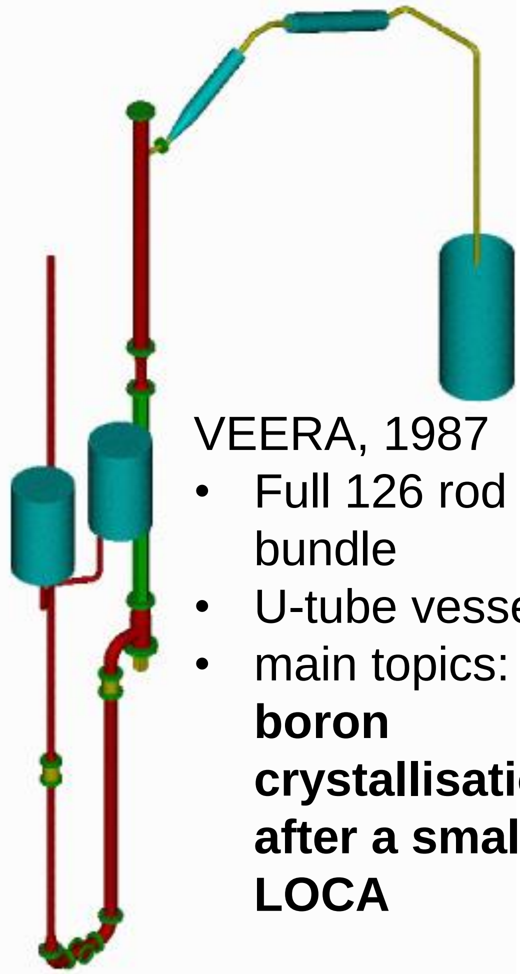
REWET-II, 1980

- **19** rod bundle electrically heated
- **U-tube reactor vessel simulation**, prototypic heights
- main topics: large LOCA reflood, given **gravity flooding**
- **ECCS accumulator and pumps** simulated

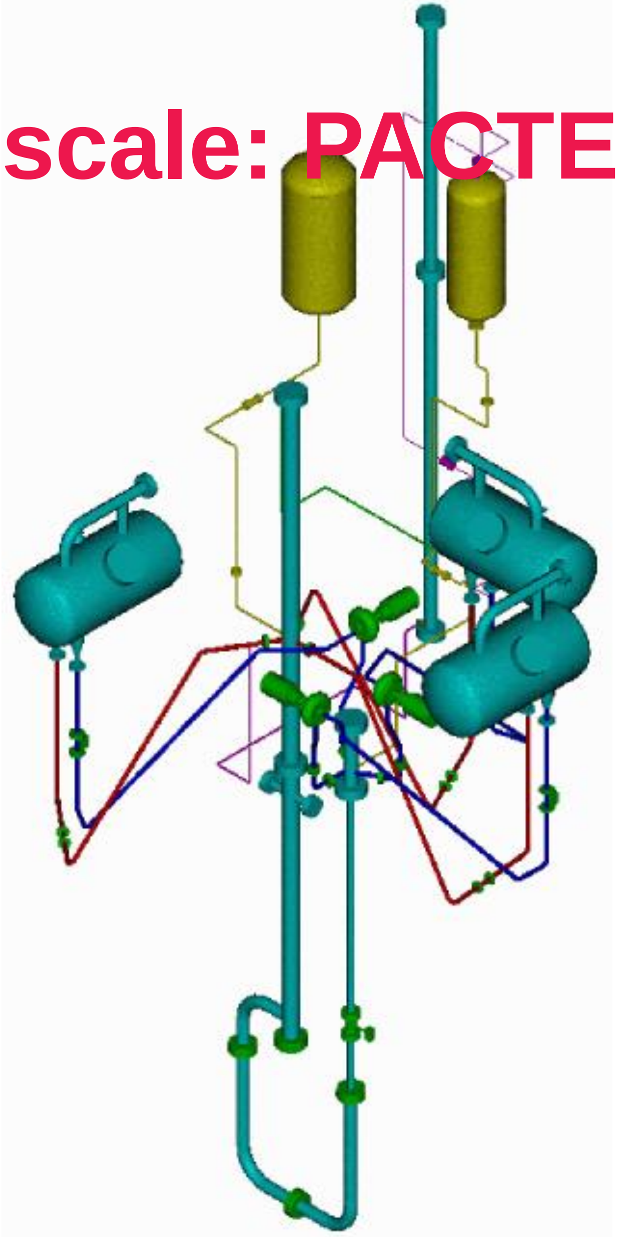
REWET-III, 1984. 1:2333

- 19 rod bundle
- U-tube vessel
- **hot and cold leg loop seals** with prototypic elevations
- **horizontal steam generator** prototypic tubes
- main topics: **natural circulation** heat removal
- **small LOCAs** incl. boron crystallisation

Going to bigger scale: PACTEL (1980s)

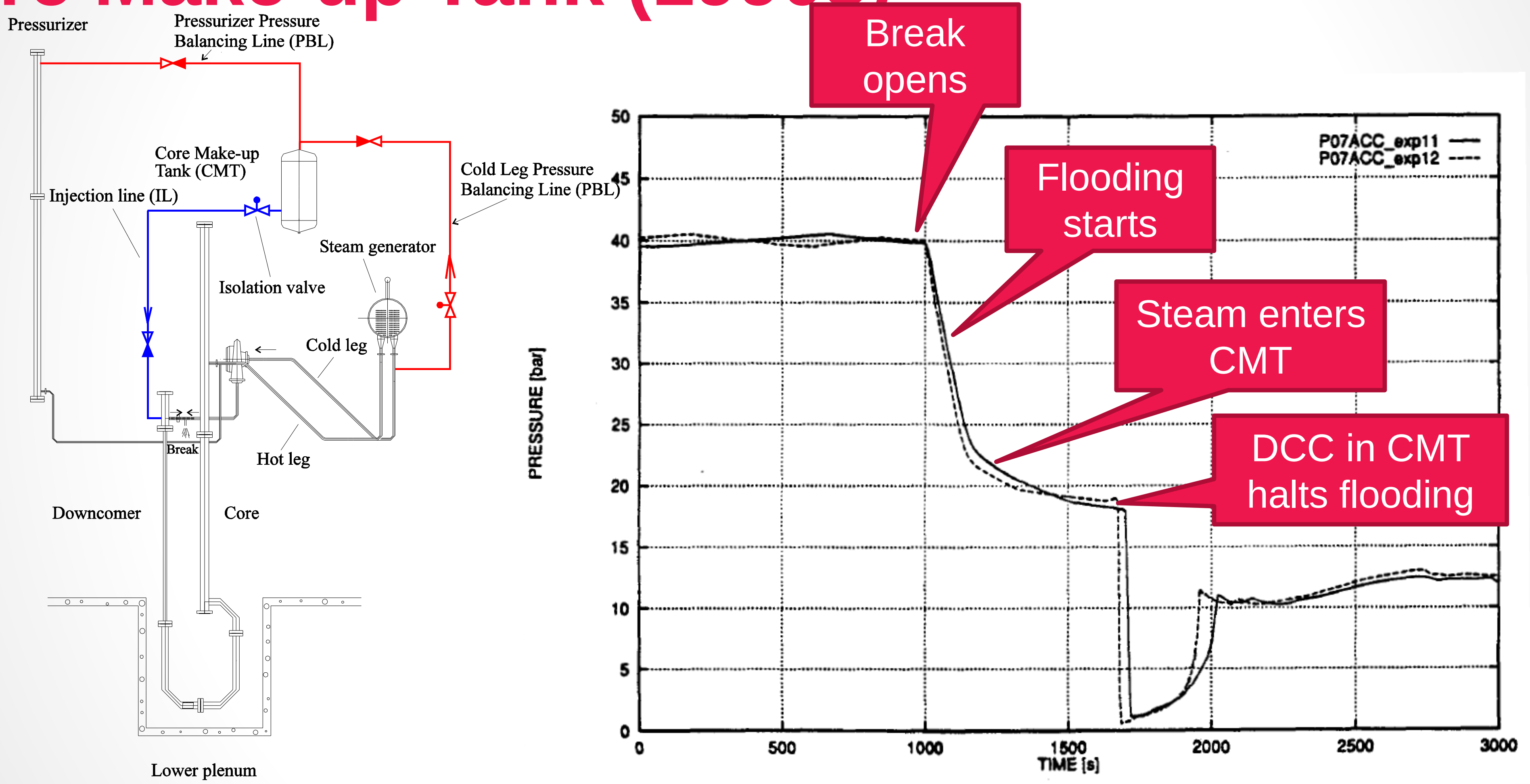


VEERA, 1987
- Full 126 rod bundle
- U-tube vessel
- main topics: **boron crystallisation after a small LOCA**



