ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

Overview of the RELAP5-3D code activities in ENEA

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Contents

- Framework
- Recent activities using RELAP5-3D code
  - OECD/NEA KALININ 3 benchmark
  - OECD/NEA OSKARSHAMN-2 benchmark
- Conclusions

Framework - ENEA & the SIMING Lab

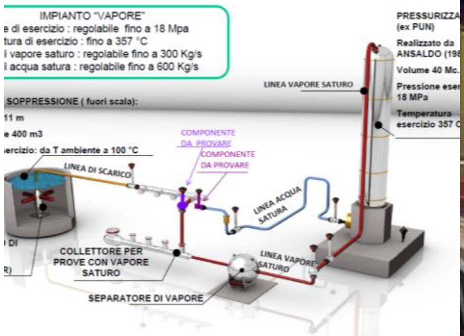
- **ENEA** is the Italian National Agency for New Technologies, Energy & Sustainable Economic Development
- A branch of **ENEA** actively involved in **researches** for fission nuclear power technology
  - Research Reactors (e.g., TRIGA & Tapiro)
  - Experimental Engineering (e.g., AP600 components testing)
  - Nuclear Material Characterization
  - Models & Simulation
  - Integrated Services (e.g., waste management)
  - Metrology & Radioprotection
  - Advanced Nuclear Systems (e.g., Gen IV, LFR)

TRIGA Reactor (1 MW)

TAPIRO Fast Neutron Source

- The **ENEA-SIMING Lab** performing R&D activities **NPP simulations & engineering simulators** at the Casaccia Research Center (Rome)

- Acting as *Technical Support Organization* (TSO) for the Italian Nuclear & Industrial Safety Authority (ISPRA)



Vapore TH facility

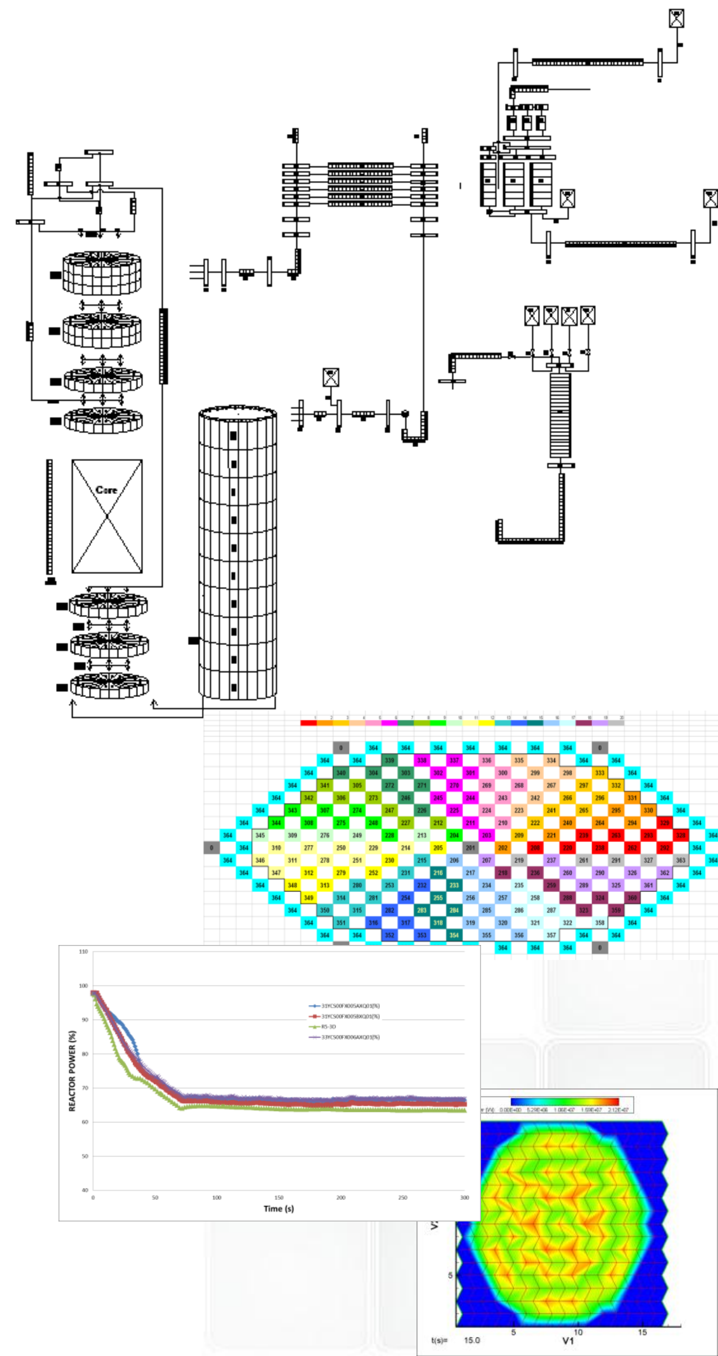
SPES-2

Recent activities using RELAP5-3D code

- RELAP5-3D code used for studying NPP transients and accidents
- Participating to coupled code benchmarks organized by OECD/NEA
  - **"KALININ-3": VVER-1000 MCP-1 switch off @ HFP**
  - **"OSKARSHAMN-2": BWR Global Core Instability Event**
- Objectives:
  - to explore the capabilities of the coupled codes in simulating NPP behavior during AOO/DBA
  - to quantify codes and models uncertainties

Recent activities using RELAP5-3D code

- **KALININ-3** benchmark
  - Model developed in the past years
  - Presented in the last IRUG meeting
  - Final results being submitted to the benchmark organizers by the end of the year
  - Primary & secondary circuits modeled
    - 3D TH components for RPV
    - 3D NK core model
    - Detailed TH nodalization for selected FA
  - Demonstrated capabilities of RELAP5-3D in modeling core asymmetric coolant temperature perturbations with high resolution degree

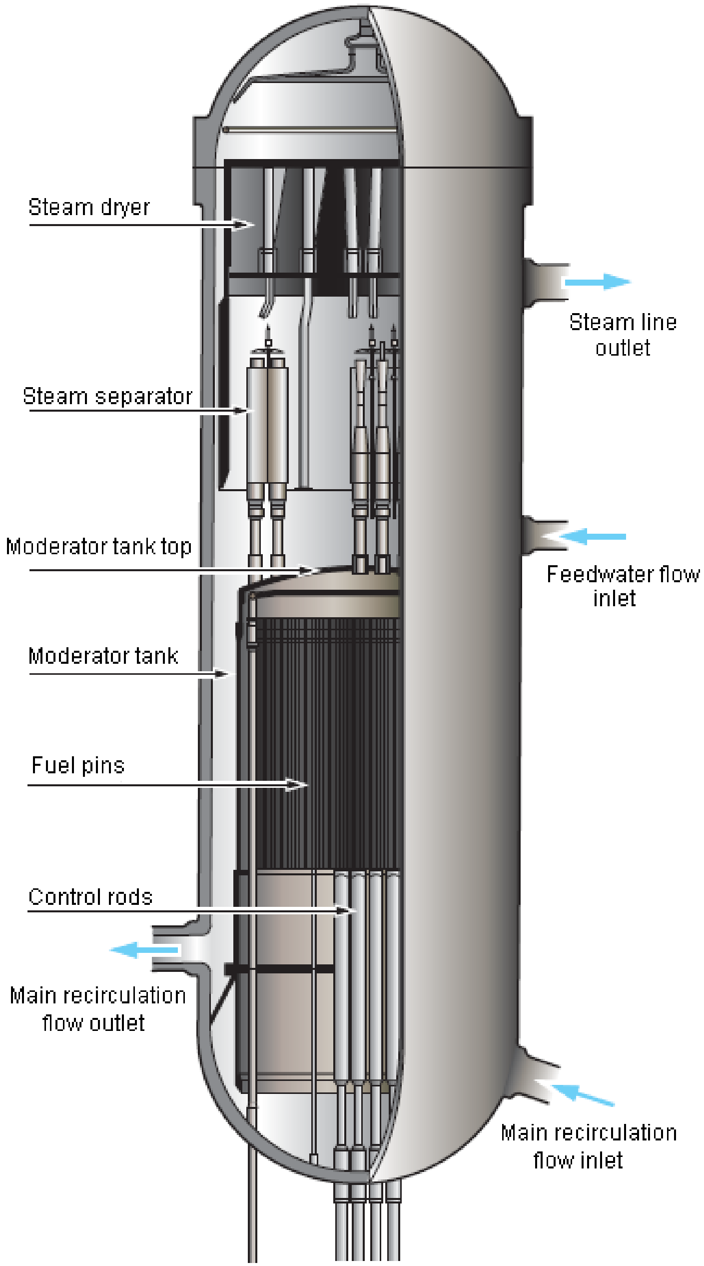


Recent activities using RELAP5-3D code

- **OSKARSHAMN-2** benchmark
  - Launched by OECD/NEA last year → release 1.0 of specifications → definition of several parameters still in progress
  - Previous instability benchmarks (Forsmarsk and Ringhals) characterized by decay ratio<1.0 & based on noise measurement of a stable reactor
  - **O-2** 1999 event is an instability event with a DR>1 (diverging oscillation)
  - Challenging simulation for a coupled code
    - Detalied RPV/core nodalization needed
    - Core parameters changing on a great magnitude
      - Core power going from 60% up to 130%
    - Tightly coupled NK-TH transient

