EASI-SMR Workshop 1 Scaling issues 2025

Evaluation of applicability and limitations of existing scaling techniques: Experience from LUT

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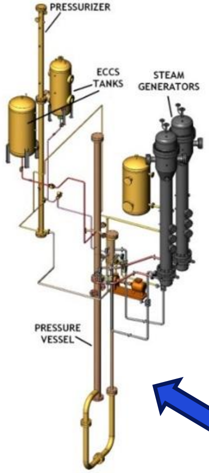
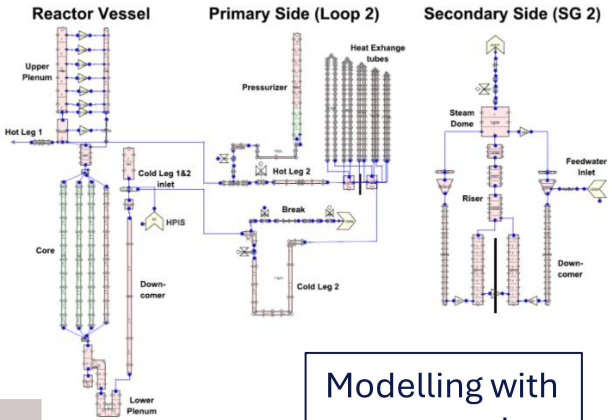
Steady Energy

Scaling background

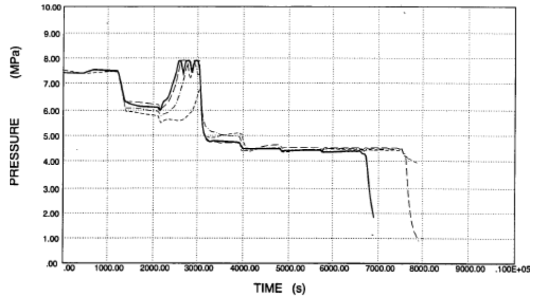
- Tests on real plants are not allowed (except for commissioning tests)
  - ➢ Test facilities are needed
- Building full-scale experimental facilities is expensive
  - ➢ Scaling is needed or only section of the system



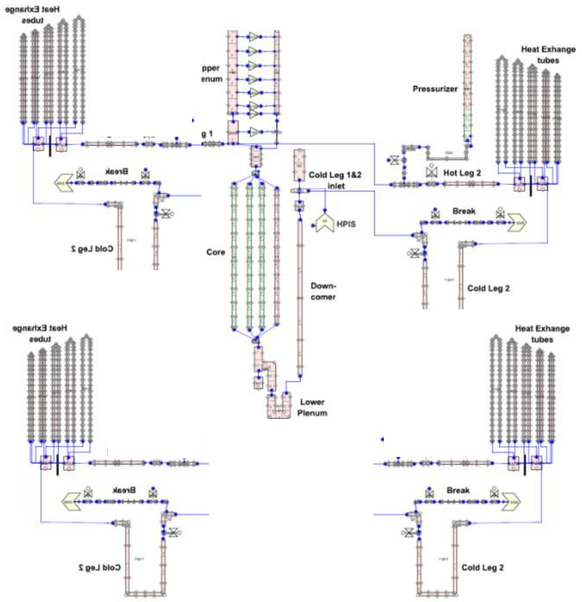
Representative tests



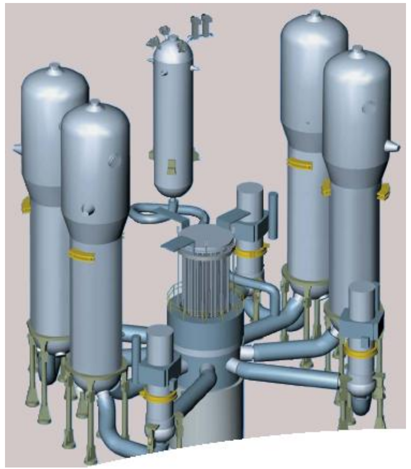
Modelling with system codes



Similarity with test and simulation results



System code modelling of full-scale reactor



Knowledge of system behavior with limited certainty

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Scaling methods

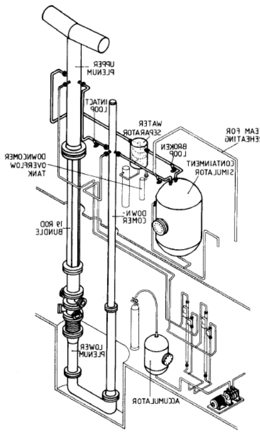
There are two main scaling approaches

- Few effecting phenomena to be modelled
  - ➢ Scale model, SET -> dimensionless numbers (Re, Nu, Pr, Fr, Gr, Ma)
- Multiple effecting phenomena
  - ➢ Difficulties with applying dimensionless numbers
  - ➢ Scaling methods have been developed where the flowing medium and operating conditions are kept same

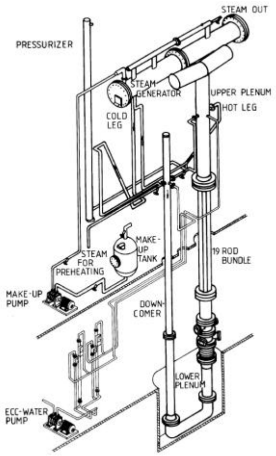
1. Time-reduced scaling
   - Most useful when the forces caused by gravity are small compared to the forces caused by pressure difference
2. Volumetric scaling
   - Easiest to use and most common
   - Advantages: preservation of heights, real-time phenomena, availability of comparable results
3. Ideal scaling
   - Advantages: 3D test facilities, real-time phenomena
   - Disadvantage: change in heights

ITEs at LUT (volumetric scaling)

