EASI-SMR Workshop 1 Scaling issues 2025

Limitations of Existing Scaling Methods – Experience from Framatome GmbH

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Methodology

Selection of scaling approach/methodology according to:

Complexity of “problem”

- Number of known influence parameters (PIRT easily doable)
  - Separate-Effect Test Facility (SETF) with preservation of appropriate number(s) of similarity → JULIETTE, MAGALY etc.
- Multitude of influence parameters (PIRT suspiciously incomplete and ranking dubious)
  - Best approach (FRA-G experience): employ prototypic fluid properties and operating conditions at (ideally) large scales (volume-to-power, 1:1 height) → UPTF, PKL, INKA (T/H-loops), SOPHIE, a full-scale U-tube test bench (FIV), etc.

Objectives

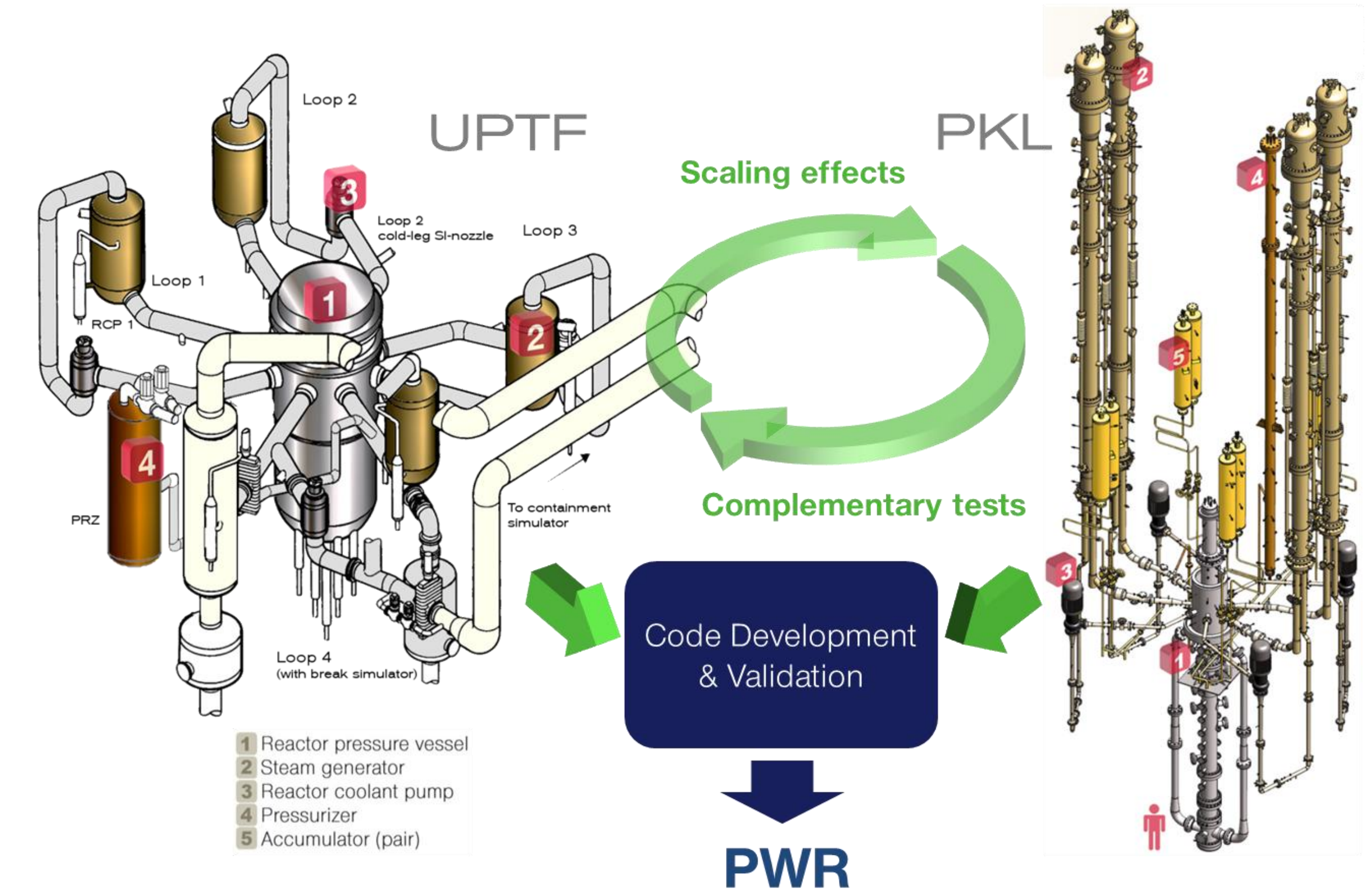
- Code validation exercises (usually higher density of instrumentation, CFD validation usually conducted against data from SETF) → EASI-SMR COSAC
- “Demonstrator” – ideally in 1:1 configuration (heights/heat fluxes), if reduced scale, then volume-to-power + heights 1:1, focus on selected transients, usually few key parameters/figures of merit → INKA

