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# Assessment of Scalability from Numerical Simulation of Air Flow through RCCS Riser of NACEF and NSTF

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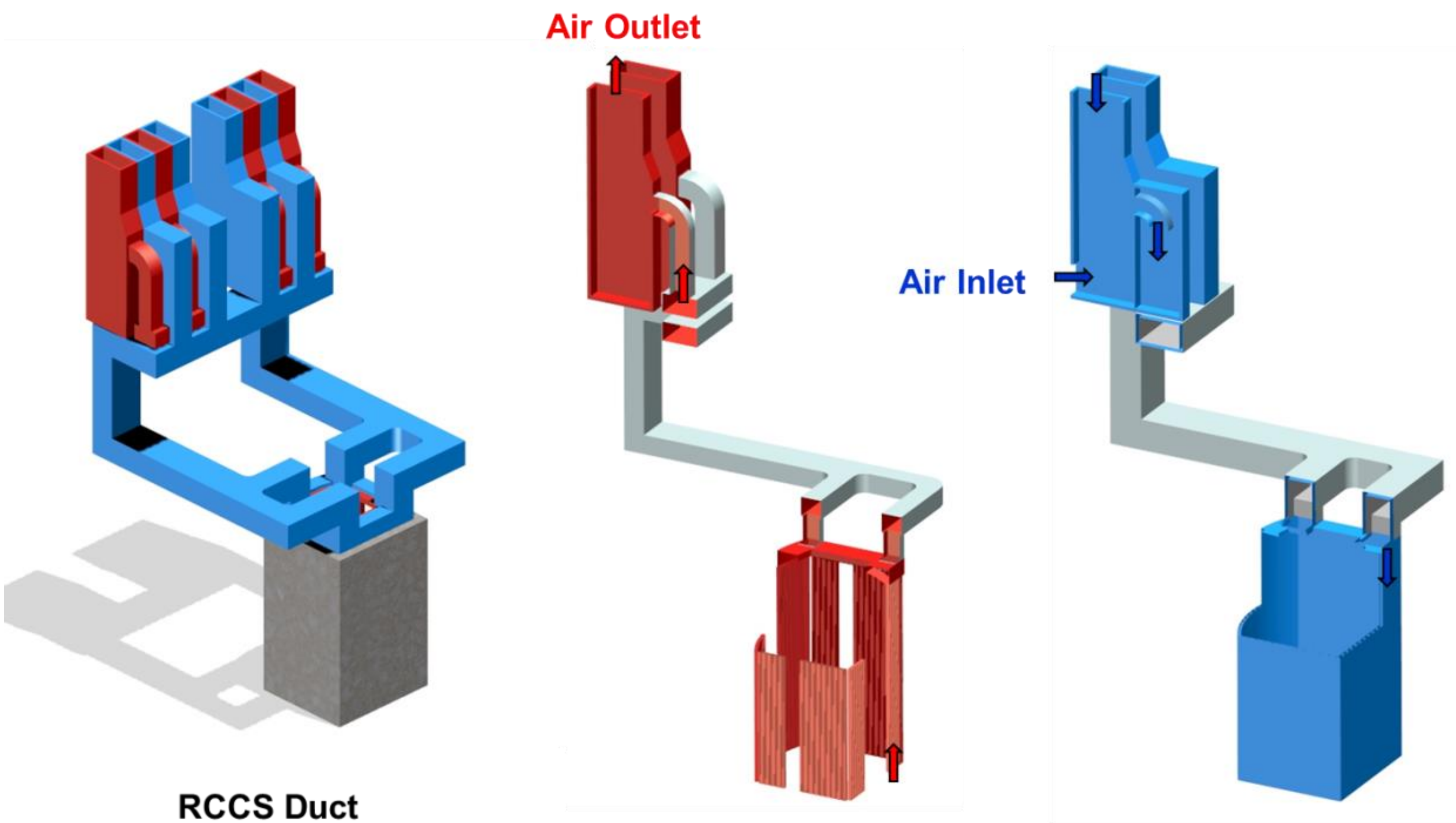
# PMR200 RCCS RIser