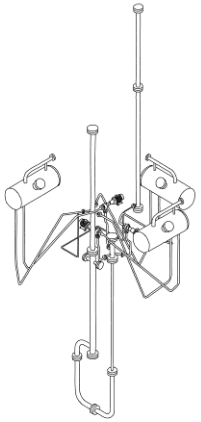
Loviisa nuclear power plant (The annual report of Finnish radiation safety authority on nuclear safety control 2007, p. 18, Public Domain, https://commons.wikimedia.org/w/index.php?curid=4075357)



REWET-II:
Height scale 1:1
Volume scale 1:2333

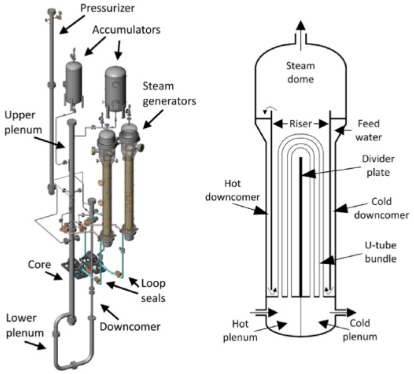


REWET-III:
Height scale 1:1
Volume scale 1:2333



PACTEL:
Height scale 1:1
Volume scale 1:305

Olkiluoto 3 nuclear power plant (TVO)



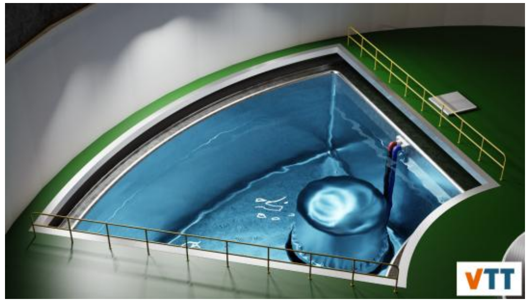
PWR PACTEL:
Height scale 1:1
Volume scale 1:405

- To maintain hydrostatic pressure differences, heights are important in LOCA situations
- Gravitational forces dominate -> vapor and liquid phases separate too easily
- With volume scaling phenomena occur at the same speed and in the same order
- Pressure, temperature and power limitations (expensive to build, available power)

ITEs at LUT (volumetric scaling)

- Consequences
  - Thin pipes -> 1D, pressure losses not 1:1, flow separation in two-phase natural cycle does not occur correctly
  - Heat losses increase (proportional to the square root of the scaling factor) -> insulation / surface resistance
  - Heat capacities of structures do not scale correctly (more steel compared with reference)
  - Water and structure ratio (heat capacities, more steel relative to the volume of water in experimental facilities)
  - Time scale may change effect on coolant flow in natural circulation situations
- Use of dimensionless numbers (hot and cold legs, pressurizer line, and emergency cooling system lines)
  - Scaled using Froude number for pipeline diameters (lengths calculated using volume scaling)
    - ➢ pressure losses also decrease
    - ➢ phenomena are in real-time

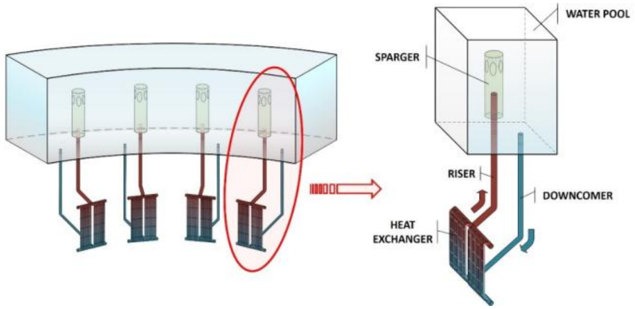
SETs at LUT (dimensionless numbers)



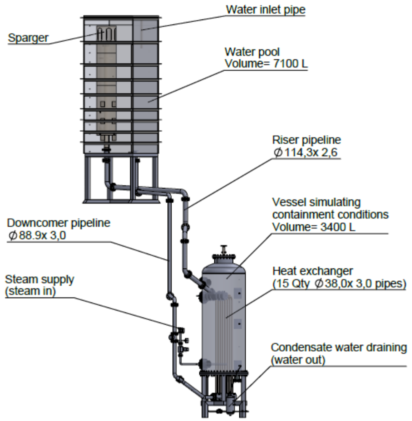
LDR-50 (Jaakko Leppänen, LDR-50 District Heating ReactorTechnology, SYP2022, November 2, 2022)

FHEASIK:
Rayleigh number
Same heat flux

- Convection heat transfer is the dominant phenomenon characterizing the behavior of heat removal in the annular containment
- Aspect ratio, i.e., height of containment gas space divided by gap width is maintained, the gap width being 1:3 with respect to LDR-50
- Convection scales with Rayleigh number → FHEASIK dimensioned so that the convective flow is in turbulent region likewise in LDR-50
- Prototypic pressure and heat flux



PHRS-C system of AES-2006 (Bezlepkin et al., https://doi.org/10.1007/s10512-014-9774-7.)



PASI:
Height scale 1:2
Grashof number

- Height scaling 1:1 was not possible → riser/downcomer diameters were scaled applying Grashof number – relation between driving and resisting forces of natural circulation flow
- Heat exchanger was designed to optimize the number of tubes in relation to the nominal heat exchange power and the natural circulation flow rate in the loop
- Flow velocity scaled with square root of height scale factor
- Prototypic *T*, *p* inside the containment

Scaling test results to plant scale

- Tests are ultimately performed to improve plant safety (directly or through code validation)
  - The significance of test results on a plant scale should always be considered
  - Decades of small-scale experiments and validation of computational codes
  - Time to move to scaling experimental results directly to the plant scale
  - The NEA SYSTHER project aims to take steps in that direction

Olkiluoto 3 nuclear power plant (TVO)

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