Adequacy Assessment on a Conceptual Design of the Water-cooled RCCS for HECTAR High Temperature Gas-cooled Reactors

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Purposes and Ultimate Goal

Purposes : To analyze conjugate heat transfer phenomena over the structures and components inside the HECTAR RCCS (Reactor Cavity Cooling System) by using CFD(Computational Fluid Dynamics) technology, for assessing the design adequacy

Ultimate Goal : Development and validation of the HECTAR RCCS design

Conceptual Design of HECTAR RCCS

HECTAR (HElium Cooled Thermal Application Reactor):

- A high temperature gas-cooled reactor (HTGR) generating 90MWt
- A new GEN-IV HTGR design concept under development in KAERI

RCCS (Reactor Cavity Cooling System):

- Water-cooled RCCS by buoyancy-driven natural circulation in two separate closed loops
- Ultimate heat sink is two dry cooling towers by air natural convection cooling.
- Total heat removal capacity of RCCS is 450 kW (0.5% of normal power generation); 225 kW for each loop.
- **RCCS thermal design requirements**

Parameter	Condition	Temp. Limit
Concrete Temp.	Normal Operation	65 ºC
	Accident	177 ºC
RPV Outer Surface Temp.	Normal Operation	371 ºC
	Pressurized Conduction Cooldown	427 ºC
	Depressurized Conduction Cooldown	482 ºC

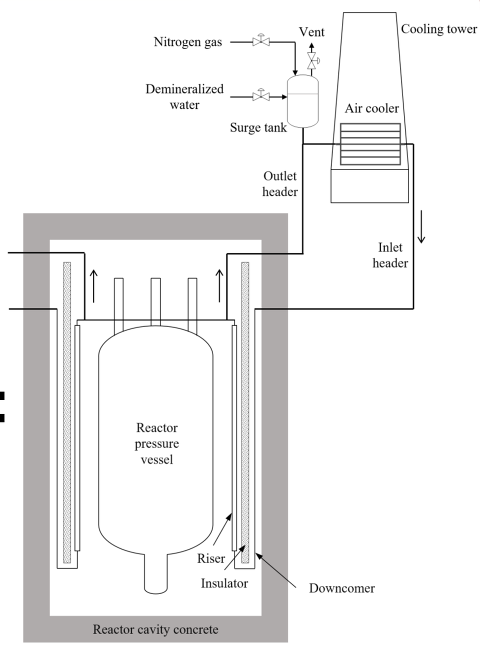


Fig. Conceptual Diagram of HECTAR RCCS

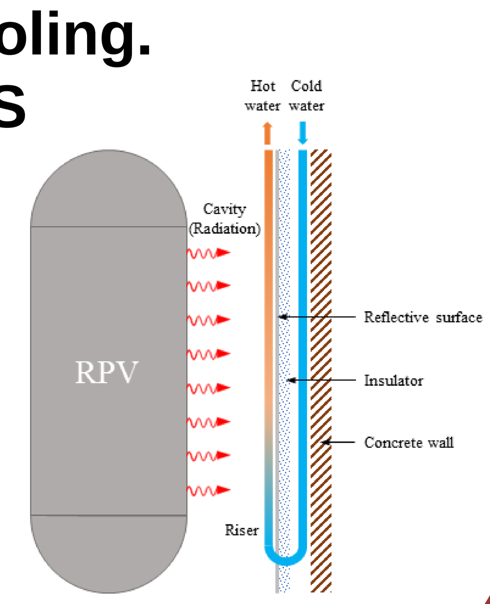


Fig. Thermal Design Concept of HECTAR RCC

CFD Analysis Methodology

Part Geometry: generated by ANSYS SpaceClaim

- 1/60 geometry model (6º sectored domain)

