Karlsruhe Institute of Technology

KIT Results For Open Phase Of IAEA Benchmark CRP - I31038

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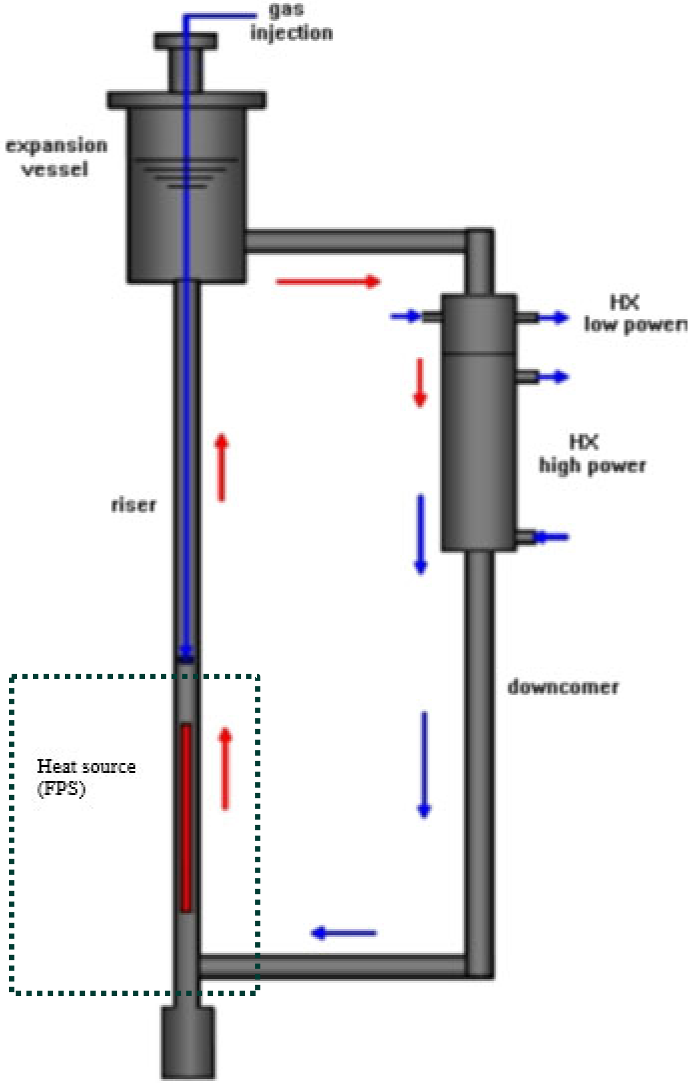
Contents

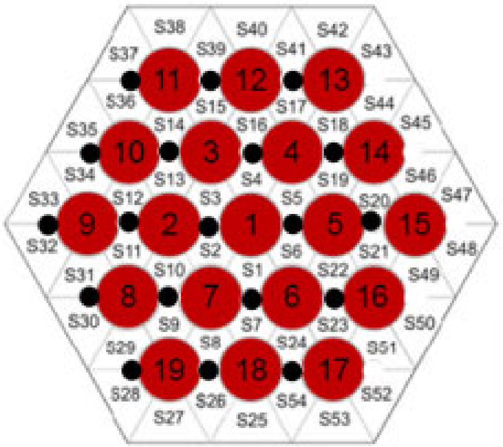
Schematic representation of the NACIE-UP primary loop



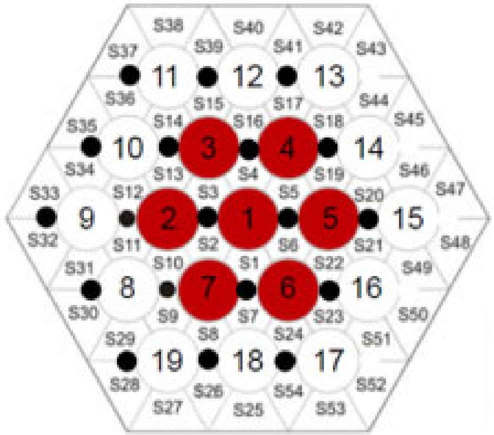
FPS design parameters

Parameter	Value
D_{pin}	6.55 mm
P	8.4 mm
P/D	1.2824 mm
d_{wire}	1.75 mm
P_{wire}	262 mm
L_{total}	2000 mm
L_{active}	600 mm
$D_{H,nom}$	3.84 mm

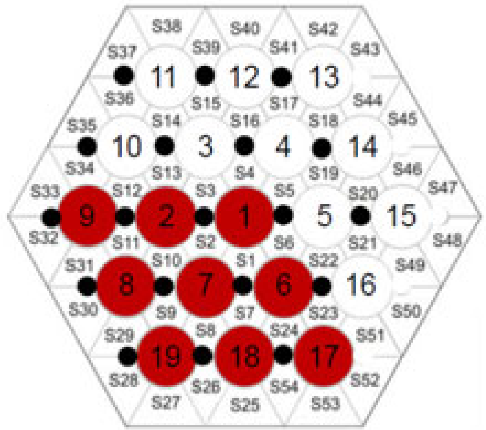
Benchmark of Transition from Forced to Natural Circulation Experiment with Heavy Liquid Metal Loop