→ Contribution to improvements in safety of operation of NPP

(Historical) Background

UPTF
Geometrical full-scale mock-up of the primary system of a 4-loop 1300 MW PWR (scaling 1:1 in areas of interest), max. 18 bar

PKL
Scaled-down mock-up of the primary and secondary side of a4-loop 1300 MW PWR (volume-to-power scaling, heights 1:1)



PKL & UPTF

Construction of Upper Plenum Test Facility (UPTF) in response to insufficient applicability of PKL to address phenomena distorted by scaling effects, e.g.:

- ECC flow-paths from hot-side through UP during LB-LOCA
- Mixing of ECC in Cold-leg and RPV-DC
- CCFL in SG-inlet chamber & hot-leg ("Wallis-Parameter)
- Sweep-out of coolant from HL during PDE

Use of results for (e.g.):

- Operating procedures (incl. EOP),
- Generation of tools (KWU-Mix),
- Code validation (incl. CFD)
- Training

\+ Direct application of results to PWR

\- Expensive (erection & operation)

Scaling Test-Results to PWR

Tests at ITF (Limitations Imposed by Cost Control)

Designing facilities for prototypic pressure and/or 1:1 geometry is associated with high erection & maintenance cost, less flexibility (welded seams),
Solutions employed by Framatome:

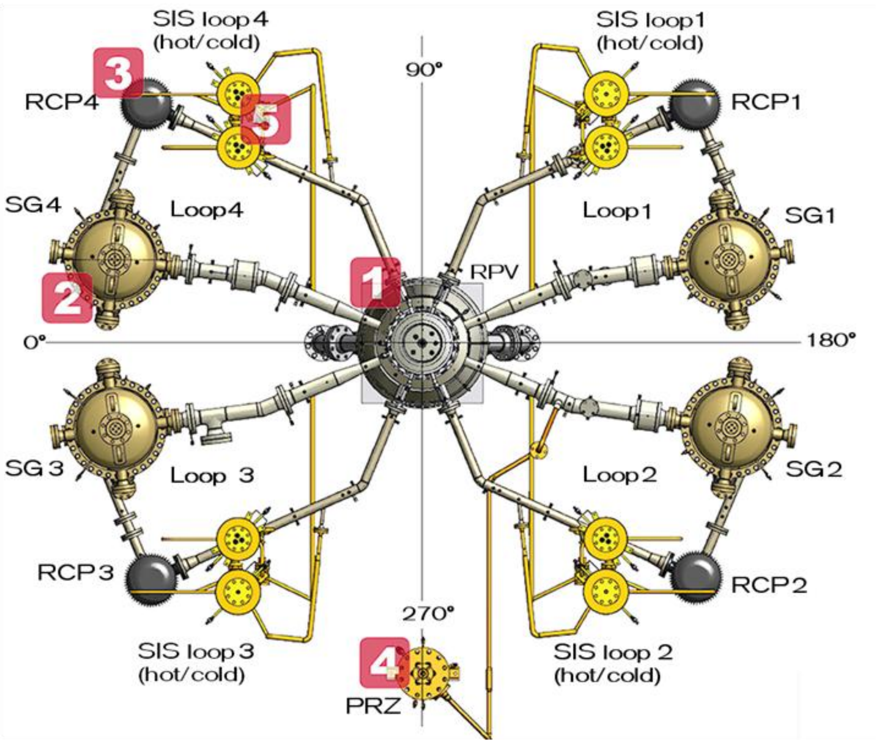
- →**Reduced max. pressure** (UPTF) requires precise analysis of pressure-dependent influence parametersfor sequences/transients out of pressure scope, may also combined with:
- →**Volume-to-power scaling** (PKL) (pressure scaled sequences not suitable for direct application to PWR, application to PWR usually requires intermediate step with code analysis/validation exercises)
- →**H2TS-method** chose number of similarity for individual components as necessary (e.g., mixing Fr, free convection: Ra, etc.) (requires a fully developed PIRT for each subsection)
- →**All scaling methods imply adoption of (constructive) compromises**