Mesh: Unstructured tetrahedral meshes with 4 prism layers in fluid regions

- Total cell number = ~ 27,000,000

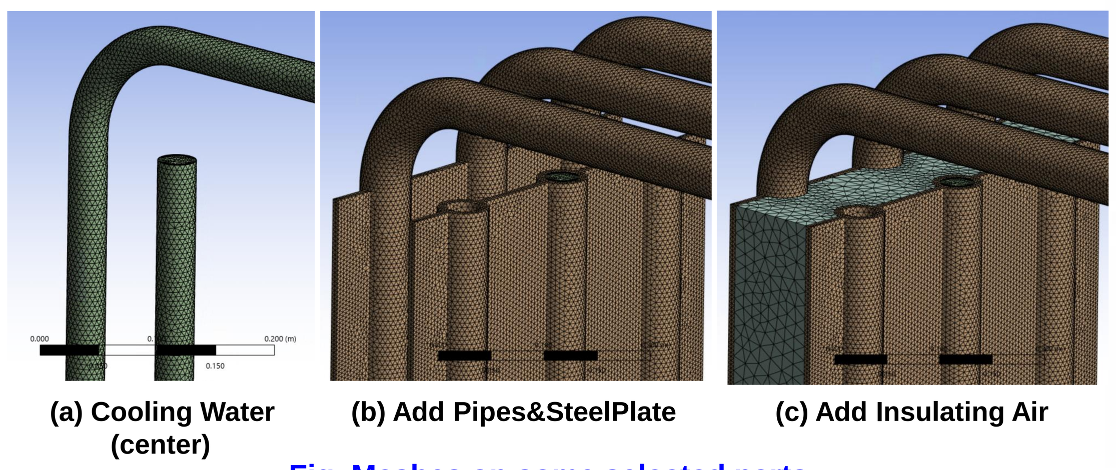


Fig. Meshes on some selected parts

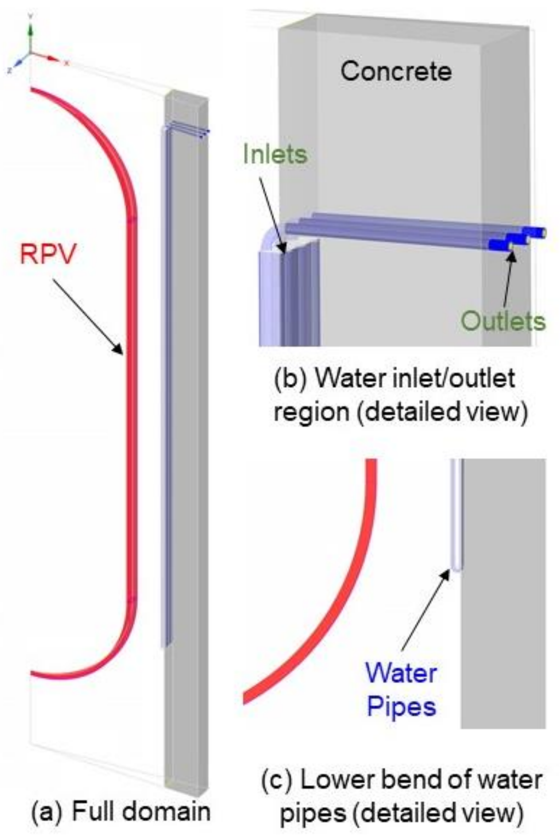


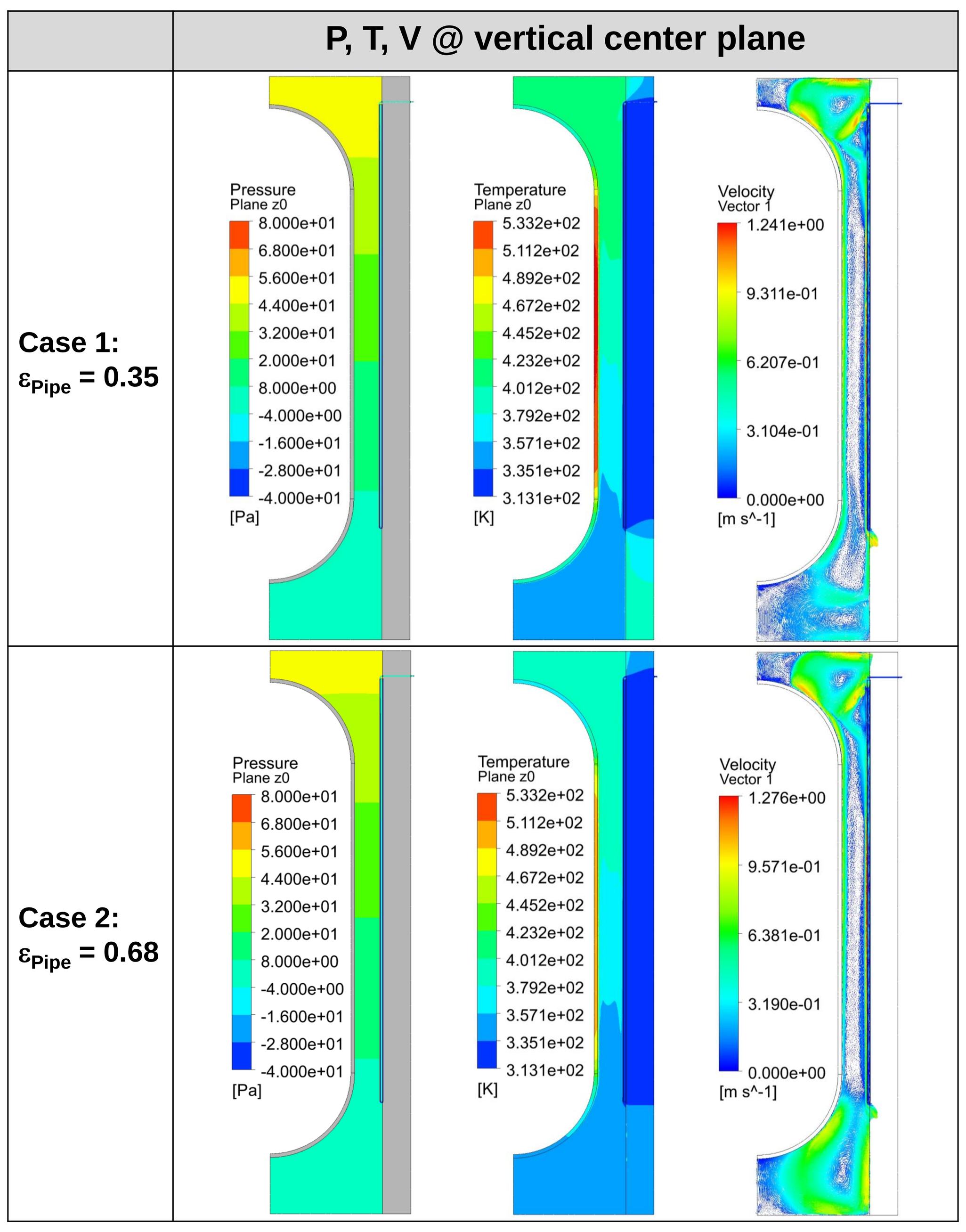
Fig. Computational domain

Physics Models:

- Shear Stress Transport (SST) turbulence model with automatic wall function
- Monte Carlo radiation model for the domain with periodic BC's

Simulation Condition: Steady-state normal operating condition (100% full power)

CFD Analysis Results of Different Emissivity Values



Confirming the baffle interfaces:

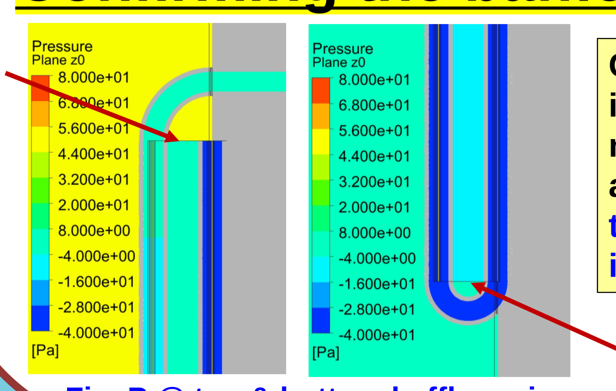


Fig. P @ top & bottom baffle regions

Confirming that the interfacial condition of thin metal plates work properly as baffle interfaces between the atmospheric and insulating airs.