ADP10
full heating, 30kW



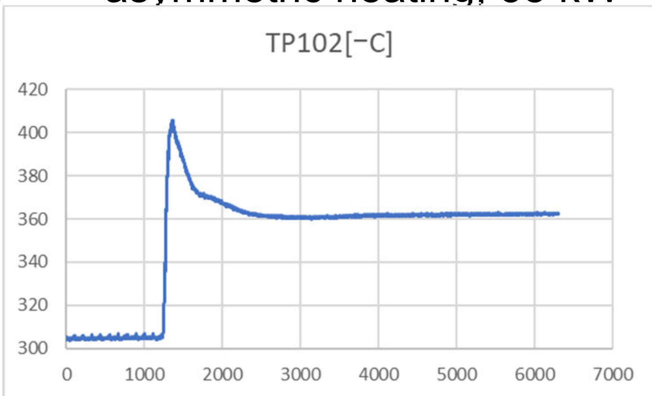
ADP06
central heating, 30kW



ADP07
asymmetric heating, 38 kW

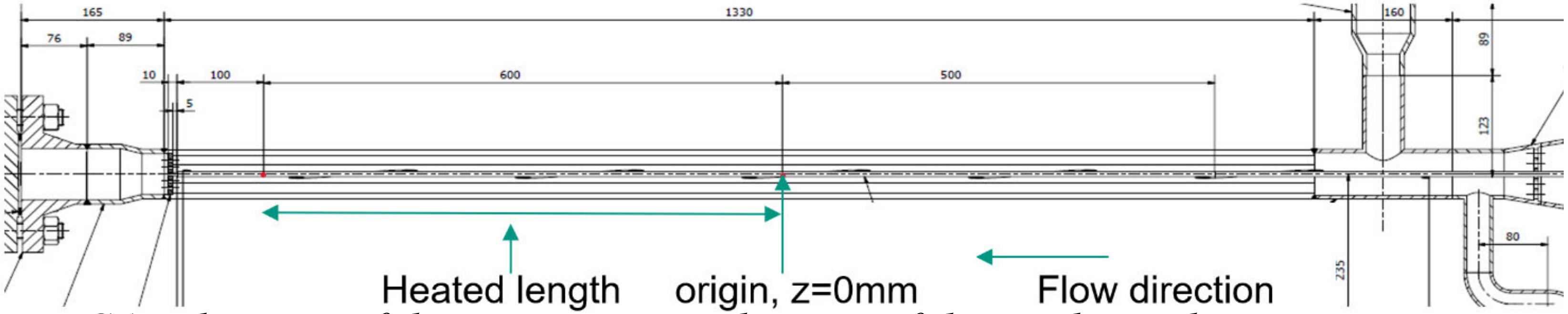
Test ADP10	Steady state 1			Steady state 2		
Parameter	Data	σ	σ[%]	Data	σ	σ[%]
$\dot{m}_{gas}$ (Nl/min)	10	0.5	5	0	0	0
$\dot{m}_{LBE}$ (kg/s)	2.56	0.28	11	1.31	0.14	11
$T_{IN,FPS}$ [°C]	231.3	1.5		219.5	1.5	
ΔT_{FPS} [°C]	72	0.7	0.9	140.6	0.3	0.2
Q_{nom} [w]	30000	50	0.2	30000	44	0.1
Q_{eff} [w]	27000	1053	3.9	27000	1010	3.7
Q_{pre} [w]	2236	403	18	2339	217	9.3
Q_{tfm} [w]	1915	3	0.2	1644	4	0.3

Integral parameters of the test ADP10

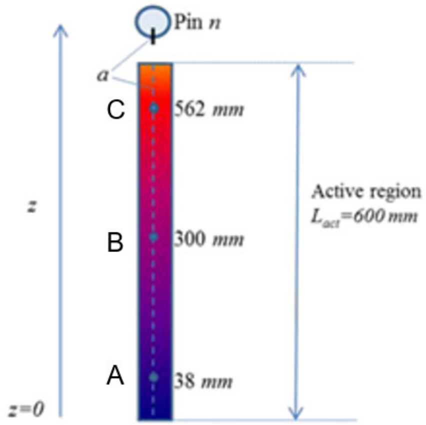


LBE temperature at the outlet of the test section TP102

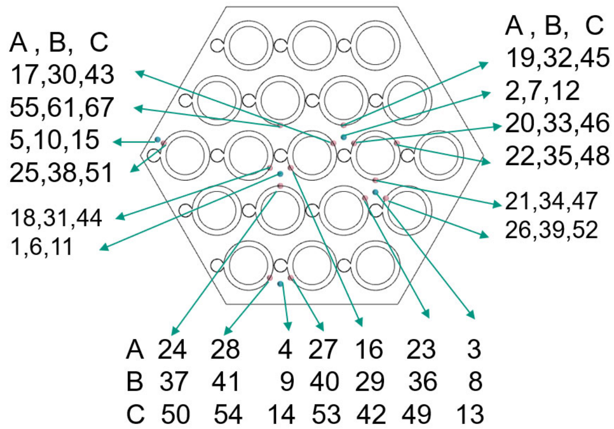
Benchmark data / TC locations in the test section



CAD drawing of the test section and origin of the used coordinate system



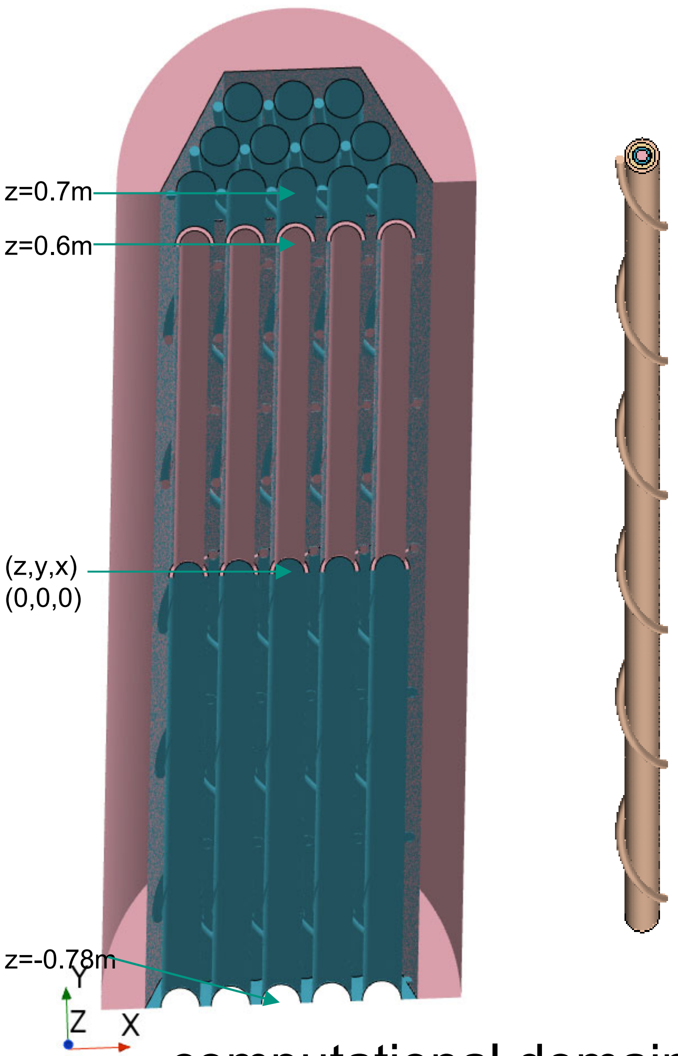
Location of planes for TC measurements in the test section (A at 38mm, B at 300mm and C at 562mm)