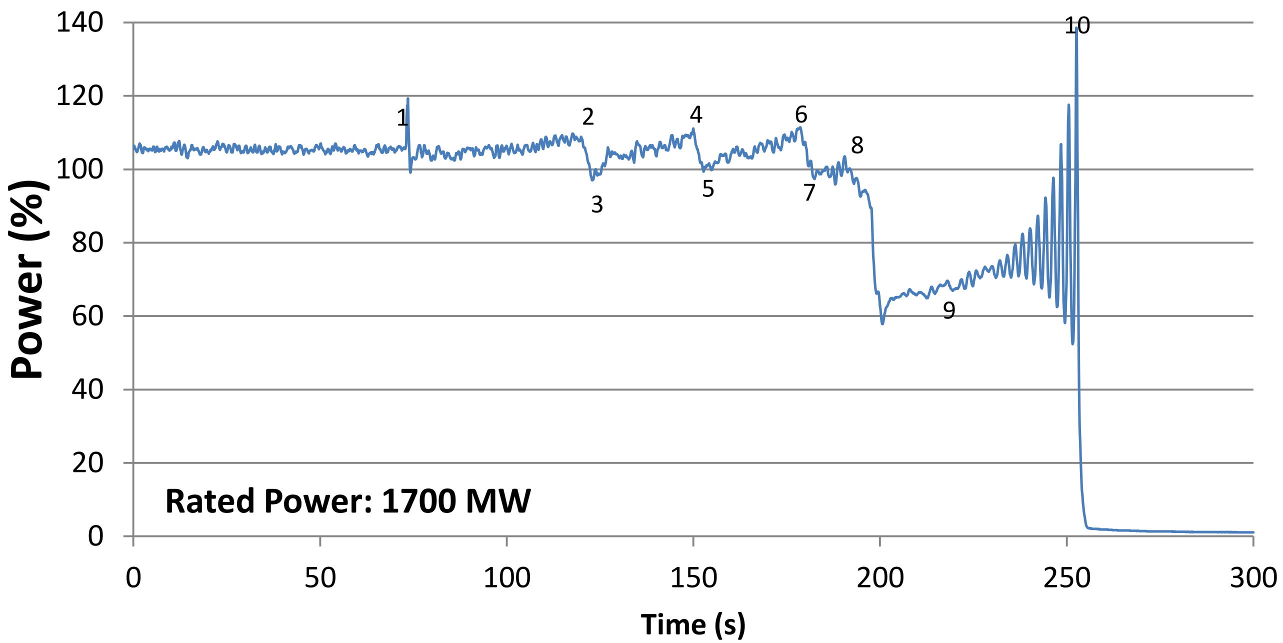
The Oskarshamn NPP

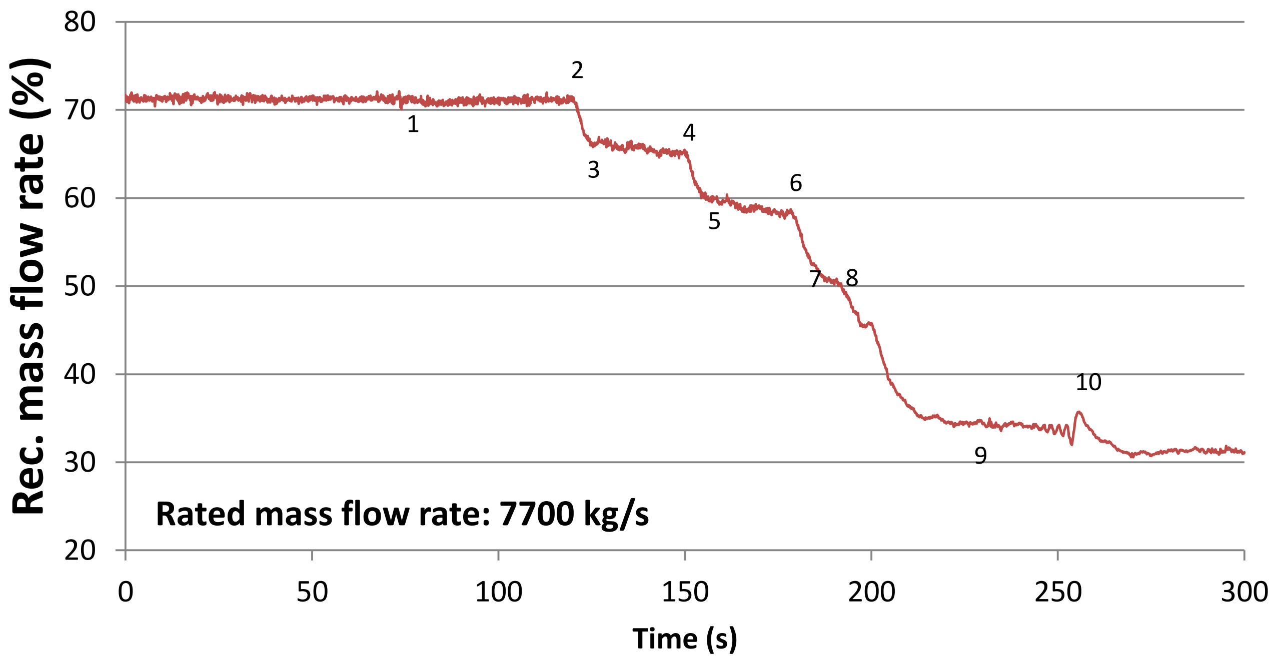
Reactor Coolant System modelling



Design operating conditions		
Rated thermal power	MWt	1700
Dome pressure	MPa	7.0
Steam flow rate	kg/s	900.0
Reactor pressure vessel geometry		
Internal height	m	20.0
Internal diameter	m	5.2
Weight	t	530.0
Wall thickness	mm	134.0
Core geometry		
Equivalent core diameter	mm	3672
Equivalent core height	mm	3712
Number of fuel bundles	-	444
Control rods		
Absorbing material	-	B_4C
Number of CR	-	109

The 1999/02/25 event

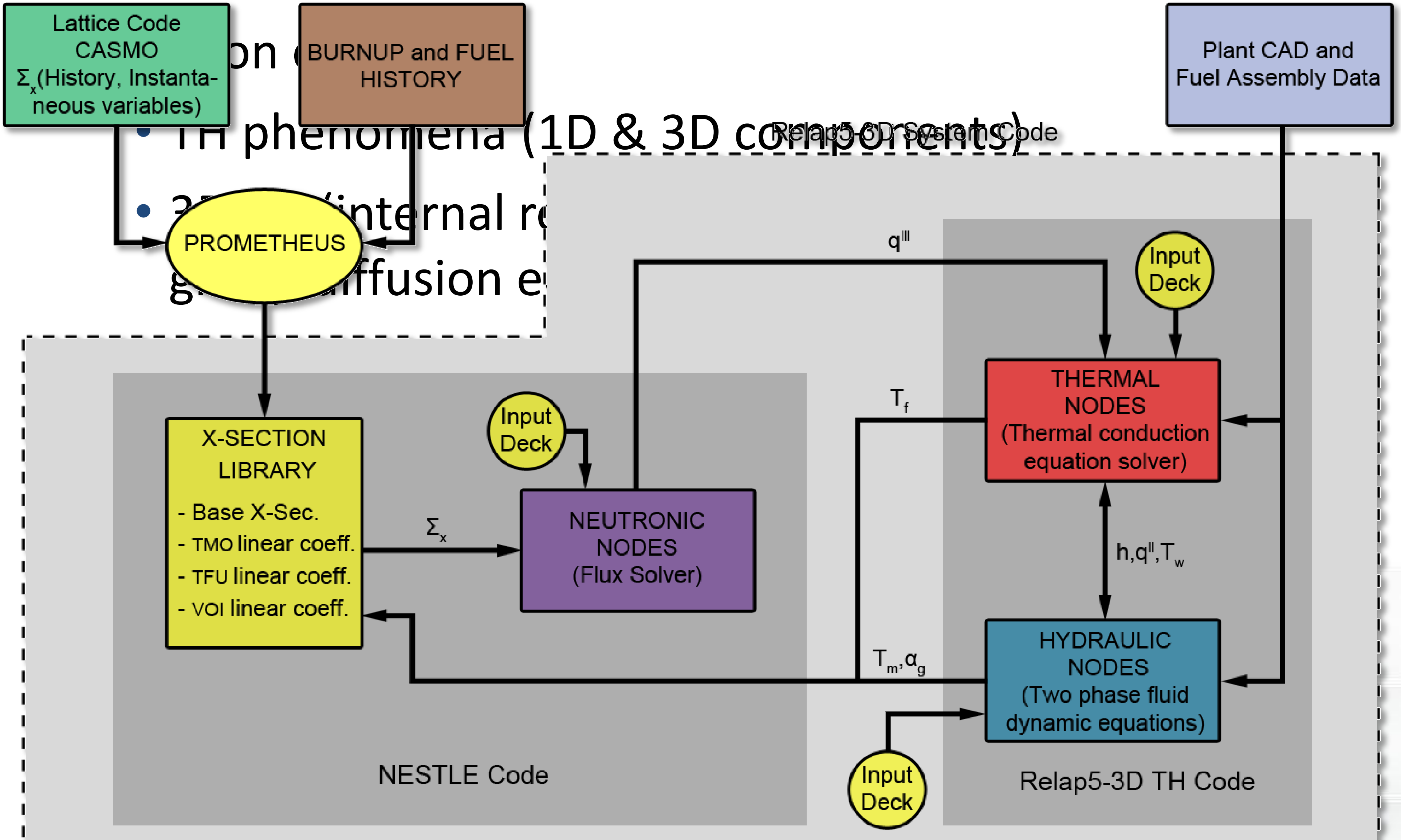




Event Description	
1	Turbine trip and bypass valves opening
2	First 108% power level exceeding
3	Stop Reducing pump velocity
4	Second 108% power level exceeding
5	Stop Reducing pump velocity
6	Third 108% power level exceeding
7	Stop Reducing pump velocity
8	Operator Partially scrammed the reactor and reduced to the minimum the pump velocity.
9	Reactor enter in the unstable region of the power/flow map
10	The reactor scrammed because the power exceeded 132 %

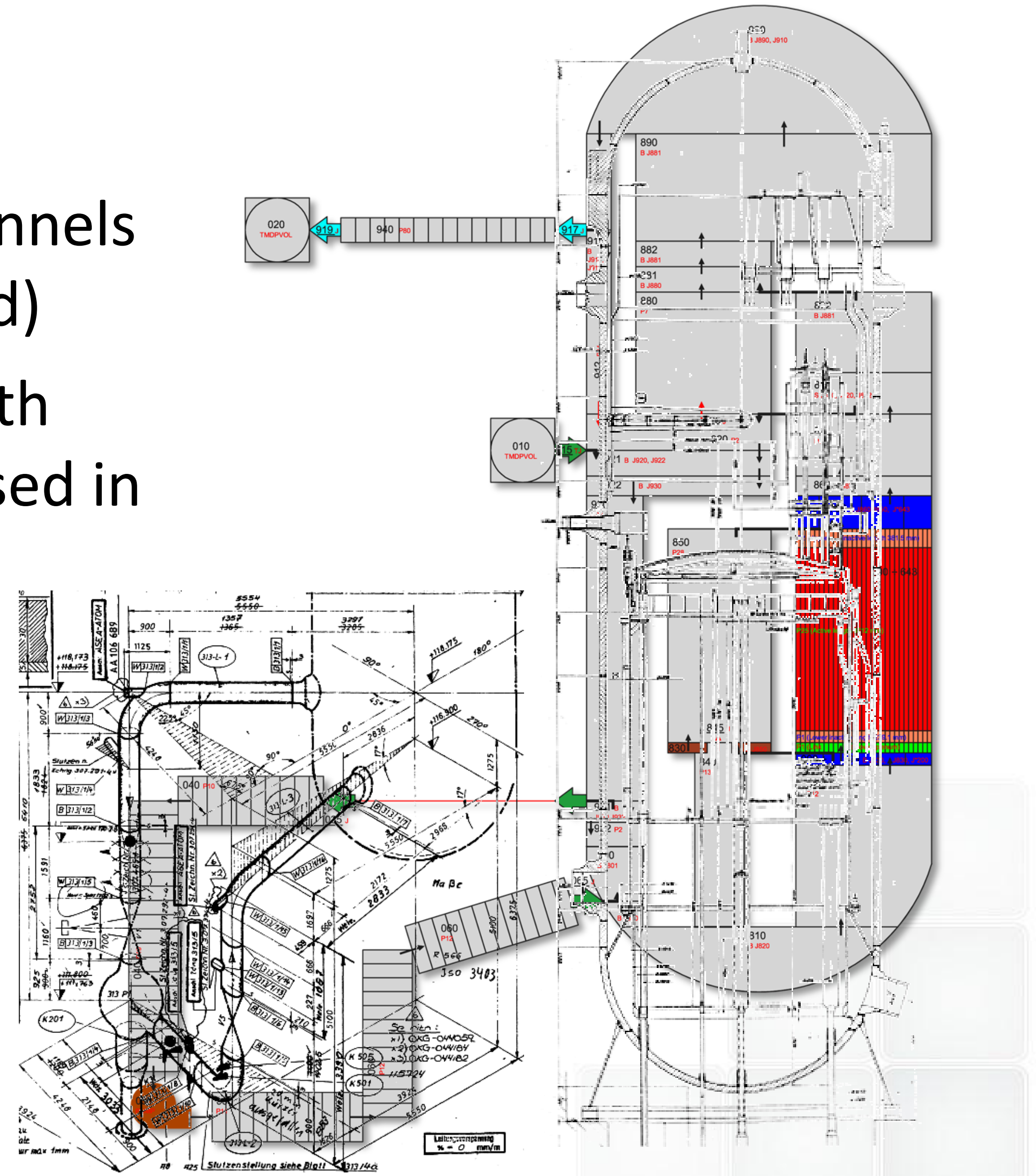
Code Used

- **RELAP5-3D©** used for the Oskarshamn-2 benchmark
  - TH phenomena (1D & 3D components)



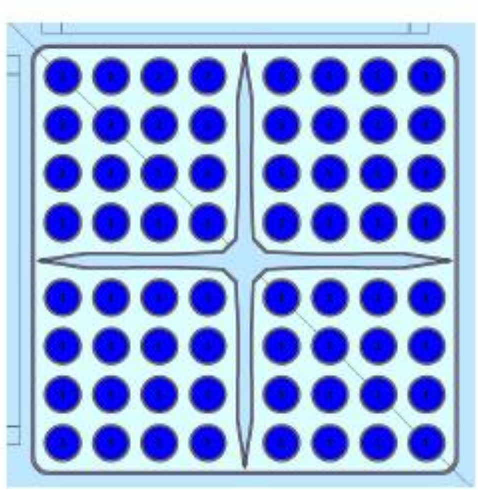
Reactor Coolant System modelling

- RCS TH nodalization
  - Number of Hydraulic volumes: **489** (core channels and bypass not included)
  - **4** recirculation loops with external pumps (collapsed in one)
  - **4** steam lines (collapsed in one)
  - Passive Heat structures still not simulated