Maximum & Minimum Temperatures

Table. Maximum Temperatures at Selected Structural

Surface	Maximum temperature [ºC] Case 1 (ε_{Pipe} = 0.35)	Case 2 (ε_{Pipe} = 0.68)
RPV_{bot} outer surface	185.22	158.87
RPV_{center} outer surface	261.23	222.89
RPV_{top} outer surface	197.72	165.20
Inner bare concrete surface	118.74	93.20
Pipe-&-SteelPlate inner surface	62.05	62.75
Interface between the Pipe-&-SteelPlate and the concrete	58.34	57.14
T_{riser_top} (at center-line of center pipe)	54.05	54.47
T_{outlet} (center pipe)	54.78	54.94
Concrete outer wall (with adiabatic BC)	109.60	80.97

Checking design requirements:

- T_{RPV} and $T_{concrete}$ behind SteelPlate are well below the temp. limits.
- Only $T_{concrete}$ near some bare concrete surfaces exceed the temp. limit of 65ºC.

Need some measures to prevent the heat up due to radiative direct heating and hot atmospheric air at upper region of the cavity. (eg. Thermal shield)

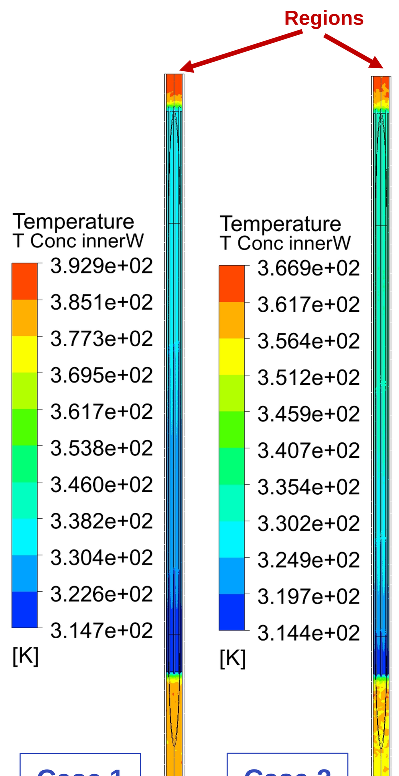


Fig. Temperature on Bare Concrete and Pipe&SteelPlate

Conclusions & Future Works

Sensitivity study on the water pipe emissivity:

- Higher pipe emissivity increases the heat removal capacity of RCCS cooling water circulation.

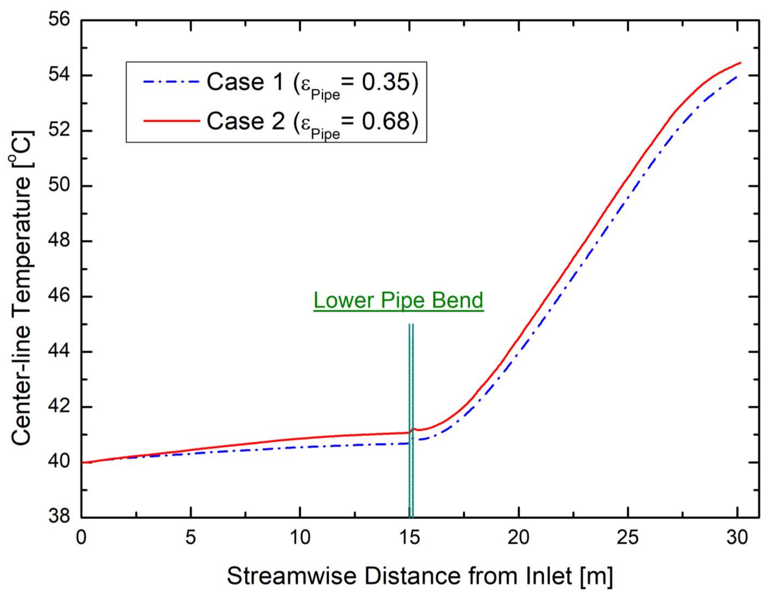


Fig. Center-line water temperature profile along the streamwise distance from the inlet.

Then, higher pipe emissivity decreases other structural temp.

Future Works:

- Design improvement for meeting the design requirements
- Design development for the whole RCCS (including water pipe layout and cooling tower, etc)
- Validation of using Monte Carlo radiation model for the domain with periodic or symmetric BC's