PACTEL, 1989.   1:305
- 144 rods in three segments
- U-tube vessel
- **three** symmetric **loops**, each representing two of the VVER-440; with **loop seals** and **horizontal steam generators**
- pressuriser
- ECCS pumps and accumulators
- Broad range of topics: **natural circulation, small LOCAs, primary-to-secondary leaks, steam generator behaviour, non-condensable gases**
- International Standard Problem ISP-33

Direct contact condensation in AP1000 Core Make-up Tank (1990s)



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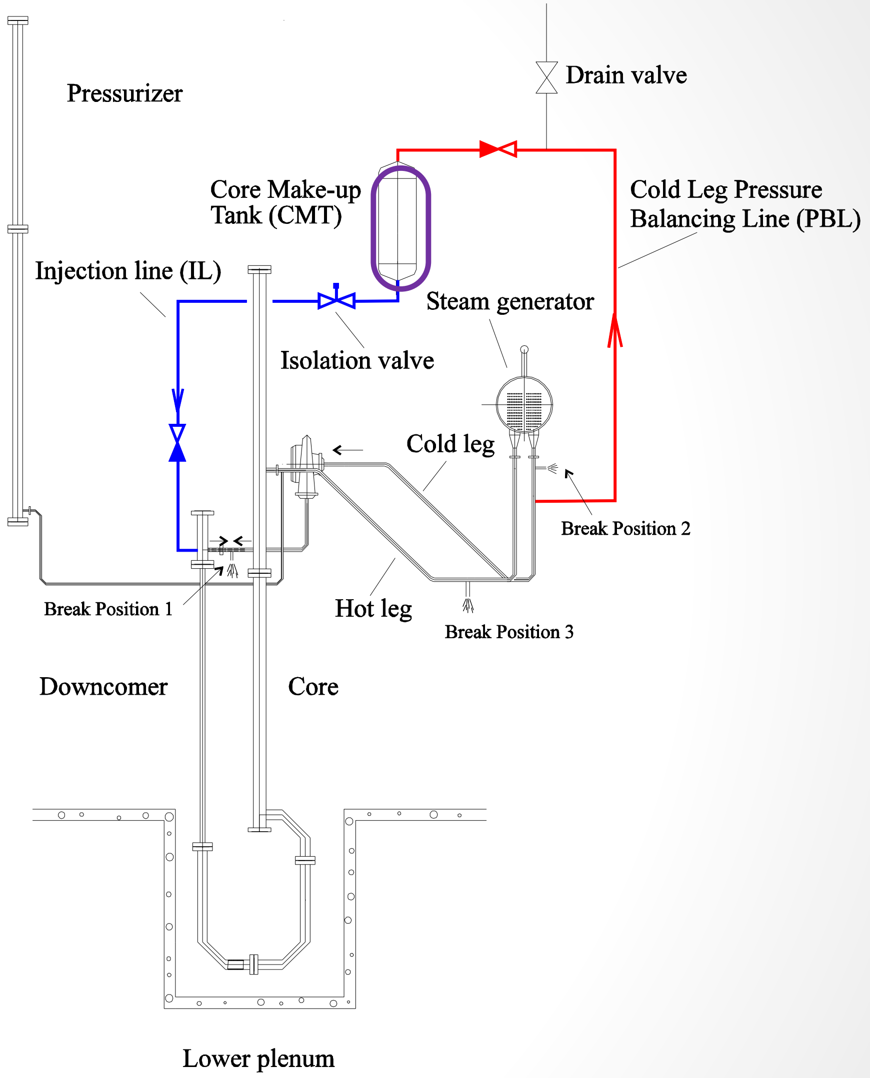
Improved PBL design

Direct contact condensation is due to steam contact with deeply subcooled liquid in CMT

Solution: connect PBL to the cold leg

→eliminates rapid direct contact condensation risk

→ECCS injection slows down but becomes stable

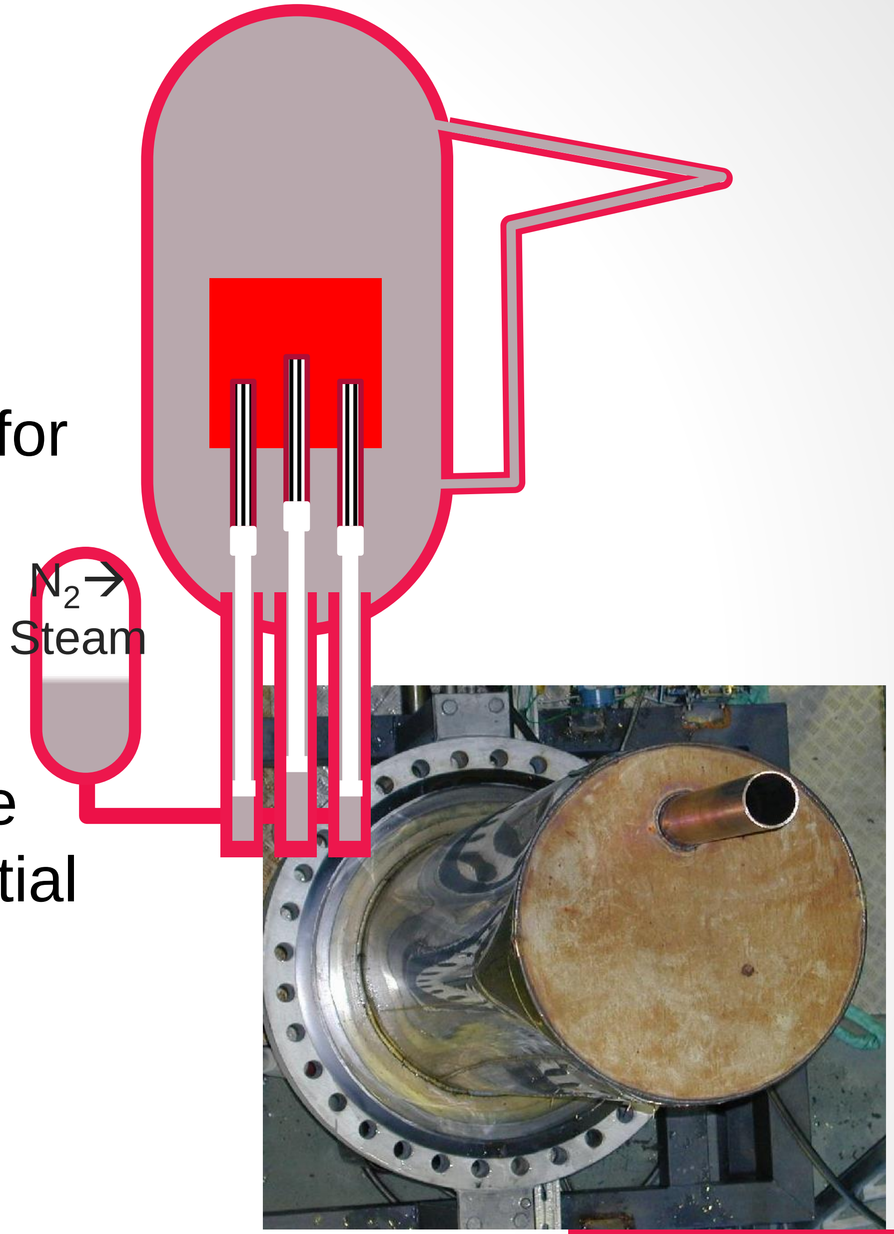


Other passive injection devices (1990s)

