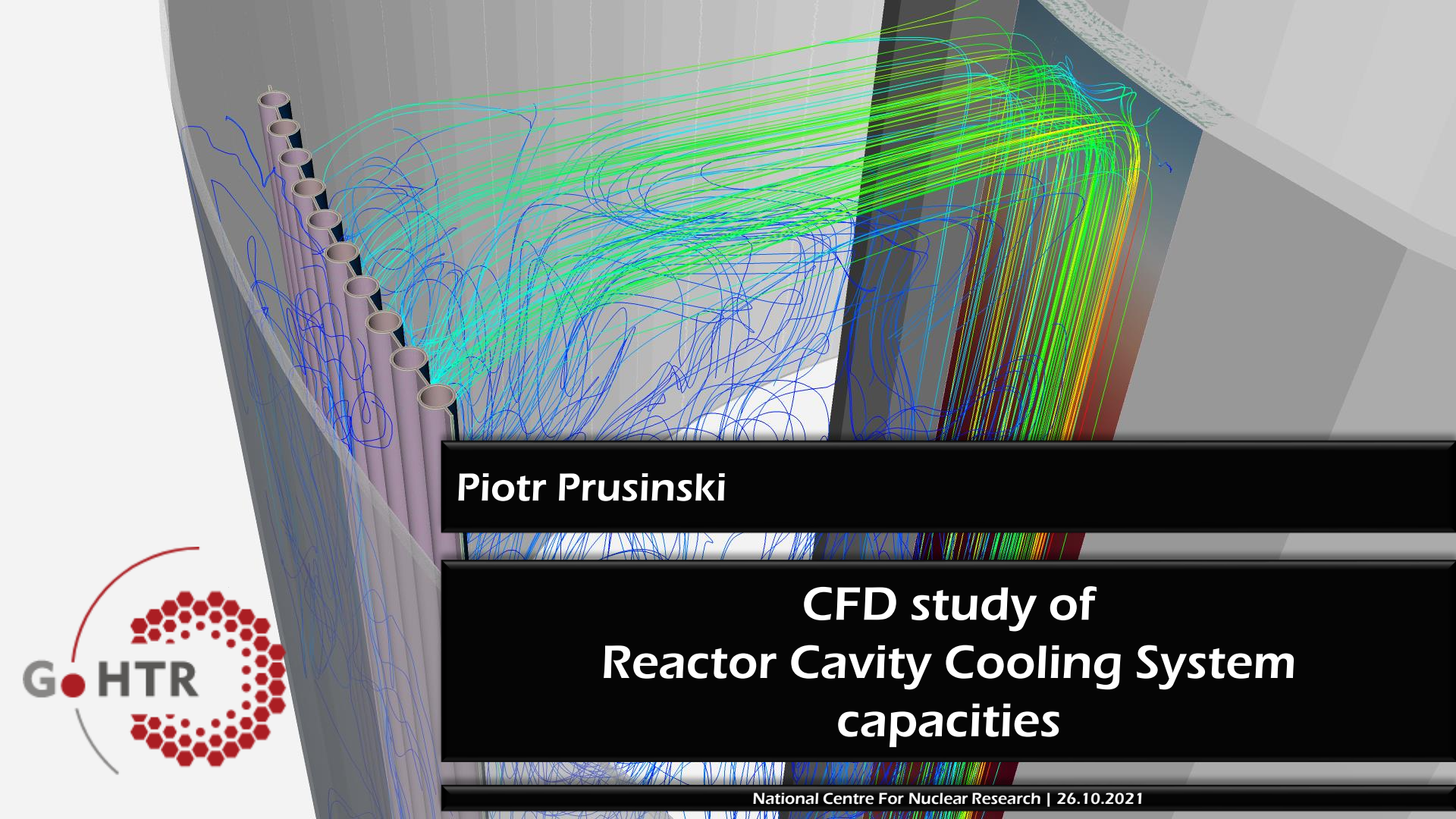


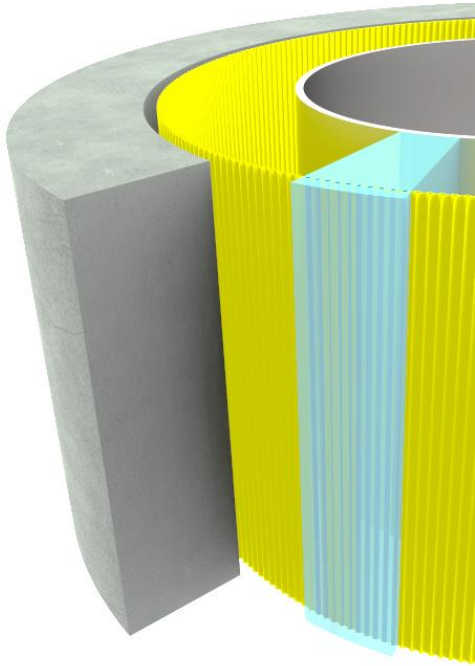
Piotr Prusinski

CFD study of Reactor Cavity Cooling System capacities

INTRODUCTION

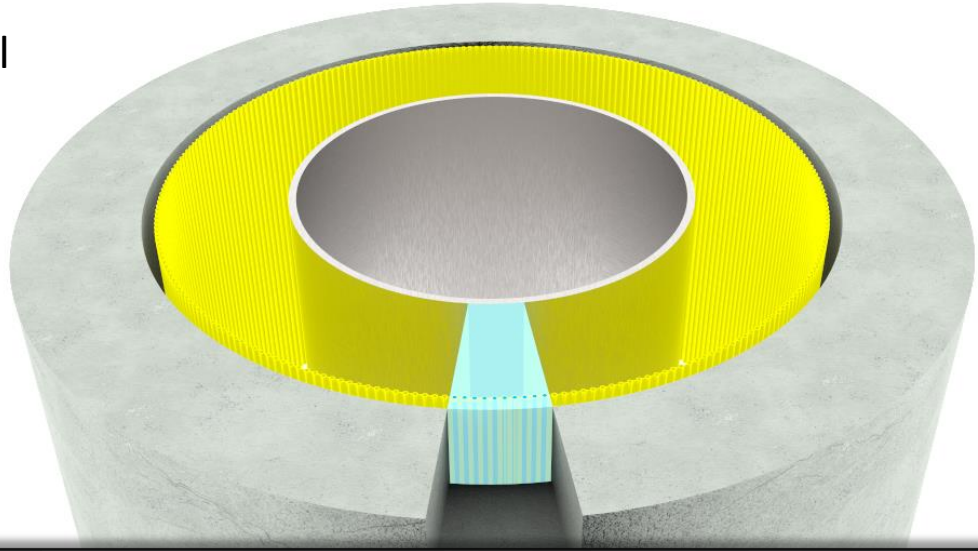
Scope of the task

- Literature study
- Define scenarios and its assumptions
- Define minimal required set of data
- Create CAD geometry
- Discretize geometry for CFD analysis
- Apply given scenario conditions, material properties etc. to the model
- Run simulation (@HPC) to the satisfactory convergence
- Extract/Visualize & Check results based on reasoning on physics
- Verify model sensitivity to preliminary assumptions
- Find Best Fit

