A Study on Temperature Distribution in the Hot Leg Pipes considering the Variation of Flow Rate in RCS

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Contents

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Introduction

◇ **The purpose of this study is:**

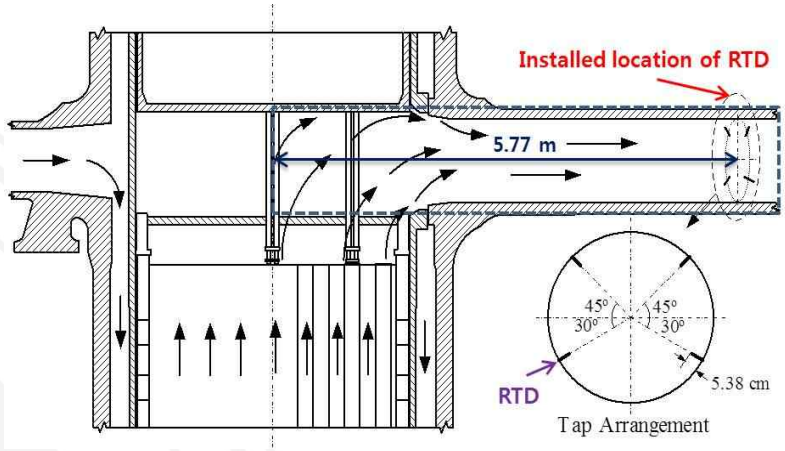
- **There is a deviation in temperature distribution in the hot leg pipe due to the sudden changes in the flow direction and area from the reactor core exit to the hot leg pipe.**

- **The non-uniform temperature distribution in the hot leg pipe can affect the measurement of the plant parameters such as the reactor power and the reactor coolant flow rate.**

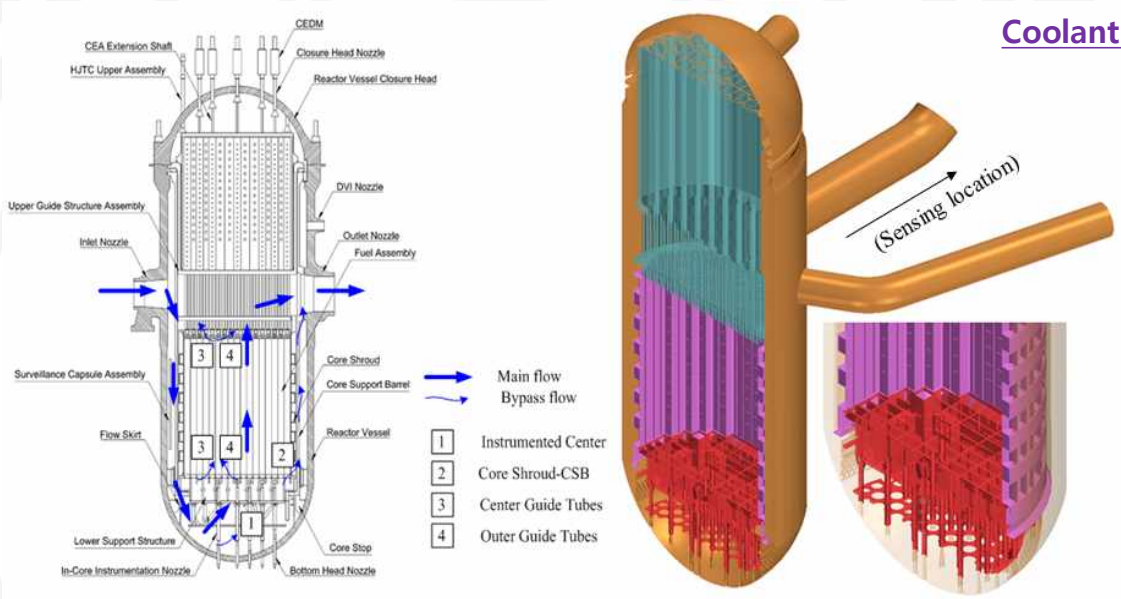
- **In this study, a computational analysis is performed to predict the deviation in the temperature distribution in the hot leg pipe according to the flow rate variation in RCS.**