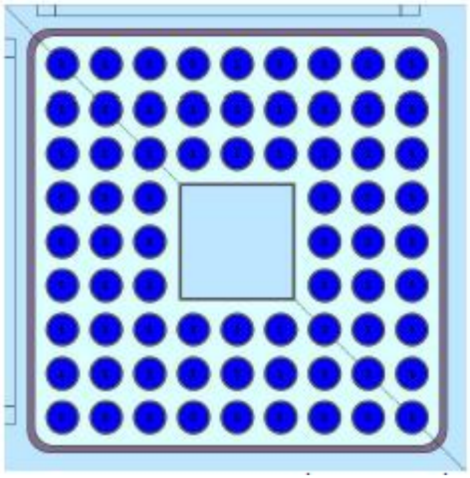


Fuel

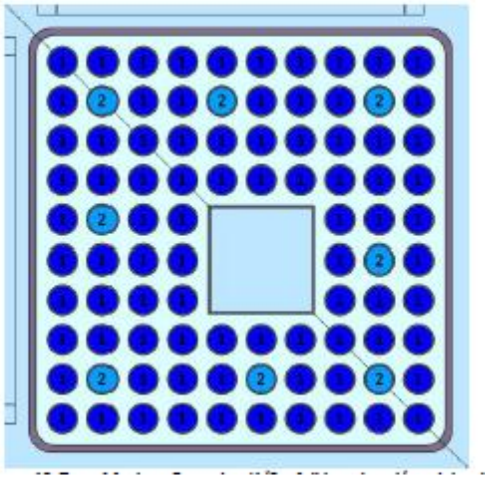
- **4** Different FA type of different fuel vendors present in the core



Type 1



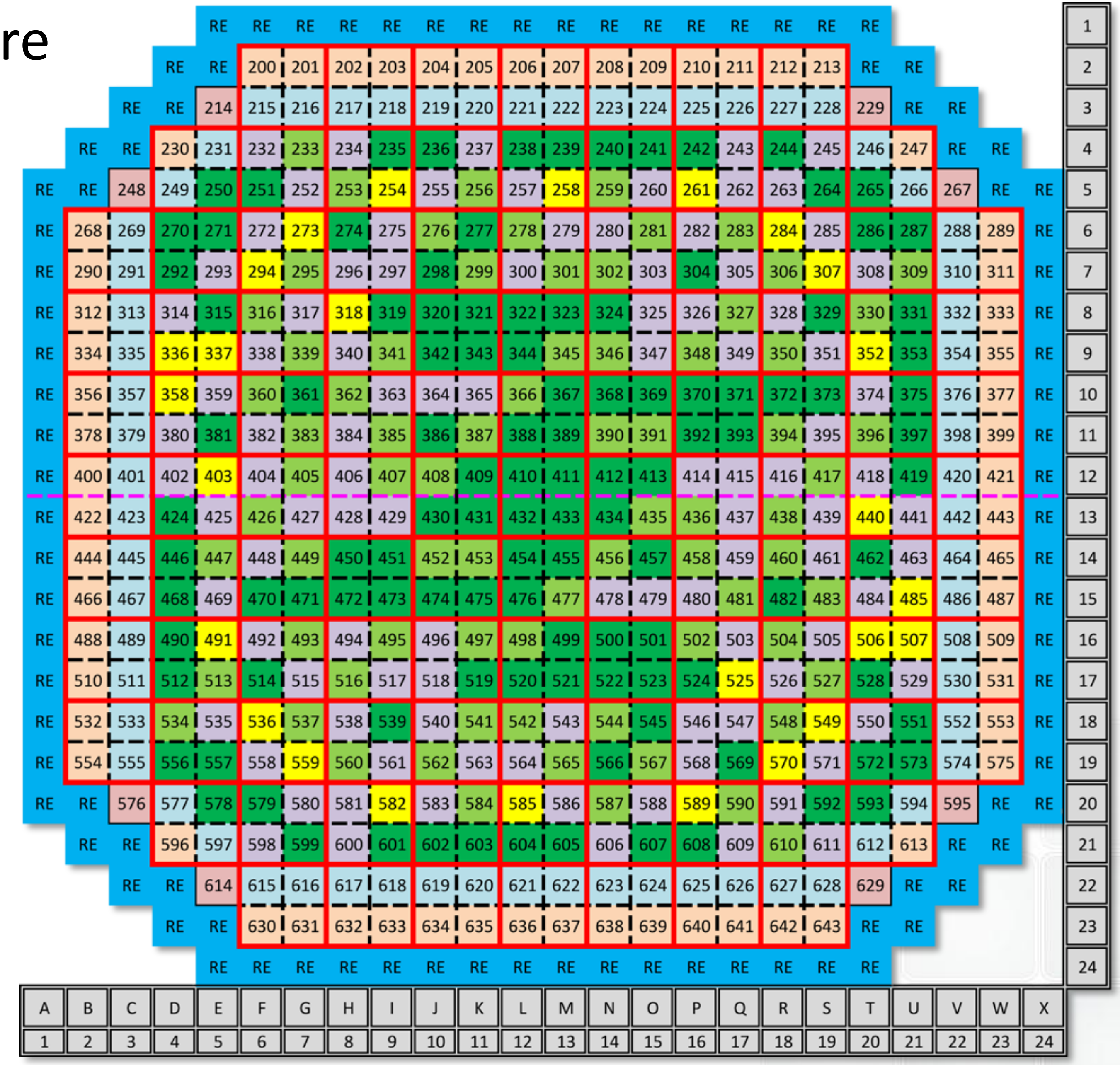
Type 2 & 3



Type 4

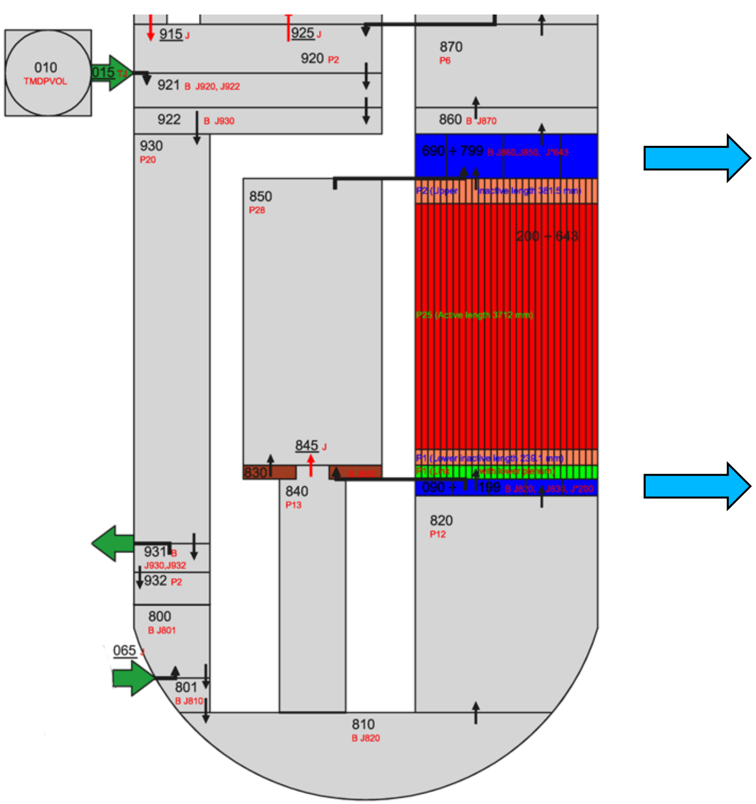
Core modelling

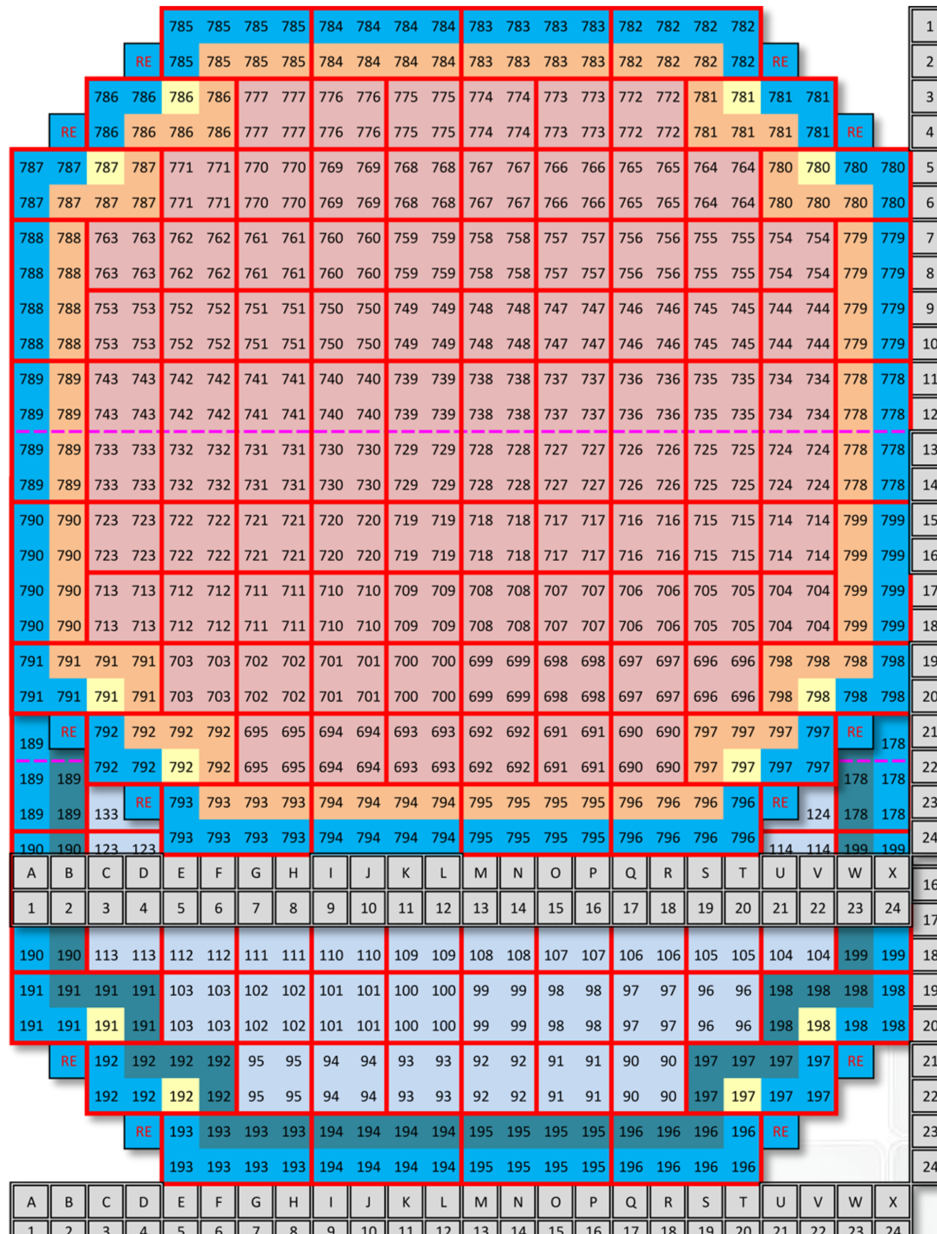
- **444** Channels core nodalization



Core modelling

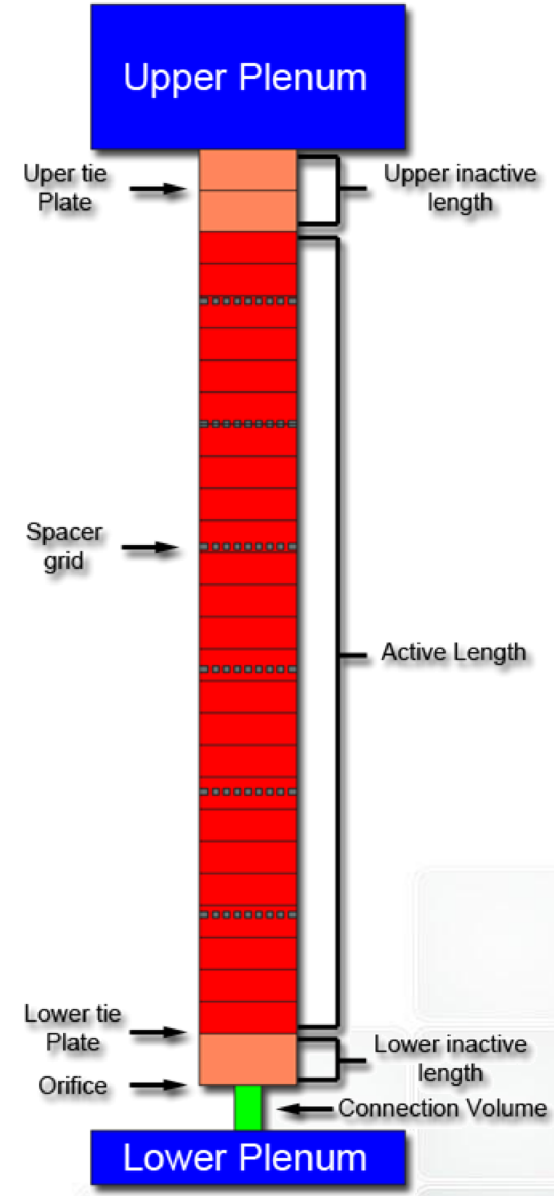
- **110** interconnected branches at the inlet/outlet of the core