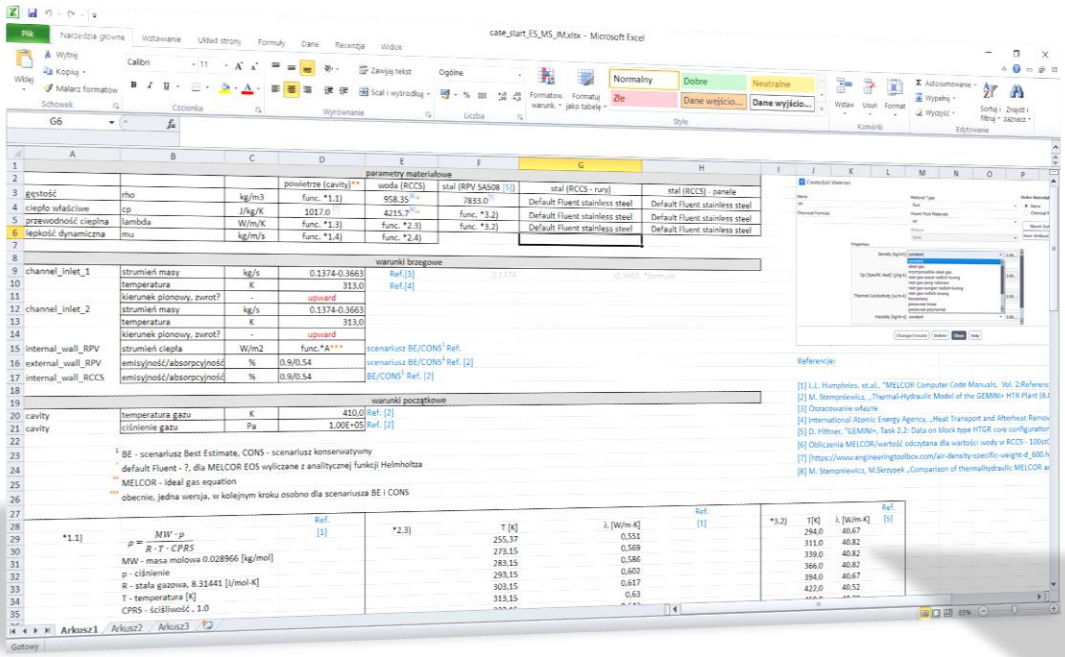


RCCS - brief overview

- 260 equidistant water pipes and flat panels in-between lined-up in circular pattern
- Every 2nd pipe (alternately) belongs to 1 out of 2 RCCS subsystems allowing for safety feature redundancy
- Over 8 m in diameter
- RCCS mantle separated from RPV wall at a distance of 1.5+ m with air cavity



Minimal required set of data



				parametry materiałowe			
			powietrze (cavity)**	woda (RCCS)	stal (RPV SA508 [5])	stal (RCCS - rury)	stal (RCCS) - panele
gęstość	rho	kg/m3	func. *1.1)	958.35	7833.0	Default Fluent stainless steel	Default Fluent stainless steel
ciepło właściwe	cp	J/kg/K	1017.0	4215.7	func. *3.2)	Default Fluent stainless steel	Default Fluent stainless steel
przewodność cieplna	lambda	W/m/K	func. *1.3)	func. *2.3)	func. *3.2)	Default Fluent stainless steel	Default Fluent stainless steel
lepkość dynamiczna	mu	kg/m/s	func. *1.4)	func. *2.4)			
				warunki brzegowe			
channel_inlet_1	strumień masy	kg/s	0.1374-0.3663	Ref.[3]			
	temperatura	K	313,0	Ref.[4]			
	kierunek plonowy, zwrot?	-	upward				
channel_inlet_2	strumień masy	kg/s	0.1374-0.3663				
	temperatura	K	313,0				
	kierunek plonowy, zwrot?	-	upward				
internal_wall_RPV	strumień ciepła	W/m2	func.*A***	scenariusz BE/CONS[1] Ref.			
external_wall_RPV	emisyjność/absorpcyjność	%	0.9/0.54	scenariusz BE/CONS[1] Ref. [2]			
internal_wall_RCCS	emisyjność/absorpcyjność	%	0.9/0.54	BE/CONS[1] Ref. [2]			
				warunki początkowe			
cavity	temperatura gazu	K	410,0	Ref. [2]			
cavity	ciśnienie gazu	Pa	1,00E+05	Ref. [2]			

[1] BE - scenariusz Best Estimate, CONS - scenariusz konserwatywny

* default Fluent - ?, dla MELCOR EOS wyliczane z analitycznej funkcji Helmholtza

** MELCOR - Ideal gas equation

*** obecnie, jedna wersja, w kolejnym kroku osobno dla scenariusza BE i CONS

Referencje:

[1] L.L. Humphries, et.al., "MELCOR Computer Code Manuals, Vol. 2:Reference

[2] M. Stempniewicz, „Thermal-Hydraulic Model of the GEMIN+ HTR Plant (8.

[3] Oszacowanie własne

[4] International Atomic Energy Agency, „Heat Transport and Afterheat Remov

[5] D. Hittner, "GEMIN+, Task 2.2: Data on block type HTGR core configuration

[6] Obliczenia MELCOR,wartość odczytana dla wartości wody w RCCS - 100st

[7] [https://www.engineeringtoolbox.com/air-density-specific-weight-d_600.h

[8] M. Stempniewicz, M.Skrzypek „Comparison of thermalhydraulic MELCOR a

*1.1) $\rho = \frac{MW \cdot p}{R \cdot T \cdot CPRS}$ Ref. [1]

MW - masa molowa 0.028966 [kg/mol]

p - ciśnienie

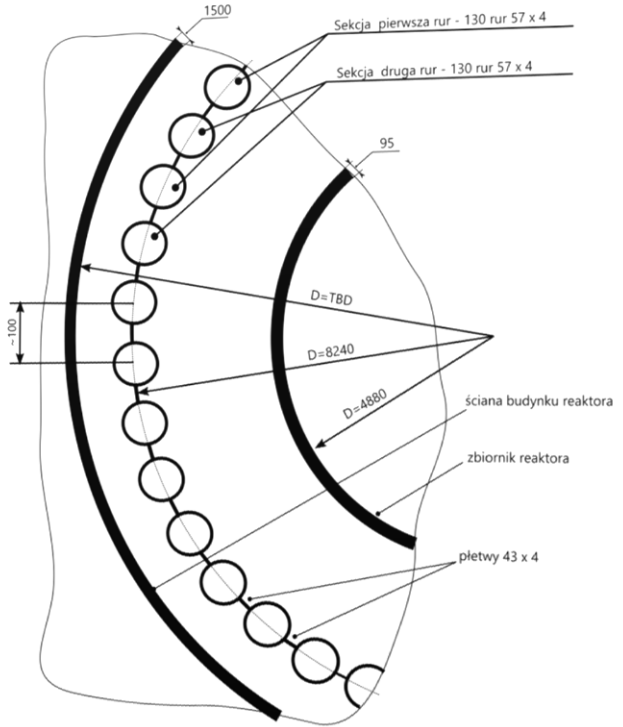
R - stała gazowa, 8.31441 [J/mol-K]

T - temperatura [K]

CPRS - ściśliwość , 1.0

*2.3) T [K]	λ [W/m-K]	Ref. [1]
255,37	0,551	
273,15	0,569	
283,15	0,586	
293,15	0,602	
303,15	0,617	
313,15	0,63	