Limitation of scaling concept and distortions imposed by scaling must be known

→Develop concepts/workarounds to tackle distortions imposed by scaling:

- Counterpart Testing, Similar Testing, e.g. PKL/LSTF/ATLAS) counterpart activities in NEA joint-research projects)
- Use codes to calculate parts of the transient at high pressure range to serve at BIC for tests at ITF/SETF
- Complementary experiments at SETF to plug (known) holes in scaling concept of ITF

PKL ITF (Historical)



Objective

Replicate T/H-behaviour under accidental condition (reference case 1Φ-NC, replication of sources of head losses acc. to commissioning data of reference PWR)

- Reduced diameters of pipes but replication of gravitational forces
- Classic Volume-to-power scaling (preservation of time constants)
- Reduction of max. pressure (cost saving) → preservation of heat capacity ratio (fluid/structures)

PKL ITF (Historical)

ITF PKL (features) >

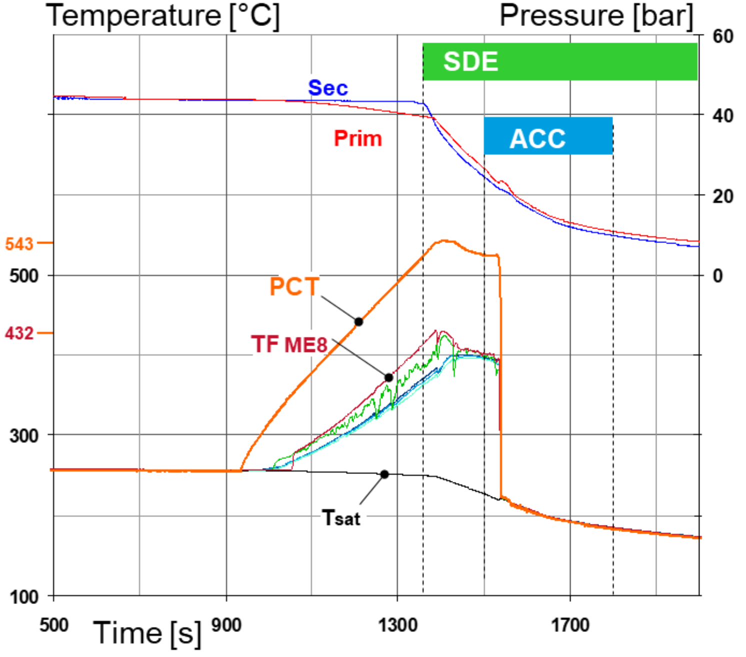
Attention to details in scaling of components and placement of adequate measurements

Replication of T/H-phenomena in specific components

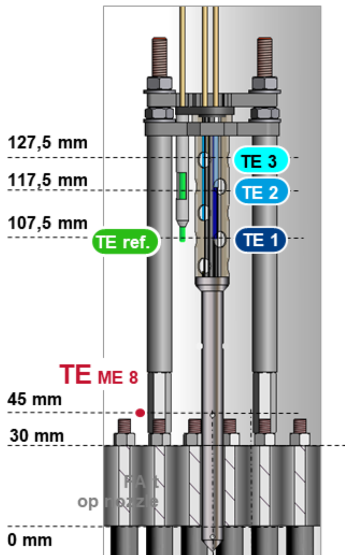
→ Thermocouples for CET and cladding temperatures

→ Code validation exercises for phenomena associated with specific components e.g. CET/PCT relation