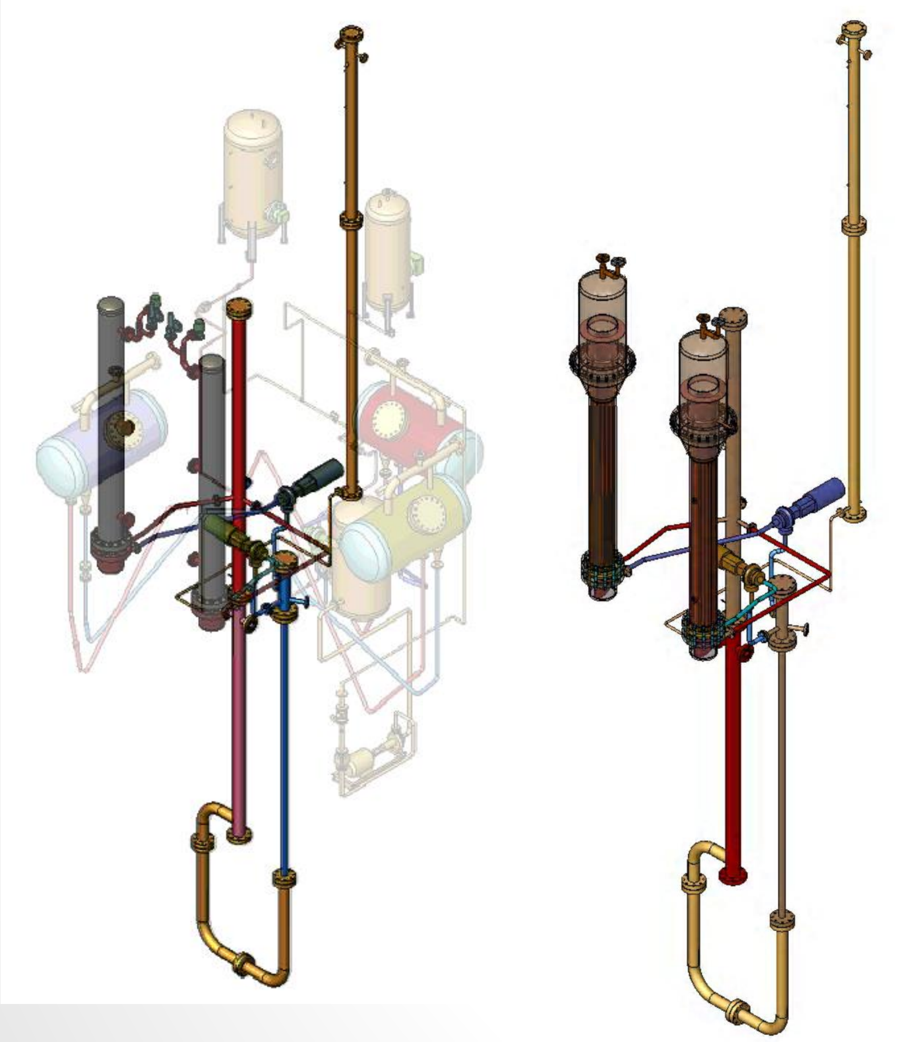
Passive boiling water reactor SWR-1000 (Kerena) foresaw steam-driven systems for

- Hydraulic scram
- Boron injection

Direct contact condensation was possible in the scram tank, and occurred in the initial tests, due to design features of tank internals



From VVERs to PWRs (2000s)



PWR-PACTEL, 2006.   1:~470

- 144 rods in three segments
- U-tube vessel
- **two** symmetric **loops**, each representing two of the EPR; with no hot leg loop seals and **vertical steam generators**
- pressuriser
- ECCS pumps and accumulators
- Range of topics: **natural circulation, small LOCAs, steam generator behaviour**
- OECD/PACTEL project, jointly with PKL (Germany) and ROSA (Japan)

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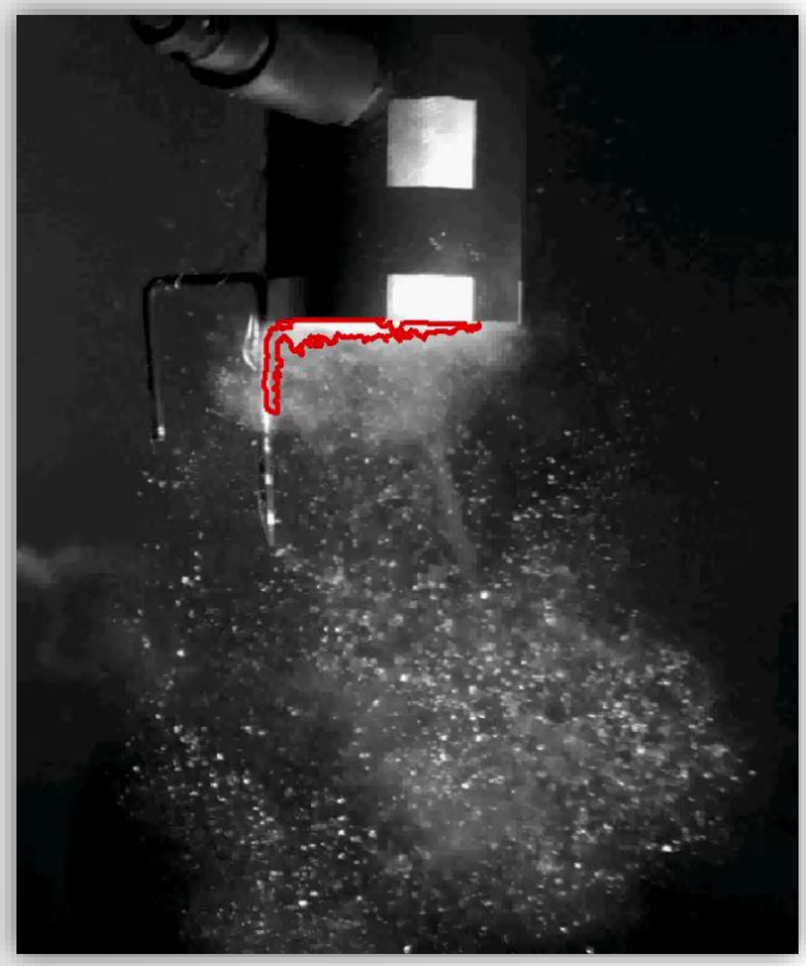
BWR Suppression pool dynamics (2000s)