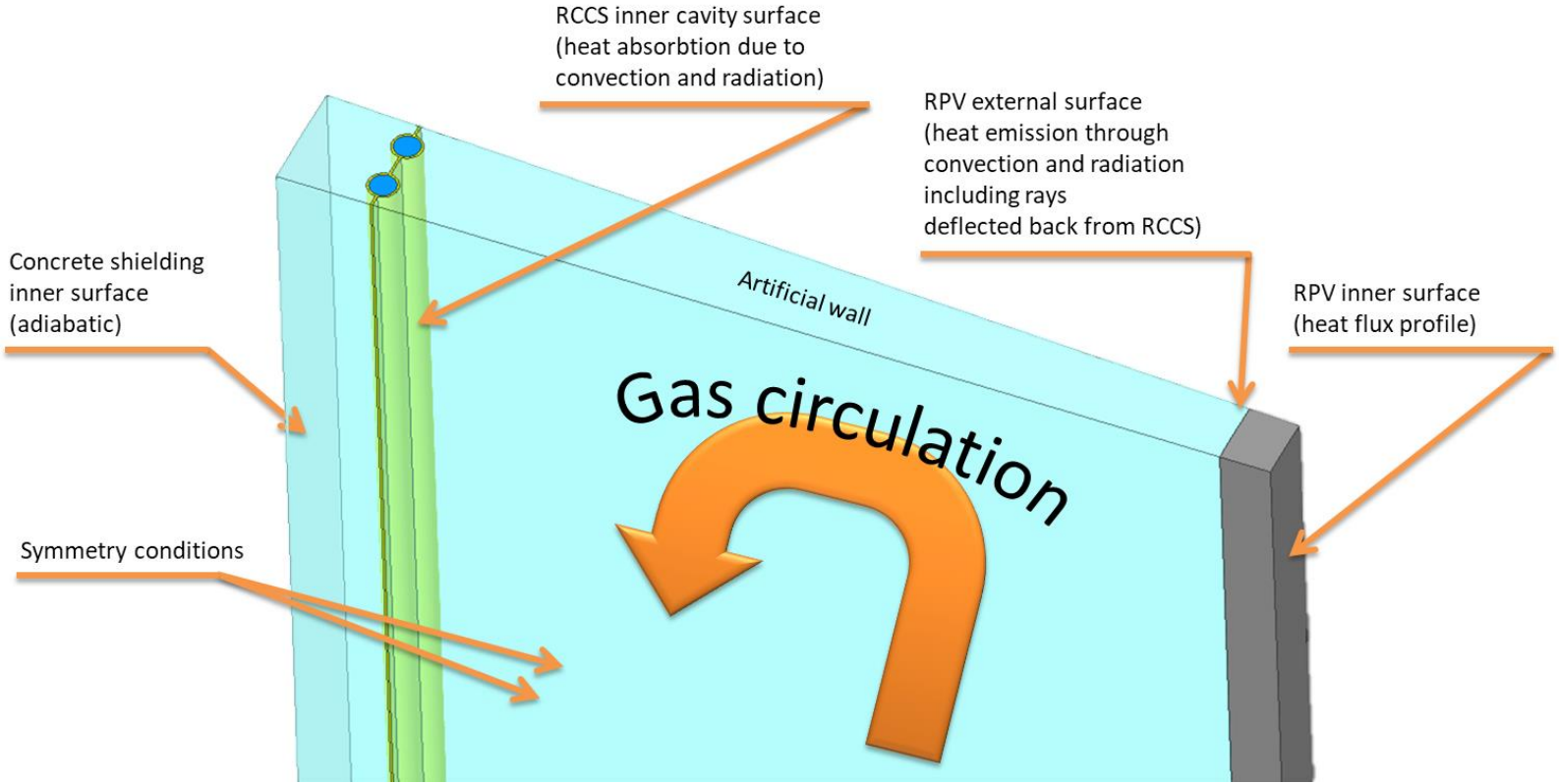
*3.2) T[K]	λ [W/m-K]	Ref. [5]
294,0	40,67	
311,0	40,82	
339,0	40,82	
366,0	40,82	
394,0	40,67	
422,0	40,52	



Scenarios

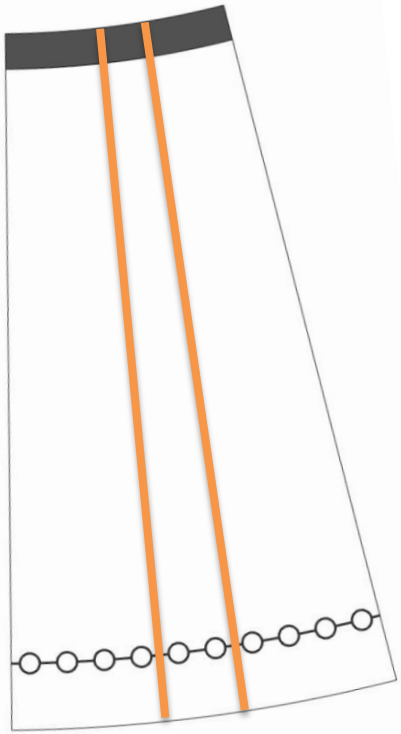
- Basic
  - Inner RPV wall heated with a constant axial heat flux profile
  - All RCCS channels allowing for flow of 0.1374 kg/s water each at a temperature of 313 K at inlet (bottom)
- Variant #1
  - RCCS cooling medium circulating the other direction
- Variant #2
  - One of the RCCS subsystems shutdown

Assumptions (1/2)

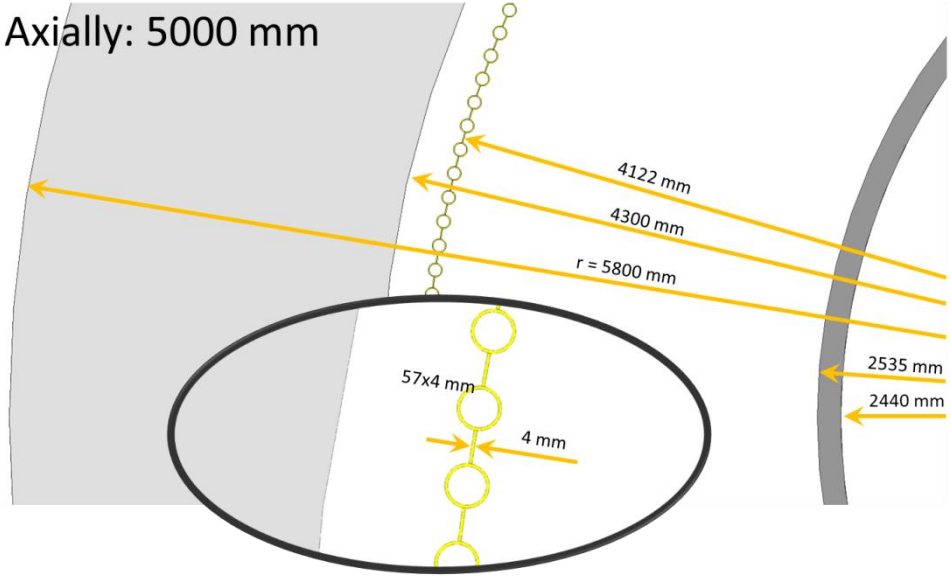


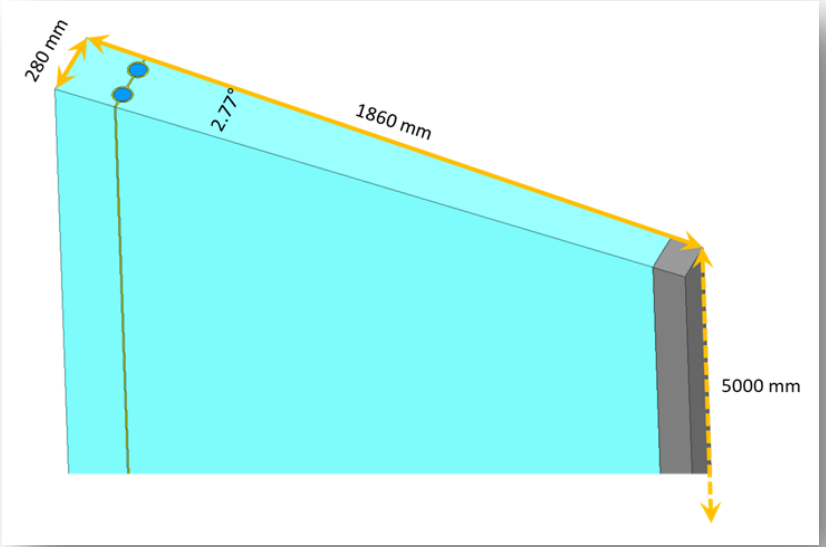
Assumptions (2/2)