Core TH & NK nodalization

- Core Axial meshing:
  - Uniform meshing for the active part **25** Hydraulic mesh + **25** Thermal mesh + **25** Neutronic mesh
  - **3** Hydraulic mesh + **2** Neutronic mesh for the bottom & top reflector
  - **1** Hydraulic meshes for FA inlet zone
- Core statistics
  - **444** independent TH channels +**1** (Bypass)
  - **12876** Hydraulic volumes+ **29** (Bypass)
  - **14472** NK nodes (including Reflector)



Benchmark uncertainties ongoing definition

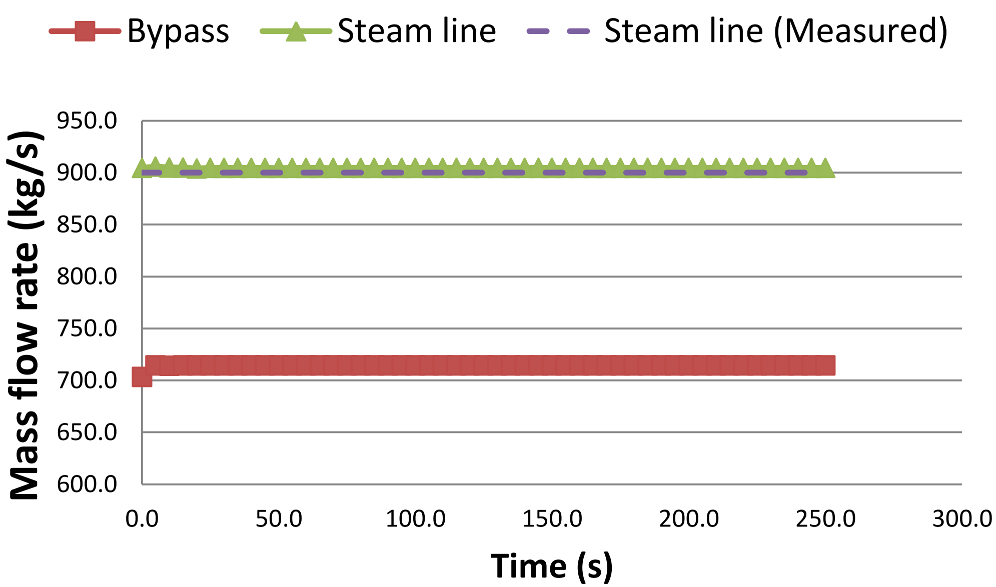
- Several Benchmark "Uncertainties" identified
  - Cross section library specifications (NEMTAB format still not available, CR specifications)
  - Channels pressure drop coefficients
  - Materials thermal capacity and conductivities
  - Configuration of the channel connection to the lower plenum
- Missing data replaced by engineering judgment and in-house developed tools (e.g., CASMO Xsec interpolator)

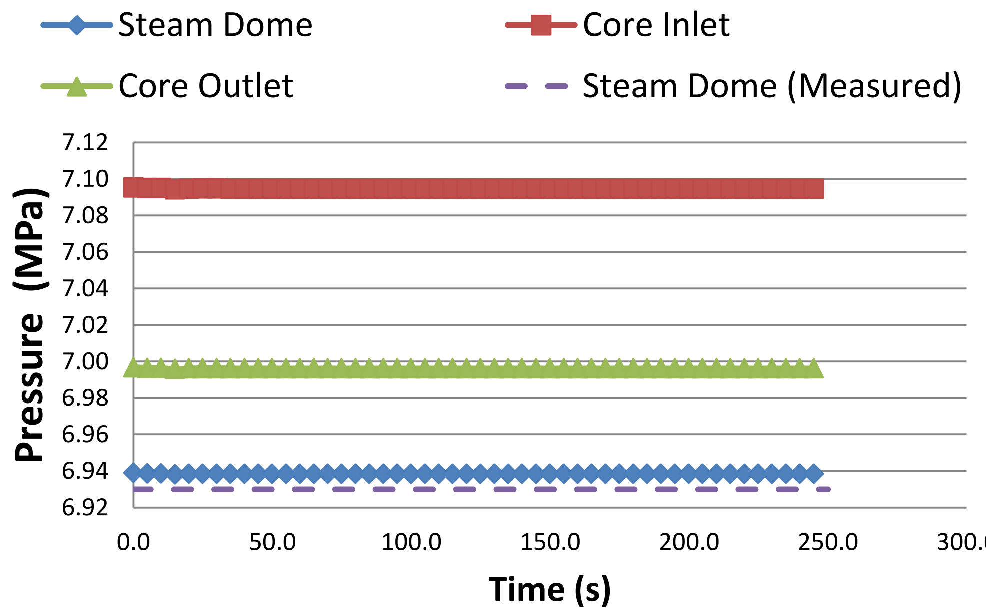
Steady state analysis results

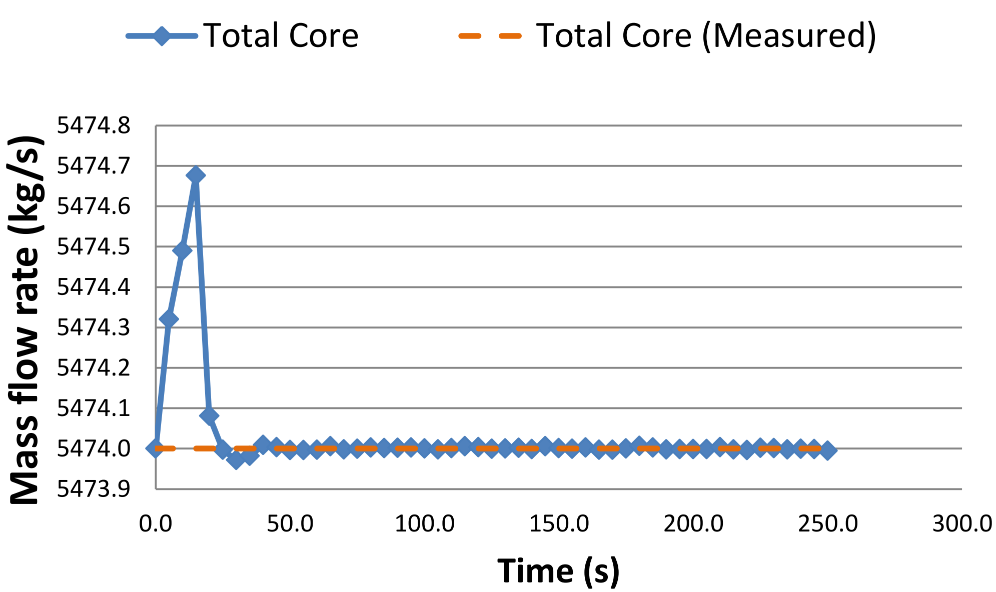
NAME	u.d.m	NPP	NPP Code	RELAP5-3D	Rel. error
Reactor Power	MW	1798.6	1802	1798.6	IMPOSED
Steam Dome Pressure	MPa	6.93	7.00	6.94	0.12%
Core Inlet Pressure	MPa	N/A	7.166	7.095	-0.99%
Core Outlet Pressure	MPa	N/A	7.067	6.996	-1.00%
Core ΔP	kPa	N/A	98.8	98.5	-0.34%
Channel ΔP	kPa	N/A	46.0	50.8	10.36%
Orifice & Lwr plate ΔP	kPa	N/A	52.8	47.7	-9.66%
Core Average Void	//	N/A	0.42	0.44	4.19%
Core Average Fuel Temp	K	N/A	816.7	854.7	4.65%
Feed water Temperature	K	457.6	N/A	457.7	IMPOSED
Core Inlet Temperature	K	547.30	548.05	547.1	-0.03%
Steam Temperature	K	N/A	N/A	557.9	N/A
Pump Speed	Rad/s	N/A	N/A	99.78	N/A
Total Core Flow Rate	kg/s	5474.0	5515.9	5474.0	0.00%
Active Core Flow Rate	kg/s	N/A	4793.5	4759.7	-0.70%
Steam Flow Rate	kg/s	900.0	976.0	904.5	0.50%
Downcomer Water Level	m	N/A	N/A	8.4	N/A
K-eff	//	N/A	1.0026	1.0056	30 pcm