location and names of thermocouples in measurements sections.

The accuracy of the thermocouples according to the rule IEC 60584-3 (2007) are: ±1.5 ℃ from -40℃ to +375 ℃; ±0.004 T from 375 ℃ to 1000 ℃.

Numerical Model



computational domain

Model:

- SST turbulence model
- All y+ wall treatment
- Second order convection schema
- Model default parameters
- Adiabatic condition applied, neglecting heat losses to environment
- Conjugate heat transfer to rods and wrapper

Simulation:

- First run: simplified short heater, heat flux imposed at inner side of cladding
- Second run: full details of heater layers simulated

Thermo-physical properties

LBE physical properties, OECD/NEA Handbook 2015

LBE properties as a function of temperature (T in Kelvin, SI Units)

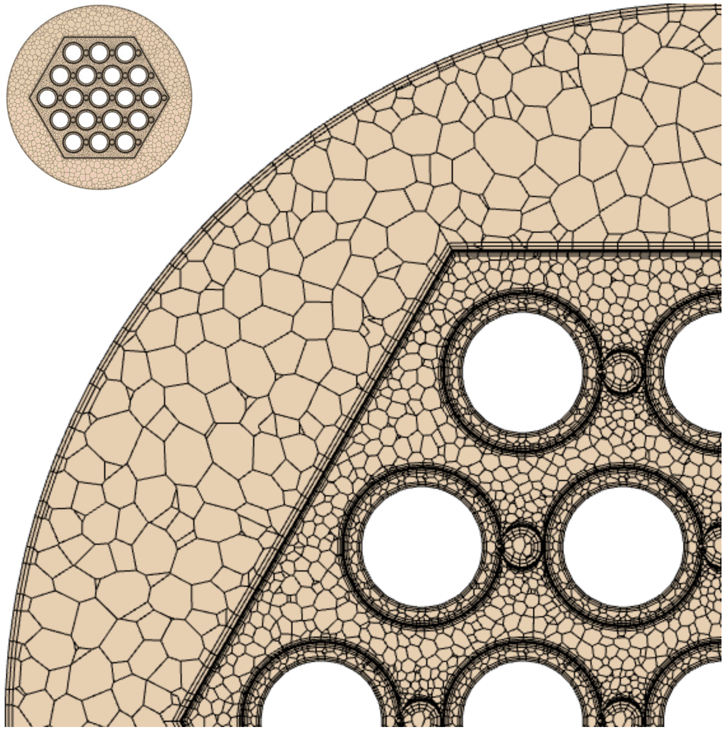
Property	Symbol	Correlation	Maximum Uncertainty	Standard deviation
Density	$\rho(T)$	$11065 - 1.293 \cdot T$	$\leq 0.8\%$	0.58%
Heat capacity	$c_p(T)$	$164.8 - 3.94 \cdot 10^{-2} \cdot T + 1.25 \cdot 10^{-5} \cdot T^2 - 4.56 \cdot 10^{5} \cdot T^{-2}$	$\leq 5.0\%$	2.4%
Dynamic viscosity	$\mu(T)$	$4.94 \cdot 10^{-4} \exp\left(\frac{754.1}{T}\right)$	$\leq 6.0\% - 8.0\%$	7.2%
Thermal conductivity	$k(T)$	$3.284 + 1.617 \cdot 10^{-2} \cdot T - 2.305 \cdot 10^{-6} \cdot T^2$	$\leq 10.0\% - 15.0\%$	6.2%

For other materials, benchmark specifications are used

Mesh and turbulent Model

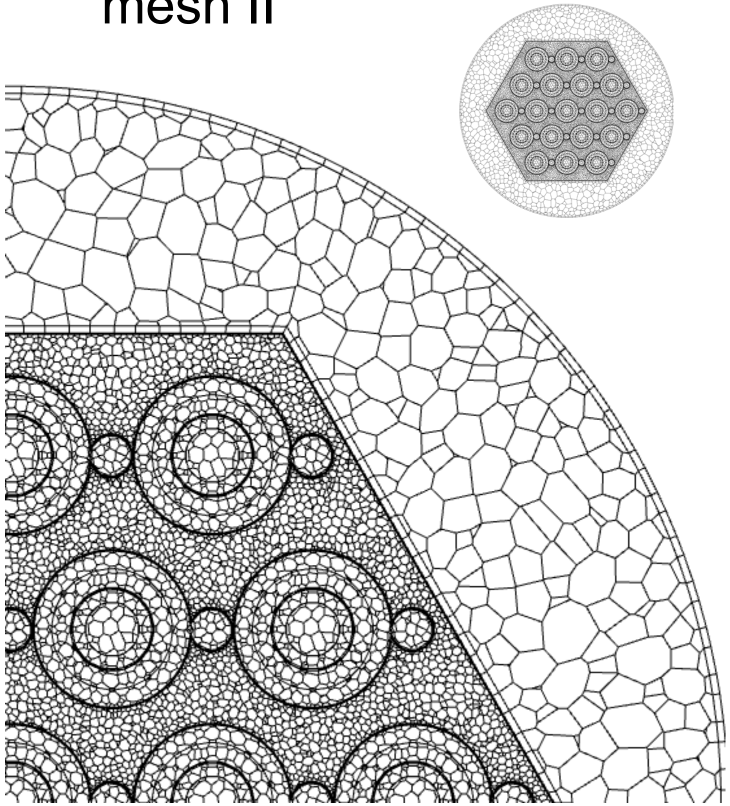
- SST All y+ wall treatment, Star CCM+
- Y+ small resolving buoyancy near heated walls