- Geometrical:
  - Only angular slice under consideration
  - Only 5 m long section covering reactor core active zone
- Boundary Conditions:
  - Constant heat flux profile attached to inner RPV wall (heat flux assumes only 4.8 m long profile)
  - Adiabatic concrete wall
  - Symmetry conditions at sides
  - Top and bottom = wall:
    - mass transfer not allowed
    - air cavities coupled thermally with artificial BC
  - RCCS flow direction: bottom to top
- Time:
  - Just steady-states!



CAD creation

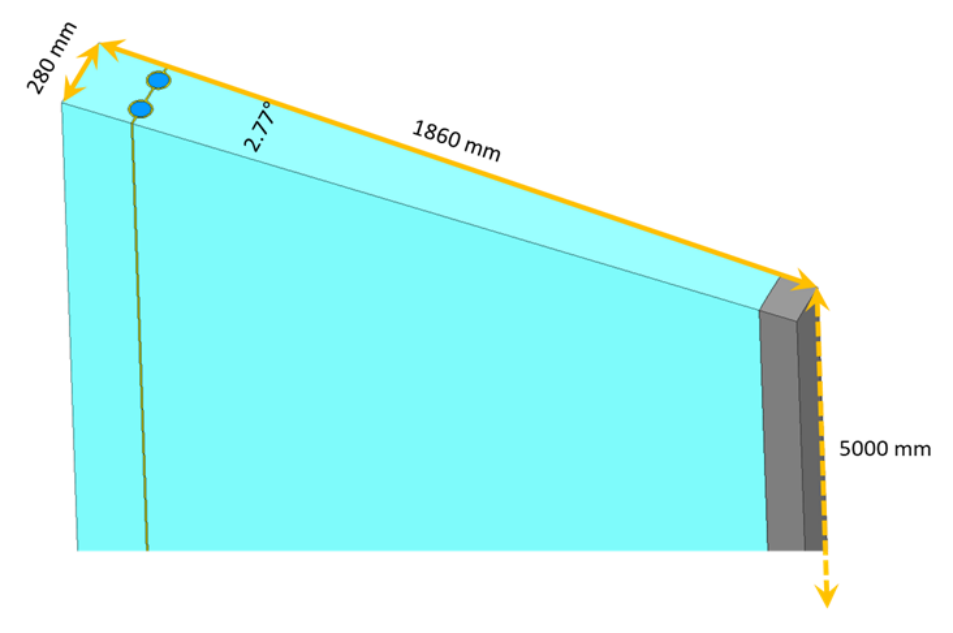




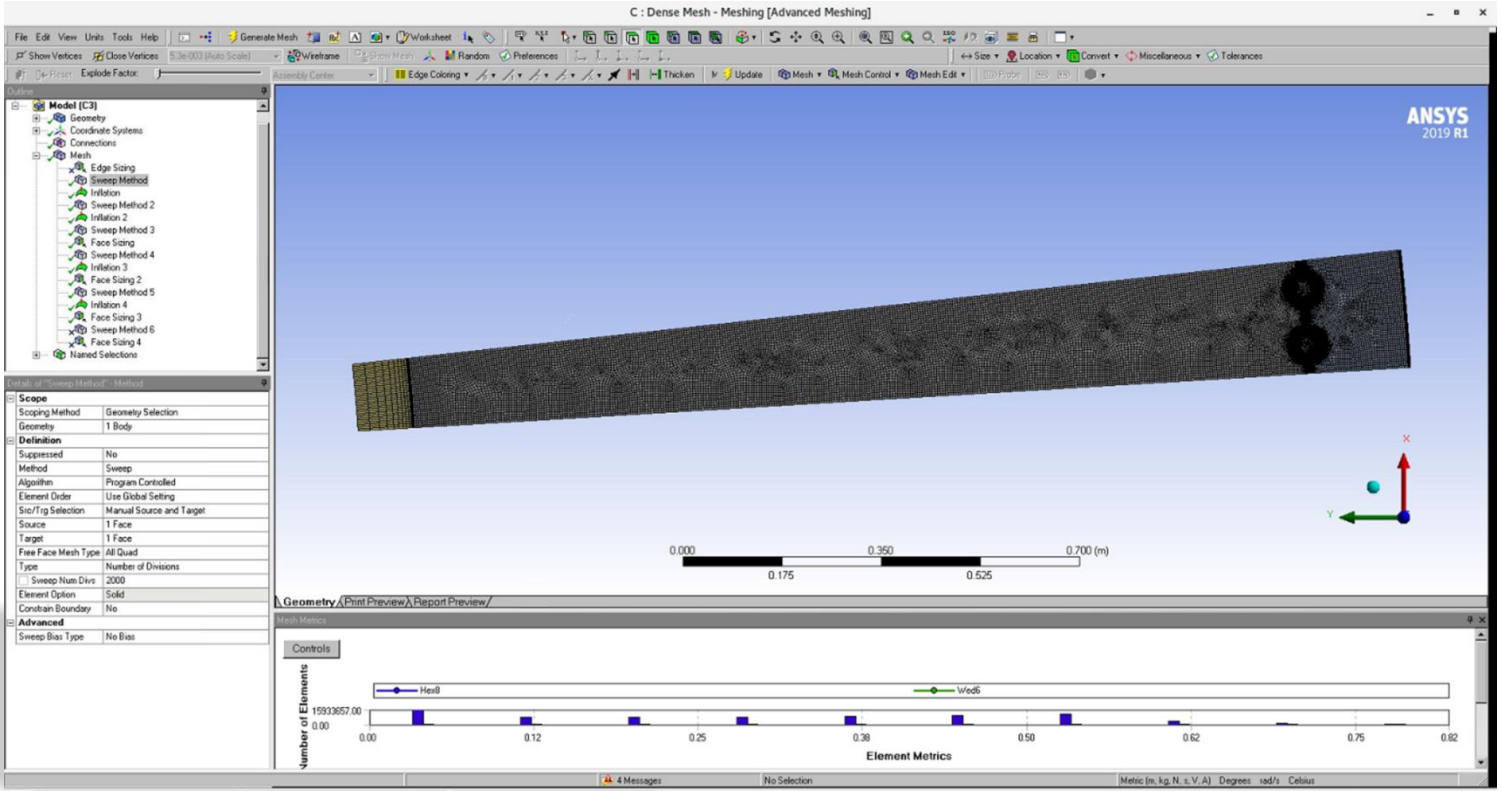
Some digits worth to keep in mind

Volumes	[m³]	[kg]
RPV wall	0.057	447.32
Inner cavity	1.263	1.10
RCCS – pipe & panels	0.008	67.19
RCCS – water (single channel)	0.009	9.03
Outer cavity	0.168	0.18
TOTAL	1.515	533.86