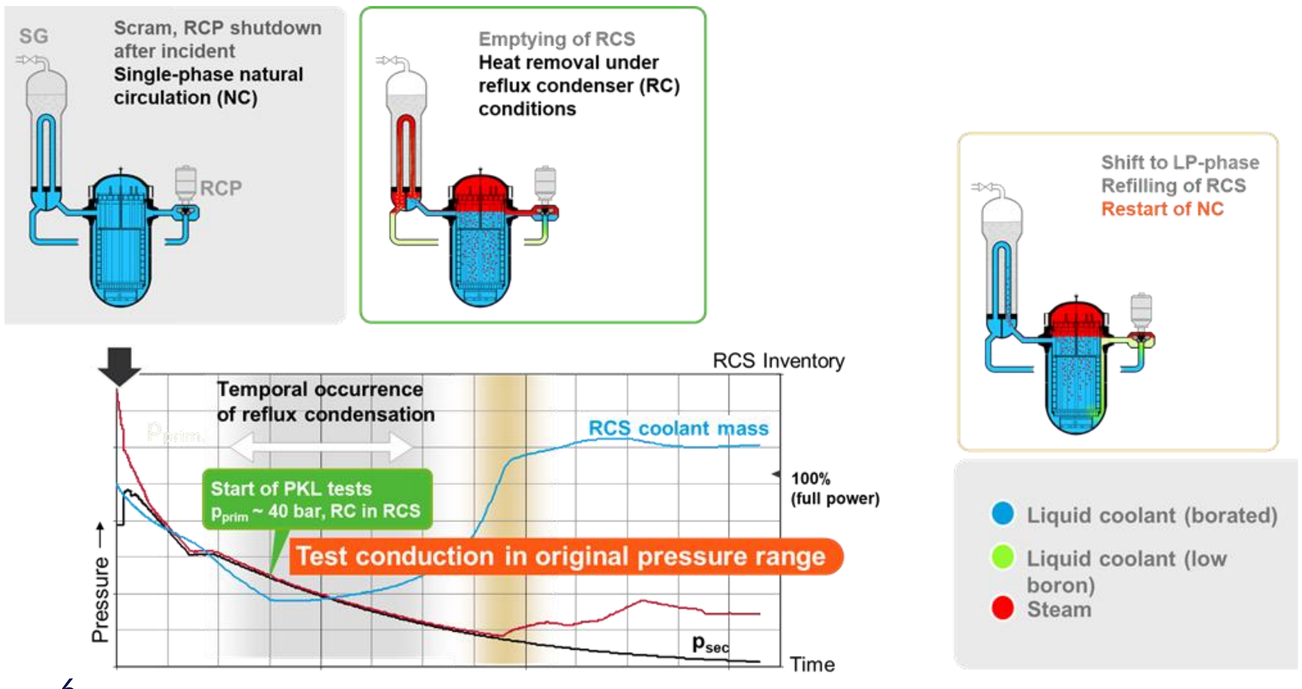
→ **Generate knowledge on transients**



CET thermocouples



"CET performance"



< Inherent Boron Dilution (German approach)

Attention to details in scaling of components and placement of adequate measurements

Combine Code analysis (PWR at 40 bar)

→ conduct test at ITF (with application of conservatisms)

