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KIT Results for the Phase 1

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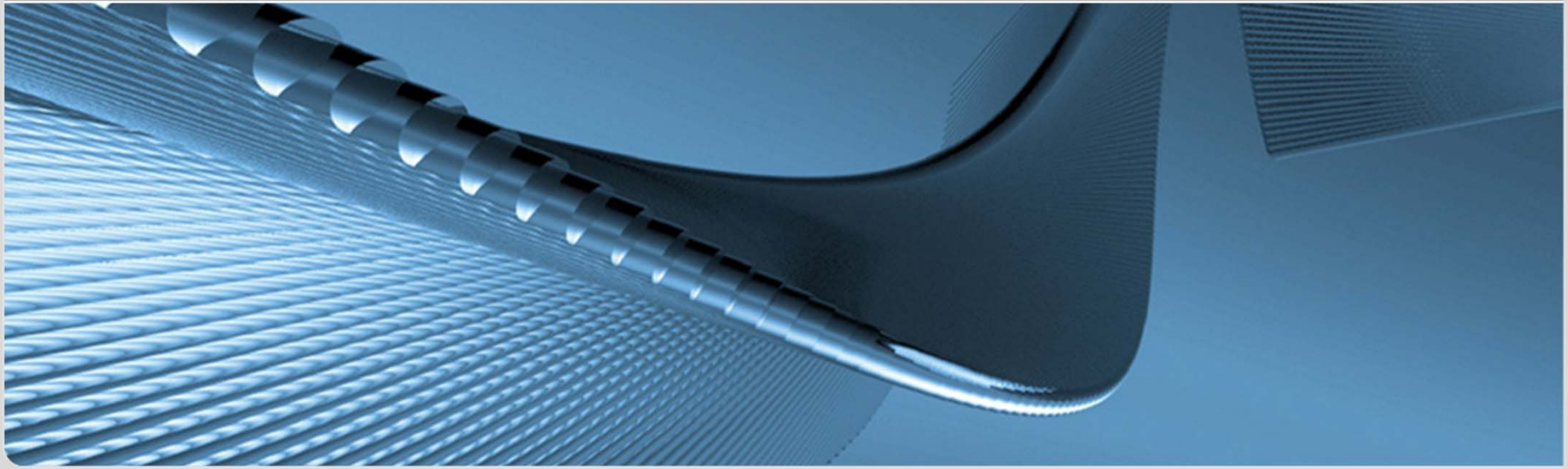

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- Summary of last year presentation in the 2nd Workshop (O2-2)
  - Focus on differences between V5P2/V5P3
- Optimisation of the KIT Model for the Oskarshamn plant
  - Improvements in the TRACE/PARCS code models
- Comparison of TRACE V5P3/PARCS predictions using the best set of combine parameters with experimental data
- Summary and Conclusions
- Outlook

Introduction to the O2 Instability Benchmark

- Scope of O2 Benchmark:
  - Exercise 1: Feedwater transient (stability event) from 25.02.1999
  - Exercise 2: Five stability test performed on 12.12.1998, 10 weeks before the event
  - Exercise 3: Five stability test performed on 13.03.1999, 3 weeks after the event

- Scenario description of Exercise 1:
  - Initial event: loss of feedwater pre-heaters and failure of the control system logic lead the plan to high feedwater flow and low feedwater temperature conditions without reactor scram
  - Interaction of the automatic power and flow control system caused the plant to move into the low flow – high power regime
  - The combination of these events culminated in diverging power oscillations which triggered an automatic scram at high power

Benchmark Phases and Exercises

- **Phase 1 – 1999 Event Analysis**
  - Part 1.1 – Plant system model initialization
    - Predefined power history for the event so that users can initialize their system model
  - Part 1.2 – 3D core model initialization
    - Steady-state calculations at HZP and Event Points 1, 4, 6, 8, 11
    - Comparison of k-eff, reactivity coefficients (void), CR worth, 3-D power and void distributions, active/bypass flows, pressure drops
    - Comparison of frequency and decay ratio for Event Points 1, 4, 6, 8, 11
  - Part 1.3 – Coupled plant system/3-D core simulation
    - Best-estimate simulation of the event
    - Comparisons of frequency and decay ratio from reactor power and selected LPRMs
    - Comparisons of 3-D power distributions and local maximum oscillations (hot channel)

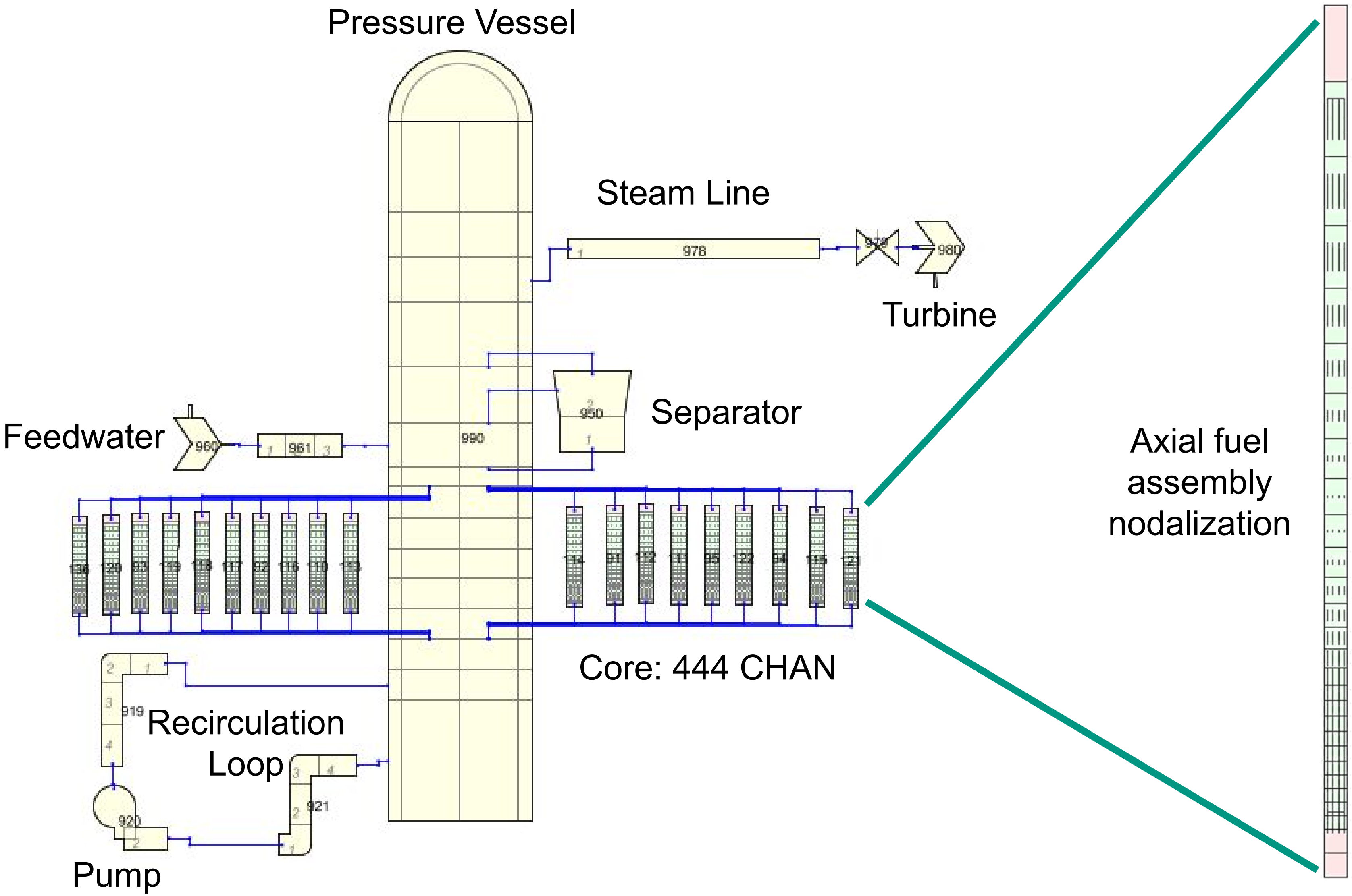
KIT Simulation Strategy

- Codes: TRACE and PARCS

- Simulation strategy:
  - Step1: Initialization of TRACE model ➔ stand-alone TRACE simulation
    - Comparison of predicted with measured data
  - Step 2: Initialisation of coupled TRACE/PARCS simulation: Steady state run
  - Step 3: Coupled TRACE/PARCS transient run for given boundary conditions

- Comparison of predicted and measured data
  - Global parameters

Integration of the Core Model in TRACE Plant Model



Thermal-hydraulic Core Model: TRACE

TRACE Code Version Used

- TRACE-V5 Patch 3
  - **Same Core model used in TRACE-V5 Patch 2**
- Core model:
  - Thermal-hydraulic models (TRACE):
    - Stand-alone steady state simulation:
      - **Radial: 444 CHANS**
      - Axial: 25 axial levels with varying elevation (for the time being)
    - TRACE restart input deck for steady state coupled simulation (TRACE/PARCS)
      - Implement given time-dependent boundary conditions
  - Neutron Kinetics core models (PARCS):
    - Basic core model for coupled steady state simulation (TRACE/PARCS)
      - Radial: 444 radial nodes
      - Axial: 25 axial nodes + 2 for lower and upper reflector
    - Transient core model (PARCS) for coupled transient simulation using TRACE/PARCS
    - XS data set provided by benchmark team

Initial and boundary conditions

- All the conditions are acording to the specifications sent from the benchmark organizators except the “Wall Roughtness of the Channels”

  - Wall Roughtness

Benchmark Specifications	KIT Model
1.0 E-5	4.0 E-7

    - Simulations in TRACE with Wall Roughtness according to Benchmark Specifications were really far from the plant meassured data.

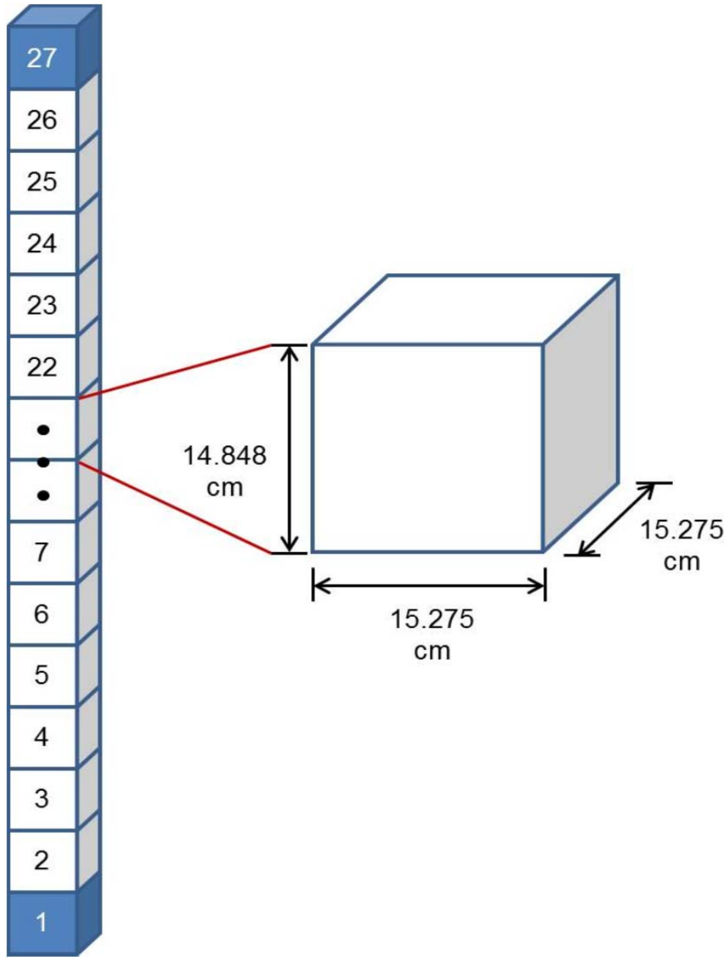
  - Values of the most important points taken for the reference simulation

GAP Value	Roughness Value	Carry-Over Value	Carry-Under Value
6000	4.0E-7	0.00	0.00

Neutron Kinetic Core Model: PARCS

PARCS Core Model

- Radial neutronic nodes: 444
  - 109 cruciform elements of B4C
- Radial reflector nodes: 92
- Axial nodes:
  - Lower reflector: 1
  - Active core: 25
  - Upper reflector: 1
- Critical control rod position:
  - Bank 1 to 17: 100 % out of the core
  - Bank 18: 23 % out
  - Bank 19: 98 % out