BWR suppression pool is a passive device

Volume scale to plant ~1:330

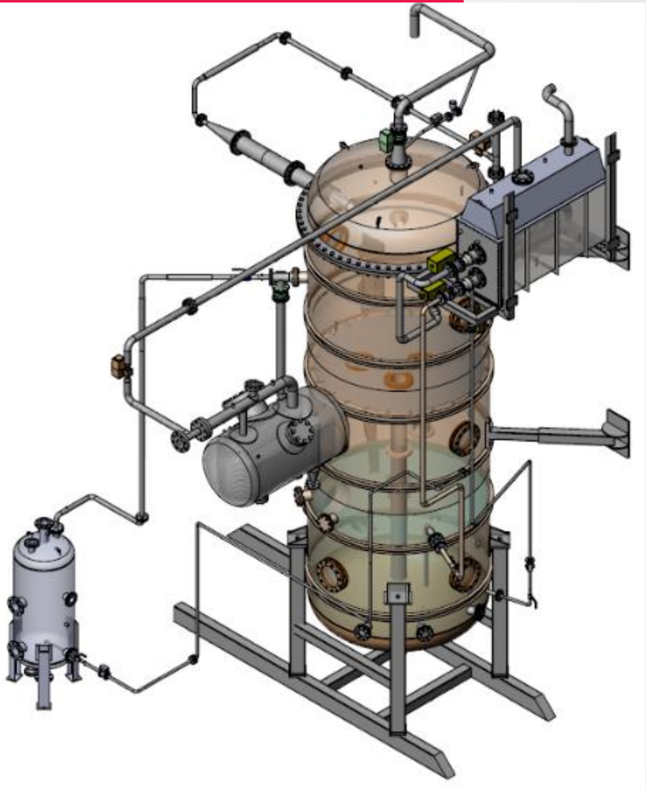
Suppression pool performance: chugging due to direct contact condensation

- Elina Hujala's DSc thesis defence on November 1, 2019

Also thermal stratification, ECCS air ingestion, strainer clogging

Passive containment cooling systems

PPOOLEX (2006)



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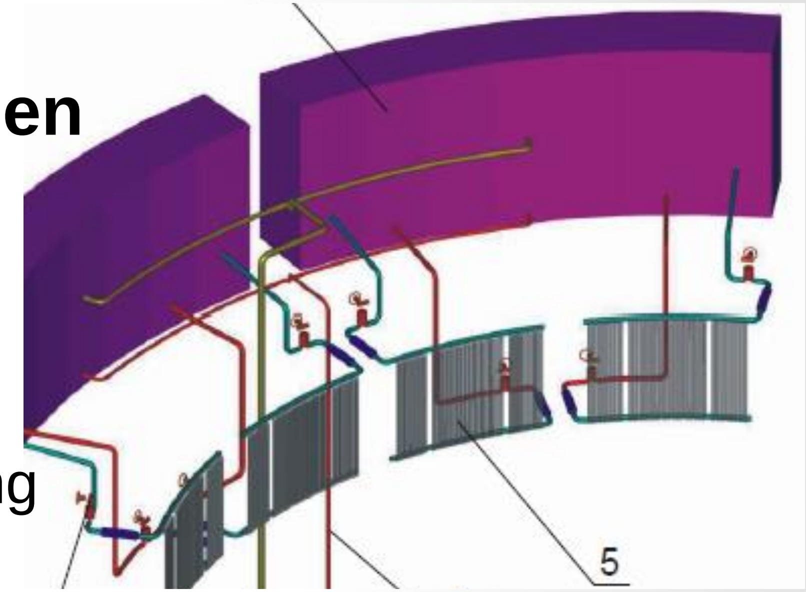
Passive heat removal system: PASI facility (2010s)

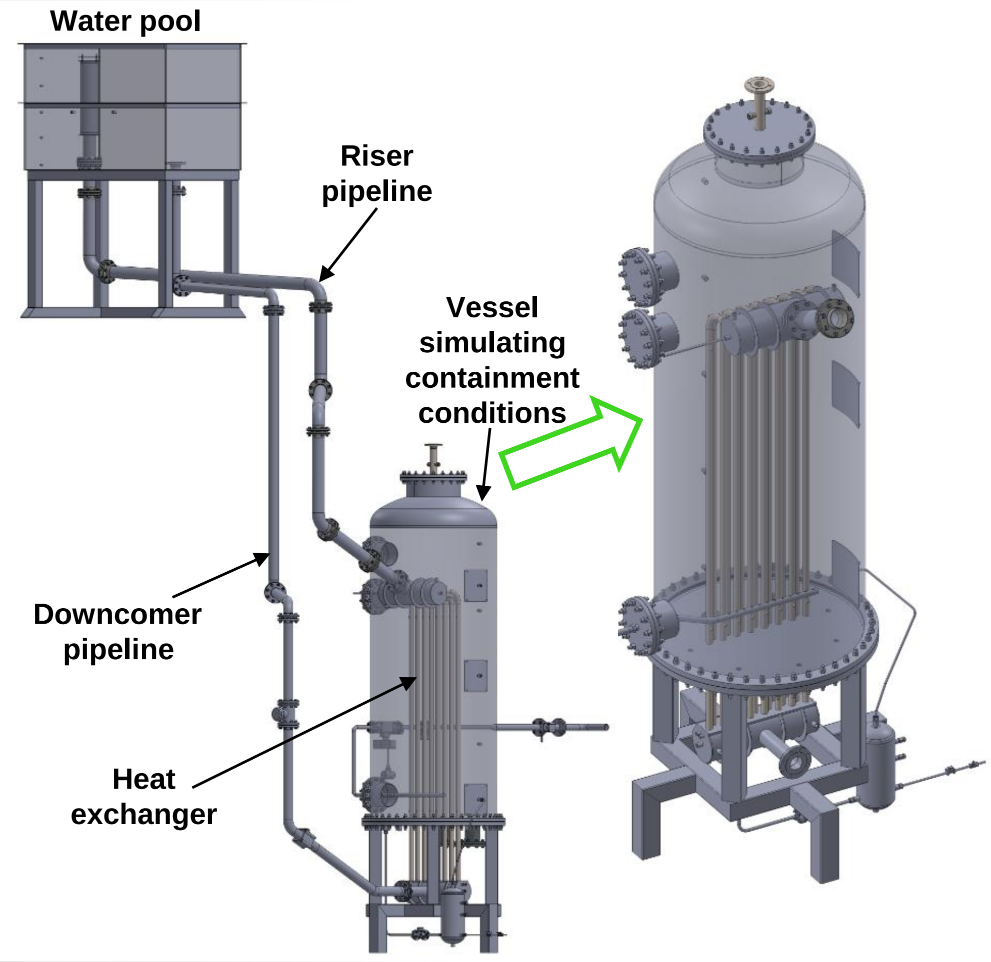
Models the PHRS-C system of AES-2006, an open containment cooling loop

- **Test objectives**
  - ➢ Measure system characteristics
  - ➢ Detect issues, especially those with potential to preventing passive system from functioning as designed



- Pre-review in 2015 on passive systems by LUT
  - ➢ Focus on open loop heat removal at low pressure – generically applicable to open loop low pressure systems

PASI facility characteristics



CHARACTERISTICS	PASI
Reference system	PHRS-C (AES-2006)
Height scale (riser & downcomer pipelines, heat exchanger)	1:2
Number or heat removal loops	1
Height of heat removal loop [m]	8.0
Maximum pressure inside vessel simulating containment conditions [bar]	5
Maximum temperature inside vessel simulating containment conditions [°C]	170
Height of heat exchanger [m]	2.8
Number of heat exchange tubes	15
Heat exchange tube outer diameter / wall thickness [mm]	38 / 3
Riser pipeline outer diameter [mm]	~110
Downcomer pipeline outer diameter [mm]	~85
Main material of components	Stainless steel
Insulation material / thickness [mm]	Rockwool / 50