Configuration of geometry model

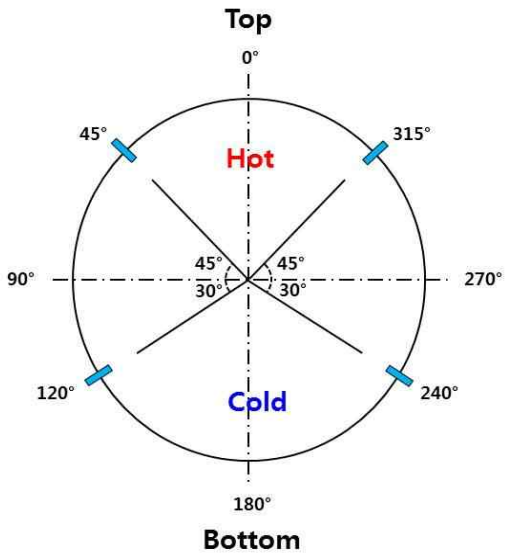
- RTDs are installed at 5.77m away from the vertical center line of RV.
- The wall boundary of reactor outside is adiabatic condition.



Coolant flow path from core exit plane to RTDs location



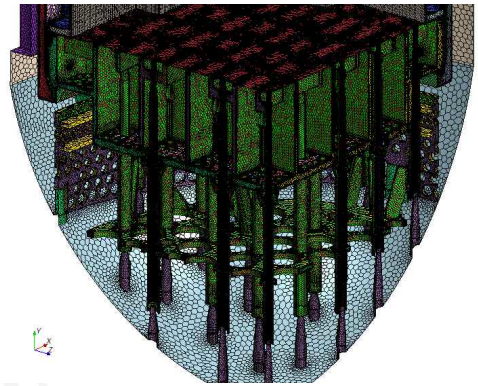
Schematic diagram of APR1400 RV



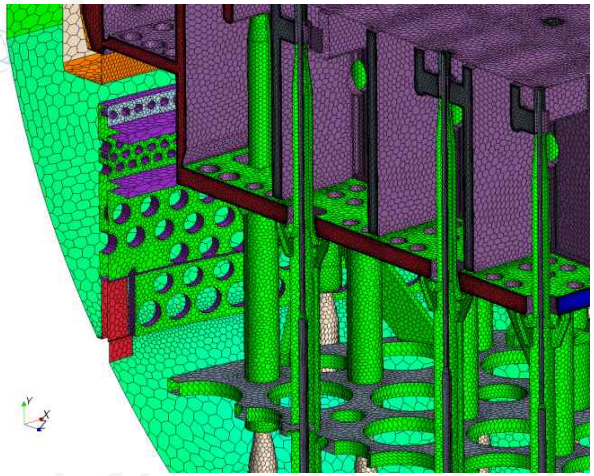
Circumferential location of RTDs

Grid Generation

- Polyhedral elements are used
- Three grid sizes are generated
- Porous medium method is used for reactor core
- The ½ model of the reactor vessel is used



Grid test	Coarse	Medium	High
Number of Grid	$37x10^6$	$61x10^6$	$70x10^6$



- A mesh with $37x10^6$ cells was generated, “coarse mesh”
- Maximum $y^+ > 30$, refinements in RVI internal structure
- Using medium mesh,
  refine internal fluid volume and prism layer, “fine mesh”