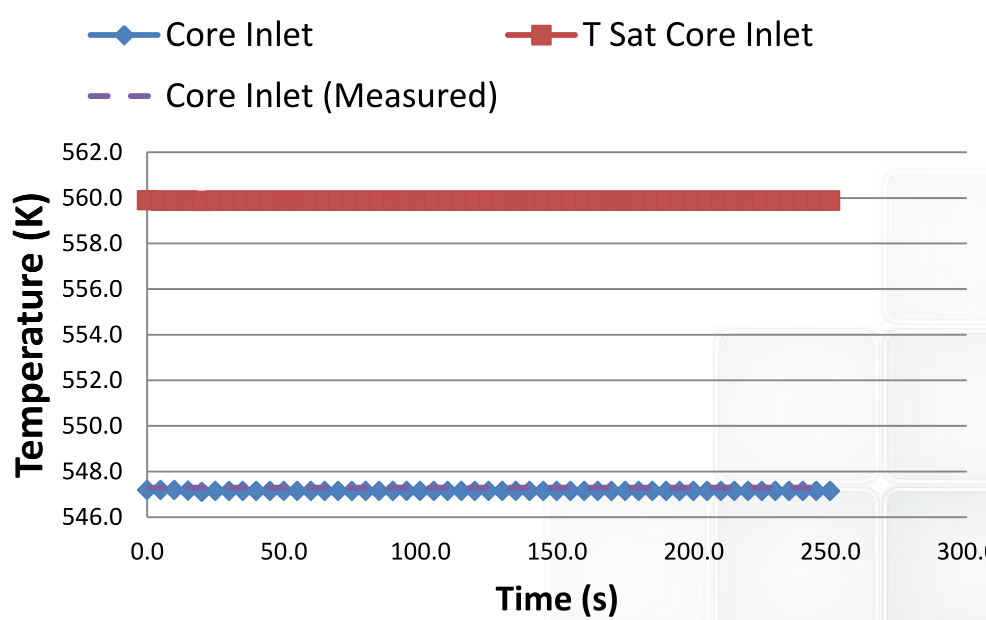
Steady state results

- Mass Flow Rate, Pressure and Temperature convergence



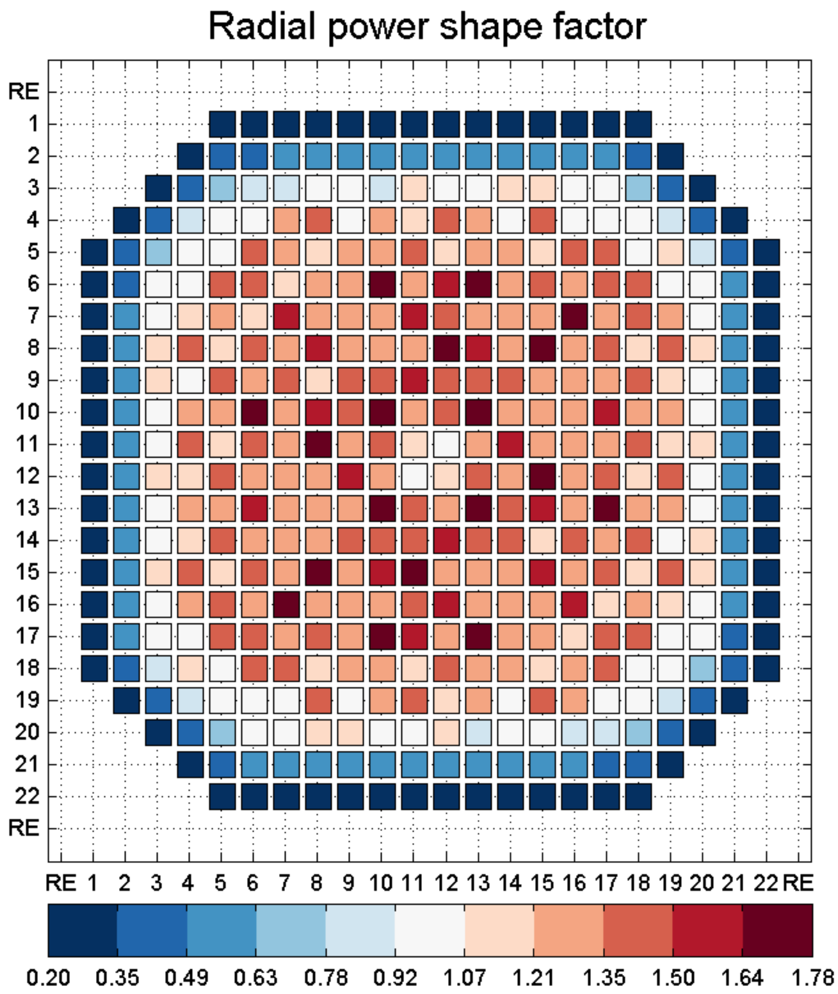


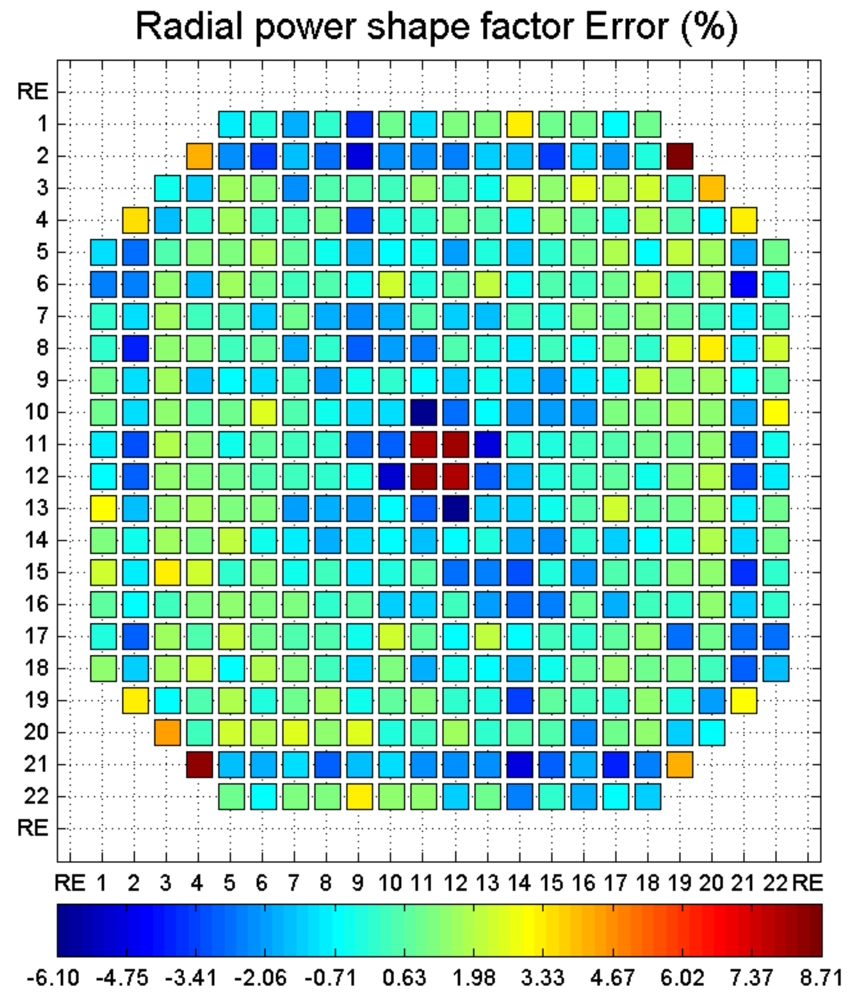




Steady state analysis results

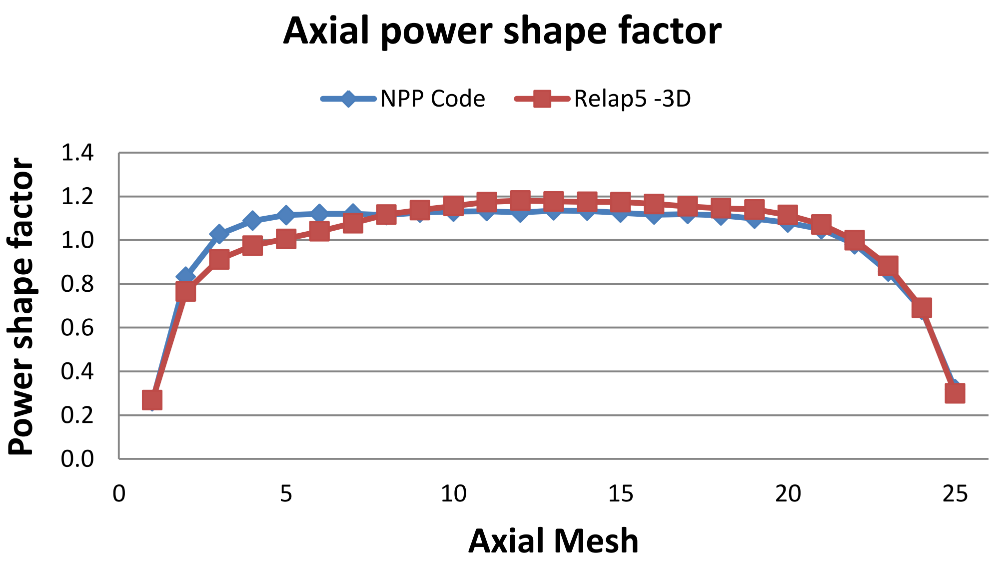
- Power Radial shape factor and relative error for all 444 FA