PASI status

Designed and constructed under the SAFIR program 2016 - 2018

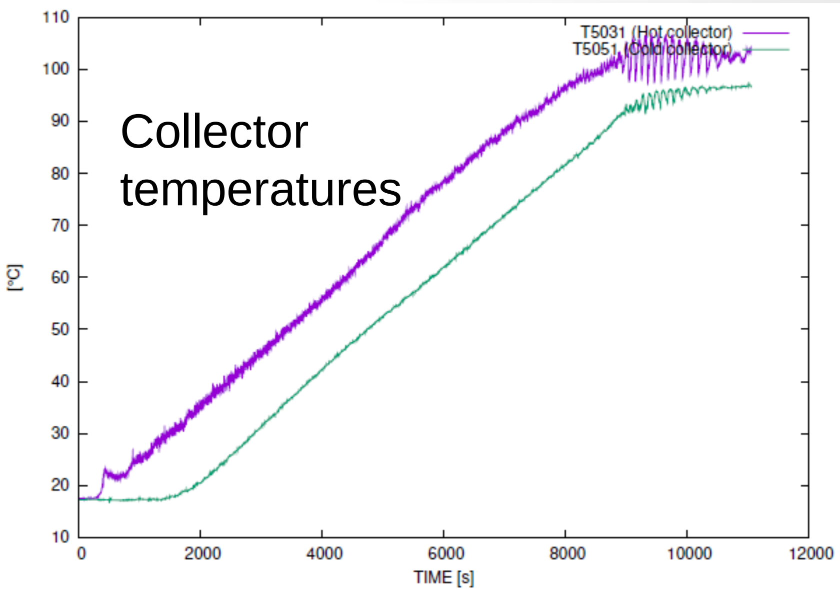
- Shakedown tests 2018
- New instrumentation, e.g. fiber optics studied
- Target: characterize performance and identify any shortcomings of this kind of a passive system
- Production runs to support Hanhikivi 1 licensing have started

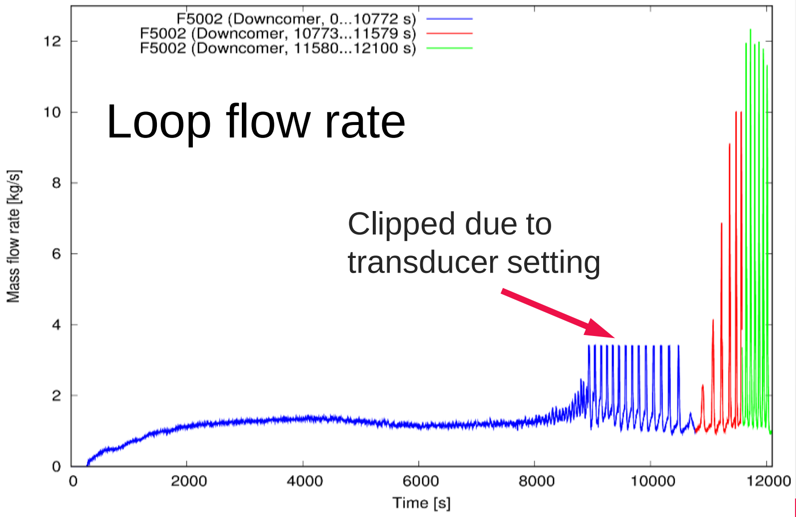
PASI shakedown results

Several operational modes can be distinguished:

- Heatup from initial (water storage cold) condition: stable heat absorption
- Quasi-steady boiling operation: periodic, geysering flow. Heat removal net capability good, but flow oscillations quite abrupt and large

Operational map to be determined



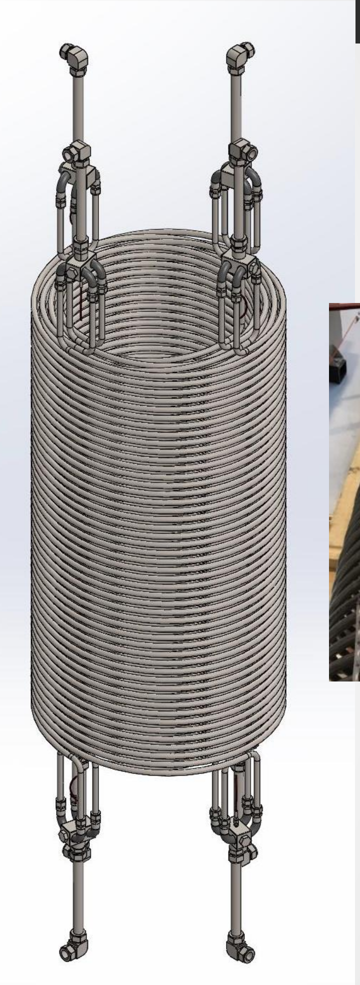


Next-generation T/H system: MOTEL (2020s)

MOdular TEst Loop

Innovative features typical to small SMRs

- Helical coil steam generators
- Gravity-driven circulation
- 12 groups of 12 heater rods, independently controllable
- 1 MW heating power (for now), power uprate planned to 2.3 MW
- Heat removal directly by conduction through vessel walls (later)
- Approx. 1:80 power scale w/r NuScale targeted → decay heat removal system testing feasible ~1:1 scale



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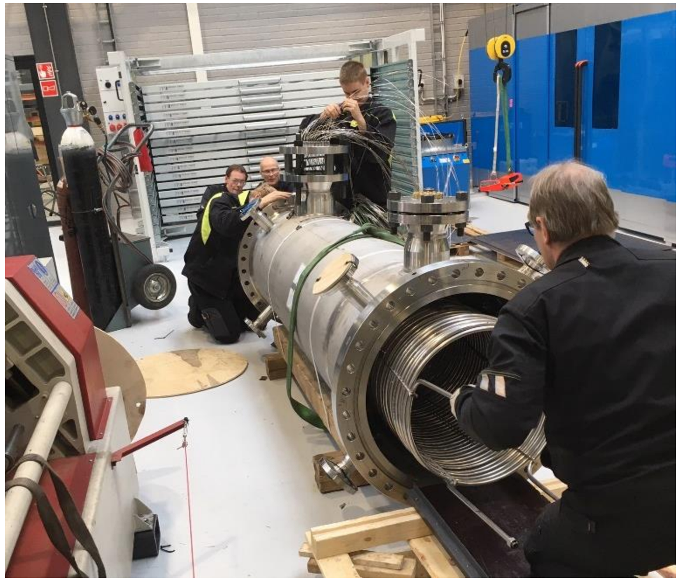
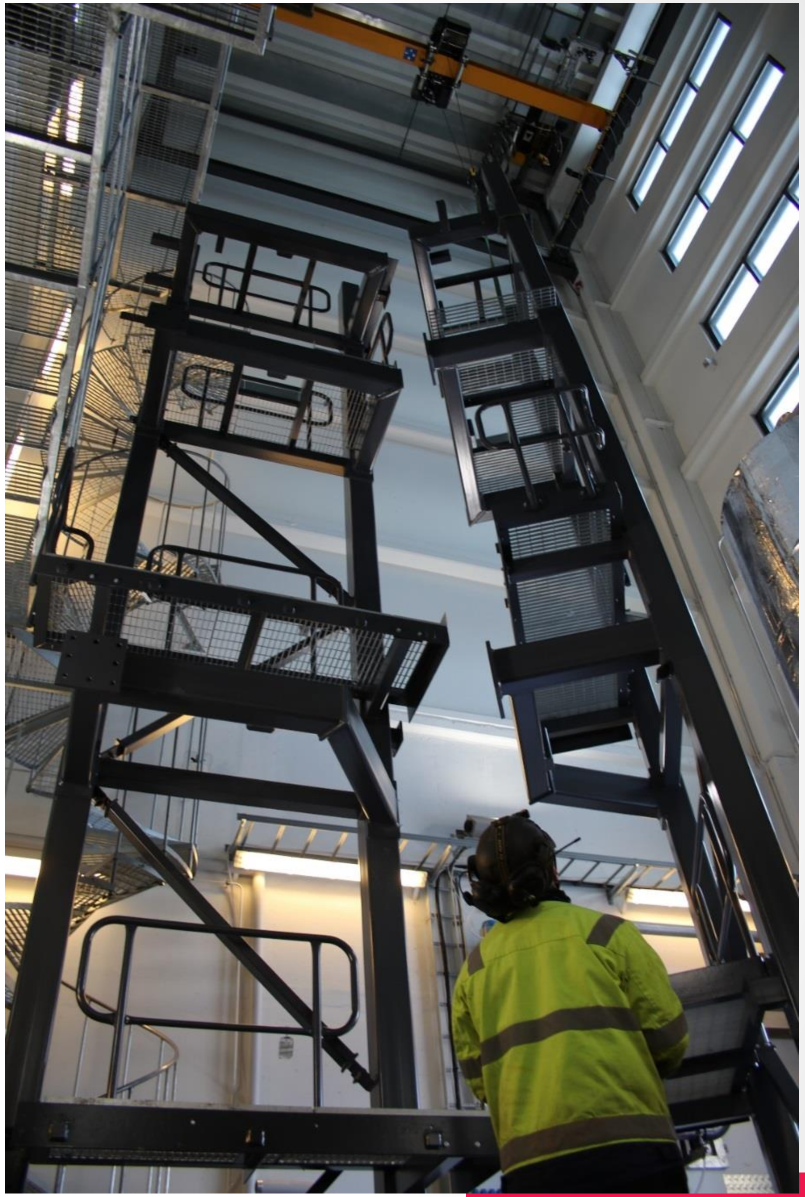
MOTEL construction