Boundary Condition

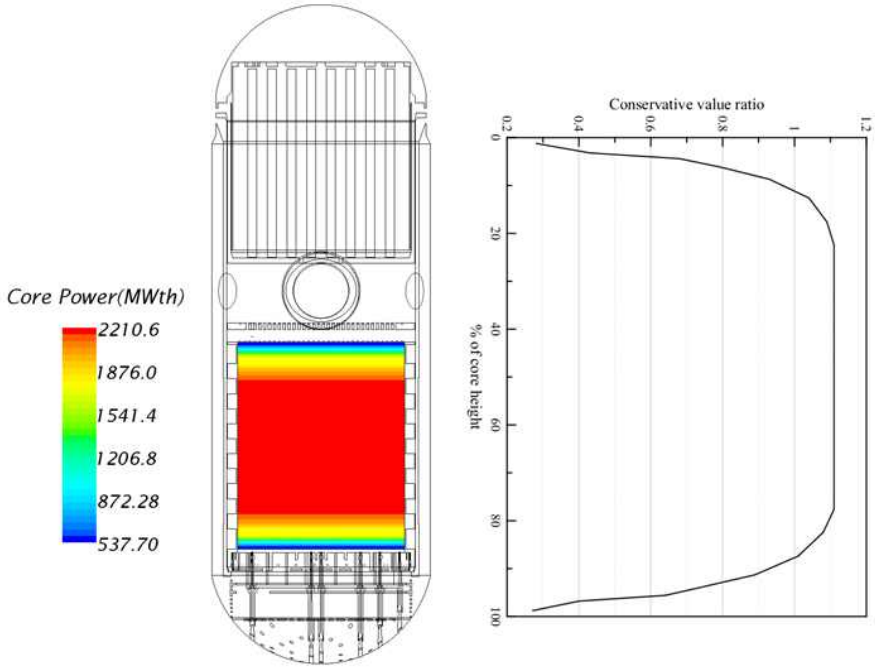
- Core Thermal Power: 3983 MWt, (½ Core Thermal Power: 1,991.5 MWt)
- Fully developed profile with a temperature of 290.6 °C and a pressure of 15.51 MPa
- The water is discharged with a temperature of 323.9 °C on operation condition
- All of the outside walls were treated as adiabatic smooth walls obeying the no-slip conditions
- The symmetry plane on both sides of a half model is adopted symmetry conditions
- Inlet flow is applied at a flow rate condition of the pump discharge, which is divided into four equal parts in the 5,231.2 kg/s

		Value	*Unit*
Thermal power		*1,991.5*	*(MWth)*
Operation pressure		*15.51*	*(MPa)*
Temperature	T_{cold}	*290.6*	*°C*
Mass flow rate		*10,462.4*	*Kg/s*

- Water properties used to IAPWS-IF97 steam table

Fuel Modeling

- **Relative Power Density of Fuel**



- **Effective thermal conductivity**

$$\rho_s c_{ps}(1-\varepsilon)\frac{\partial\langle T\rangle^s}{\partial t} = k_s(1-\varepsilon)\nabla^2\langle T\rangle^s - \nabla\left[\frac{1}{V}\int_s k_s T ds\right] - \frac{1}{V}\int_s k_s T ds$$

$$\left(\rho c_p\right)_{sf} = (1-\varepsilon)\rho_s c_{ps} + \varepsilon\rho_f c_{pf}$$