mesh I



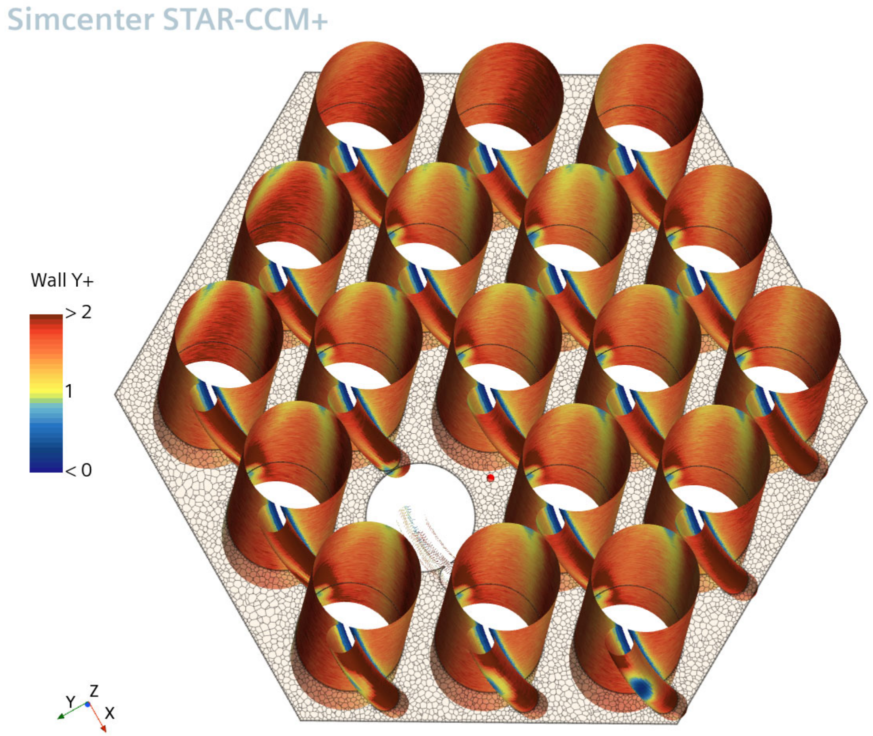
Fluid 49 M cell
Whole 62 M cell

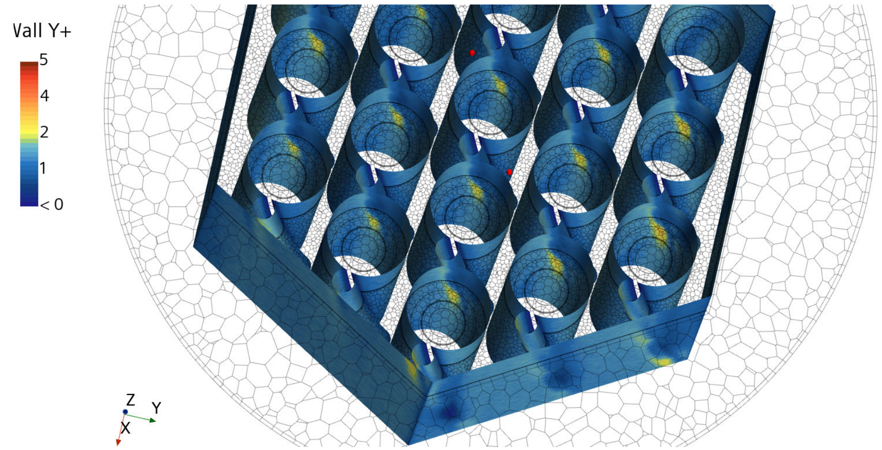
mesh II



Fluid 96 M cell
Whole 125 M cell

Y+ values, mesh II, ADP 10 case A (Forced Circulation)