MOTEL construction is nearly complete

Later adaptable to reactor system geometry of your choice





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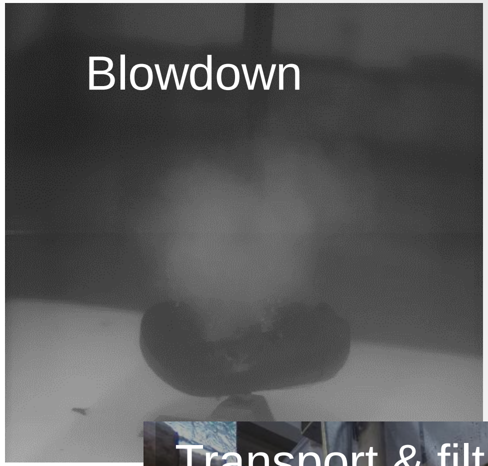
Helping OL3 get operating license

OL 3 surge line vibrated in commissioning tests

- Viscodampers are the optimal solution: broadband damping, highest damping factor
- But: the viscous damping mass (bitumen) could interfere with core cooling under accident conditions
- STUK wanted confidence that the damping mass, if accidentally liberated, does not interfere with emergency core cooling
- LUT tested viscomass behaviour and solved the problem by designing an additional trap that captures released viscomass well before coolant enters the cooling water tank IRWST

Just on time, too: the Finnish government granted the OL3 operating license on March 7 and was disbanded on March 8



Trap design

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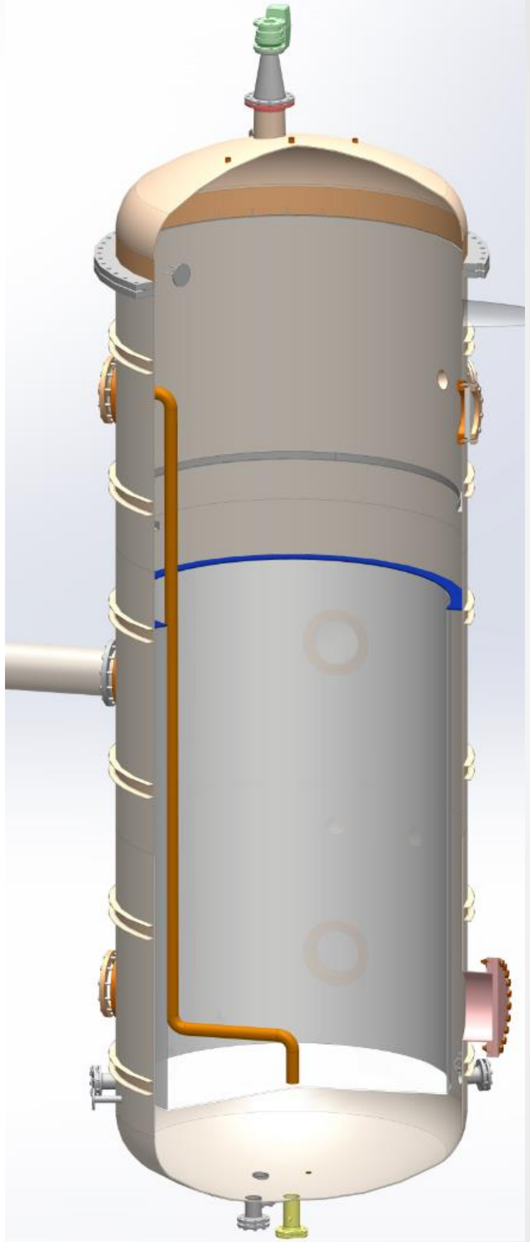
Preparing to revisit PTS

PPOOLEX suppression pool vessel can be converted to a Pressurised Thermal Shock (PTS) thermal-hydraulics test platform DOMEX, DOwncomer Mixing EXperiment

Large system:

- D_{in} = 2.4 m, allows linear scaling 1:2 or better for most old PWRs
- Nozzles ~0.3 m, compatible with linear scaling

Excellent **visual access from inside** to study plume formation and downcomer mixing phenomena



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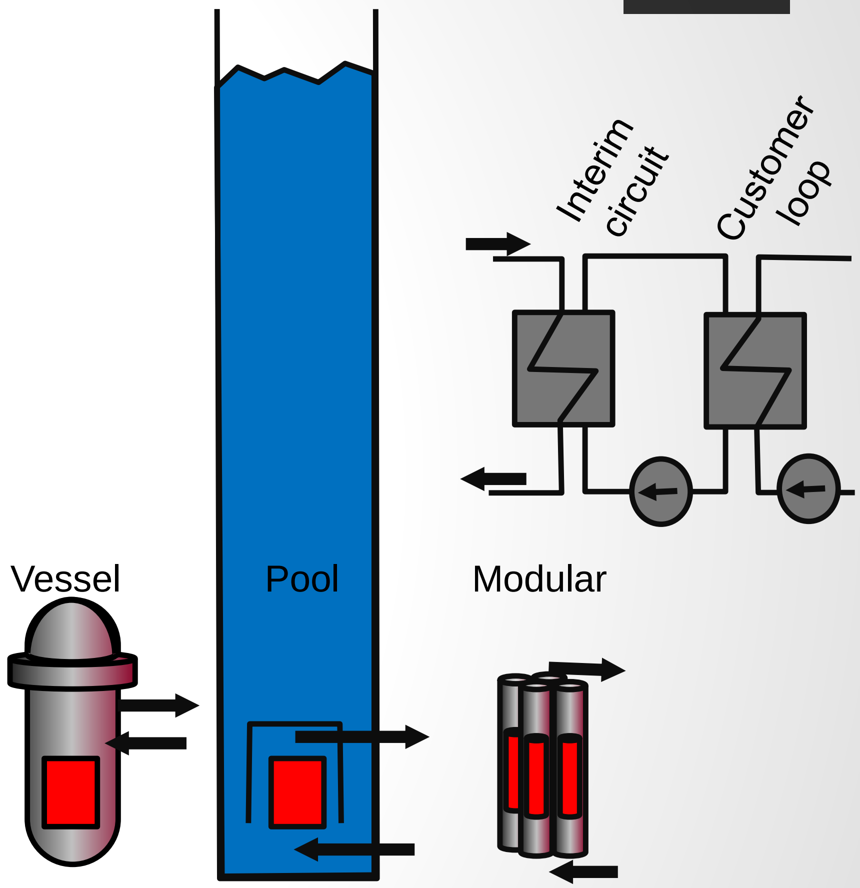
FinReactor: the solution for a simple low temperature heating reactor