$$k_{sf,xx-yy-zz} = (1-\varepsilon)k_s + \varepsilon k_f$$

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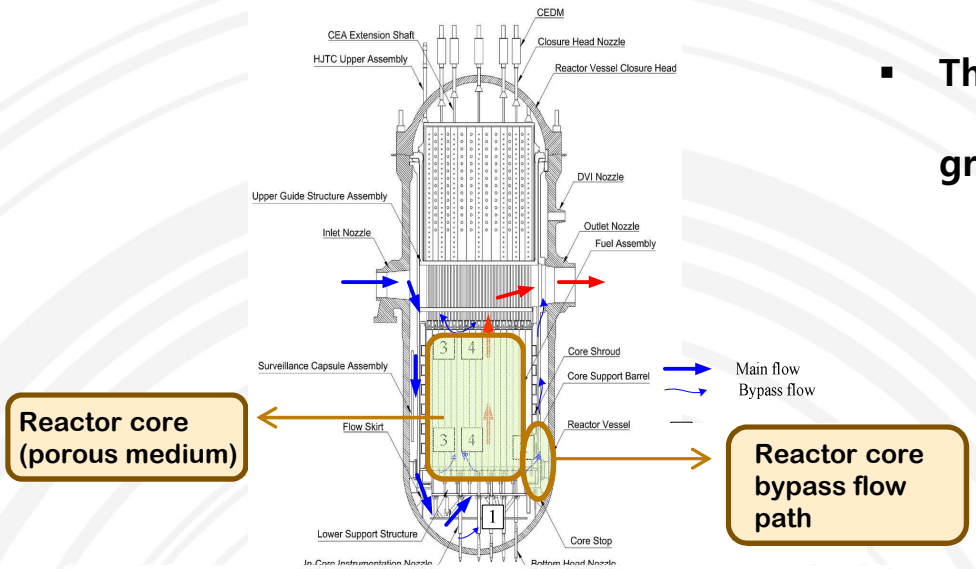
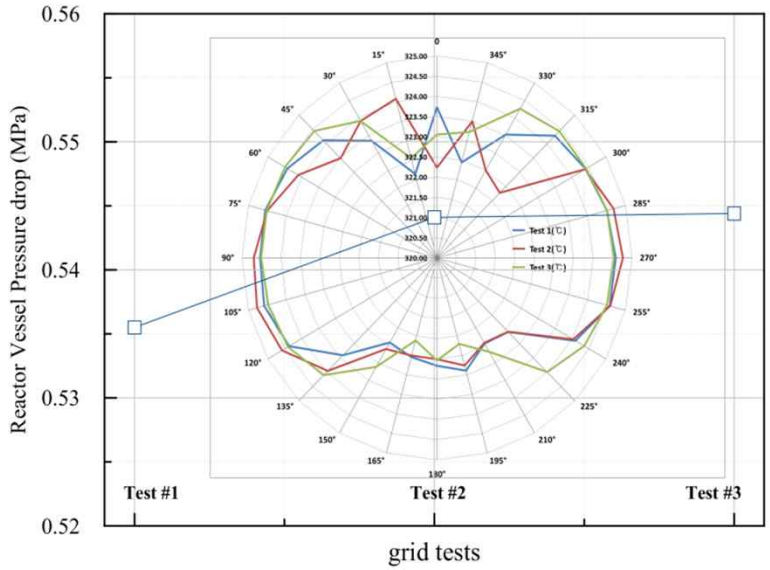
Sensitivity of grid & turbulence models



- Three parameters are compared in three cases of grid
  - Pressure drop in reactor vessel
  - Absolute pressure at reactor bypass flow path
  - Average temperature
  - Realize k-ε turbulence model



Results of Grid Test

- In order to evaluate mesh independence, all simulations are monitored with the temperature distribution and the average absolute pressure at RTDs location installed in hot leg pipe.