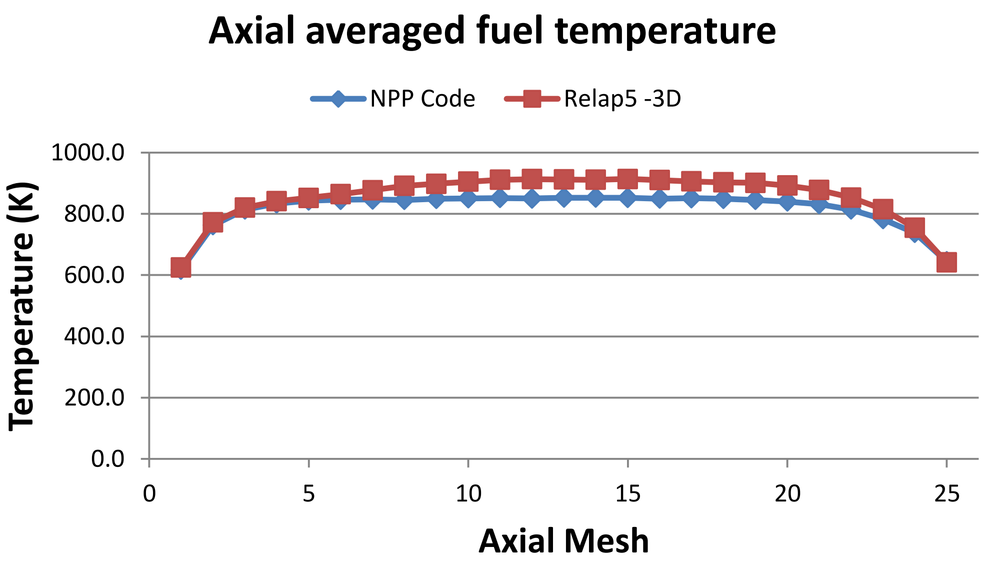


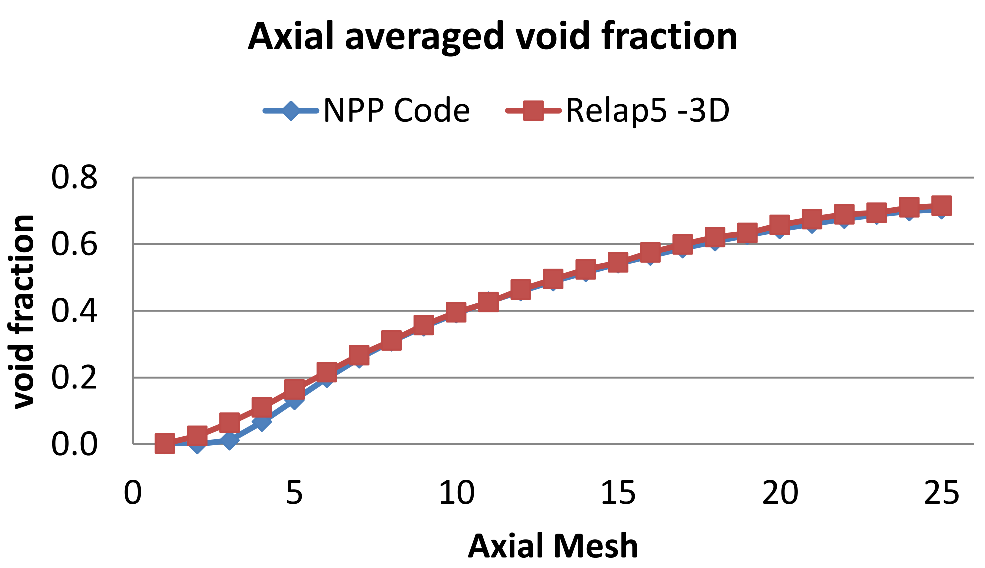


Steady state analysis results

- Axial core values

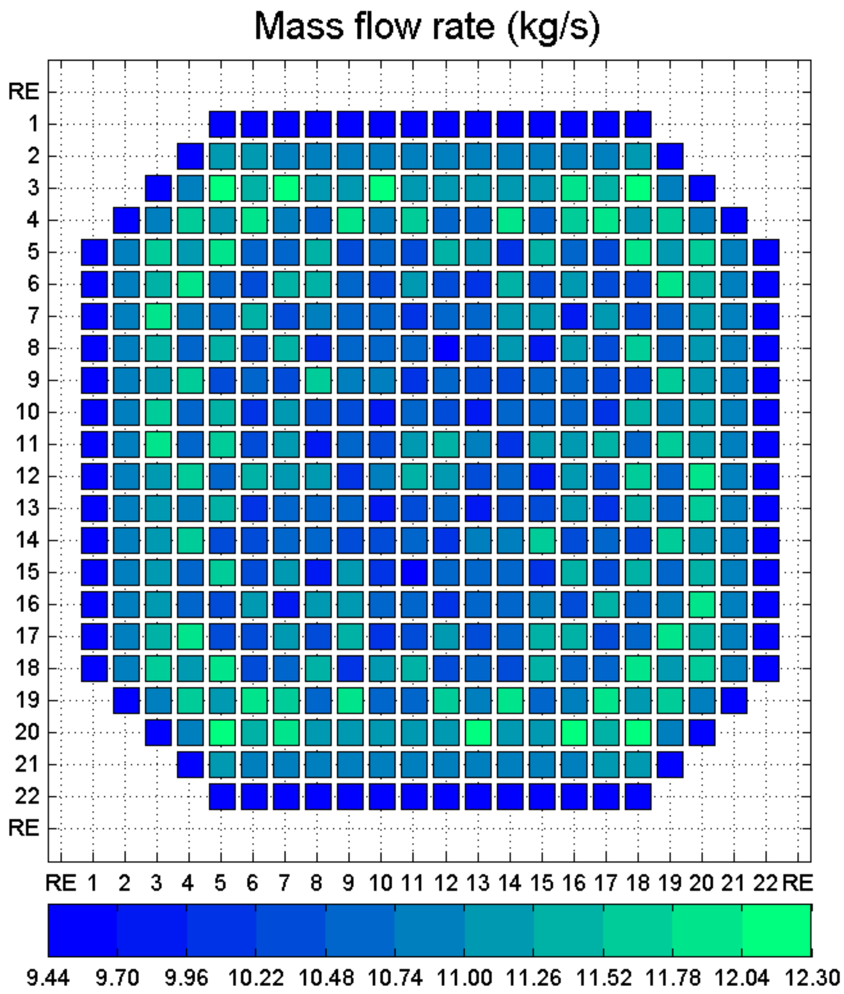


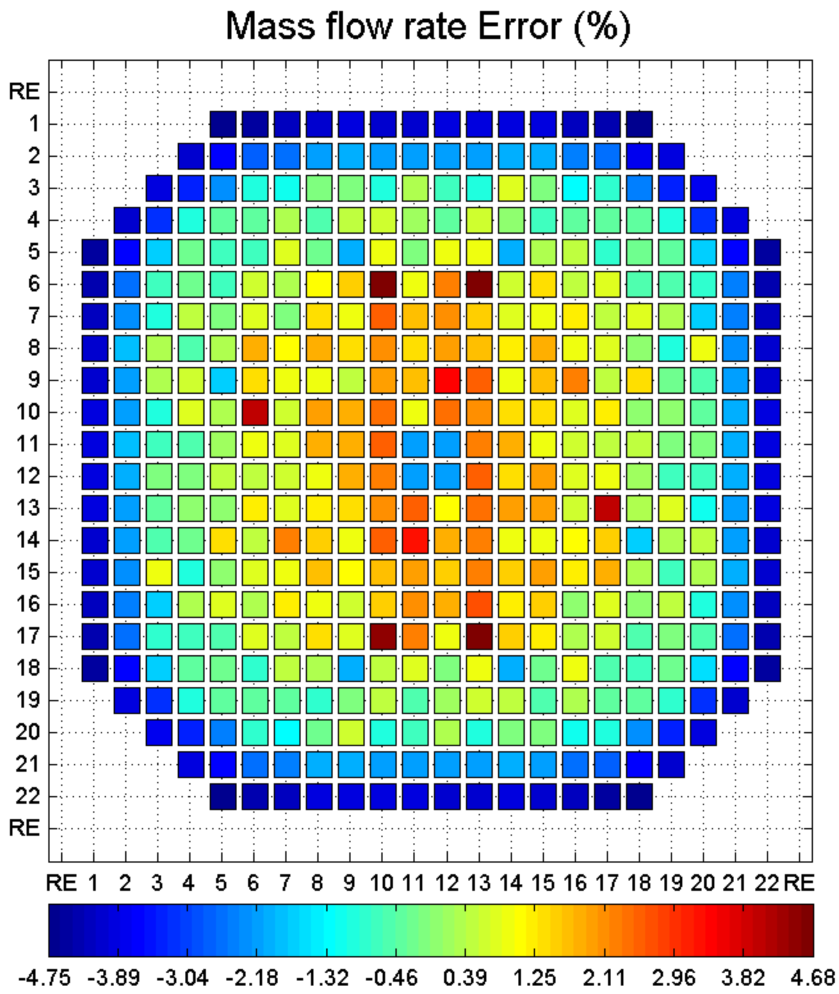




Steady state analysis results

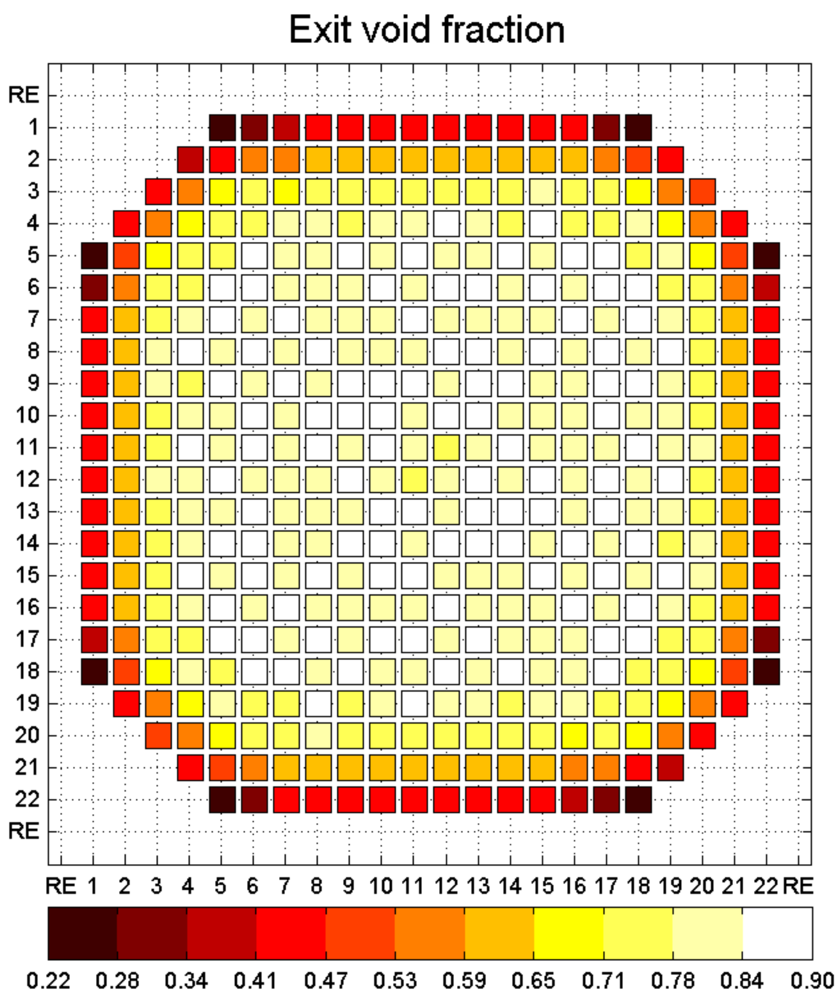
- Mass flow rate and relative error for all 444 FA

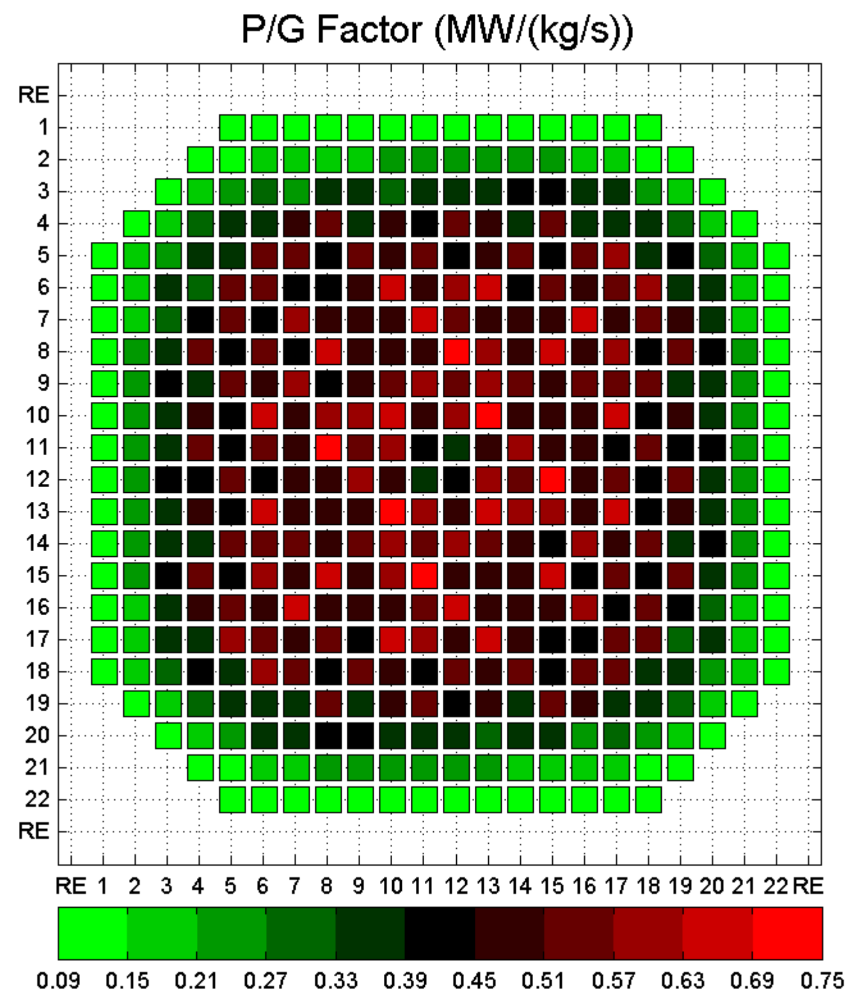




Steady state analysis results

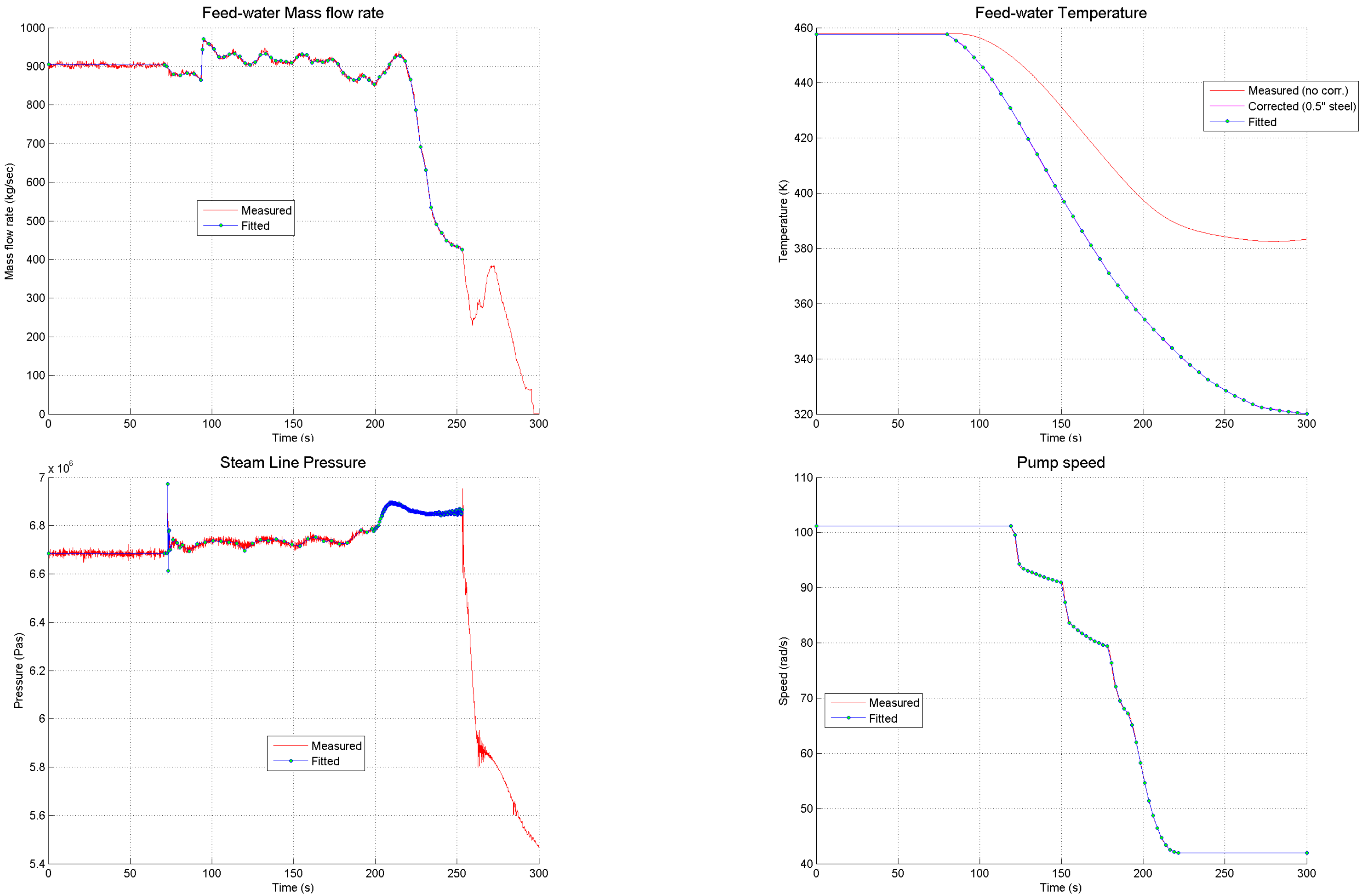
- Exit void fraction and P/G factor for all 444 FA