In Nordic countries, space heating is bigger CO2 emitter than electricity production

Low temperature and pressure: 150 °C and 1.0 MPa – component manufacture in Finland feasible

Familiar light water reactor technologies and fuels, no waste problems

Utter simplicity for low cost, simple regulation, and high safety



FinReactor: the solution for a simple low temperature heating reactor

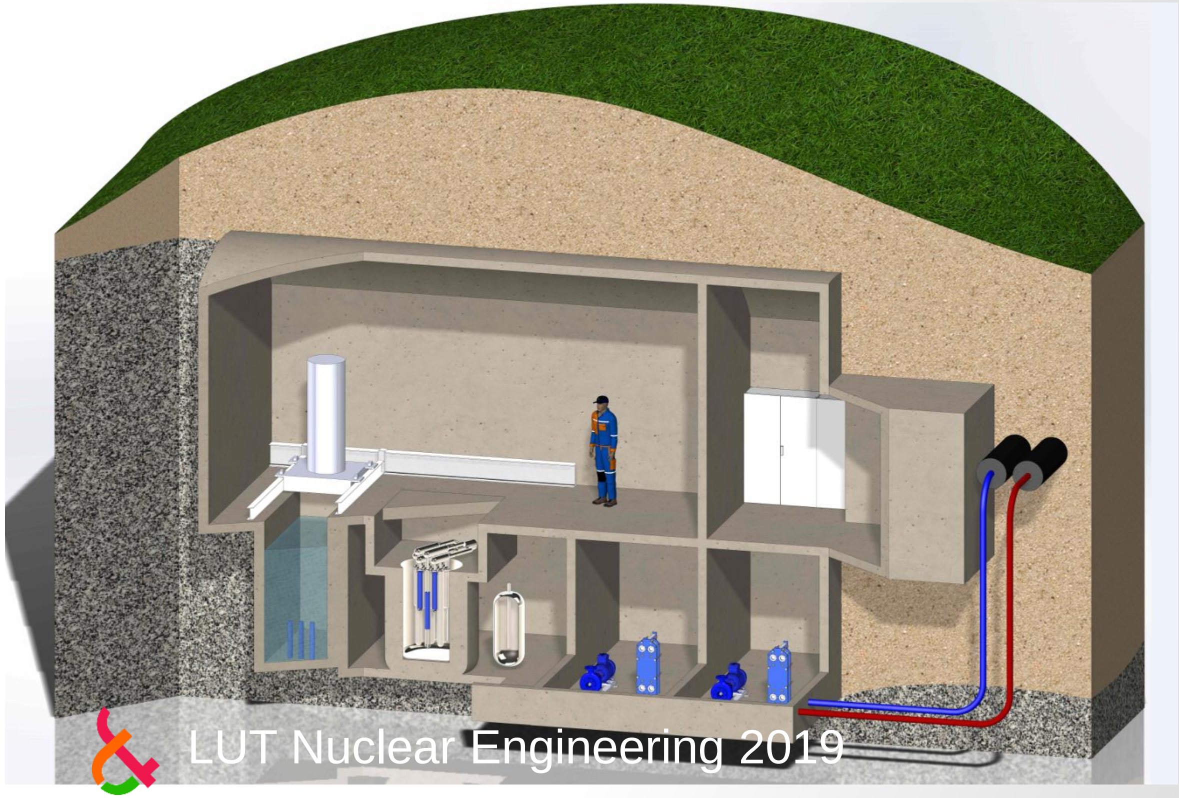
Energy efficiency near 100 %

Below-grade siting

Unmanned (remote) operation possible

Scalable modular design, standard industrial components

Inherently safe, secure and proliferation resistant



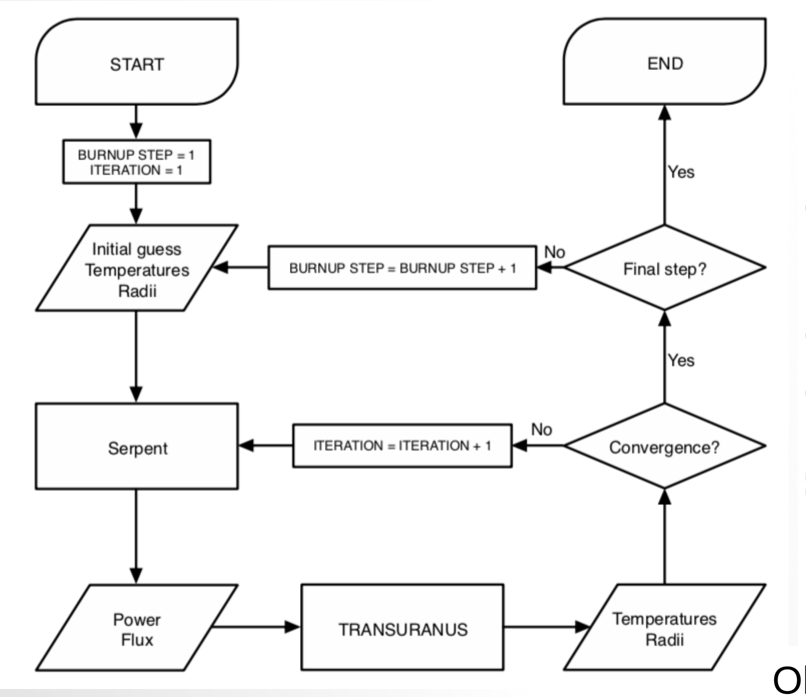
Reactor physics research

LUT Reactor physics

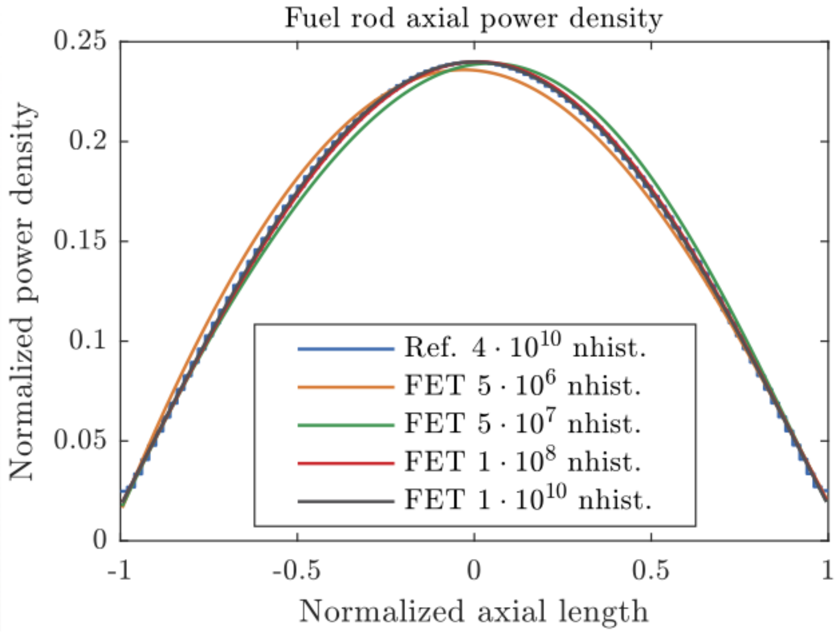
- Development of coupled calculation capabilities between various solvers for multi-physics analyses:
  - Neutronics – fuel behaviour for fuel pins
  - Neutronics – thermal hydraulics – pebble bed mechanics for pebble bed reactors (a gas-cooled SMR soon operational in China)
- Improving the performance of large scale multiphysics calculations via functional expansions:
  - Data transfer between solvers in coupled calculations
  - Acceleration of fission source convergence (ongoing)
- Also more traditional reactor physics analyses, such as criticality safety, and design of novel reactor core configurations