→ use ITF test results as input for SETF

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ITF at Framatome - INKA

INKA Test Rig at Karlstein

Full-scale integral tests at INKA

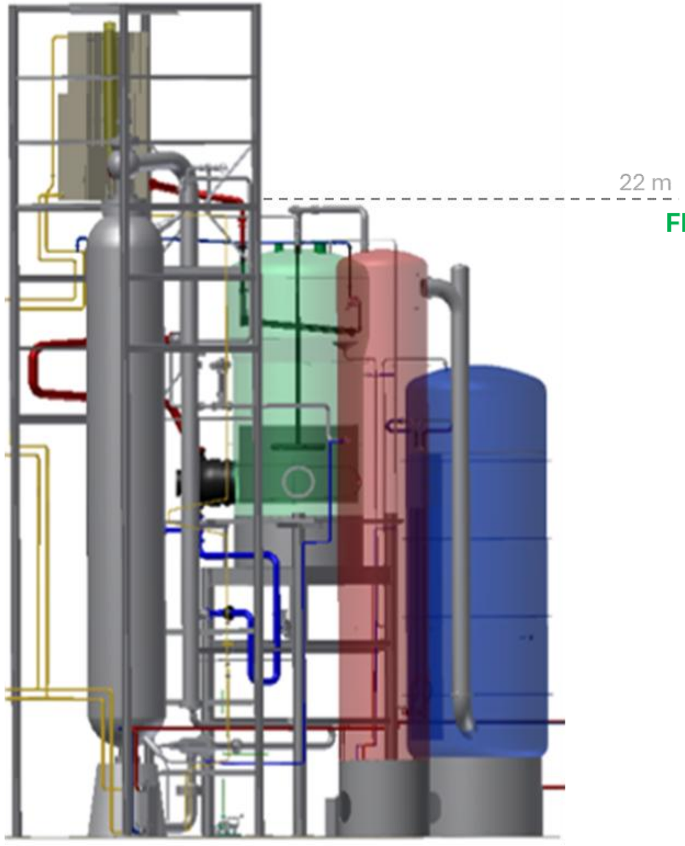
- Passive Pressure Pulse Transmitter (already tested in 2003)
- **Emergency Condenser** (full scale tube length & number of tubes)
- Containment Cooling Condenser
- Passive Core Flooding System

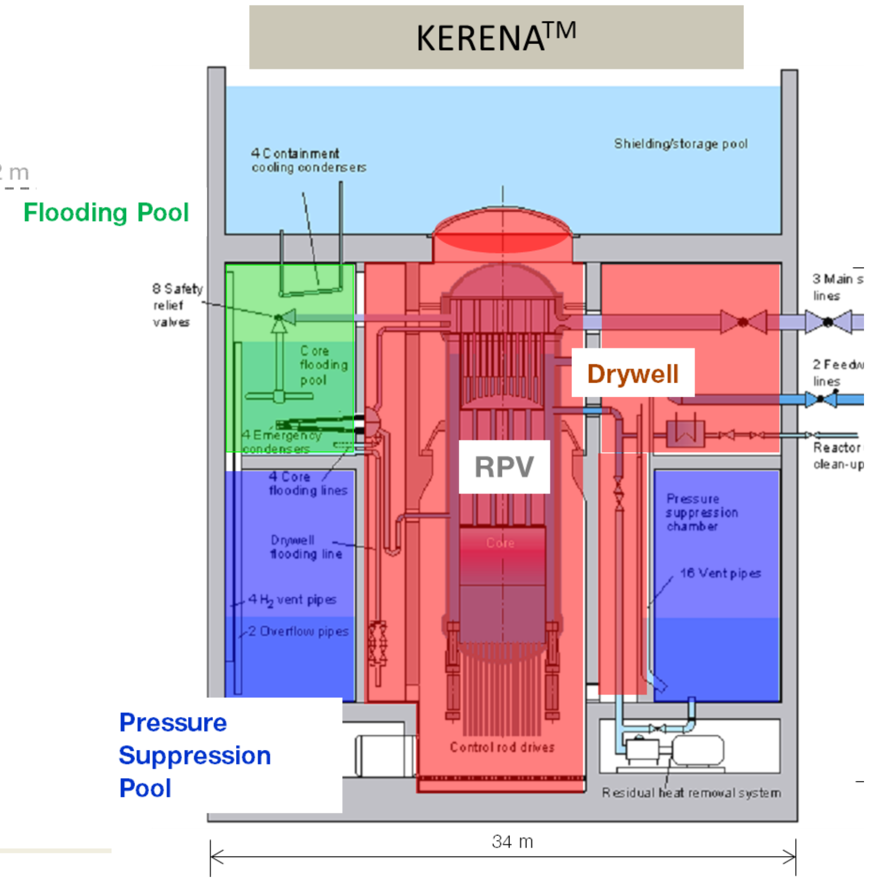
Specifications

- Vessels (green, red, blue) designed to simulate parts of BWR containment building
- Design values:
  4 bar, 160 °C
- Blue vessel
  DN5 m, H: 15 m, V:222 m³
- Green vessel
  DN5 m, H: 12m, V: 219m³