1/130



Volume discretization (1/2)

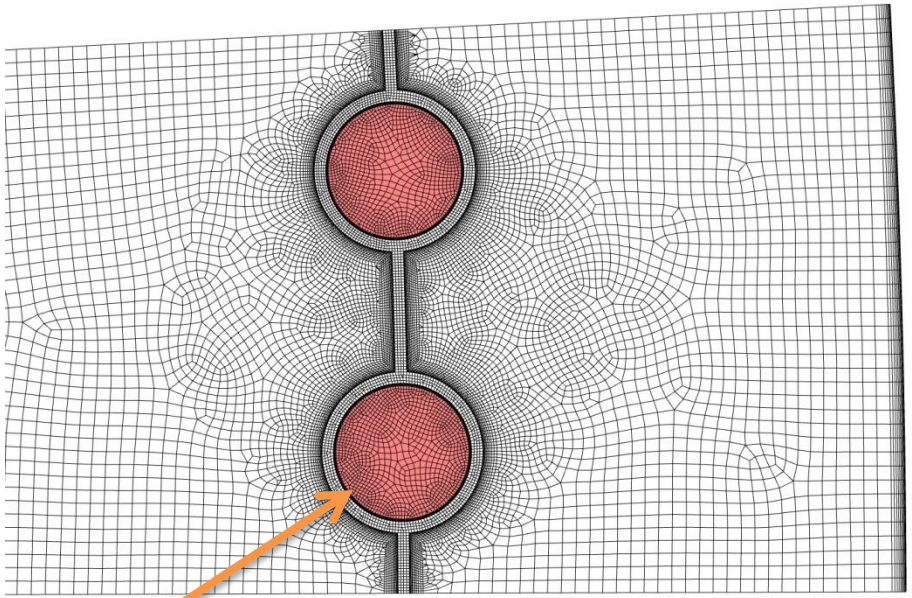


Volume discretization (2/2)

- Single-segment mesh
  - 25M: reference mesh
  - 13M: coarser axial resolution
  - 13Mv2: + wider inflation regions
- 5-segment mesh
  - 68M: based on 13M case sizings

Computational time!

Thiny inflation layer to account for turbulent water flow



Aim of the simulations

- For the given conditions, find or check:
  - Heat Transfer Coefficient axial profiles (for RPV, RCCS); *
  - how much of total heat is transfered to RCCS through radiation mechanism;
  - temperature difference between RCCS inlet and outlet.

HTC - definition

$$h = \frac{q''_{tot}}{T_{wall} - T_{fluid}}$$

q''_{tot} – total heat flux (accounting for convective and radiative heat transfer)

T_{wall} - wall surface static temperature

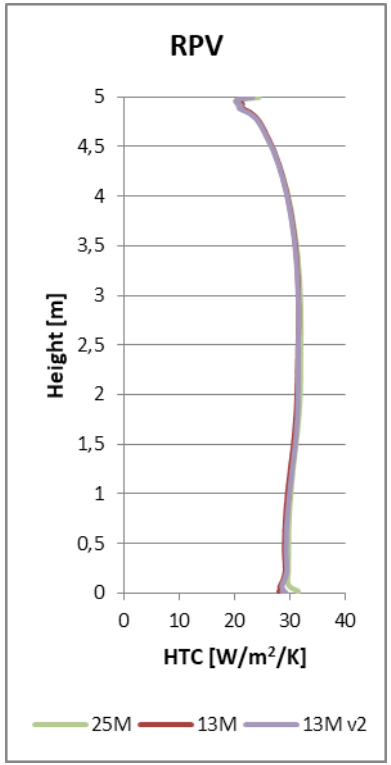
T_{fluid} - (controversial) reference temperature of fluid

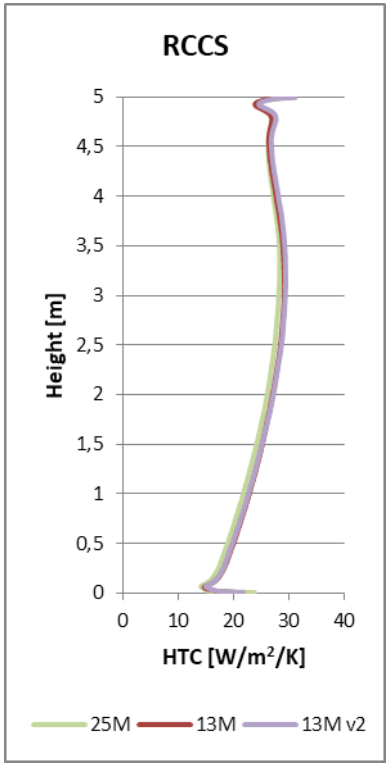
RESULT QUALITY ASSURANCE

Does the mesh resolution impact on results?

Volumes	25M	13M	13M v2
RPV wall	549.55	549.23	548.09
Inner cavity	403.30	400.68	399.30
RCCS – pipe & panels	318.76	318.77	318.72
RCCS – water	314.21	314.21	314.20
Outer cavity	318.58	316.69	315.84

Surfaces	25M	13M	13M v2
RPV inner wall	554.89	554.58	553.439
RPV to inner cavity	544.34	544.02	542.88
Inner cavity to RCCS	321.24	321.25	321.18
RCCS to water	316.97	316.98	316.93
RCCS to outer cavity	318.46	318.46	318.40
Concrete inner wall	318.46	318.08	317.94





Does the mesh resolution impact on results?

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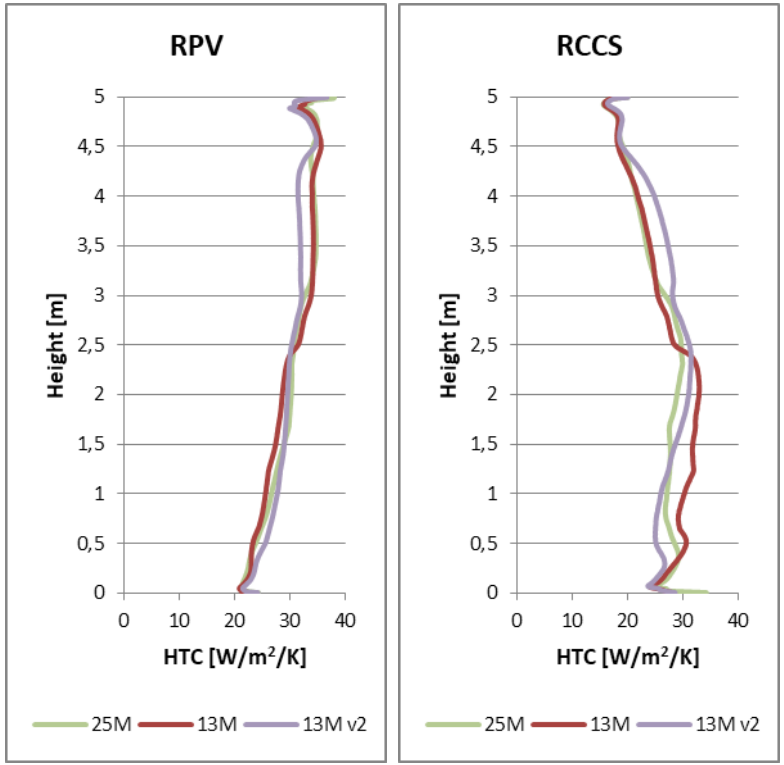
Outer cavity	318.58	316.69	315.84