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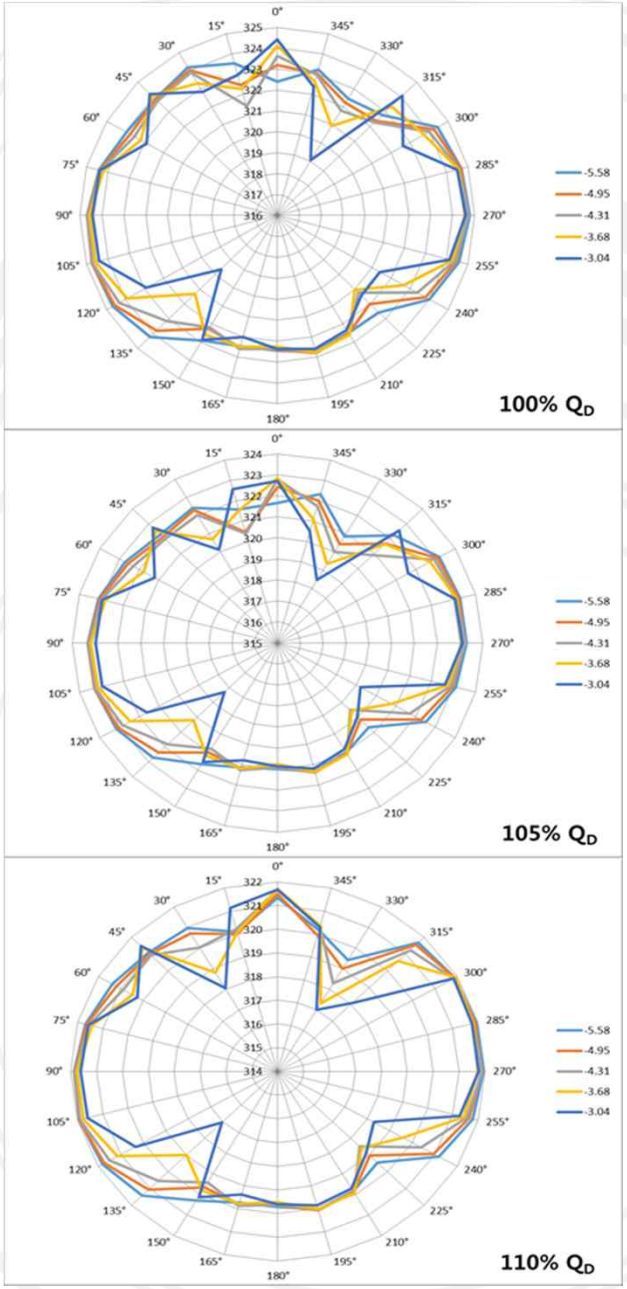
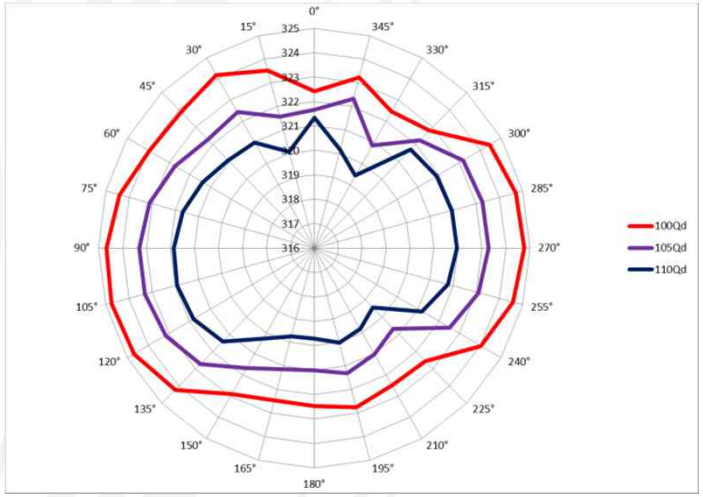
Temperature distribution & max. temperature