Preliminary Steady State Results obtained with TRACE/PARCS

SS O2 BWR Plant Conditions before the Transient

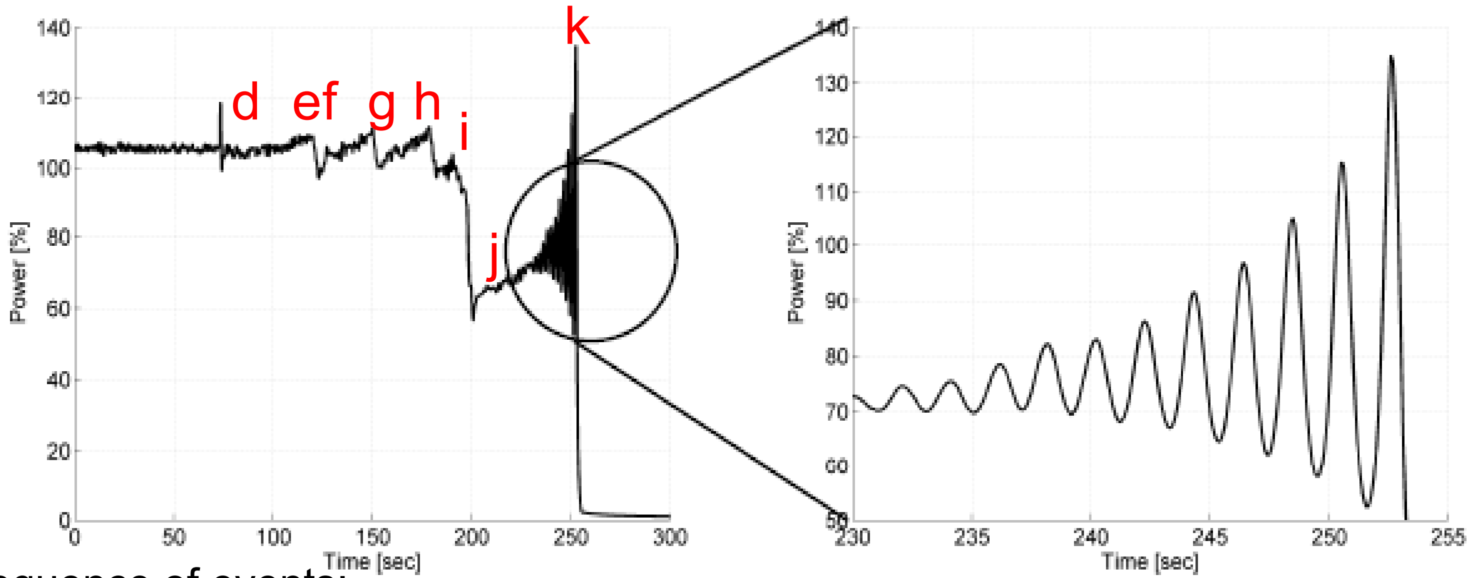
Data	Units	Data	Code 1	Code 2	KIT 444 Patch-2	KIT 444 Patch-3	Deviation Patch-2/3 (%)
Nominal thermal power	MW	**1798.6**	1802	1802	**1802**	**1802**	**0**
Steam Dome pressure	MPa	**6.93**	7.0	7.0	**7.0**	**7.0**	**0**
Core outlet pressure	MPa		7.067	7.0141	**7.06011**	**7.06010**	**3.61 E-4**
Core inlet pressure	MPa		7.1660	7.1162	**7.1657**	**7.1656**	**8.93 E-4**
Core pressure drop	kPa		98.8	102	**105.58**	**105.55**	**3.65 E-2**
Feedwater temperature	K	**457.65**		456.62	**456.6232**	**456.6231**	**6.57 E-6**
Coolant temperature at core inlet	K	**547.30**	548.05	543.57	**543.91**	**543.88**	**6.50 E-3**
Steam line temperature	K			558.48	**558.590**	**558.591**	**1.70 E-4**
Total core flow rate	kg/s	**5474**	5515.9	5515.9	**5515.89**	**5515.87**	**5.22 E-4**
Active core flow rate	kg/s		4793.5	4800.4	**4885.3**	**4885.6**	**5.44 E-3**
Steam flow rate at turbine inlet	kg/s	**900**	976	903.1	**900.9**	**900.1**	**8.13 E-2**

Pressure percentage difference of the core channels between Patch-2 and Patch-3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1					0.08	0.08	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.10	0.09	0.09	0.08				
2				0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.09	0.09			
3			0.10	0.10	0.12	0.15	0.13	0.14	0.14	0.14	0.13	0.14	0.14	0.13	0.13	0.14	0.15	0.12	0.10	0.09		
4		0.09	0.10	0.15	0.14	0.13	0.11	0.12	0.13	0.10	0.11	0.12	0.11	0.13	0.12	0.13	0.13	0.14	0.15	0.10	0.09	
5	0.08	0.09	0.14	0.14	0.13	0.12	0.12	0.11	0.12	0.11	0.36	0.11	0.39	0.12	0.10	0.12	0.12	0.13	0.14	0.14	0.09	0.08
6	0.09	0.10	0.15	0.14	0.12	0.12	0.10	0.10	0.12	0.11	0.10	0.11	0.11	0.10	0.11	0.10	0.11	0.12	0.13	0.15	0.11	0.09
7	0.09	0.11	0.14	0.12	0.12	0.10	0.12	0.10	0.11	0.12	0.11	0.11	0.12	0.10	0.10	0.11	0.09	0.12	0.10	0.15	0.11	0.09
8	0.10	0.12	0.12	0.12	0.10	0.11	0.10	0.11	0.11	0.12	0.12	0.09	0.11	0.10	0.11	0.39	0.11	0.11	0.12	0.13	0.11	0.09
9	0.10	0.11	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.12	0.12	0.12	0.36	0.12	0.14	0.11	0.10
10	0.09	0.11	0.13	0.11	0.10	0.11	0.09	0.11	0.11	0.19	0.11	0.11	0.19	0.12	0.11	0.11	0.11	0.10	0.11	0.14	0.11	0.10
11	0.09	0.11	0.13	0.12	0.11	0.11	0.10	0.19	0.12	0.25	0.14	0.15	0.11	0.11	0.10	0.09	0.10	0.12	0.11	0.13	0.12	0.09
12	0.08	0.08	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.10	0.09	0.09	0.08	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11
13	0.11	0.11	0.11	0.11	0.11	0.10	0.09	0.09	0.10	0.10	0.12	0.15	0.13	0.14	0.14	0.14	0.13	0.14	0.14	0.13	0.13	0.14
14	0.15	0.12	0.10	0.09	0.09	0.10	0.15	0.14	0.13	0.11	0.12	0.13	0.10	0.11	0.12	0.11	0.13	0.12	0.13	0.13	0.14	0.15
15	0.10	0.09	0.08	0.09	0.14	0.14	0.13	0.12	0.12	0.11	0.12	0.11	0.36	0.11	0.39	0.12	0.10	0.12	0.12	0.13	0.14	0.14
16	0.09	0.08	0.09	0.10	0.15	0.14	0.12	0.12	0.10	0.10	0.12	0.11	0.10	0.11	0.11	0.10	0.11	0.10	0.11	0.12	0.13	0.15
17	0.11	0.09	0.09	0.11	0.14	0.12	0.12	0.10	0.12	0.10	0.11	0.12	0.11	0.11	0.12	0.10	0.10	0.11	0.09	0.12	0.10	0.15
18	0.11	0.09	0.10	0.12	0.12	0.12	0.10	0.11	0.10	0.11	0.11	0.12	0.12	0.09	0.11	0.10	0.11	0.39	0.11	0.11	0.12	0.13
19		0.11	0.09	0.10	0.11	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.12	0.12	0.12	0.36	
20			0.12	0.14	0.11	0.10	0.09	0.11	0.13	0.11	0.10	0.11	0.09	0.11	0.11	0.19	0.11	0.11	0.19	0.12		
21				0.11	0.11	0.11	0.10	0.11	0.14	0.11	0.10	0.09	0.11	0.13	0.12	0.11	0.11	0.10	0.19			
22					0.12	0.25	0.14	0.15	0.11	0.11	0.10	0.09	0.10	0.12	0.11	0.13	0.12	0.09				

Preliminary Transient Results obtained with TRACE/PARCS

O2 Power Evolution measured during Feedwater Transient



- Sequence of events:
  a) Loss of external power
  b) TSV closure, opening of TBV
  c) Reduction of generator power
     - no pump cost-down
     - Plant still at full power
  d) Loss of FW-preheaters
     - FW flow does not change
  e) FW temperature reduction
  f) First RC-pump shut-down at high power
  g) Second RC-pum shut-down at high power
  h) Third RC-pum shut-down at high power
  i) Partial SCRAM by operator
     - RC-Pums go to min. pump speed
  j) Start oscillations due to decreasing flow rate and Tcoolant
  k) SCRAM at Pmax

Comparison of transient selected parameters TRACE Version Patch-2 and Patch-3 (1)

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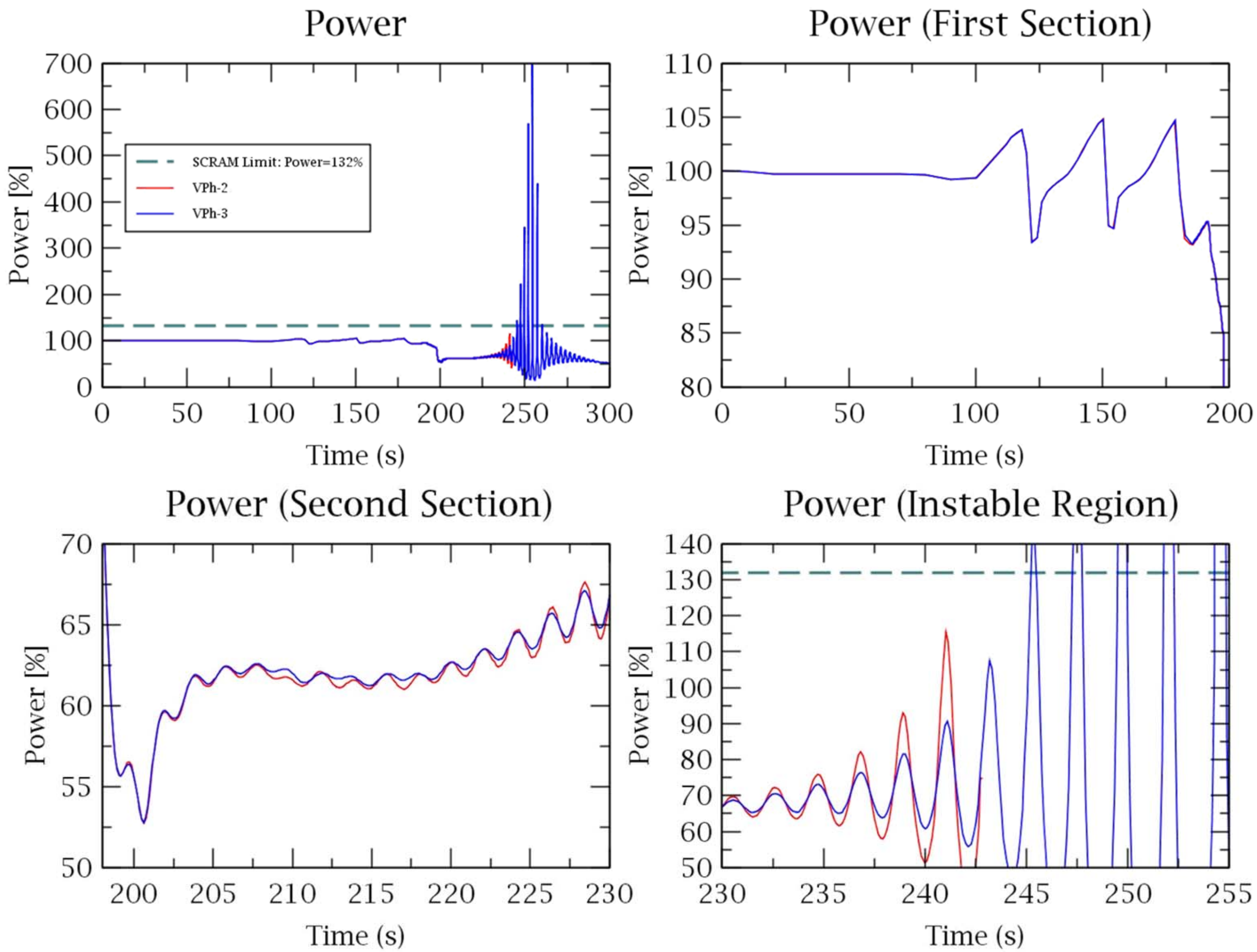
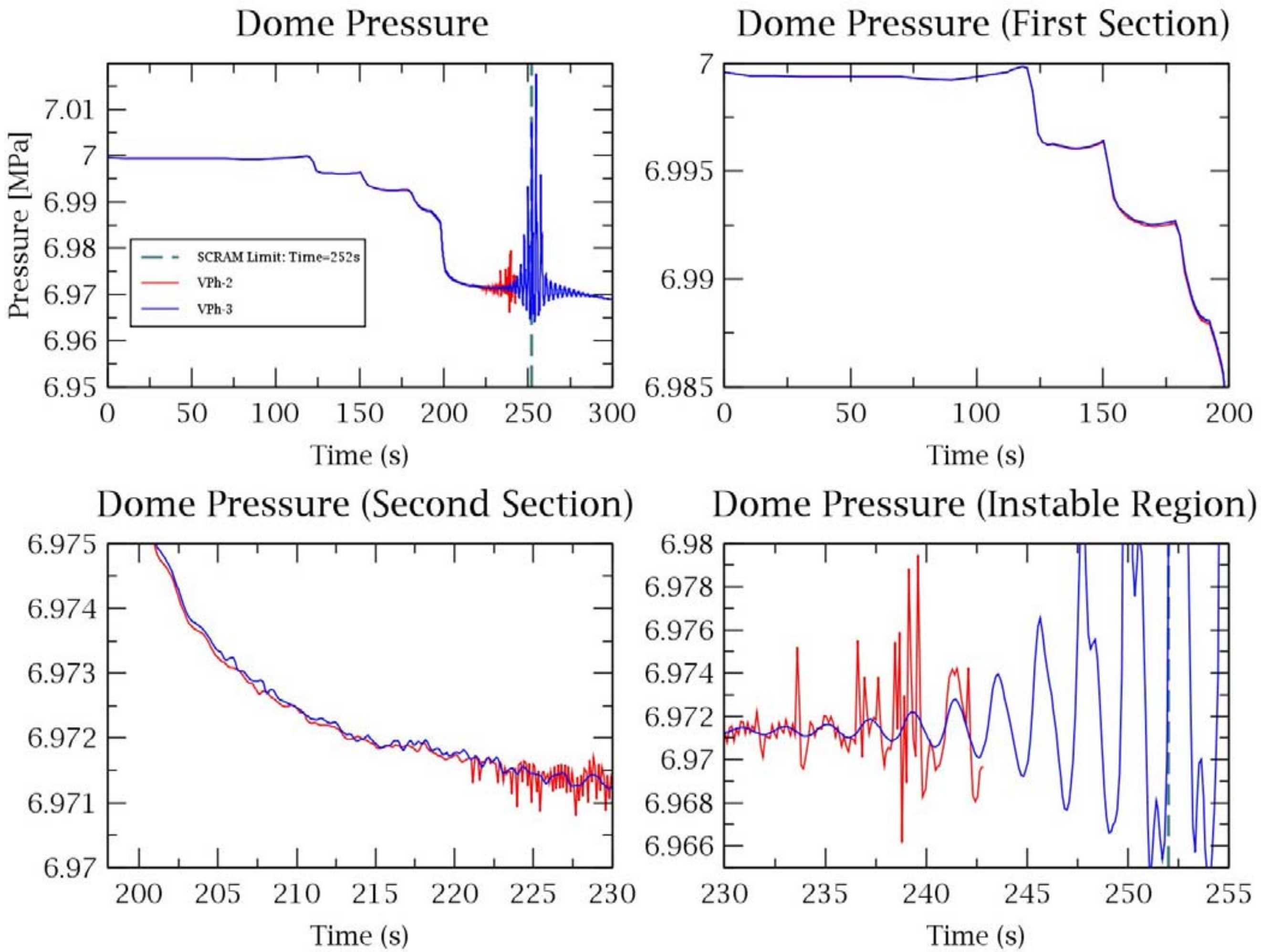
- Predicted core total power