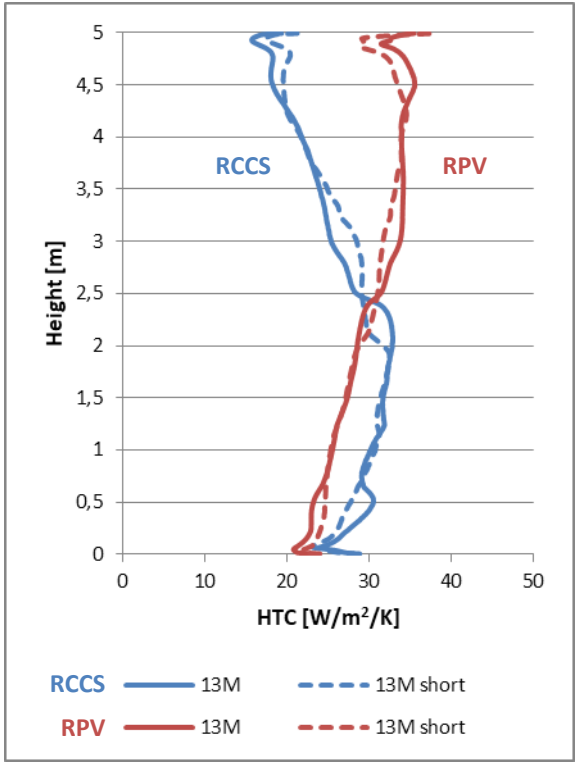
Surfaces	25M	13M	13M v2
RPV inner wall	554.89	554.58	553.439
RPV to inner cavity	544.34	544.02	542.88
Inner cavity to RCCS	321.24	321.25	321.18
RCCS to water	316.97	316.98	316.93
RCCS to outer cavity	318.46	318.46	318.40
Concrete inner wall	318.46	318.08	317.94



Does the number of iterations affect the results?

Volumes	13M	13M short	13M v2	13M v2 short
RPV wall	549.23	549.51	548.09	549.22
Inner cavity	400.68	399.78	399.30	401.05
RCCS – pipe & panels	318.77	318.83	318.72	318.79
RCCS – water	314.21	314.22	314.20	314.22
Outer cavity	316.69	316.44	315.84	317.39

Surfaces	13M	13M short	13M v2	13M v2 short
RPV inner wall	554.58	554.86	553.439	554.56
RPV to inner cavity	544.02	544.29	542.88	544.02
Inner cavity to RCCS	321.25	321.34	321.18	321.28
RCCS to water	316.98	317.03	316.93	316.98
RCCS to outer cavity	318.46	318.52	318.40	318.49
Concrete inner wall	318.08	318.16	317.94	318.24



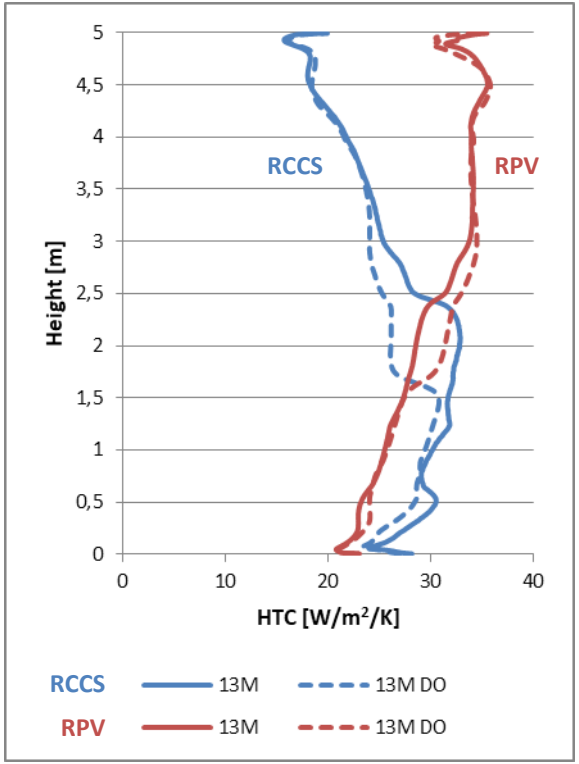
What about turbulence model choice?

- For a general perspective on physics involved, the time-averaged scope of results in steady RANS approach is suitable
- When it comes to choice of one out of all RANS models, the answer is… somehow… binary, between the two most cost-effective solutions:
  - k-ε models family
  - k-ω models family
- As we deal with a low-Reynolds flows with a heat transfer:
  - k-ω models are specifically dedicated to such application
- It is much more difficult to force k-ε models to work with radiation mechanism
- So finally, it was decided to use k-ω Shear Stress Transport model

Different radiation model, any change?

Volumes	25M	13M	13M DO	13M noRad
RPV wall	549.55	549.23	549.79	1515.41
Inner cavity	403.30	400.68	404.82	689.65
RCCS – pipe & panels	318.76	318.77	318.73	317.06
RCCS – water	314.21	314.21	314.21	313.83
Outer cavity	318.58	316.69	318.43	314.35

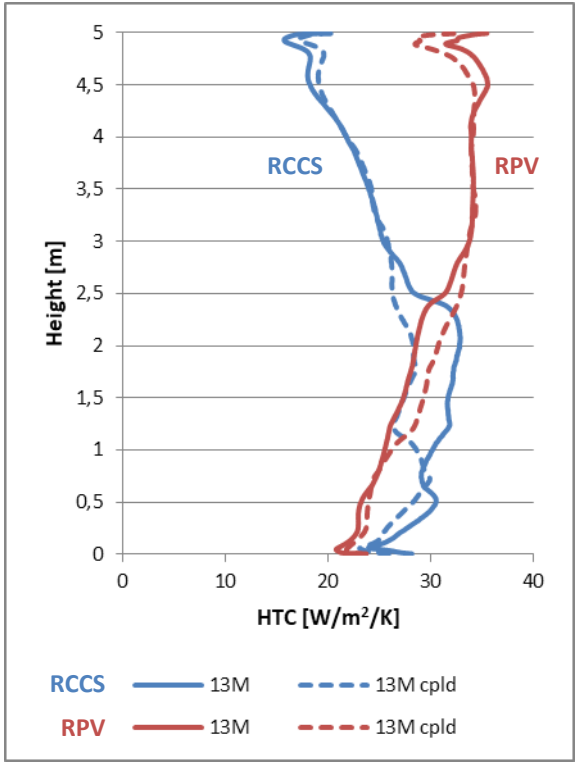
Surfaces	25M	13M	13M DO	13M noRad
RPV inner wall	554.89	554.58	555.14	1533.35
RPV to inner cavity	544.34	544.02	544.58	1498.40
Inner cavity to RCCS	321.24	321.25	321.18	319.02
RCCS to water	316.97	316.98	316.97	316.00
RCCS to outer cavity	318.46	318.46	318.36	316.39
Concrete inner wall	318.46	318.08	318.62	313.89



What if we couple inner and outer cavities?