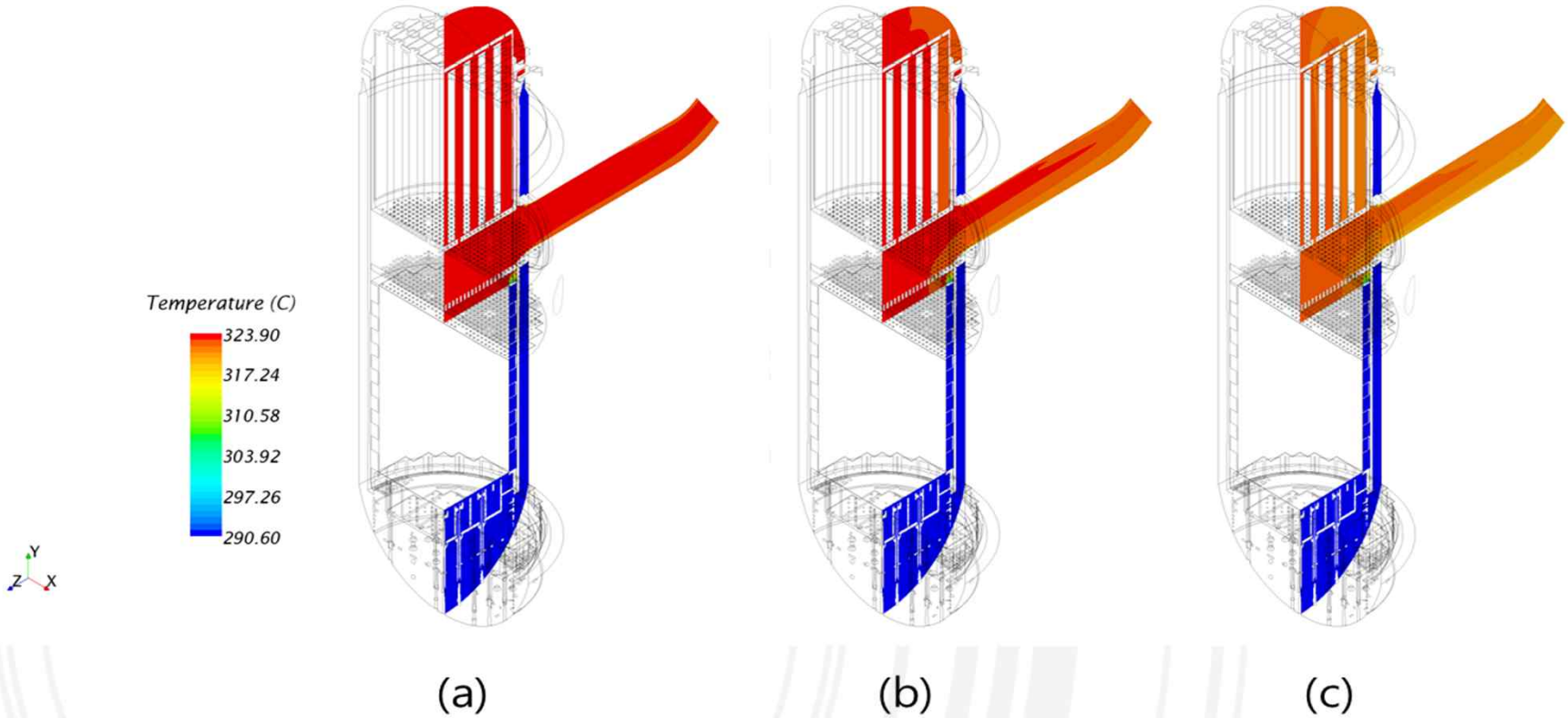


- The measured positions are the five measurement points (from 3.04m to 5.58m) according to the z-axis direction from the origin.
- The plane average temperatures of RTD location on the range of flow rates in RCS are 323.64 °C (100% QD), 322.25 °C (105% QD) and 320.94 °C (110% QD), respectively. The standard deviation for each location is about 0.91 with a constant deviation.