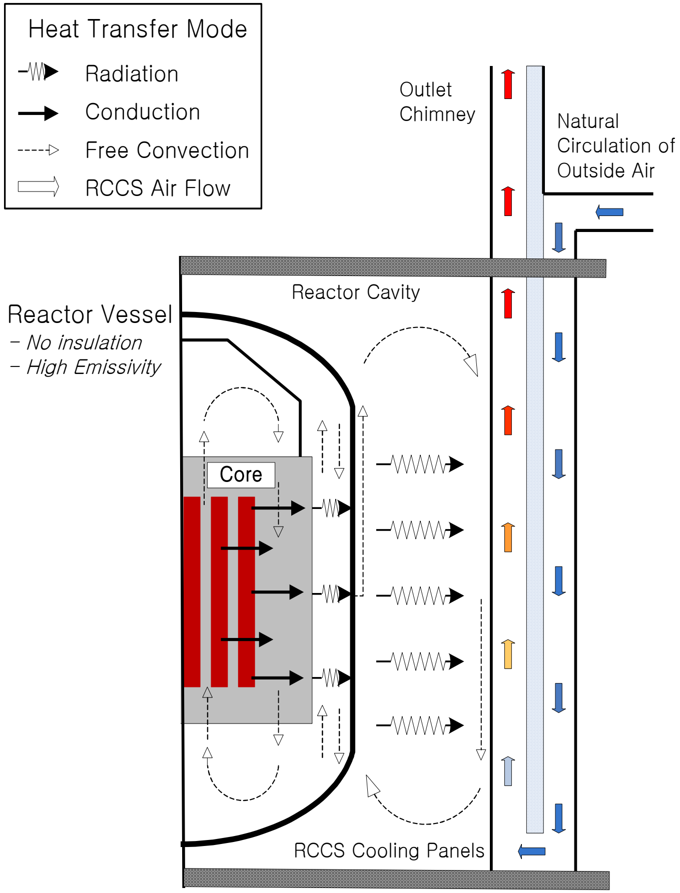
- Arrangement of RCCS Duct

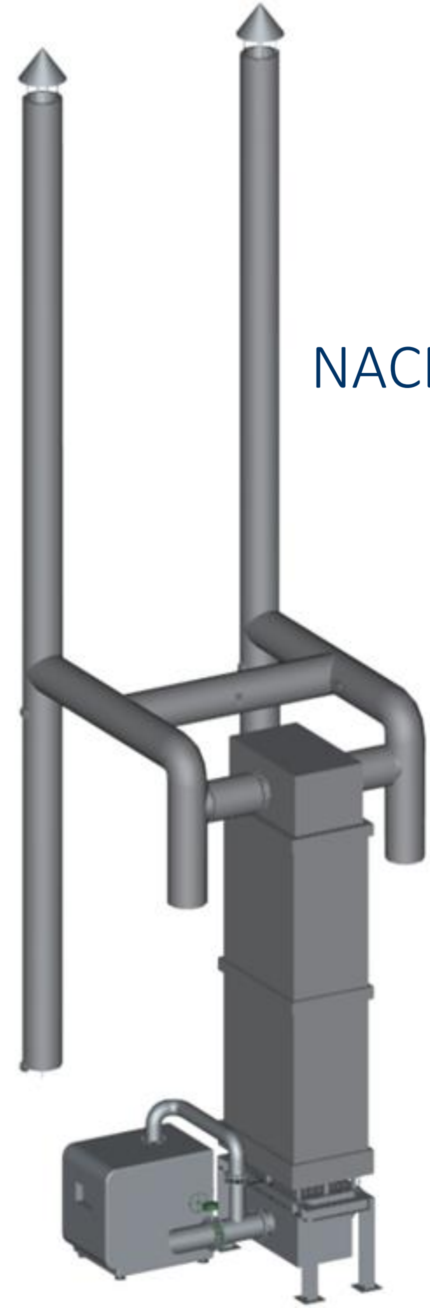



RCCS Duct Arrangement | Hot Duct | Cold Duct