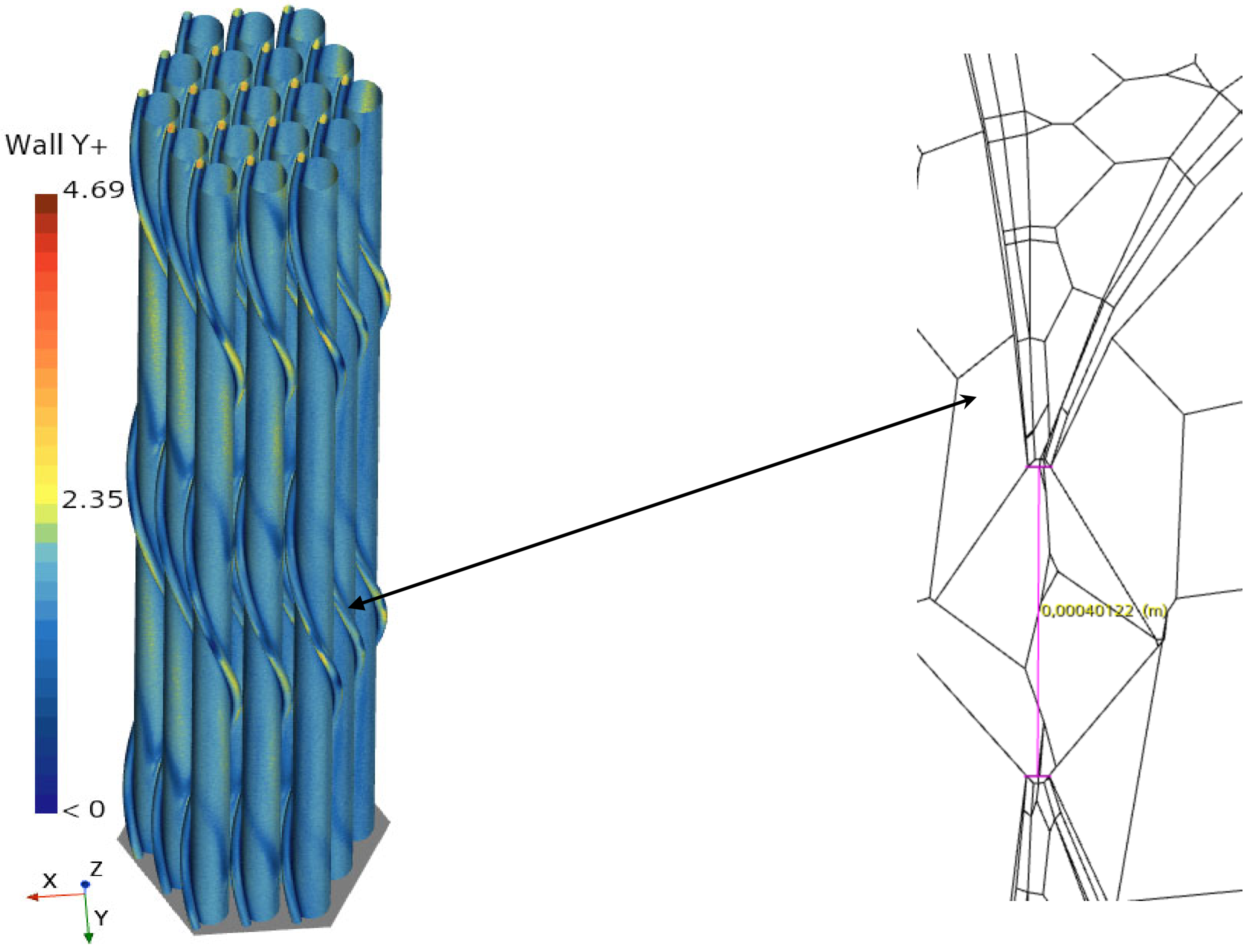




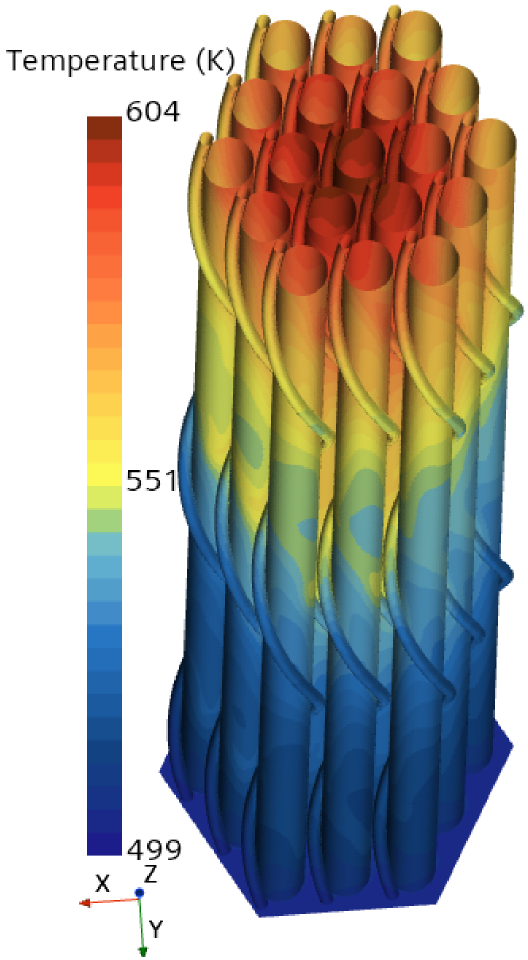
Y+ range 0 to 2 & range 0 to 5

Cross-section showing mesh in fluid domain & wrapper near section A

Mesh resolving contact of wire and pin



Results, case ADP10 steady state1, mesh II.