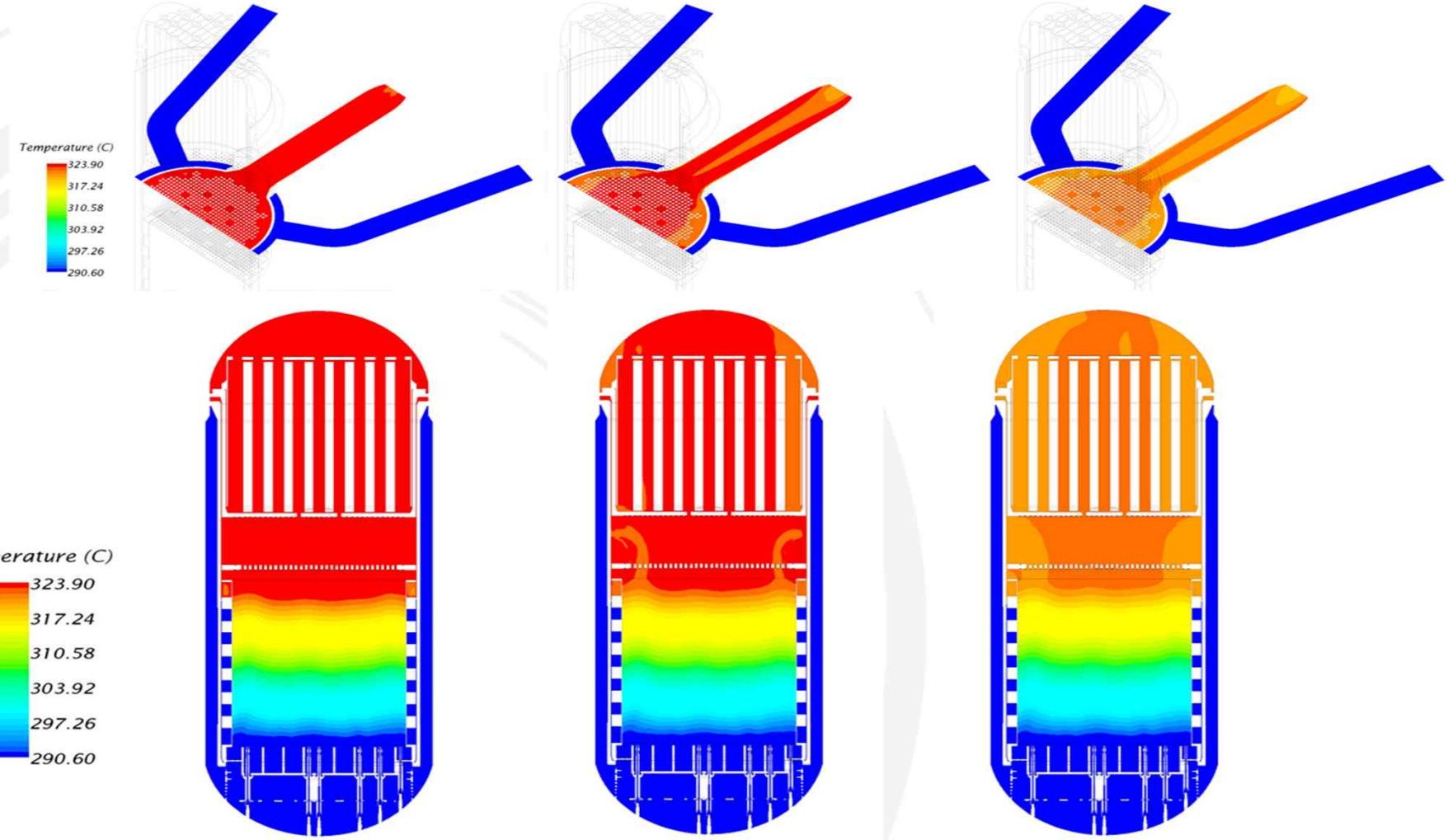
Temperature distribution & max. temperature

Temperature distribution - Z-section (a) 100% QD, (b) 105% QD, (c) 110% QD)



Temperature distribution & max. temperature

Temperature distribution - Y-section (a) 100% QD, (b) 105% QD, (c) 110% QD)



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Conclusions

- The non-uniform temperature distribution in the core exit is sustained to some extent through the entire region of hot leg pipe.
- The temperature ranges having a uniform pattern are 45 ~ 120° and 240 ~ 315°. The sensor positions of RTDs are located in this interval (45 ~ 120° and 240 ~ 315°) and this sensor positions of RTDs show the appropriate temperature measurement. Also, the temperature distribution shows the similar pattern without reference to the flow rate variation in RCS.
- In the future, the various turbulence models under the steady state condition will be performed in order to evaluate the effect of turbulent flows.