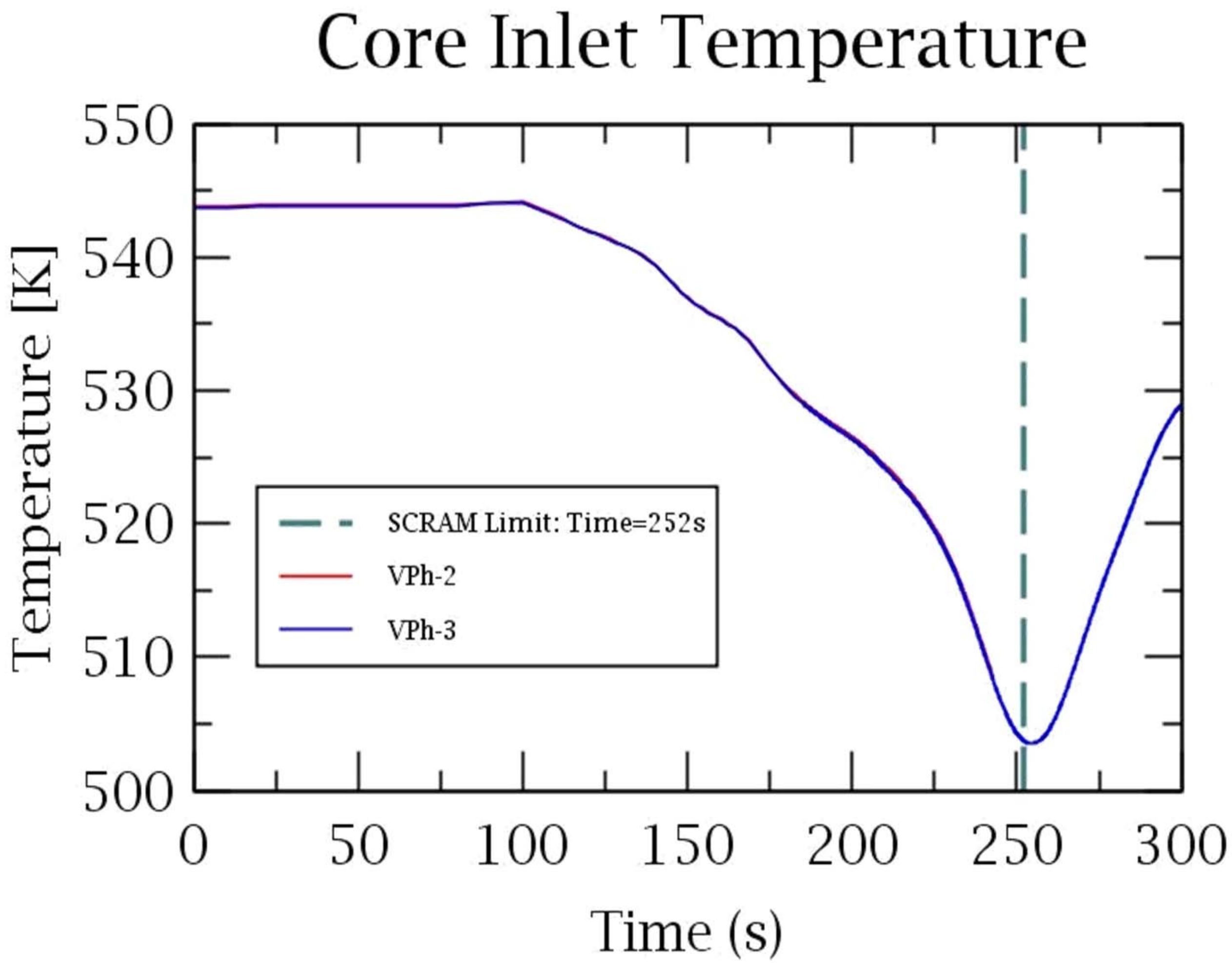
Comparison of transient selected parameters TRACE Version Patch-2 and Patch-3 (2)

- Predicted Dome Pressure



Comparison of transient selected parameters TRACE Version Patch-2 and Patch-3 (3)

- Predicted Core Inlet Temperature



Comparison of transient selected parameters TRACE Version Patch-2 and Patch-3 (4)

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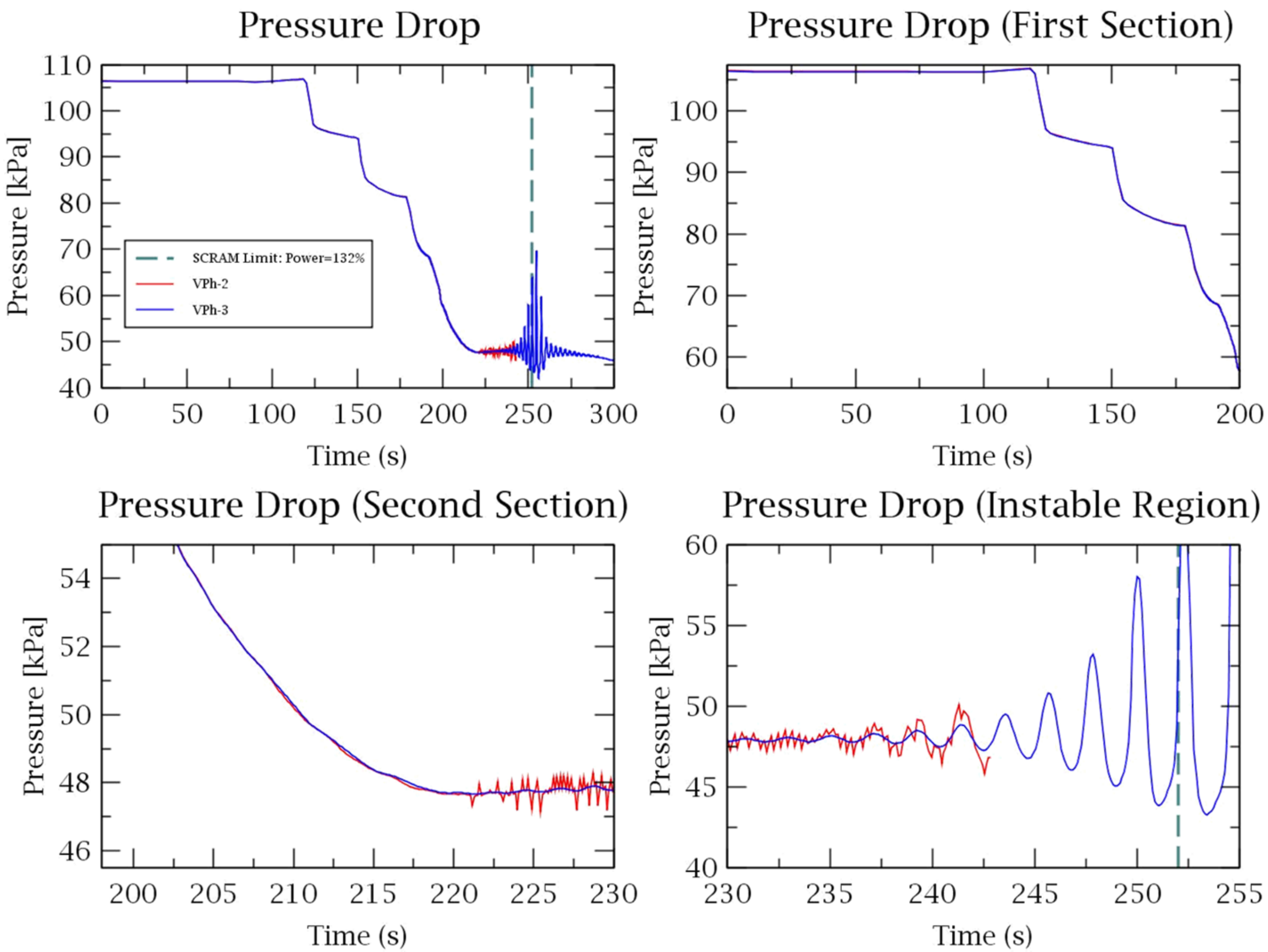
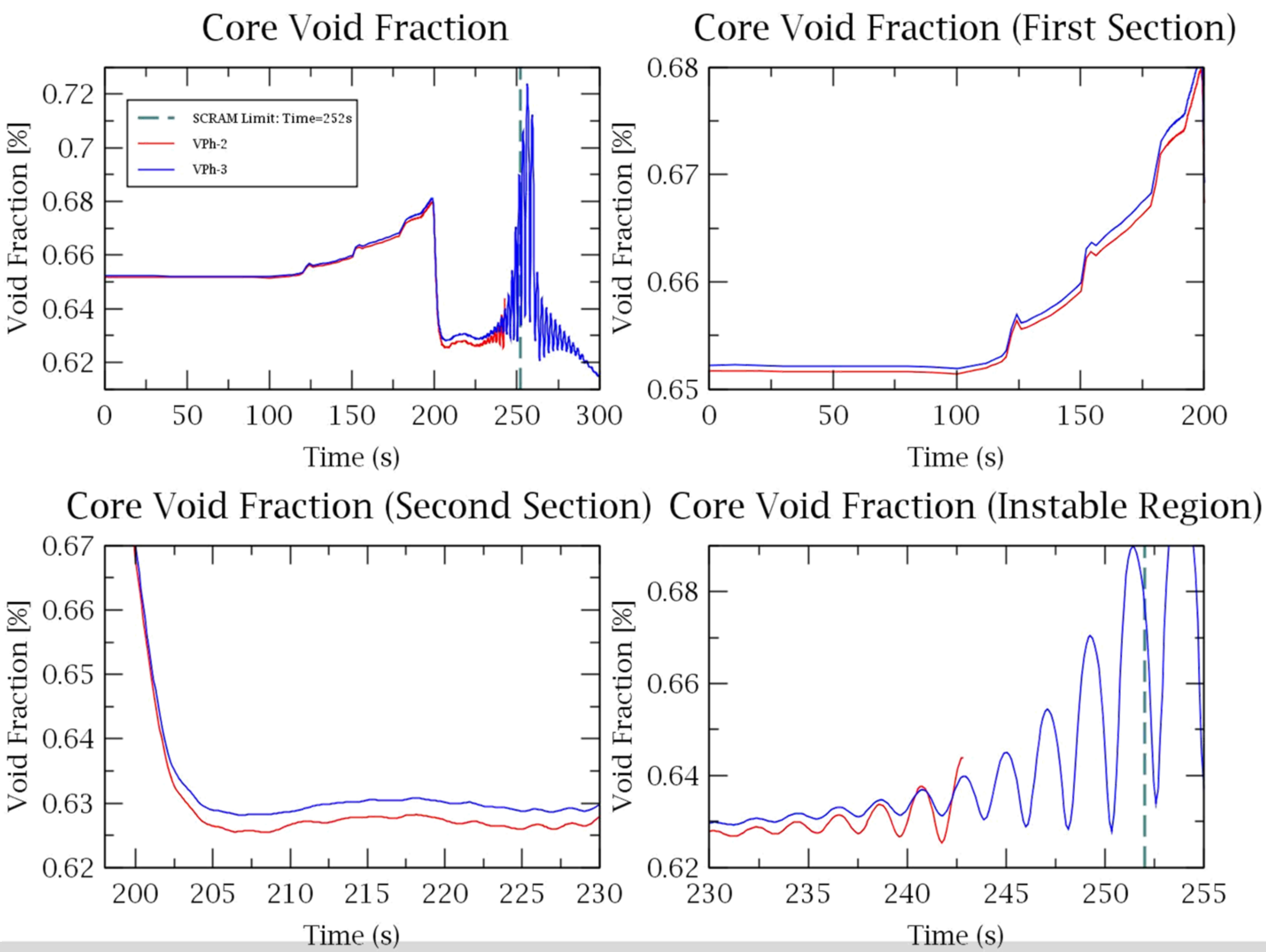
- Predicted Core Pressure Drop



Comparison of transient selected parameters TRACE Version Patch-2 and Patch-3 (5)

- Predicted Core Average Void Fraction



Comparison of transient selected parameters TRACE Version Patch-2 and Patch-3 (6)