LUT Reactor physics

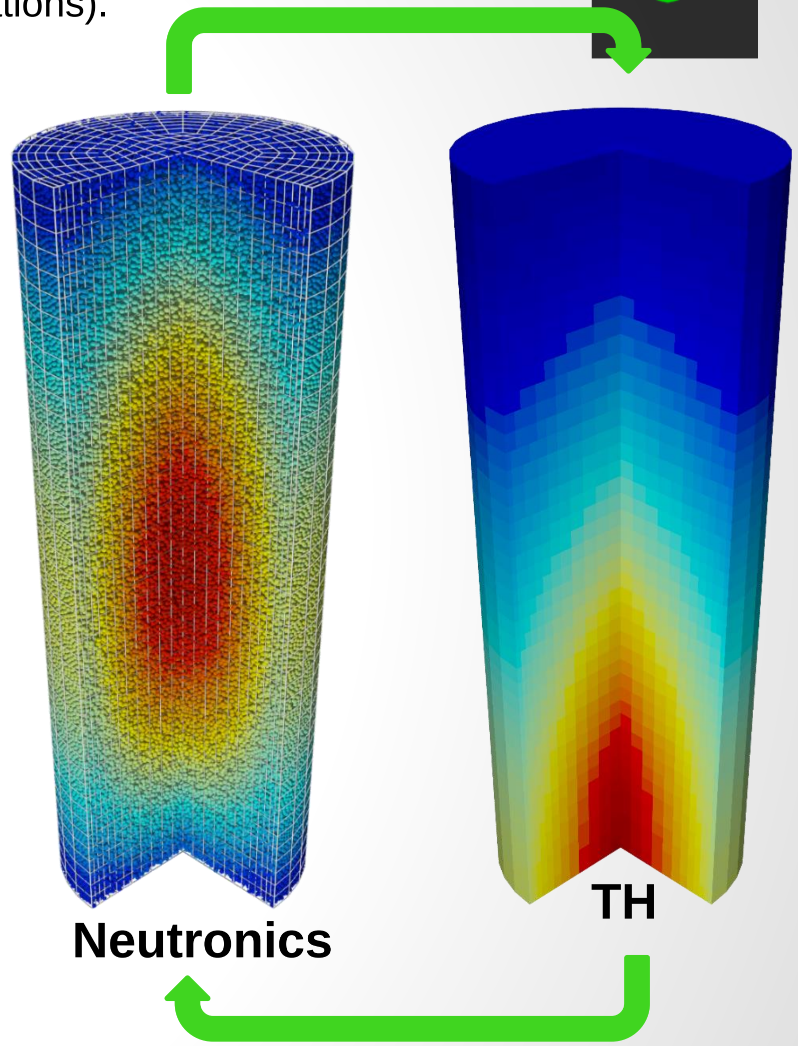
Coupled solution of reactor power and temperature distributions in a pebble bed reactor. Also solving pebble bed mechanics (fuel pebble locations).



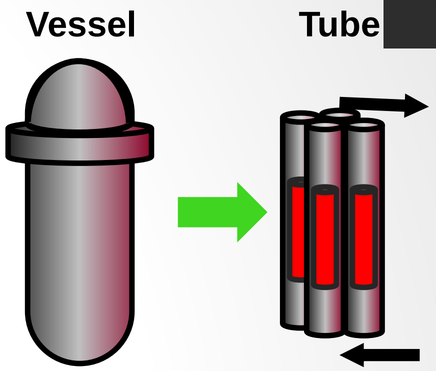
Coupled calculation process between Serpent (neutronics) and TRANSURANUS (fuel behaviour).



Obtaining axial power distribution defined by just a handful of coefficients with a functional expansion based method compared to a traditional bin-based method (staircase profile).

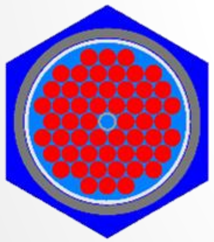


Conceptual core design for a SuoMiReaktori or FinReactor

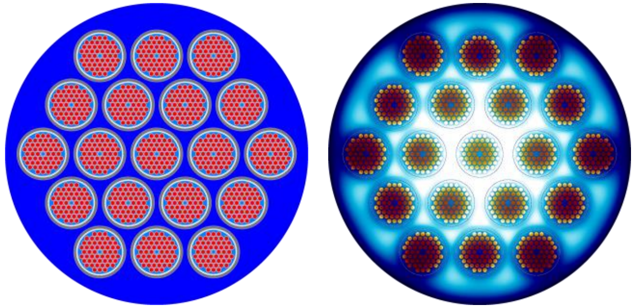


Objectives

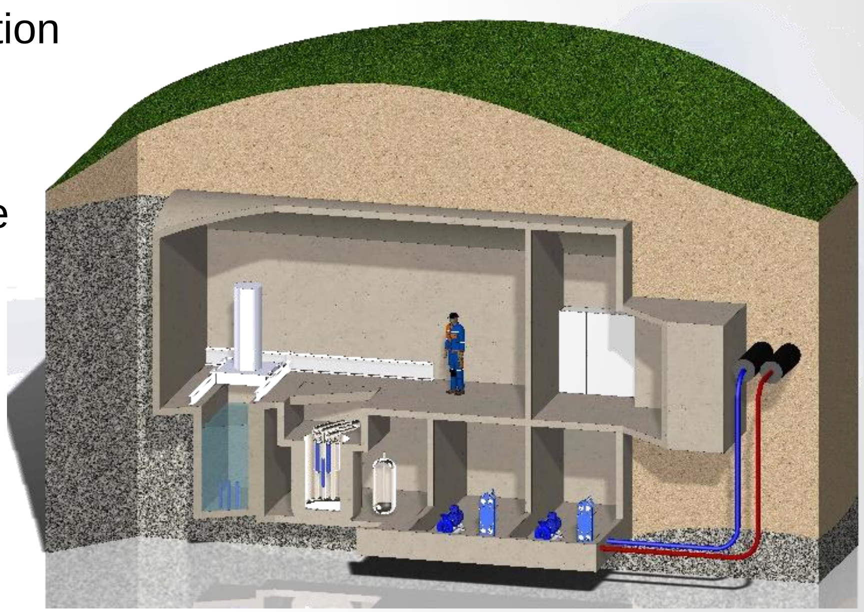
- To produce heat for low-temperature applications (i.e. district heating, desalination)
- Small modular reactor (SMR) design – pressure-channel reactor
- Utilizing available commercial reactor components and materials
- Simple systems & enhanced safety
- Moving fuel assemblies to control core reactivity and fuel burnup compensation
- Design powers: 2 | 24 | 120 MW_{th}
  - 2 MW_{th} for LUT Heating Experimental Reactor (LUTHER)
  - 24 and 120 MW_{th} for municipal utilities. Other power levels also feasible



Fuel channel and assembly



Reactor core



Nuclear district heating plant

Conclusions

Lappeenranta University of Technology has been testing thermal-hydraulic systems for decades. **Experimentation is the only way to appreciate how the world REALLY works**

- Initial driver in 1970s: Loviisa unique features
- Since 1990s: novel safety systems and components, robustness
- Acute problems: most recently viscodampers in EPRs, can be used safely with additional viscomass trap designed by LUT
- Innovative approaches to old problems like PTS are feasible for future use
- New innovative reactor technology – SuoMiReaktori, or FinReactor, to decarbonise district heating is in the works

Thank you!

juhani.hyvarinen@lut.fi