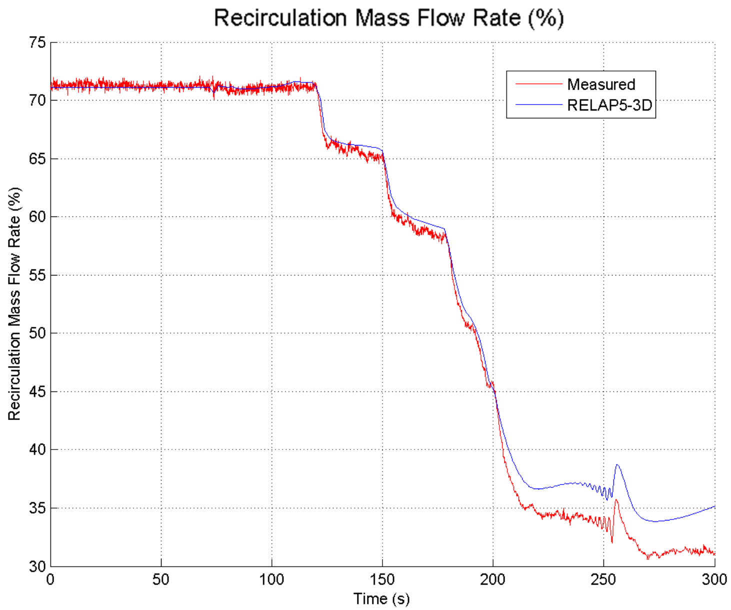
Transient analysis results

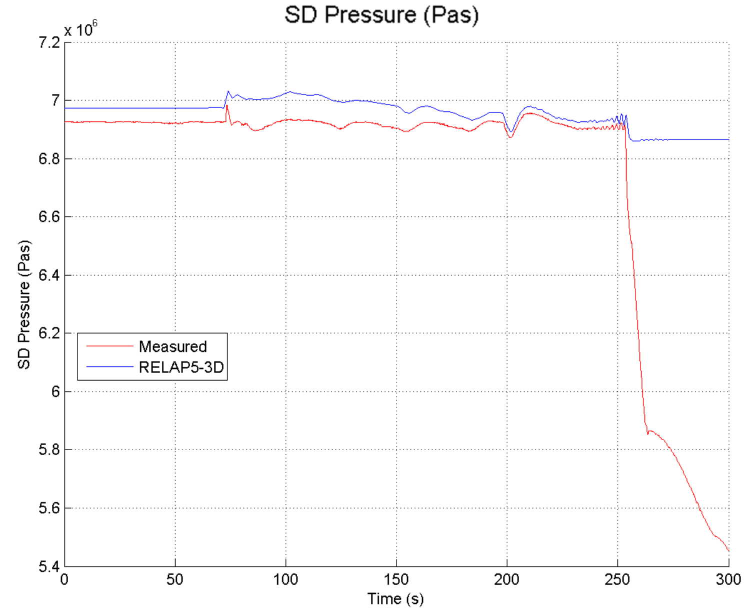
- Boundary conditions

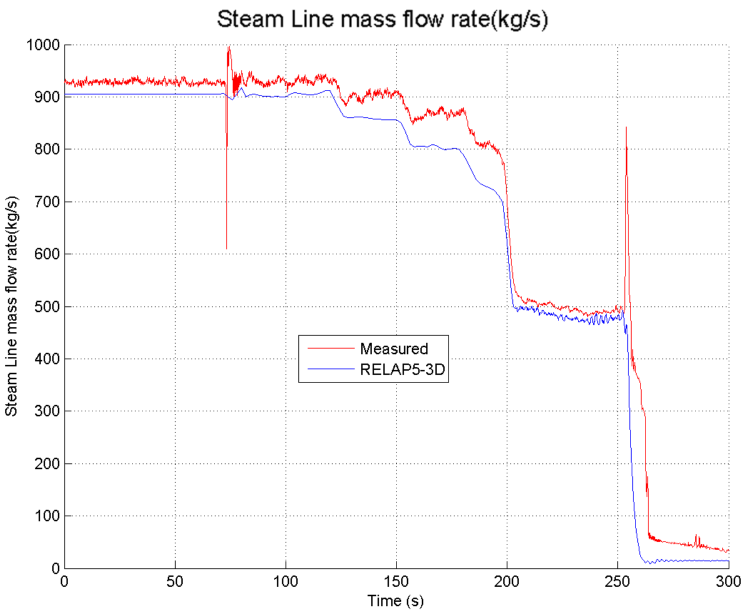


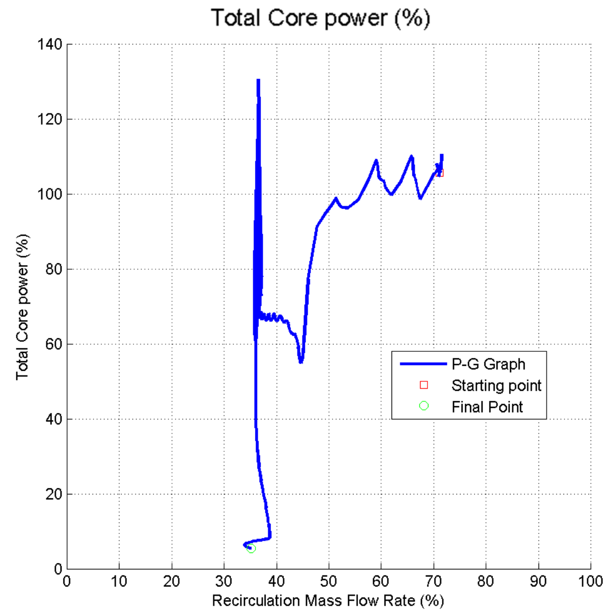
Transient analysis results

- Recirculation MFR, SD Pressure, SL MFR, Power Flow map



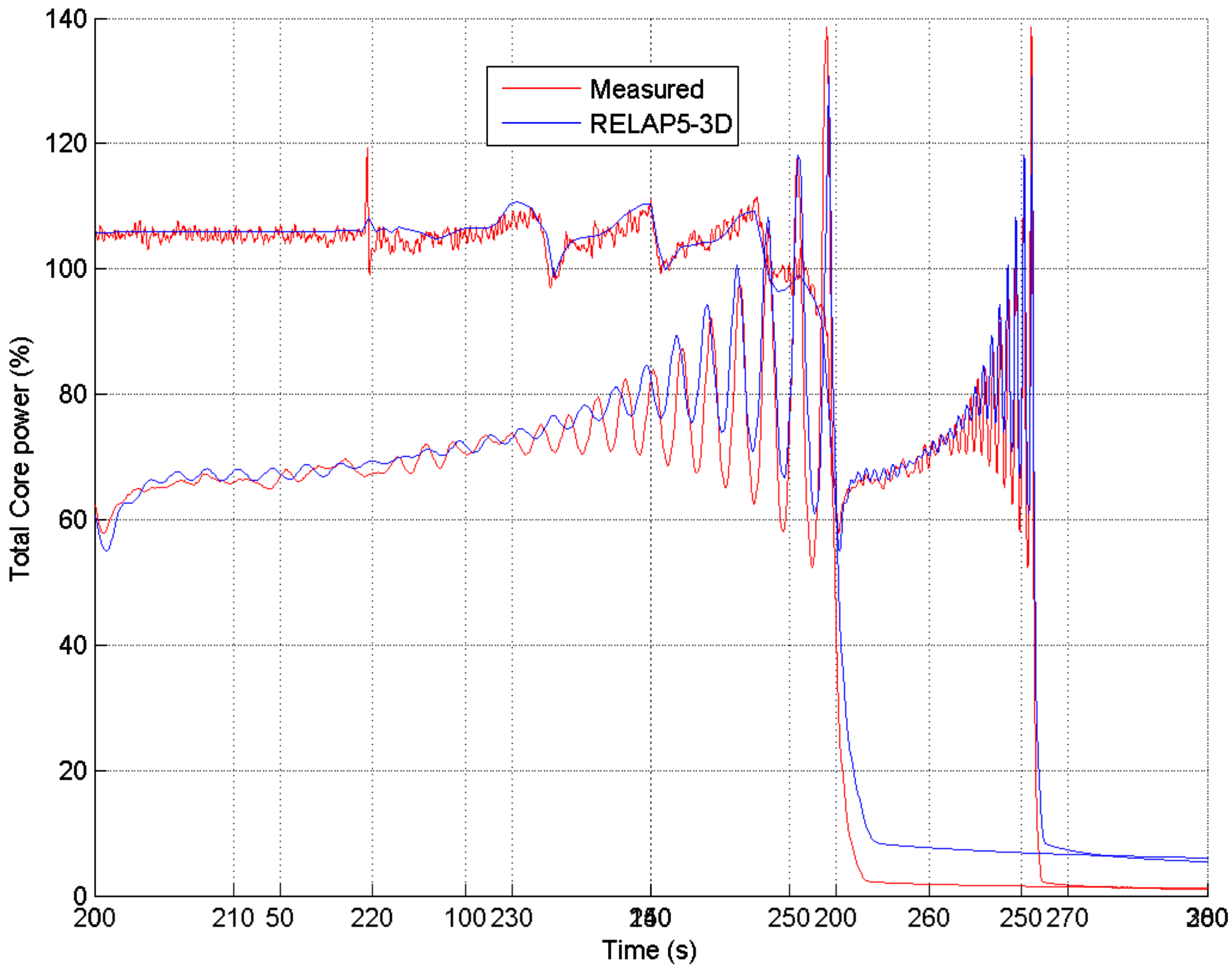






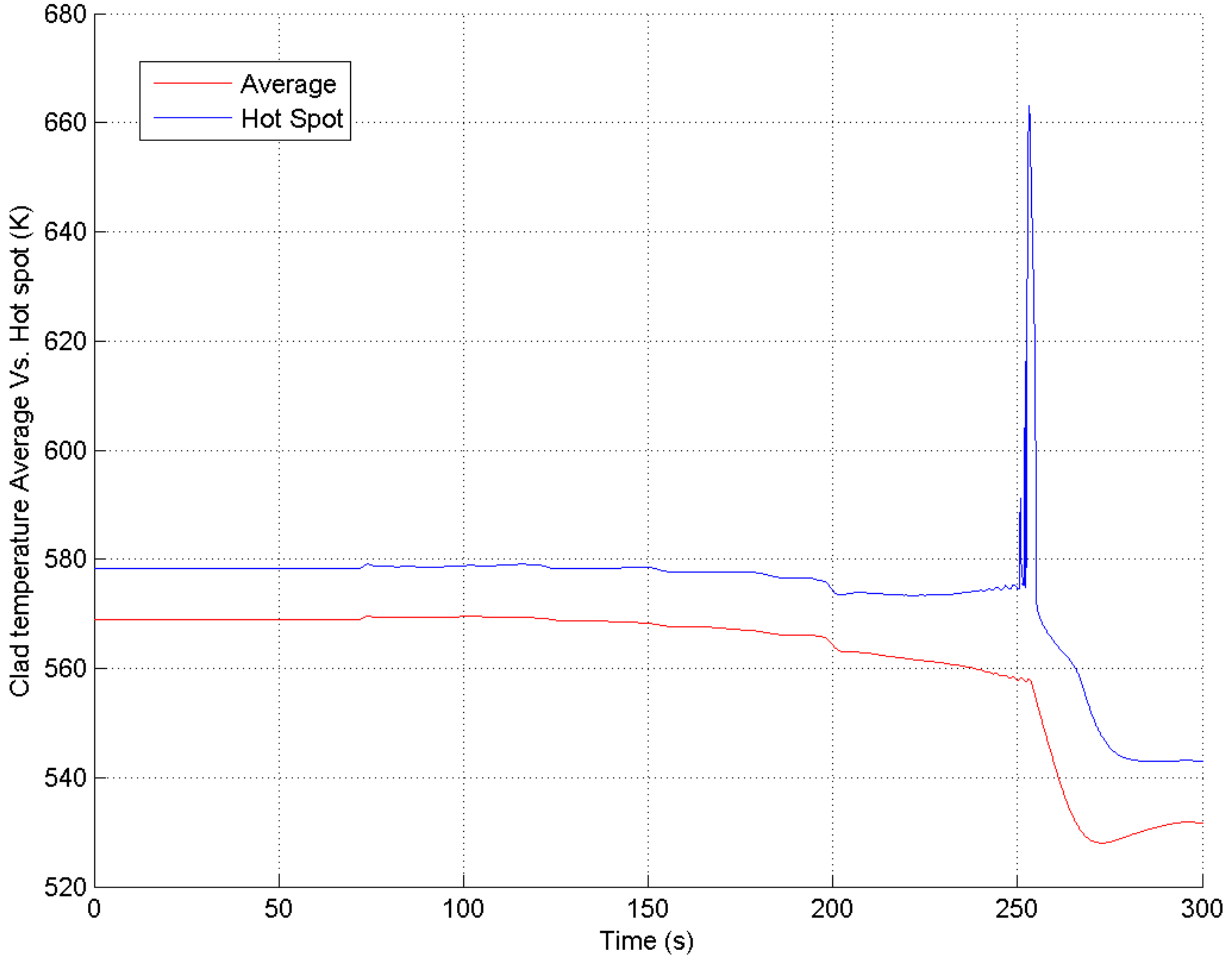
Transient analysis results

- Total core Power



Transient analysis results

- Average clad Temperature Vs. Hot Spot temperature

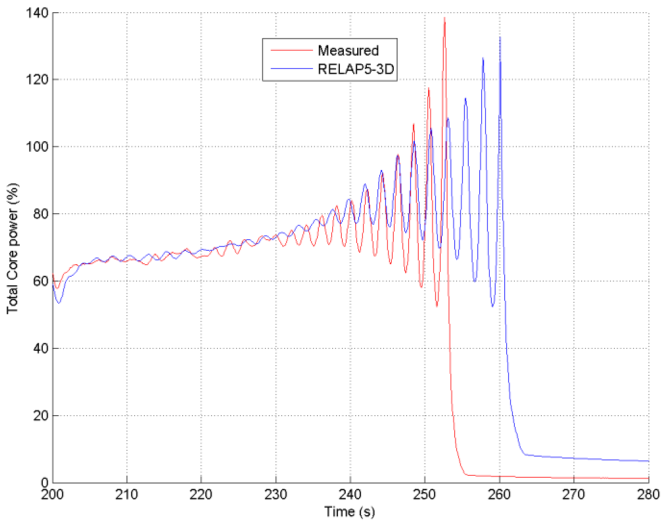


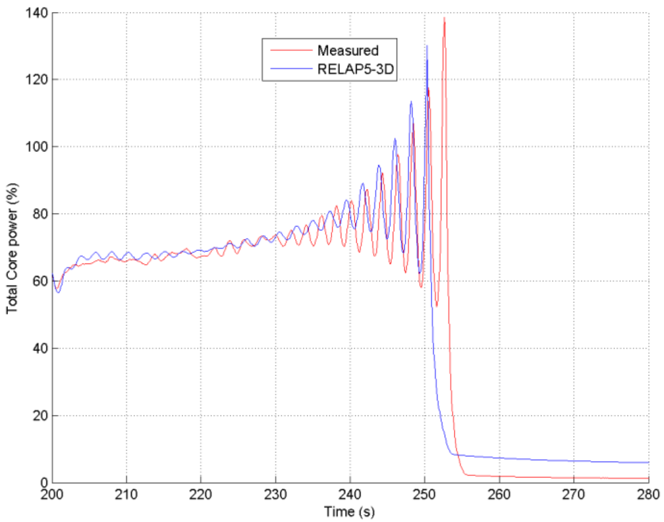
Transient analysis results

- Animation

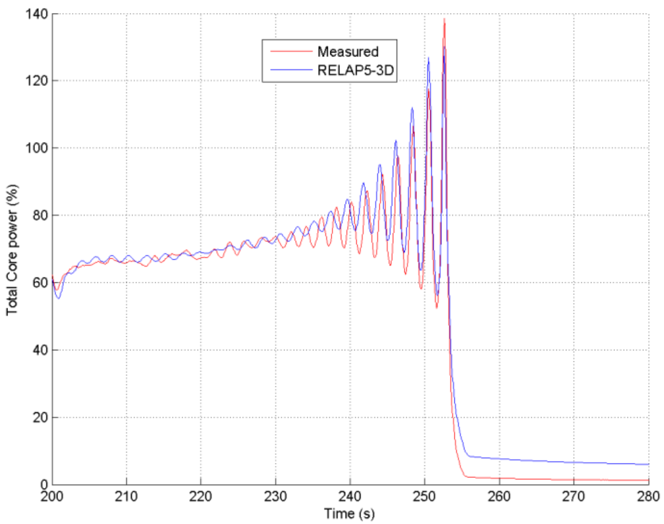
Sensitivity analysis results

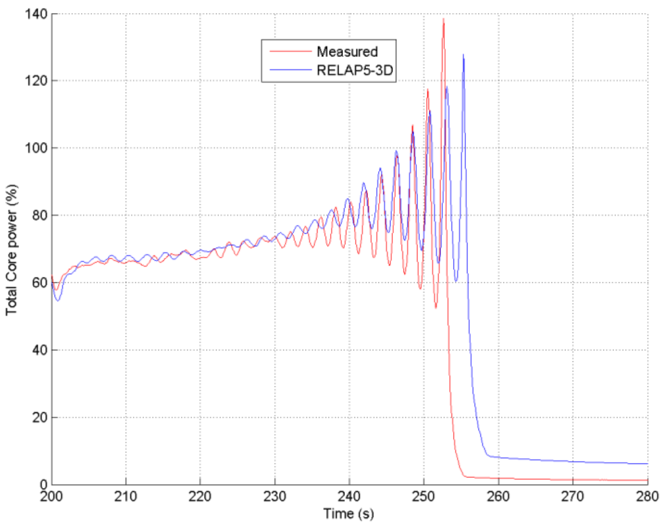
- +/- 10 % Heat Capacity of UO_2 and Clad





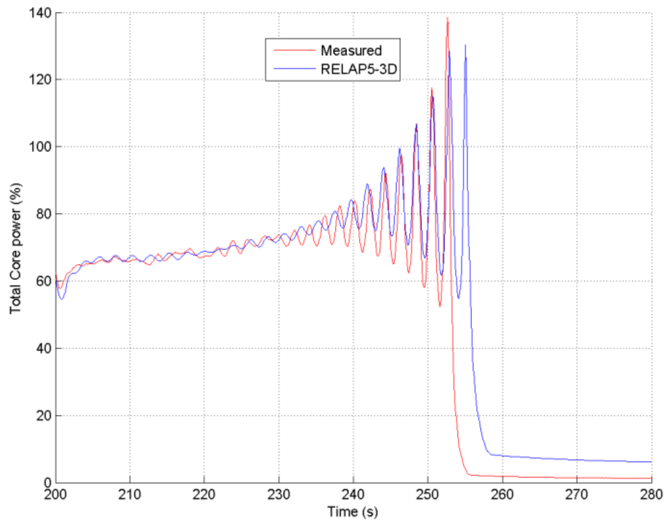
- +/- 10 % GAP Conductance

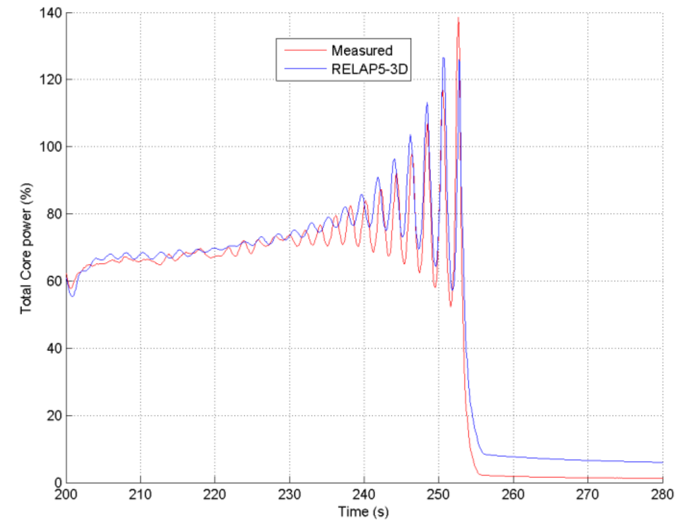




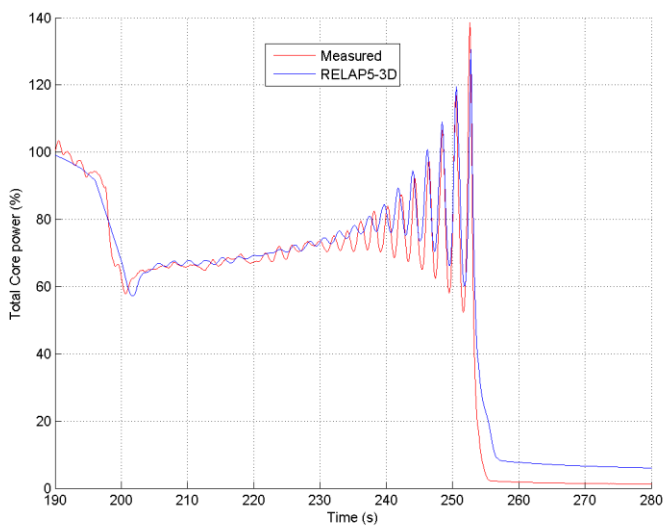
Sensitivity analysis results

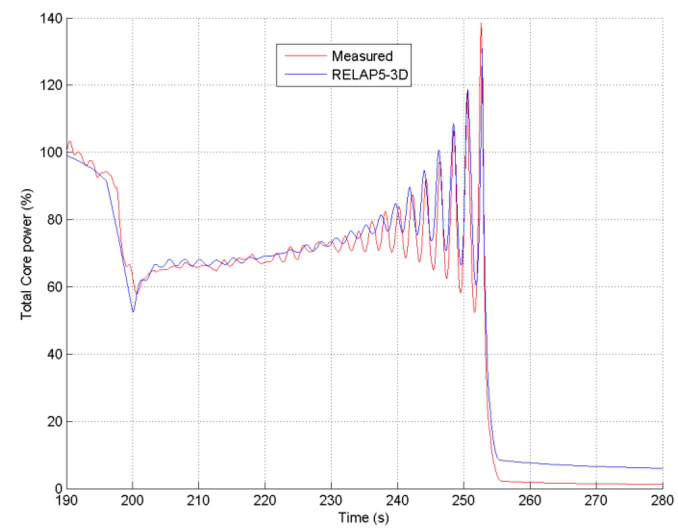
- +/- 3 K feed water temperature





- +/- 1 s CR insertion time





Notes for R5-3D developers

- Main issues during nodalization development/code run
  1. Limitation on TH mapping did not allow to connect 1:1 the TH volumes & NK nodes (9999 zone figures available vs. 444x25=11100 requested) → some "homogenization" needed →Q: is it possible to increase the zone figures number in future releases?
  2. Possibility to implement the large CASMO Xsec database (9999 compositions available) → conflicting with the input deck length → "Input too long" error message (R5v.3.0beta)
  3. Implementation of Xsec cross terms & "online" Xsec interpolation not possible

Conclusion & future steps

- ENEA is using R5-3D code as reference tool for NPP simulation
- Oskarshamn-2 BWR state-of-the-art model for RELAP5-3D© system code has been developed
  - detailed 3D neutronic coupled thermal-hydraulic model
  - developed for instability analyses → Oskarshamn-2 Feb. 1999 event
- Steady state and on transient preliminary qualification achieved
  - Main «uncertainties» of the data set identified and their effect on simulation result assessed
- Future steps for the model qualification: performing blind calculations simulating the 1999 O-2 stability tests