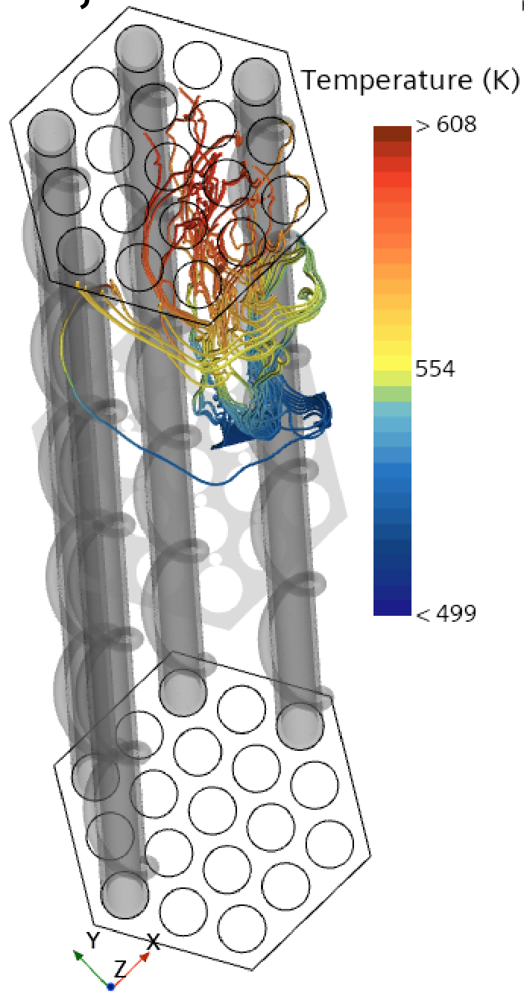


heated section
0 to 0.6 m

z=0.0 m

unheated section
-0.78 to 0 m

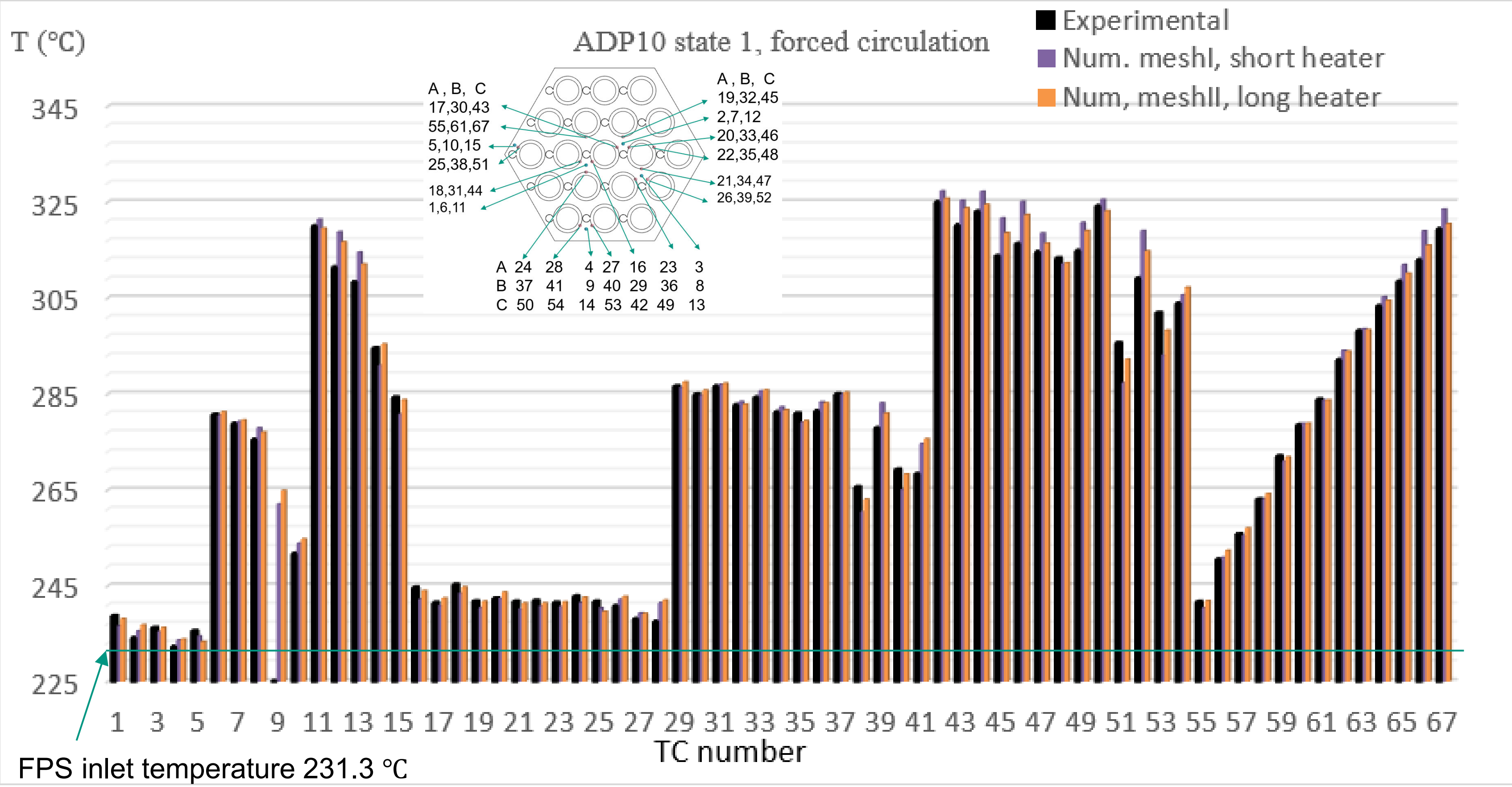
Temperature contours at heater fluid interface in heated region, z=0.0 to 0.6 m