Volumes	13M	13M cpld	13M DO	13M DO cpld
RPV wall	549.23	548.75	549.79	549.50
Inner cavity	400.68	403.96	404.82	405.73
RCCS – pipe & panels	318.77	319.03	318.73	318.99
RCCS – water	314.21	314.27	314.21	314.26
Outer cavity	316.69	324.24	318.43	325.64

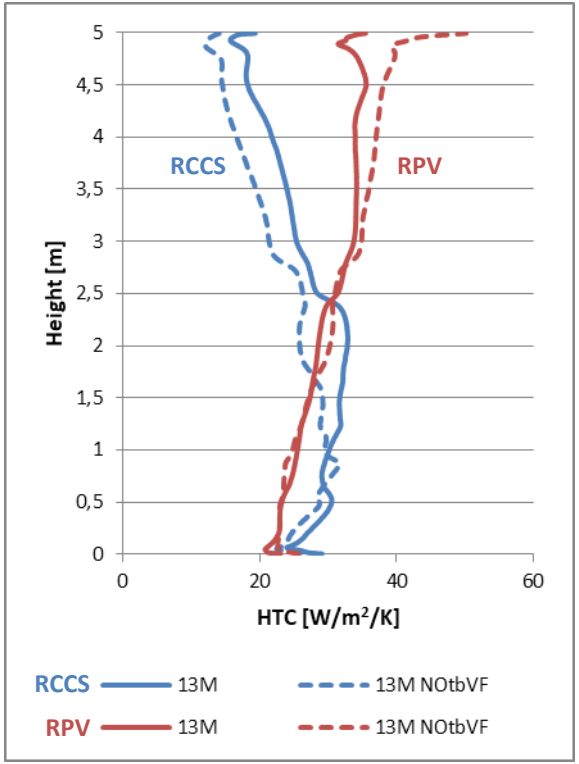
Surfaces	13M	13M cpld	13M DO	13M DO cpld
RPV inner wall	554.58	554.10	555.14	554.85
RPV to inner cavity	544.02	543.55	544.58	544.29
Inner cavity to RCCS	321.25	321.49	321.18	321.44
RCCS to water	316.98	317.17	316.97	317.17
RCCS to outer cavity	318.46	318.77	318.36	318.71
Concrete inner wall	318.08	324.45	318.62	324.73



No radiation reflection from top and bottom?

Volumes	13M	13M NOtbVF
RPV wall	549.23	538.64
Inner cavity	400.68	393.61
RCCS – pipe & panels	318.77	317.60
RCCS – water	314.21	313.95
Outer cavity	316.69	316.52

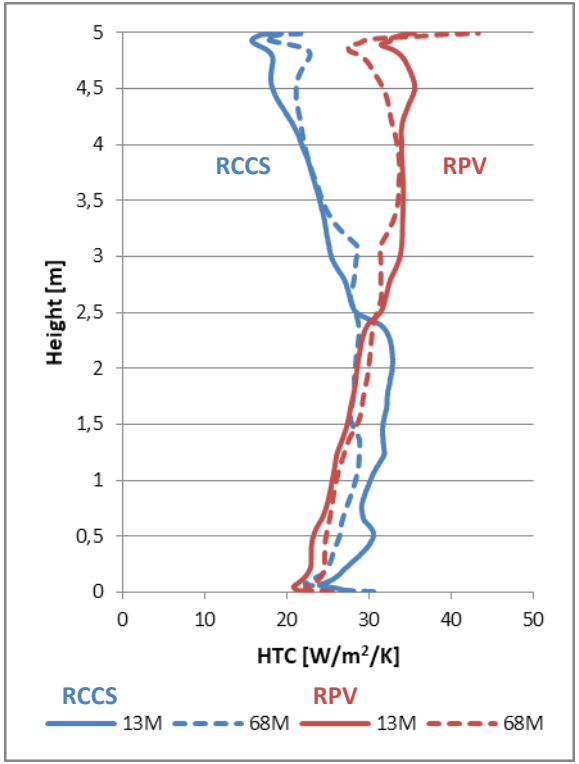
Surfaces	13M	13M NOtbVF
RPV inner wall	554.58	543.97
RPV to inner cavity	544.02	533.43
Inner cavity to RCCS	321.25	319.57
RCCS to water	316.98	316.15
RCCS to outer cavity	318.46	317.34
Concrete inner wall	318.08	316.70



What if we take wider angular section?

Volumes	13M	68M
RPV wall	549.23	549.51
Inner cavity	400.68	401.38
RCCS – pipe & panels	318.77	318.82
RCCS – water	314.21	314.21
Outer cavity	316.69	317.93

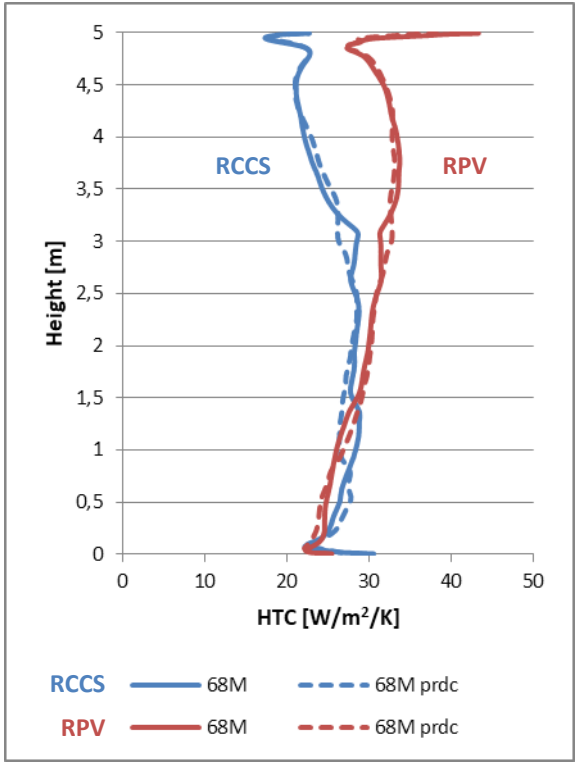
Surfaces	13M	68M
RPV inner wall	554.58	554.86
RPV to inner cavity	544.02	544.30
Inner cavity to RCCS	321.25	321.30
RCCS to water	316.98	317.00
RCCS to outer cavity	318.46	318.49
Concrete inner wall	318.08	318.35



What if switch from symmetry to periodicity?

Volumes	13M	68M	68M prdc
RPV wall	549.23	549.51	549.51
Inner cavity	400.68	401.38	401.37
RCCS – pipe & panels	318.77	318.82	318.82
RCCS – water	314.21	314.21	314.21
Outer cavity	316.69	317.93	316.83

Surfaces	13M	68M	68M prdc
RPV inner wall	554.58	554.86	554.87
RPV to inner cavity	544.02	544.30	544.29
Inner cavity to RCCS	321.25	321.30	321.31
RCCS to water	316.98	317.00	317.00
RCCS to outer cavity	318.46	318.49	318.50
Concrete inner wall	318.08	318.35	318.20

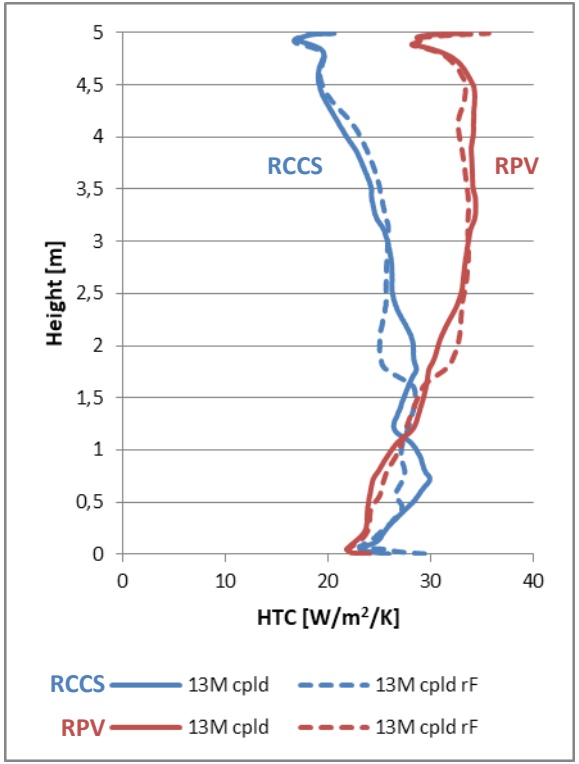


VARIANTS

Variant #1: What if we run water through RCCS the other way?