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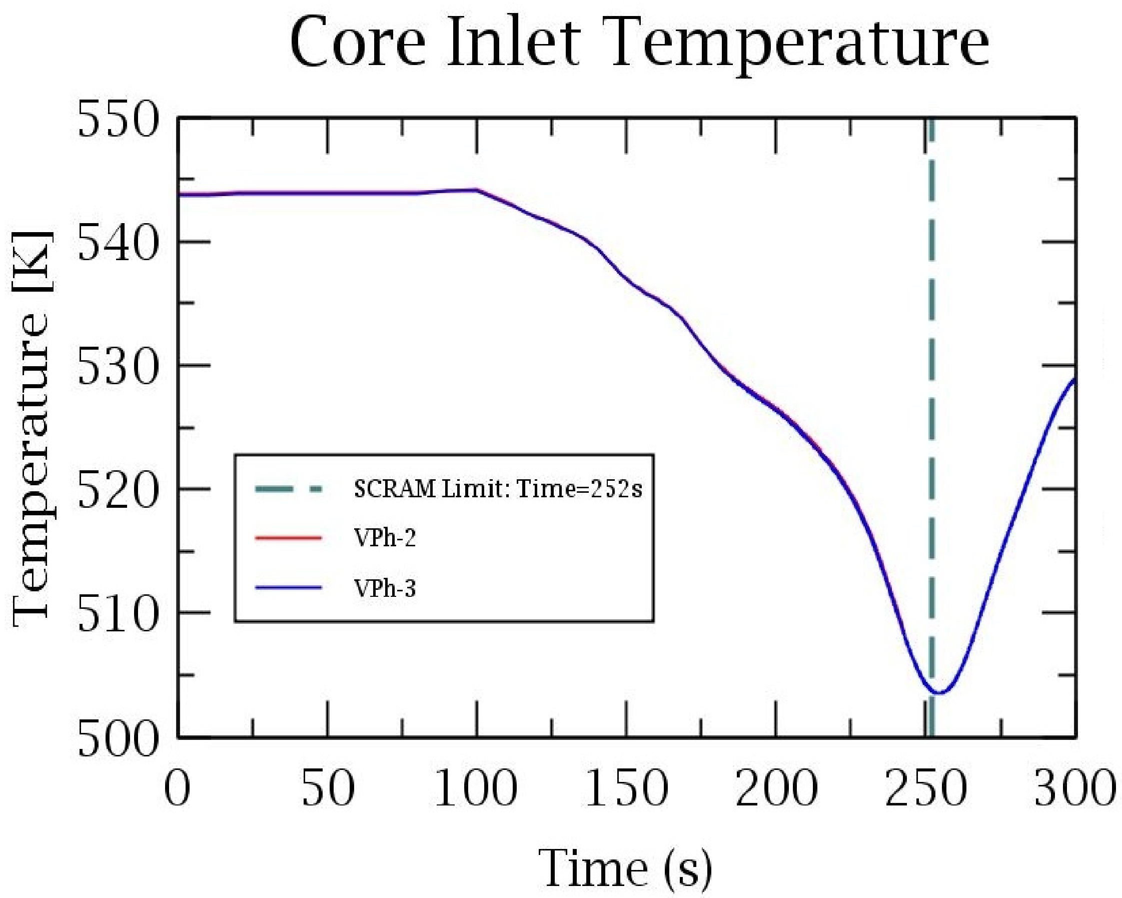
- Predicted Core Inlet Temperature



Comparison of transient selected parameters TRACE Version Patch-2 and Patch-3 (7)

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- Decay Ratio and Natural Frequency
  - Two calculations:
    - Version Patch-2 limit
    - SCRAM limit
  - Decay ratio

	O2	Patch2	ΔO2/Patch2	Patch3	ΔO2/Patch3 (%)	ΔVPh2/Patch3 (%)
Patch-2 limit	1.3296	1.7656	-32.7918	1.5900	-19.5848	9.9456
SCRAM limit	1.3619	-	-	1.7381	-27.6232	-

  - Natural Frequency

	O2	Patch2	ΔO2/Patch2	Patch3	ΔO2/Patch3 (%)	ΔPacth2/Patch3 (%)
Patch-2 limit	0.4938	0.4739	4.0419	0.4644	5.9616	2.0005
SCRAM limit	0.4819	-	-	0.4586	4.8389	-

Summary of the status in the O2-2 workshop

- Focus was on the comparison between TRACE versions P2 /P3
- Stand Alone
  - No significant changes in the results between both versions
- Transient
  - The calculation stops in Patch-2 before to arrive to the instability point and to the SCRAM zone. On the opposite, Patch-3 does not stop and it continues beyond the SCRAM time point.
  - In the instable region, the Patch-2 has bigger wave amplitude.
  - For the calculation of pressures, the Patch-2 shows an important noise around the wave.
  - Patch 3 predicts a smaller decay ratio and closer to the data measurements compared to Patch-2. However natural frequency is lower and shows larger deviation from measurements data.
- Additional work needed to find the optimal parameter combination (TRACE) for a better description of the power oscillations with Patch-3.

Optimization of the KIT Model for the Oskarshamn plant

Comparison TRACE V5P3 model vs. O2 data

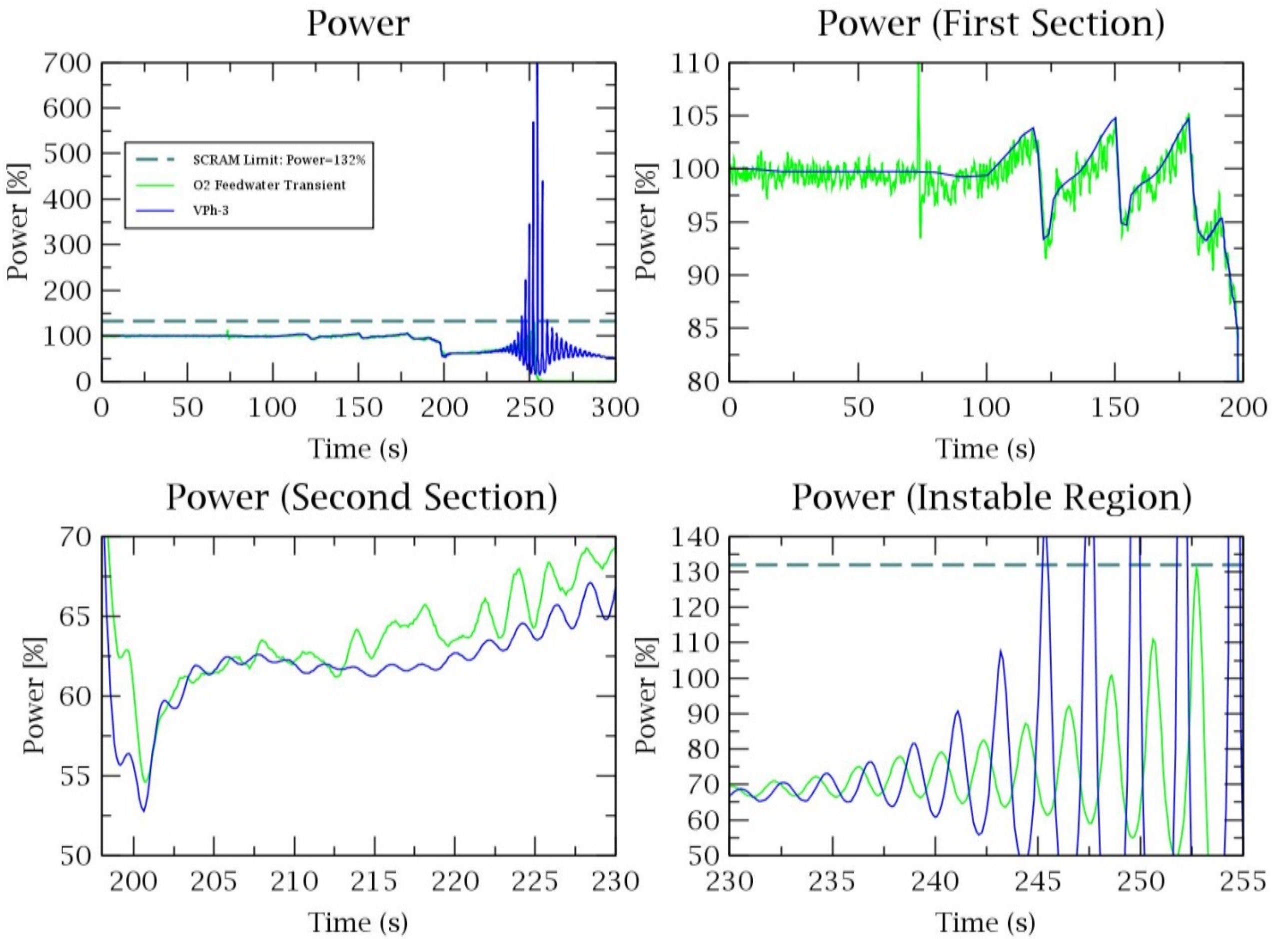
- Steady State Thermal-hydraulic parameters

	O2-Benchmark	TRACE model	Deviation %
Reactor Power (MW)	1802	1802	0
Enthalpy Balance (MW)	1799.7	1794.2	0.3069
Steam Dome Pressure (MPa)	7	7	0
Core Inlet Pressure (MPa)	7.1162	7.1656	-0.6947
Core Outlet Pressure (MPa)	7.0141	7.0601	-0.6556
Core Pressure Drop (kPa)	102	106	-3.4814
Channel Pressure Drop* (kPa)	46.9	55.1	-17.4373
Core Average Void	0.42	0.40	5.3048
Feedwater Temperature (K)	456.620	456.623	-0.0007
Core Inlet Temperature (K)	543.57	543.88	-0.0573
Inlet Subcooling (K)	16.59	16.72	-0.7654
Steam Temperature (K)	558.48	558.59	-0.0200
Pump Speed (rad/s)	94.38	101.78	-7.8381
Total Core Flow Rate (kg/s)	5515.90	5515.87	0.0005
Active Core Flow Rate (kg/s)	4800.4	4885.6	-1.7740
Steam Flow Rate (kg/s)	903.1	900.1	0.3274
Downcomer Water Level (m)	8.4	8.37	0.3635
K-eff	1.0092	1	0.9116

$$\frac{X_{O2-Benchmark} - X_{V5P3}}{X_{O2-Benchmark}} \times 100$$

Comparison TRACE V5P3 model vs. O2 data

- Coupled TRACE/PARCS Transient



Comparison TRACE V5P3 model vs. O2 data

- Comparison of predicted decay ratio and data

	O2	V5P3	ΔO2/V5P3
Decay Ratio	1.3619	1.7381	-27.6232

- Comparison of predicted natural frequency and data

	O2	V5P3	ΔO2/V5P3
Natural Frequency	0.4819	0.4586	4.8389

Optimization of the KIT model for the Oskarshamn plant

- Thermal-hydraulic Parameters

Case Number	GAP Value W/(m²K)
G0 (Original model)	6000
G1	2000
G2	4000
G3	8000
G4	10000

Case Number	Roughness Value (m)
R0 (Original model)	4.0E-7
R1	1.0E-7
R2	2.0E-7
R3	8.0E-7
R4	1.6E-6

Case Number	Carry-Over Value
CO0 (Original model)	0.00
CO1	0.005
CO2	0.01
CO3	0.015
CO4	0.02

Case Number	Carry-Under Value
CU0 (Original model)	0.00
CU1	0.005
CU2	0.01
CU3	0.015
CU4	0.02

Optimization of the KIT model for the Oskarshamn plant

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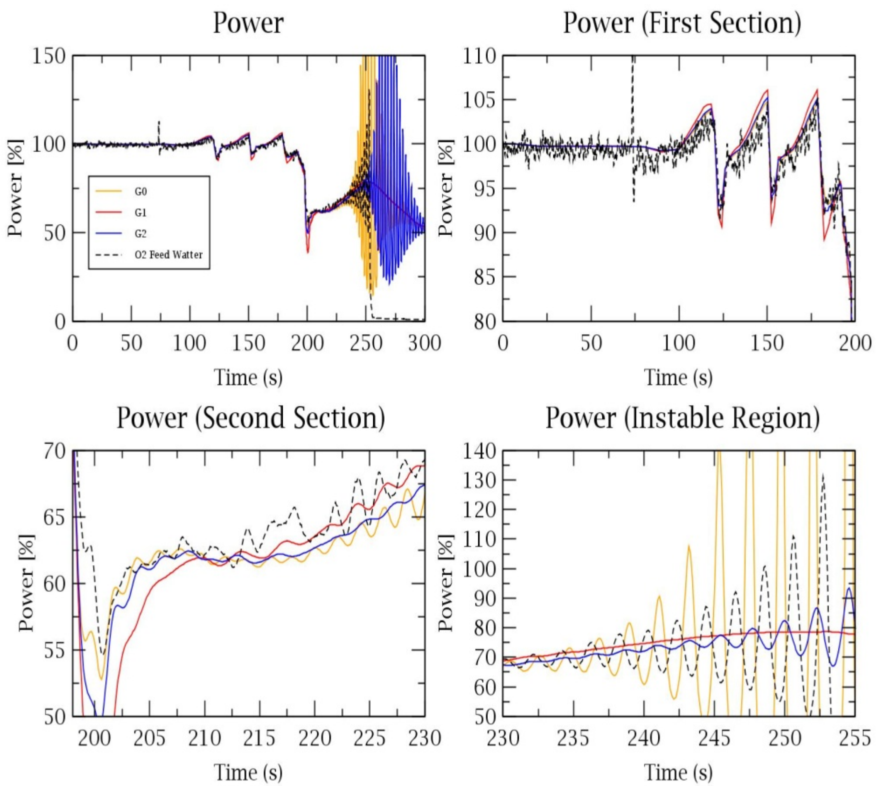
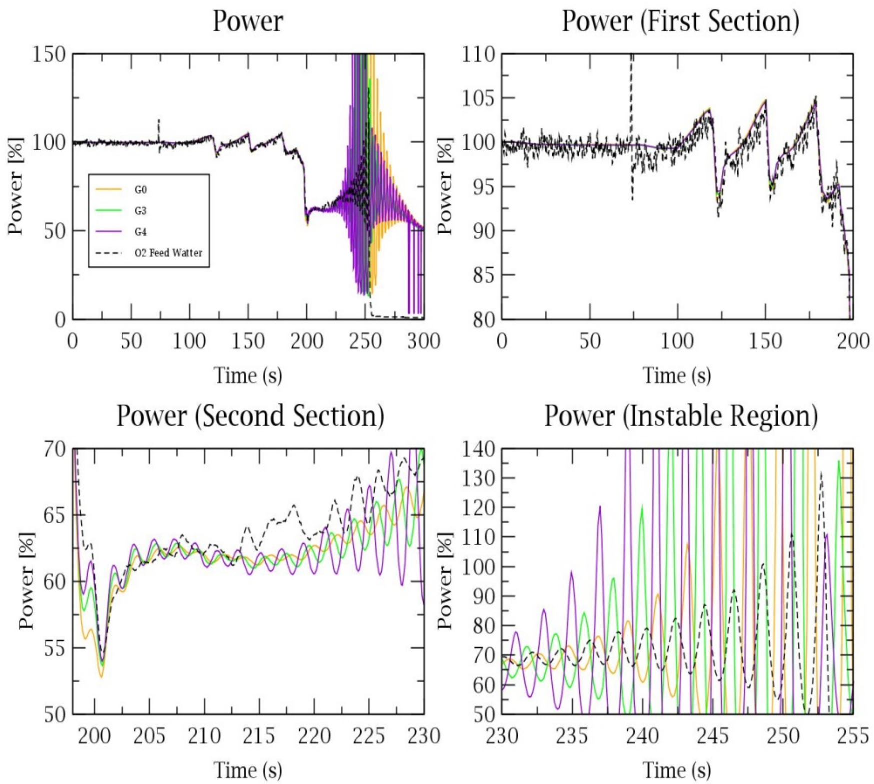
- Thermal-hydraulic Parameters
  - GAP