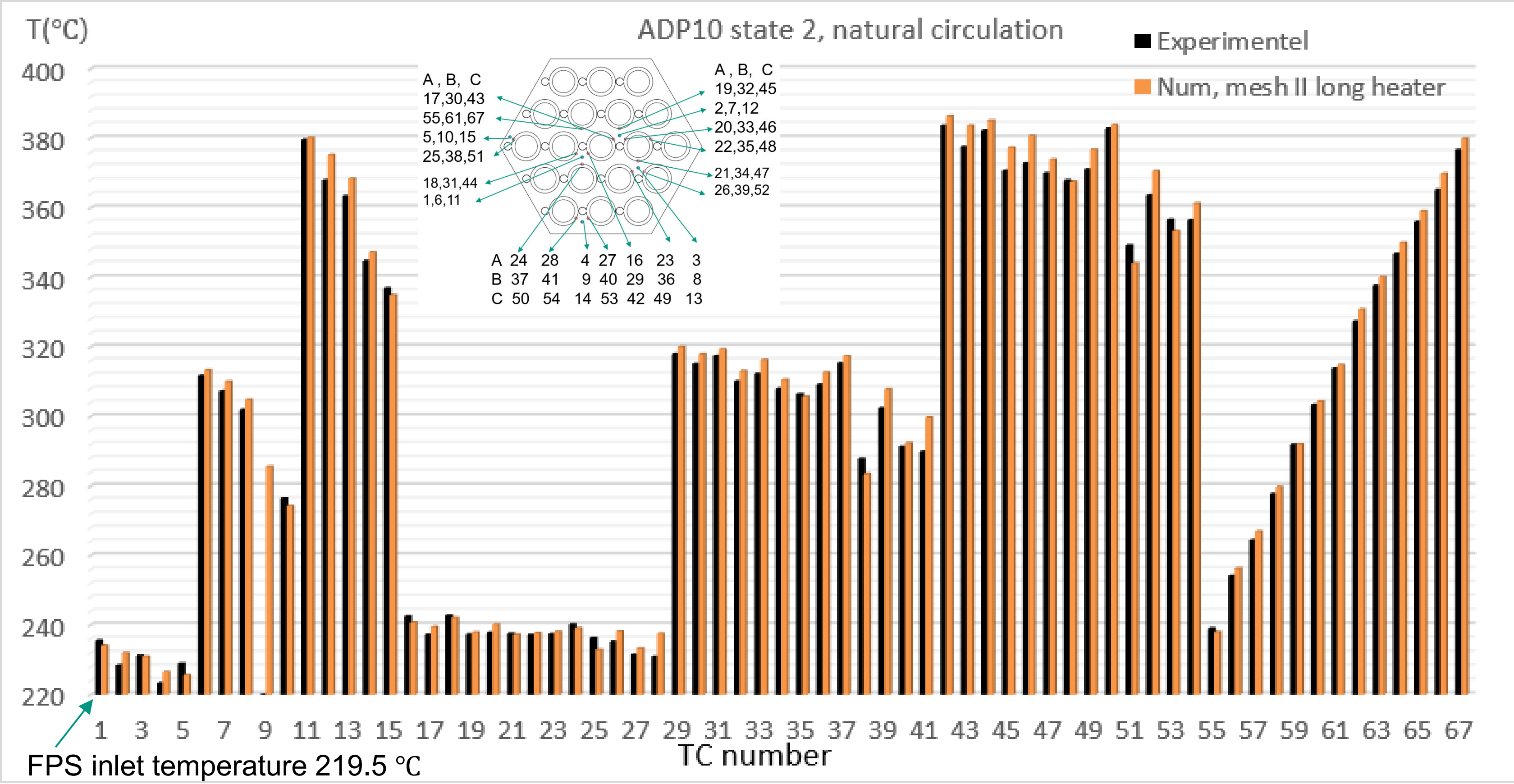
Streamlines from a line in x-y plane just downstream of start of heated zone, z=0.038 m

Forced *circulation results mesh I with short heater, mesh II with long heater (Forced convection)*