Infrastructure

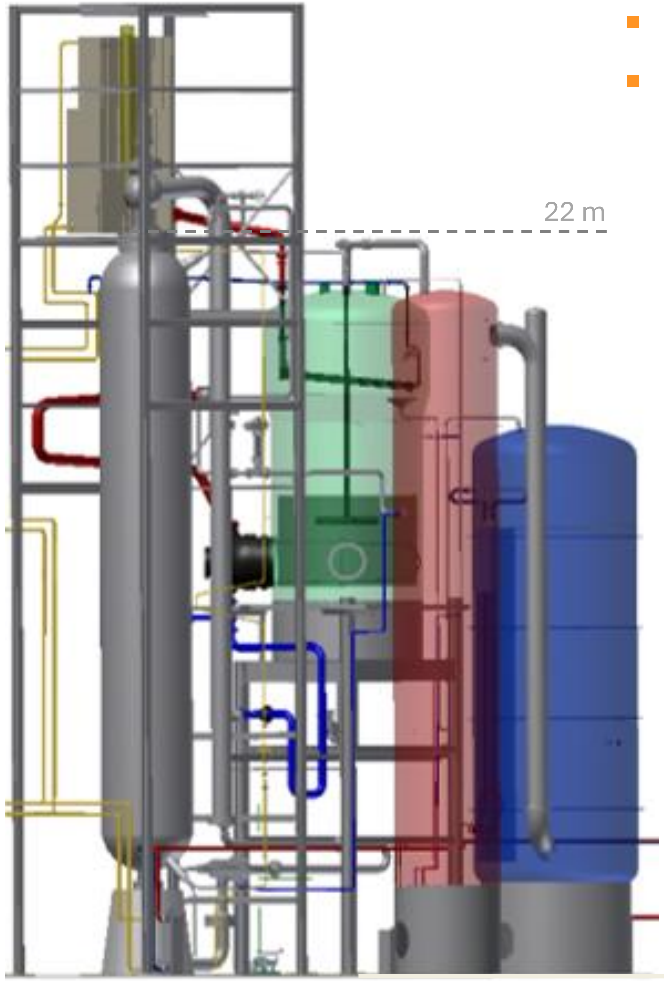
- 22 MW steam boiler





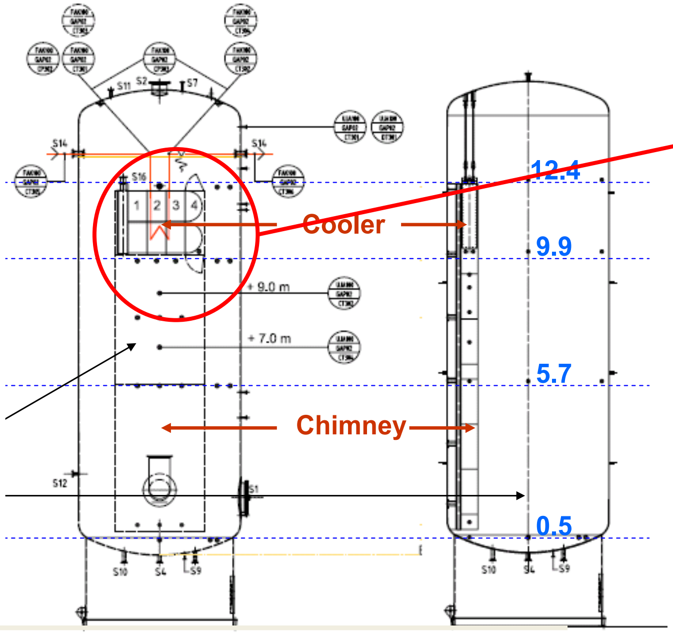
ITF at Framatome - INKA

INKA Test Rig at Karlstein



Conlusions for passive Systems

- Demonstration of effectiveness under 1:1 heights
- Scaling chosen as “as large as possible” in particular, if specific phenomena should be captured (e.g., distribution of NCG, re-absorption of NCG into condensate, deterioration of convective heat transport by presence of NCG)



Passive SFP-Cooler

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