Case Number	GAP Value W/(m²K)
G0 (Original model)	6000
G1	2000
G2	4000
G3	8000
G4	10000





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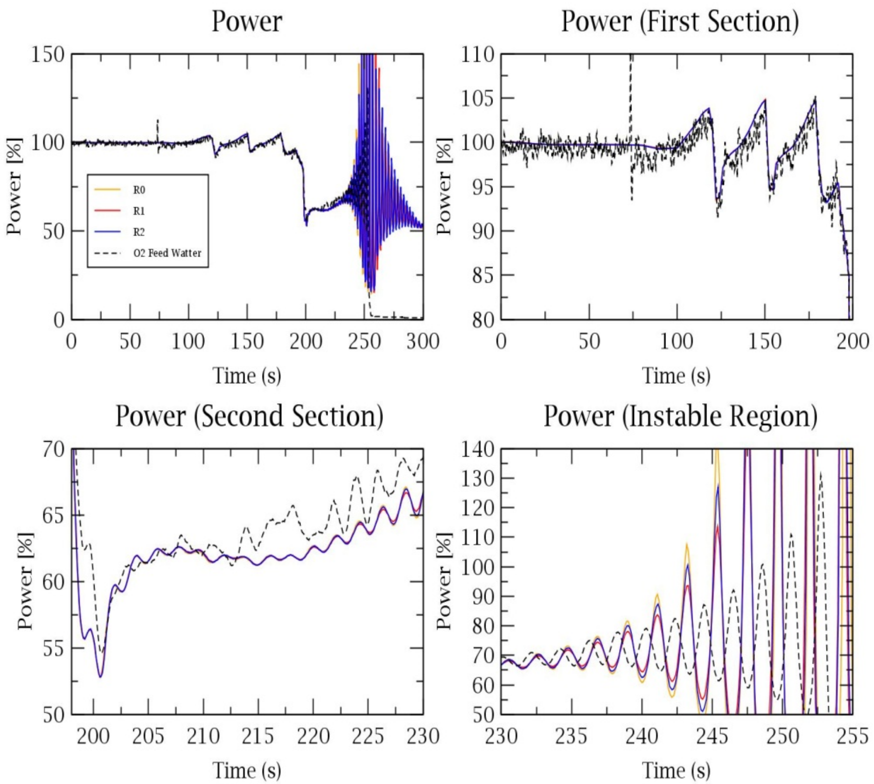
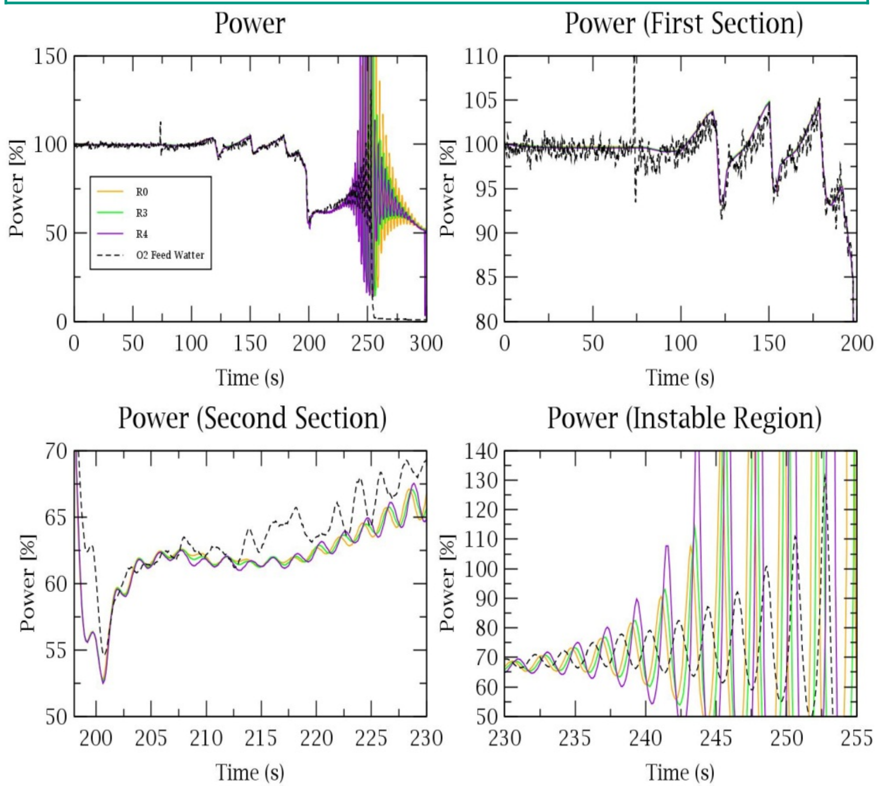
Optimization of the KIT model for the Oskarshamn plant

- Thermal-hydraulic Parameters
  - Roughness

Case Number	Roughness Value (m)
R0 (Original model)	4.0E-7
R1	1.0E-7
R2	2.0E-7
R3	8.0E-7
R4	1.6E-6

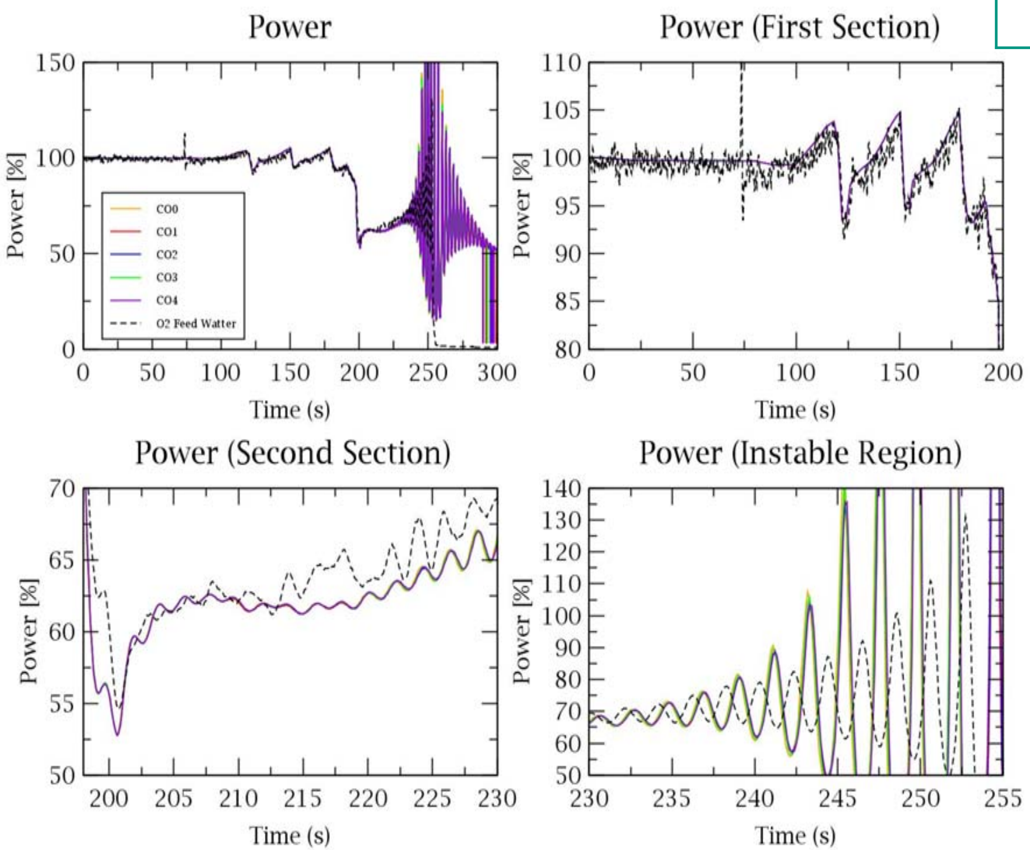




Optimization of the KIT model for the Oskarshamn plant

- Thermal-hydraulic Parameters
  - Carry-Over

Case Number	Carry-Over Value
CO0 (Original model)	0.00
CO1	0.005
CO2	0.01
CO3	0.015
CO4	0.02

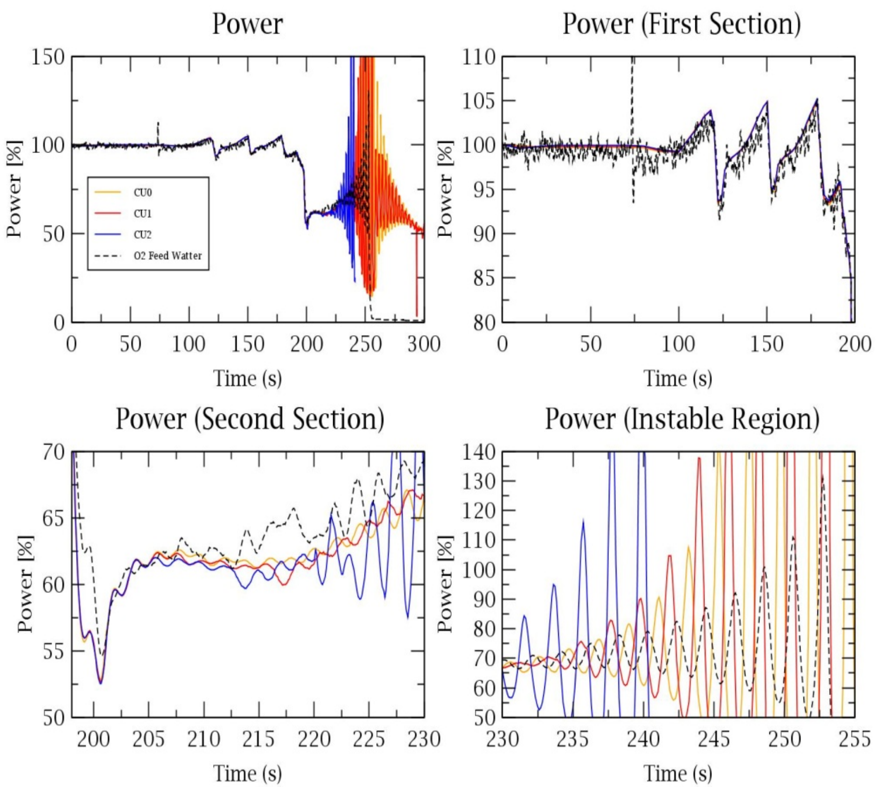


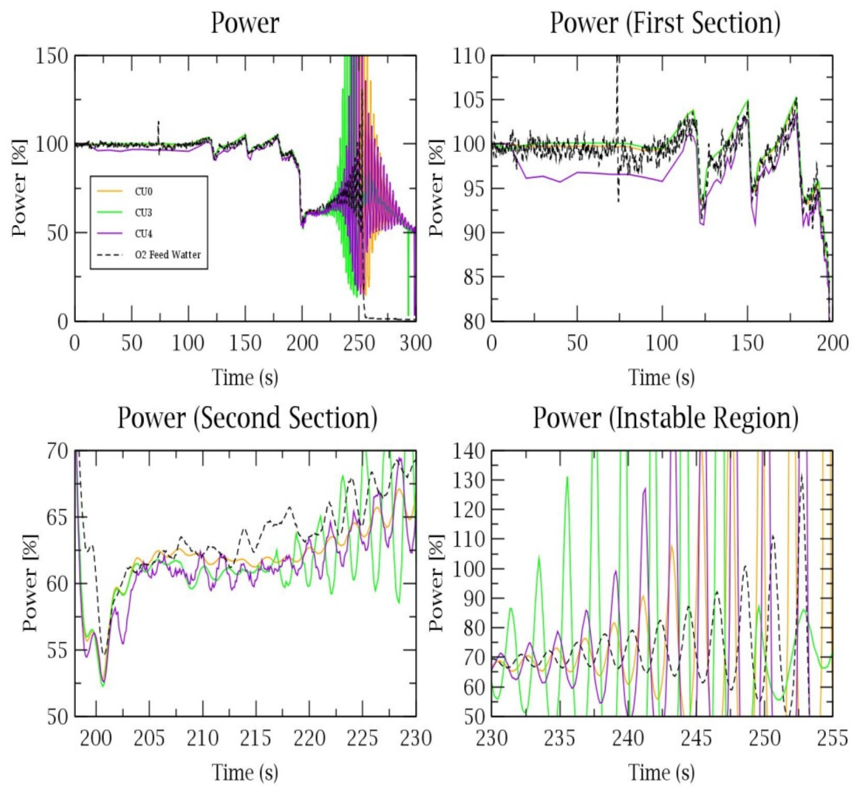
No significant impact on the DR and frequency