Comparison to experiment, averaging 100 measurements in steady period

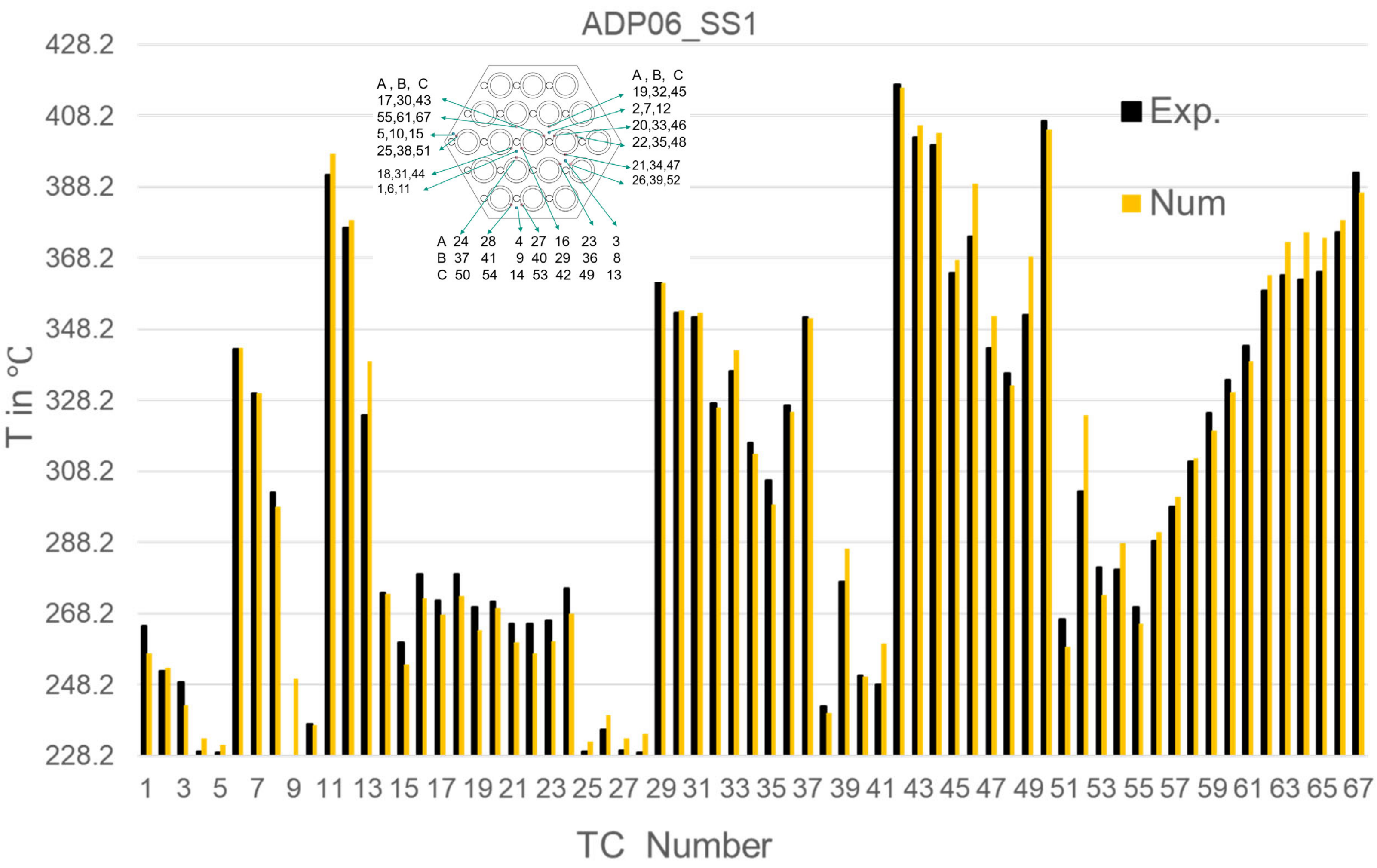


Natural convection results, mesh II with long heater

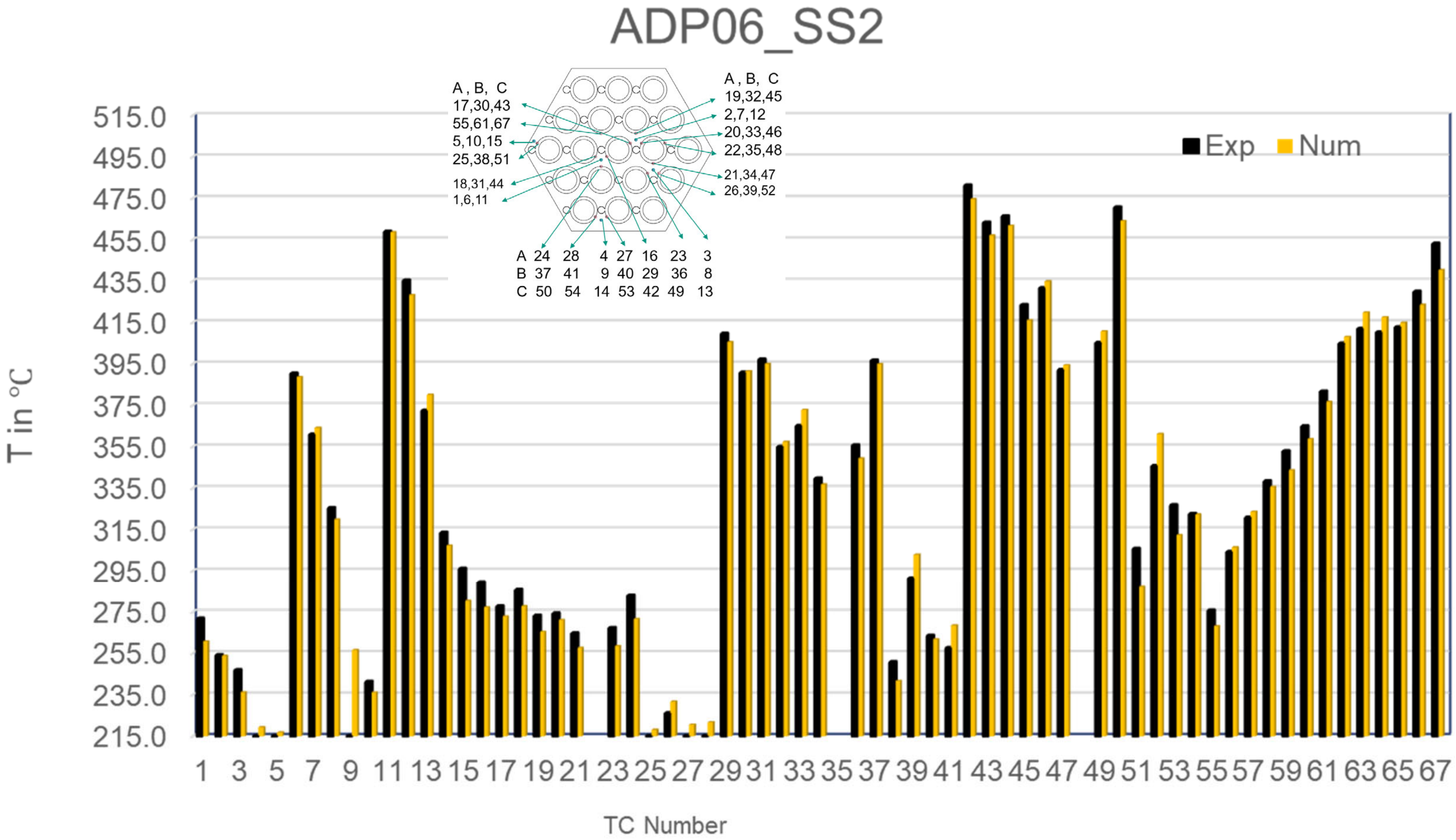


- Error within uncertainty of measurements / material properties / dimensions
- Small absolute error, no systematic trends

Forced *circulation results, mesh II with long heater*



Natural convection results, mesh II with long heater



- Error within uncertainty of measurements / material properties / dimensions
- Small absolute error, no systematic trends

Conclusions

- Test of various modelling for heater show small influence on results
- Small sensitivity of results to mesh refinement
- Selected SST model & finer mesh & details in heater model are used for blind phase case with asymmetric heating
- Results for the blind phase are submitted.
- In regions with high temperatures, errors can be related to uncertainties in heating power, benchmark specification & modelling (physical parameters, turbulence models)
- Near inlet and boundary regions (low temperatures) yields larger uncertainty due to boundary conditions and TC measurement uncertainty.

- Published results: SCOPE (**S**audi International **C**onference **O**n Nuclear **P**ower **E**ngineering) 13–15 Nov 2023 King Fahd Conference Center, KFUPM, Dhahran, KSA

ACKNOWLEDGMENTS

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