Volumes	13M cpld	13M cpld rF
RPV wall	548.75	548.85
Inner cavity	403.96	404.74
RCCS – pipe & panels	319.03	319.18
RCCS – water	314.27	314.39
Outer cavity	324.24	324.93

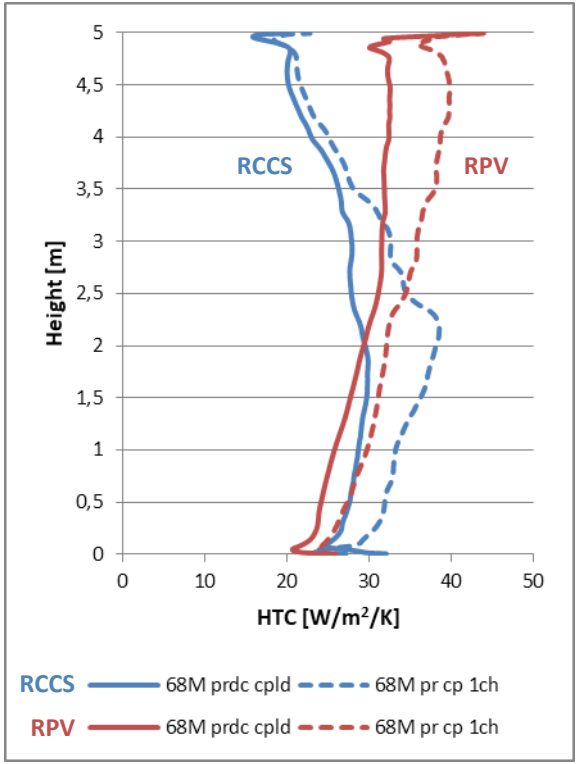
Surfaces	13M cpld	13M cpld rF
RPV inner wall	554.10	554.20
RPV to inner cavity	543.55	543.64
Inner cavity to RCCS	321.49	321.64
RCCS to water	317.17	317.32
RCCS to outer cavity	318.77	318.92
Concrete inner wall	324.45	324.56



Variant #2: What if only one RCCS subsystem works?

Volumes	68M prdc cpld	68M pr cp 1ch
RPV wall	550.25	564.14
Inner cavity	400.23	431.62
RCCS – pipe & panels	319.01	360.07
RCCS – water	314.24	315.85/398.16
Outer cavity	325.05	361.99

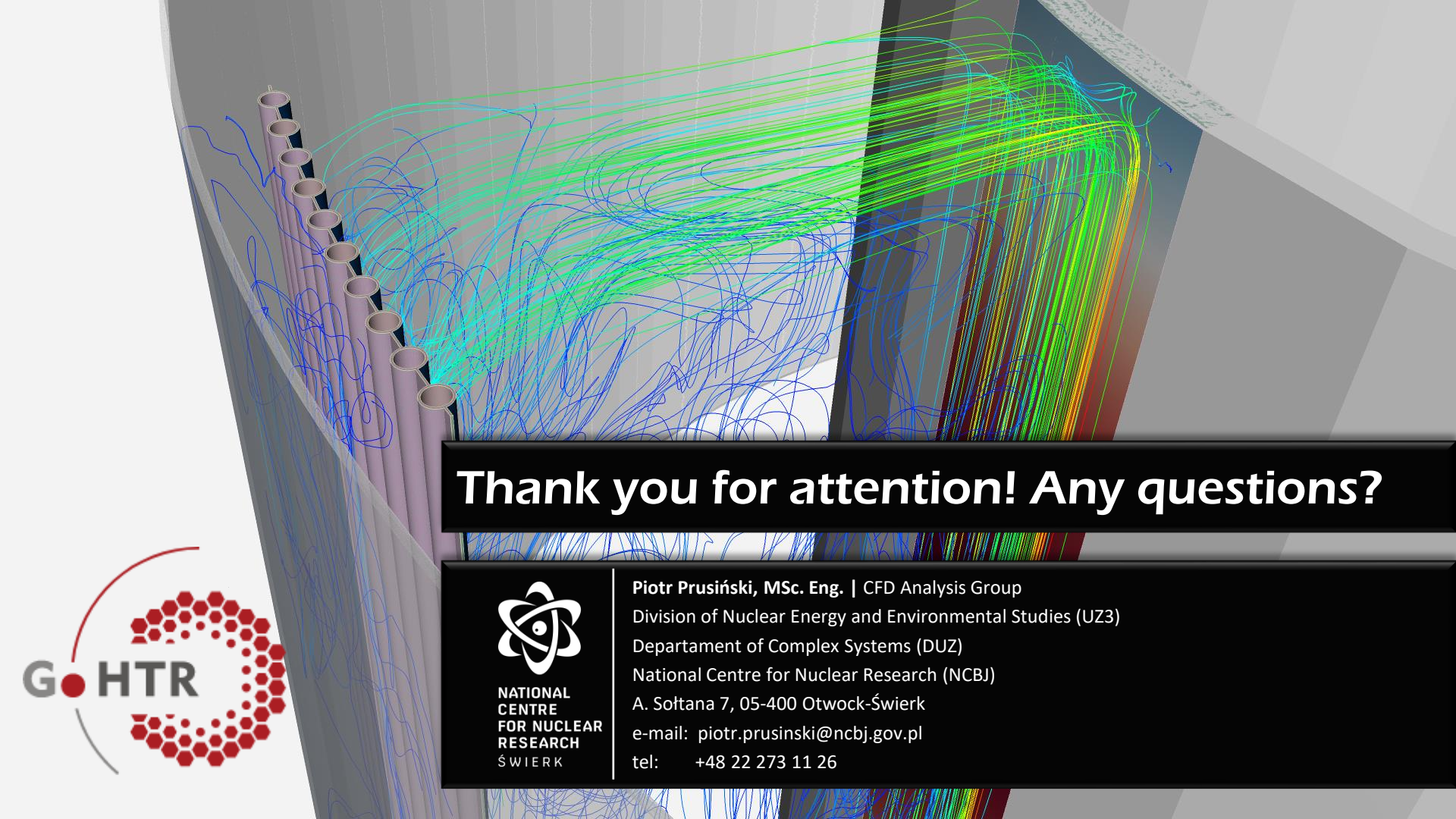
Surfaces	68M prdc cpld	68M pr cp 1ch
RPV inner wall	555.60	569.52
RPV to inner cavity	545.06	558.91
Inner cavity to RCCS	321.46	363.98
RCCS to water	317.13	321.33/395.44
RCCS to outer cavity	318.80	358.20
Concrete inner wall	324.42	363.21



SUMMARY

Final remarks

- This presentation is a summary of half-year one man work effort, based on a given specification, that started with creation of CAD geometry and yielding with a vast number of simulation data (thanks to our HPC centre – CIŚ):
  - Where the HTC axial profiles were the required product
- Applied results quality assurance policy allows for further uncertainty assessments and proves validity of several assumptions that made the simulation rich of data, keeping the process in a cost-effective manner.
- Provided variant scenarios are just examples on how to use the model for further discussions.



Thank you for attention! Any questions?

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