Optimization of the KIT model for the Oskarshamn plant

- Thermalhydraulic Parameters
  - Carry-Under

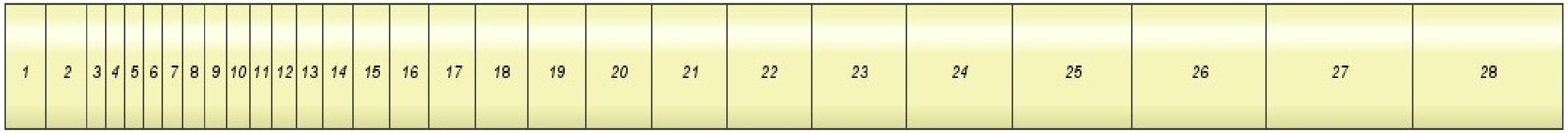
Case Number	Carry-Under Value
CU0 (Original model)	0.00
CU1	0.005
CU2	0.01
CU3	0.015
CU4	0.02



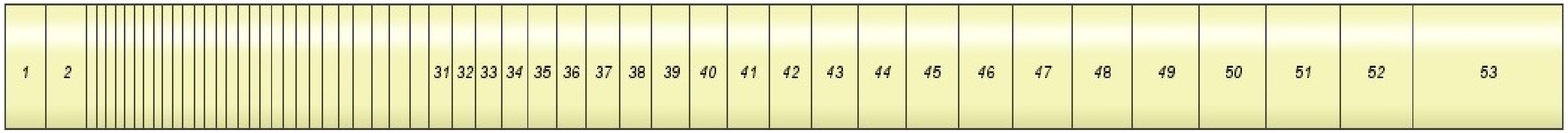


Optimization of the KIT model for the Oskarshamn plant

- Bundles nodalization
  - TRACE nodalization
    - Initial channel (28 axial nodes)



    - Final channel (53 axial nodes)

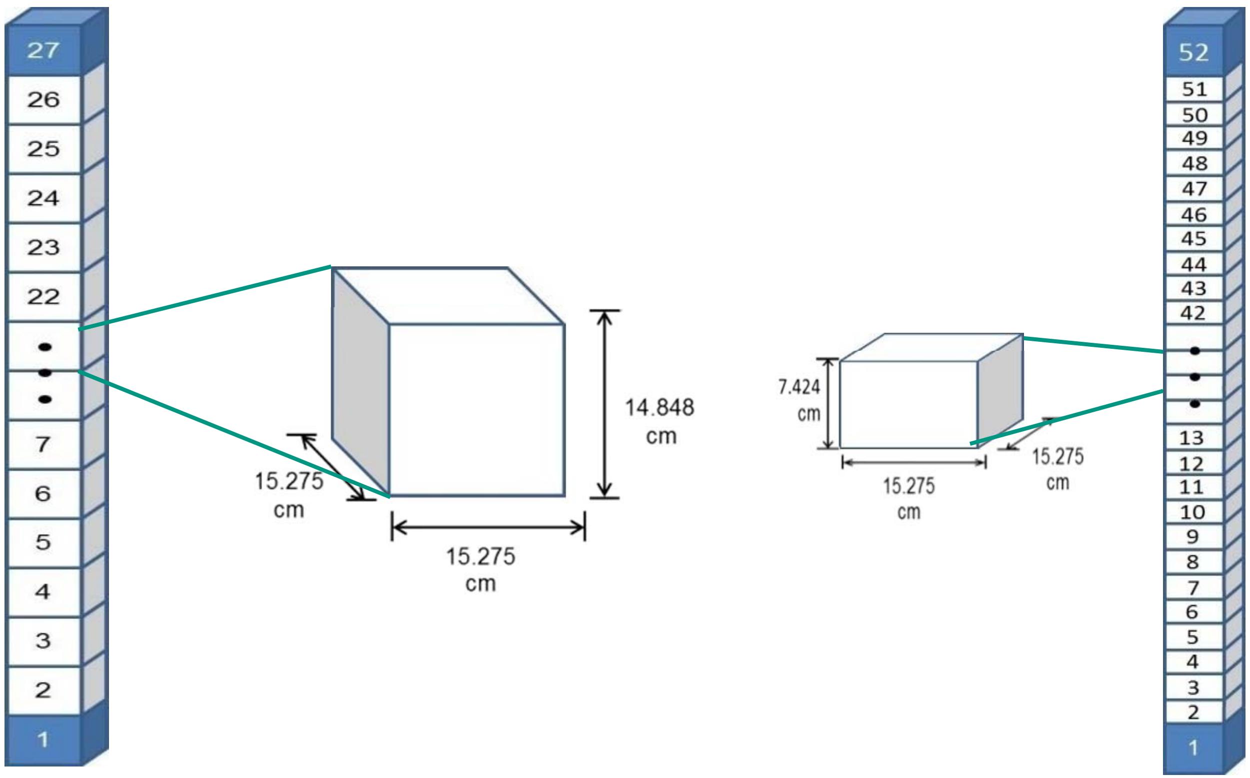


Optimization of the KIT model for the Oskarshamn plant

- Bundles nodalization
  - PARCS nodalization (2x axial discretization)

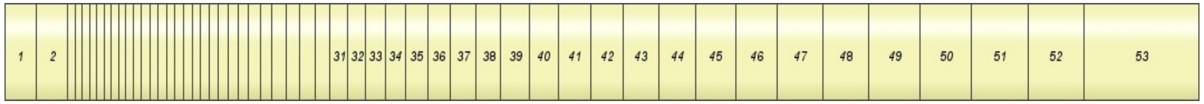
Initial Fuel assembly meshing

Final fuel assembly meshing

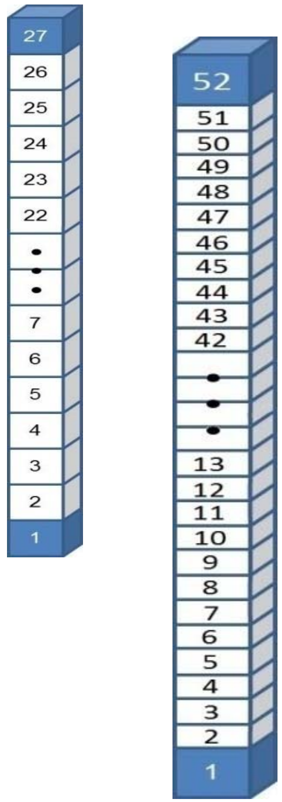


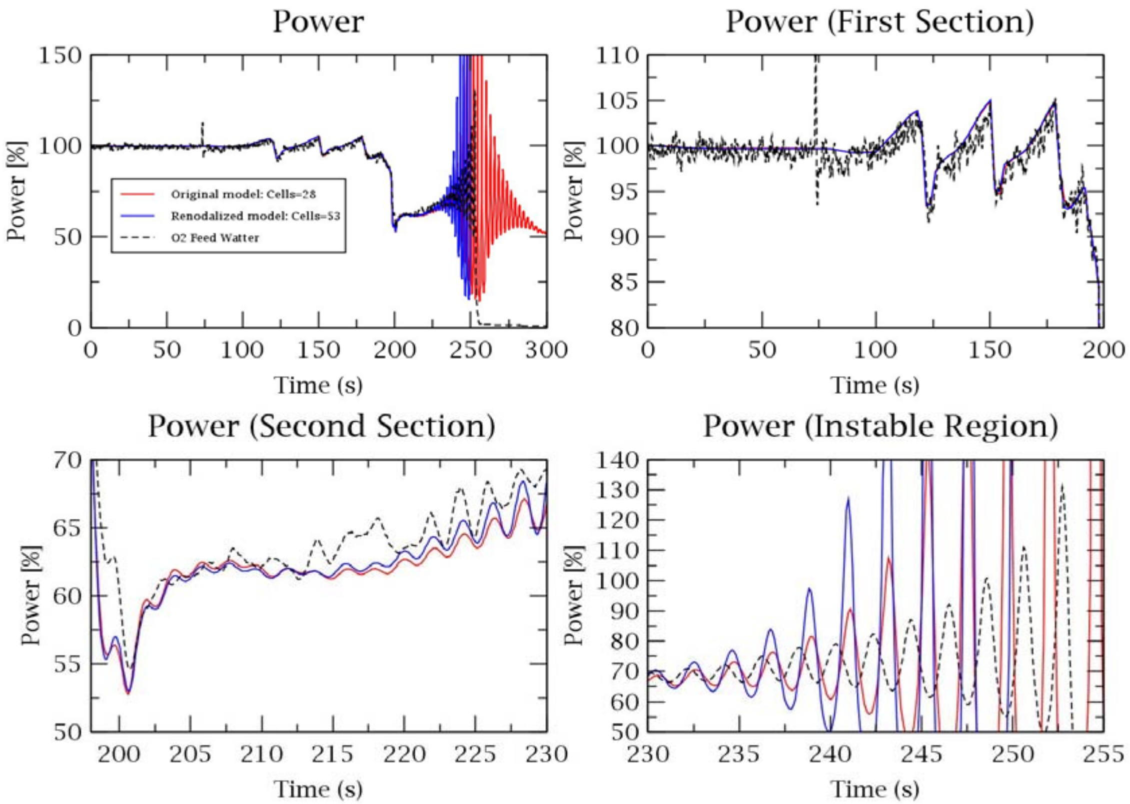
Optimization of the KIT model for the Oskarshamn plant

- Bundles nodalization
  - TRACE nodalization



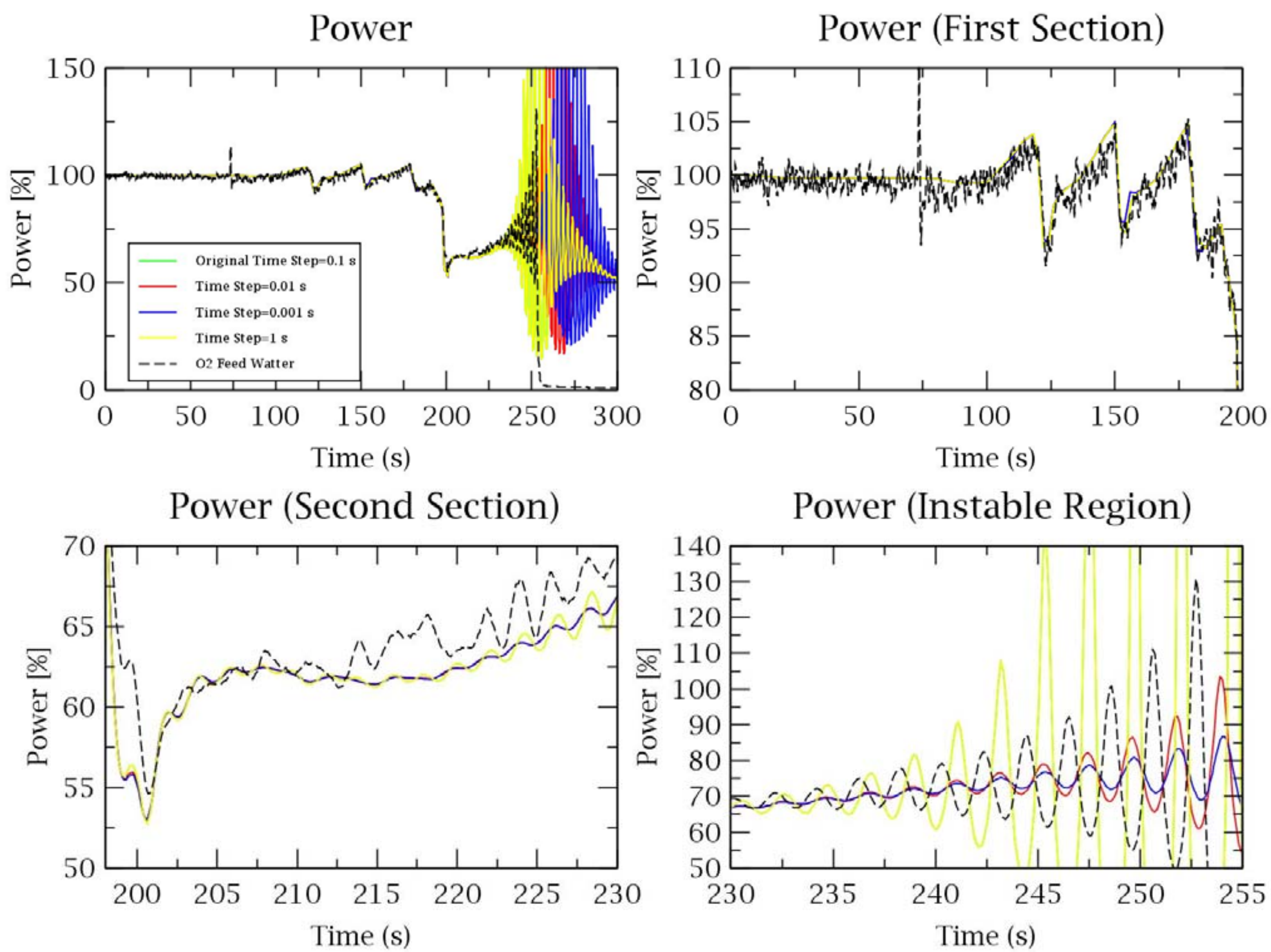
  - PARCS nodalization





Optimization of the KIT model for the Oskarshamn plant

- Time step size for the transient coupled calculation



Case Number	Time Step Values (s)
T0	0.1
T1	0.01
T2	0.001
T3	1

Case Number	Transient calculation duration
T0	4h:58m:53s
T1	10h:32m:35s
T2	4d:9h:3m:10s
T3	4h:31m:38s

Comparison of the prediction using the best set of combine parameters vs. experimental data

- Final parameters for the KIT model

	Initial KIT model	Simulation 1 Final KIT model	Simulation 2 Final KIT model	Simulation 3 Final KIT model	Simulation 4 Final KIT model
	Changes in the renodalization				
Bundles	28 cells	53 cells	53 cells	53 cells	53 cells
Time step	0.1	0.01/0.001	0.01/0.001	0.01/0.001	0.01/0.001
	Changes in the thermal hydraulic parameters				
GAP	6000	6000	6000	6500	6500
Roughness	4.0E-7	4.0E-7	2.0E-7	4.0E-7	2.0E-7
Carry-Over	0.00	0.00	0.00	0.00	0.00
Carry-Under	0.00	0.00	0.00	0.00	0.00

- A gap heat transfer of 6500 $W/(m^2K)$ is a realistic assumption
- Nevertheless the roughness value of 2.0E-7 m is not physical.

Comparison of the prediction using the best set of combine parameters vs. experimental data

- Steady State Alone

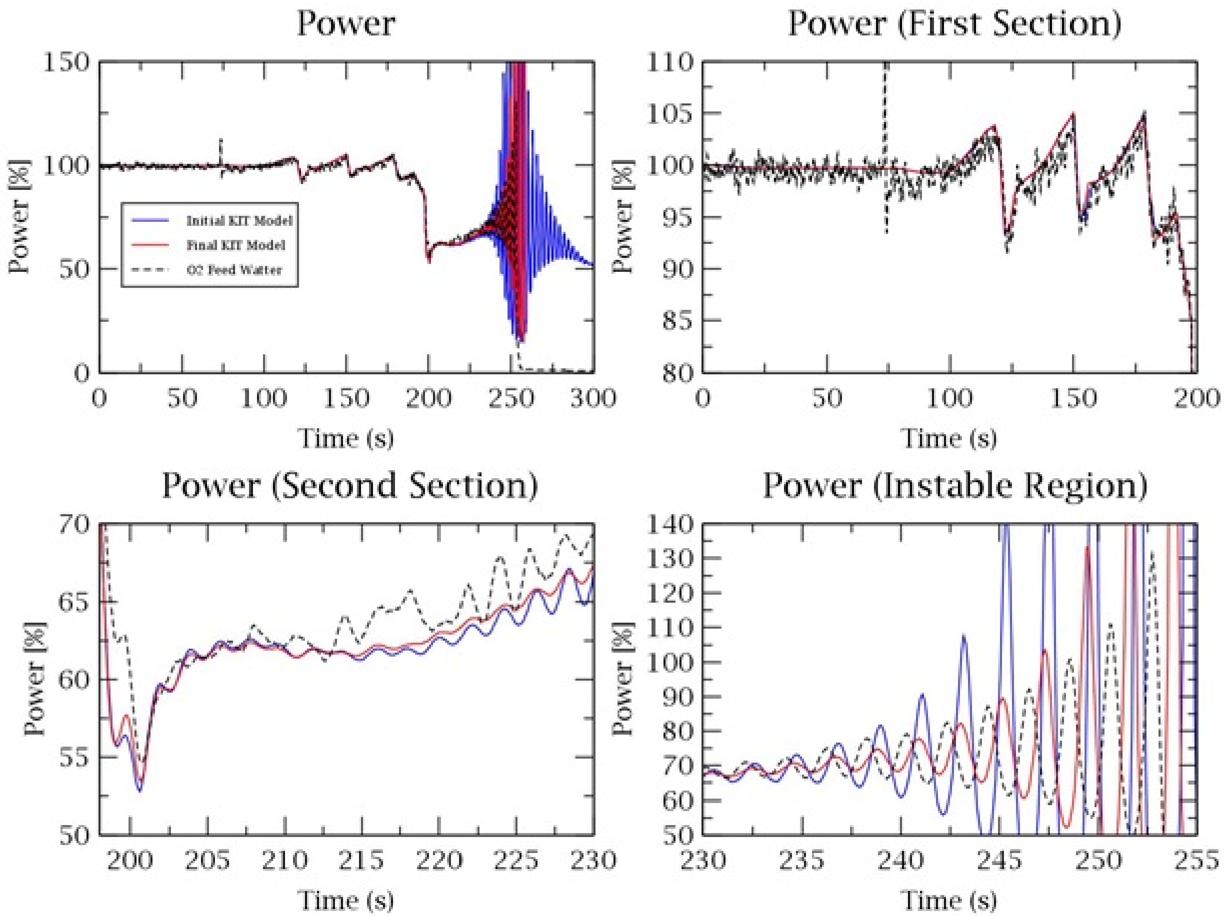
	Benchmark data	Final Model KIT	Upgrade %
Reactor Power (MW)	1802	1802	0
Enthalpy Balance (MW)	1799.7	1794.27	1.6025
Steam Dome Pressure (MPa)	7	7	0
Core Inlet Pressure (MPa)	7.1162	7.1657	-0.2094
Core Outlet Pressure (MPa)	7.0141	7.06010	-0.0359
Core Pressure Drop (kPa)	102	105.64	-2.4500
Channel Pressure Drop (kPa)	46.9	45.72	85.5712
Core Average Void	0.42	0.39	-37.6122
Feedwater Temperature (K)	456.620	456.623	0
Core Inlet Temperature (K)	543.57	543.885	-1.0589
Inlet Subcooling (K)	16.59	16.71	1.8271
Steam Temperature (K)	558.48	558.591	0.0538
Pump Speed (rad/s)	94.38	101.79	-0.2225
Total Core Flow Rate (kg/s)	5515.90	5515.87	0
Active Core Flow Rate (kg/s)	4800.4	4885.2	0.4366
Steam Flow Rate (kg/s)	903.1	900.0	-4.5973
Downcomer Water Level (m)	8.4	8.370	2.8733
K-eff	1.0092	1	0

$$\frac{\left|\frac{X_{O2-Benchmark} - X_{Original-Model}}{X_{O2-Benchmark}}\right| - \left|\frac{X_{O2-Benchmark} - X_{Final-Model}}{X_{O2-Benchmark}}\right|}{\left|\frac{X_{O2-Benchmark} - X_{Original-Model}}{X_{O2-Benchmark}}\right|} \times 100$$

- 5 equal prediction
- 6 better prediction
- 7 worse prediction

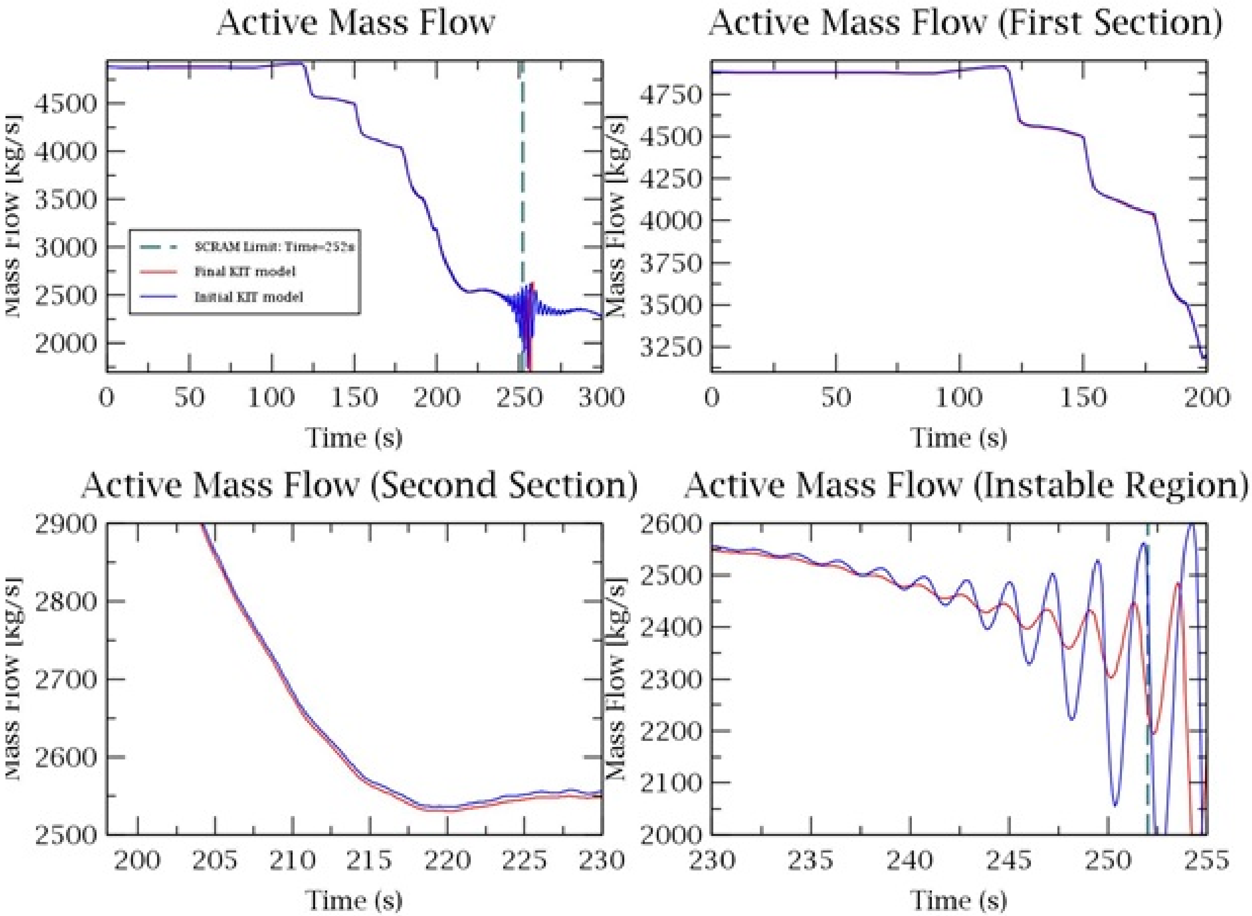
Comparison of the prediction using the best set of combine parameters vs. experimental data

- Coupled TRACE/PARCS Transient
  - Predicted core total power



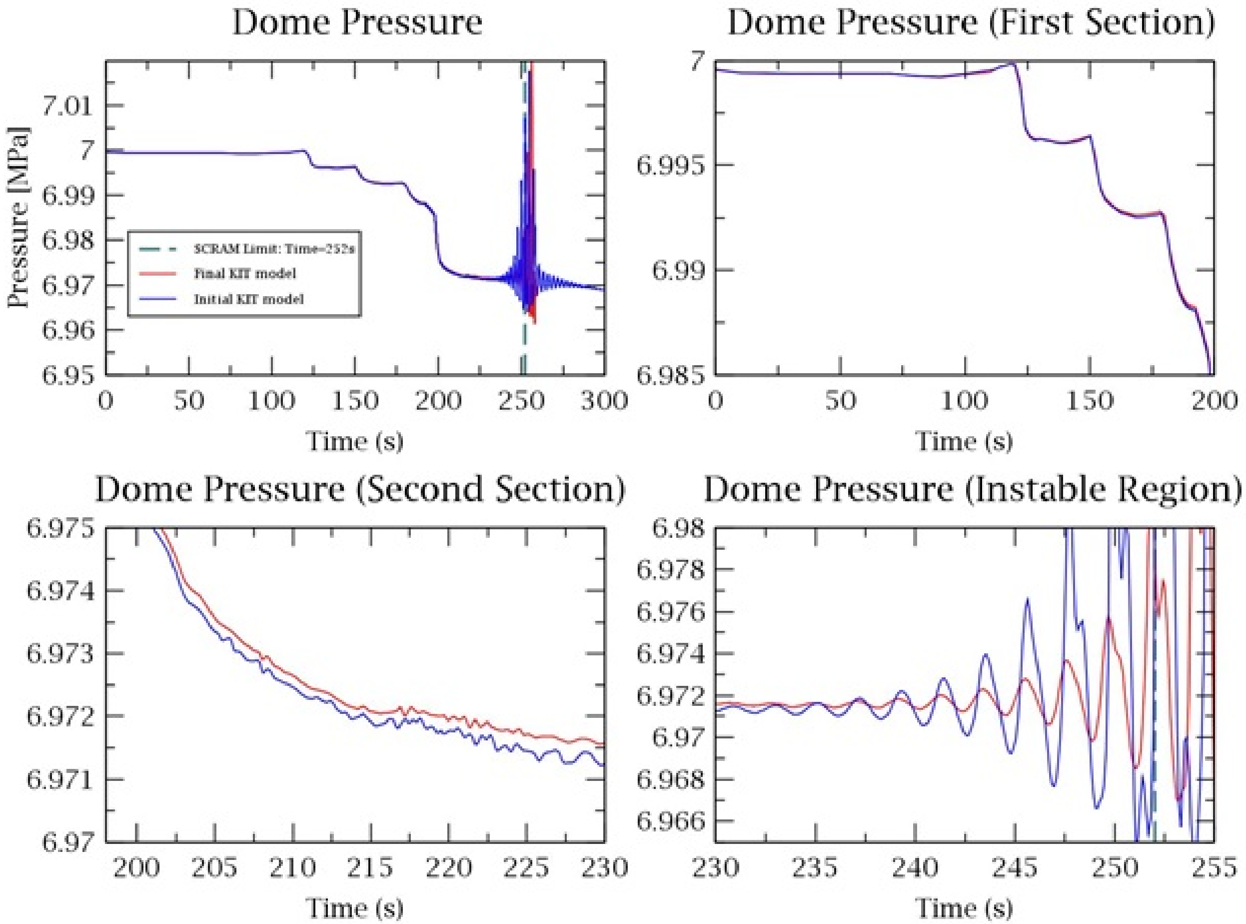
Comparison of the prediction using the best set of combine parameters vs. experimental data

- Coupled TRACE/PARCS Transient
  - Core Mass Flow Rate



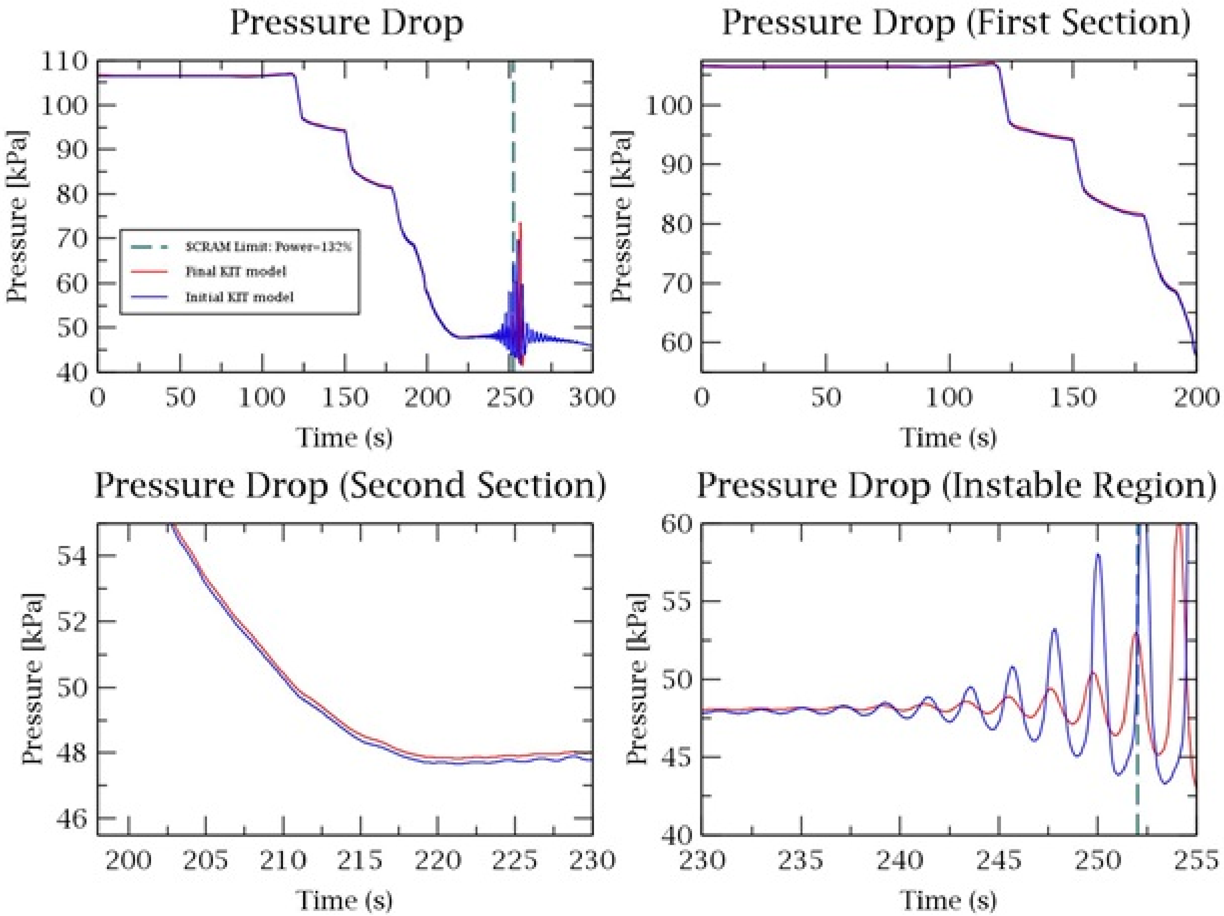
Comparison of the prediction using the best set of combine parameters vs. experimental data

- Coupled TRACE/PARCS Transient
  - Predicted dome pressure



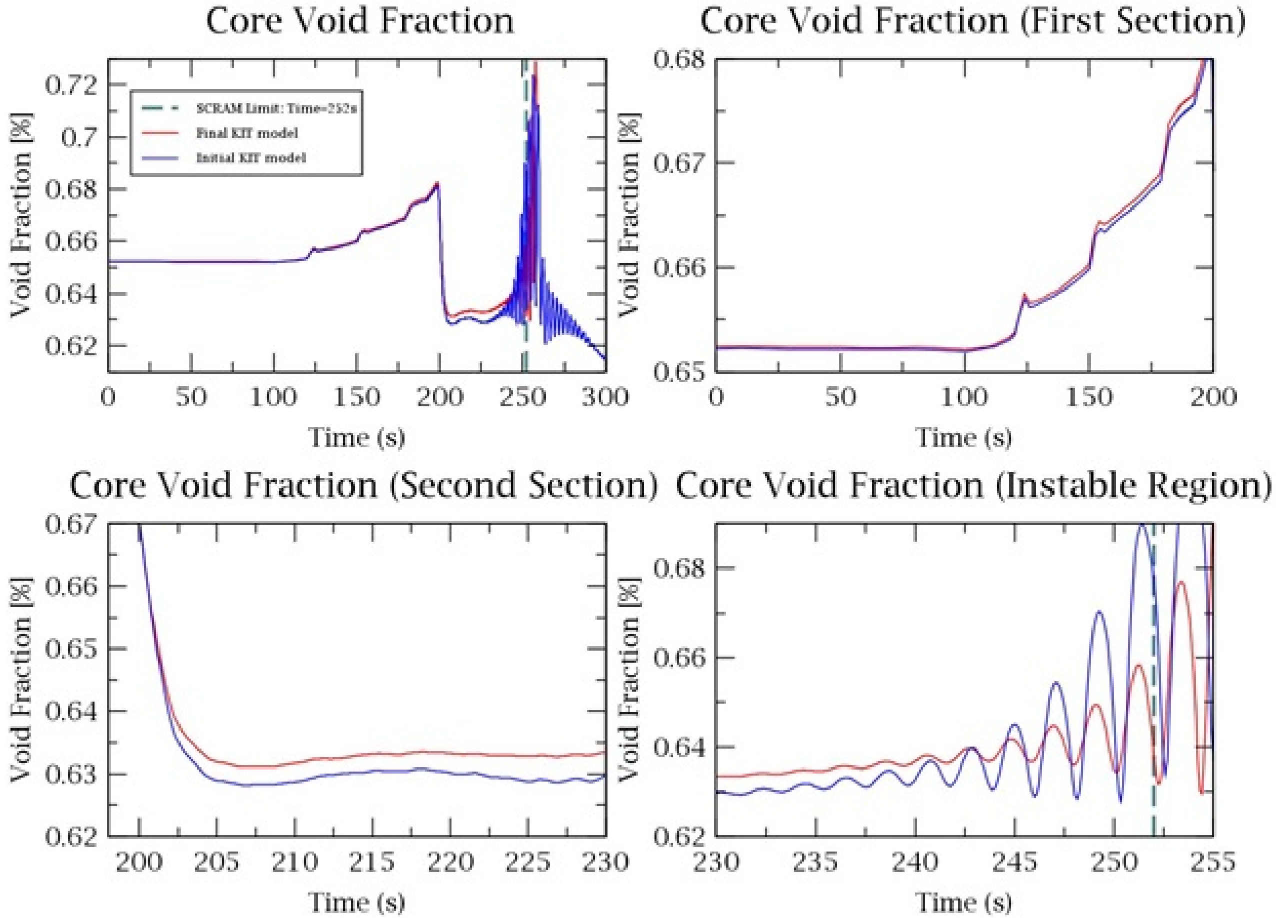
Comparison of the prediction using the best set of combine parameters vs. experimental data

- Coupled TRACE/PARCS Transient
  - Predicted core pressure drop



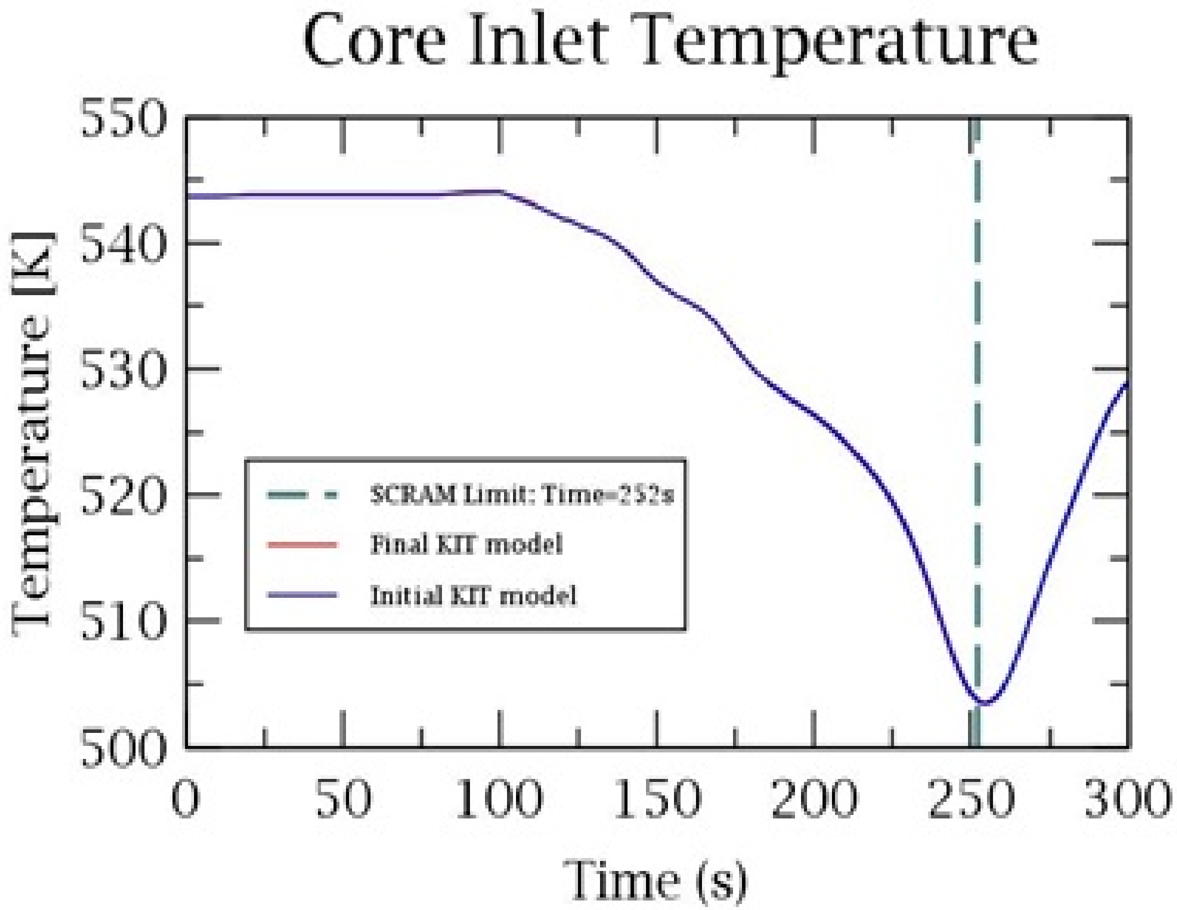
Comparison of the prediction using the best set of combine parameters vs. experimental data

- Coupled TRACE/PARCS Transient
  - Predicted core average void fraction



Comparison of the prediction using the best set of combine parameters vs. experimental data

- Coupled TRACE/PARCS Transient
  - Predicted core inlet temperature



Comparison of the prediction using the best set of combine parameters vs. experimental data

- Comparison of Decay Ratio and Frequency

	O2 Benchmark	Initial KIT model	Final KIT model	Upgrade %
Decay Ration	1.3619	1.7381	1.6803	15.3642
Natural Frequency	0.4819	0.4586	0.4706	51.5021

$$\frac{\left|\frac{X_{O2-Benchmark} - X_{Original-Model}}{X_{O2-Benchmark}}\right| - \left|\frac{X_{O2-Benchmark} - X_{Final-Model}}{X_{O2-Benchmark}}\right|}{\left|\frac{X_{O2-Benchmark} - X_{Original-Model}}{X_{O2-Benchmark}}\right|} \times 100$$

- Calculation time differences

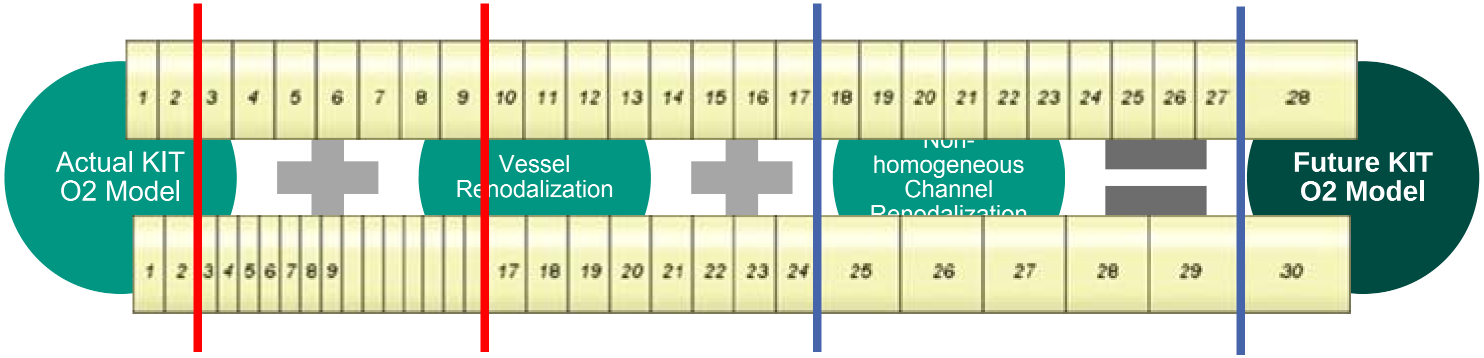
Case	Steady State Alone duration	Couple Steady State duration	Couple Transient duration	Total duration
Initial KIT model	3h:48m:40s	24m:9s	4h:58m:53s	9h:11m:42s
Final KIT model	7h:13m:55s	32m:41s	7d:10h	7d:17h:46m:36s

Summary and Conclusions

- TRACE V5P3 has several improvements compare to V5P2
- Thermal-hydraulic modifications have an important influence in the amplitude and delay of the instability prediction
- The increase of the axial cells in the channels increase strongly the wave amplitude and correct a little the delay
    - Little calculation time increase
- The finer time step decrease strongly the wave amplitude
    - Big calculation time increase
- The right combination of thermal-hydraulic parameters and renodalization can give a good approximation to the O2 real event

Outlook

- More efforts to be closer with the final model must be done
  - There are still some divergences
- Future efforts must be focused on
  - Implementation of the vessel renodalization in the final model
  - Renodalization of the channels according to a non-homogeneous configuration
- Repeat the simulations with the new release of TRACE (V5P4?/V5.1?)
- Submit the results using the official benchmark template



Thanks for your attention