# NACEF

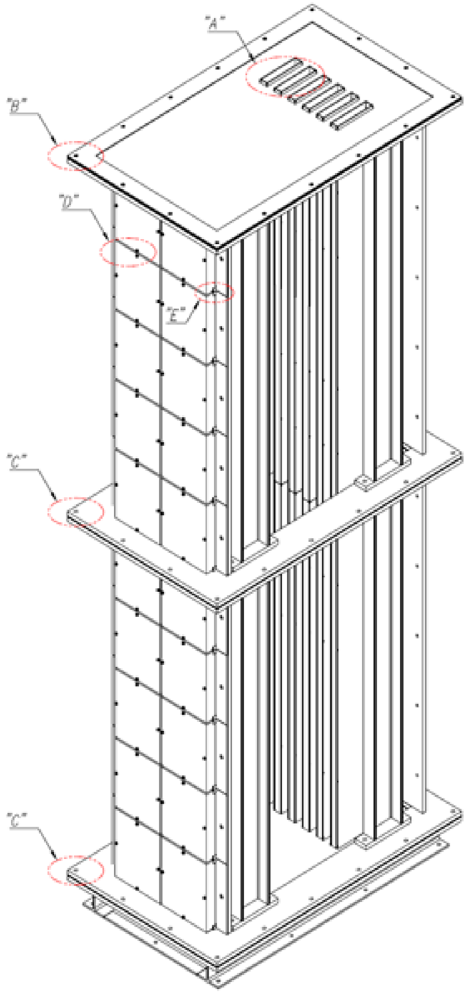
## RCCS Schematic (part)

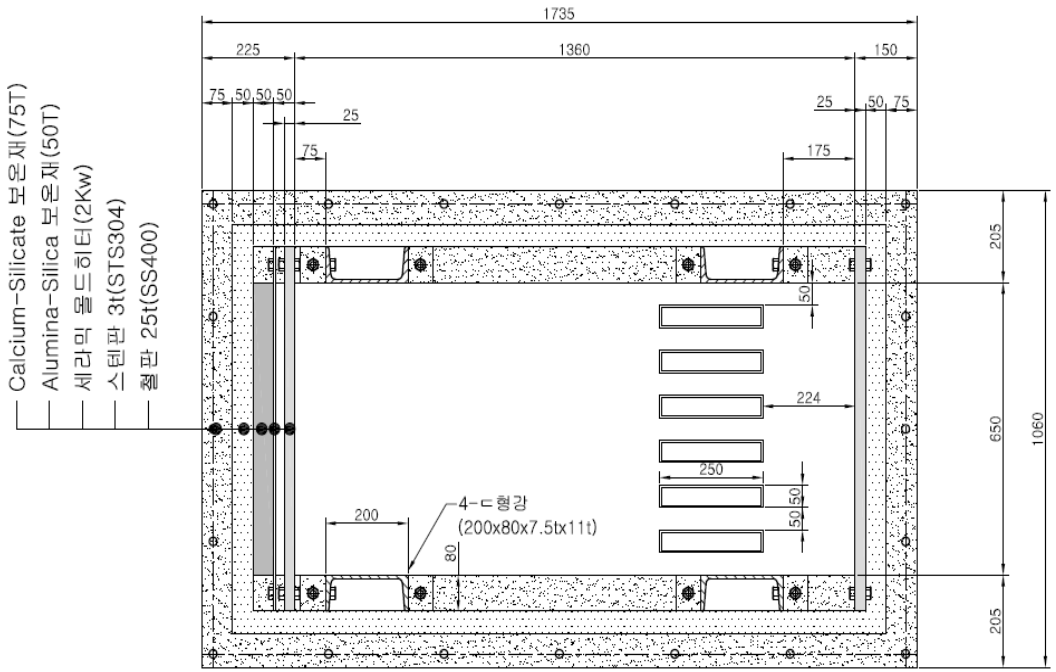


NACEF

# NACEF Heater Box

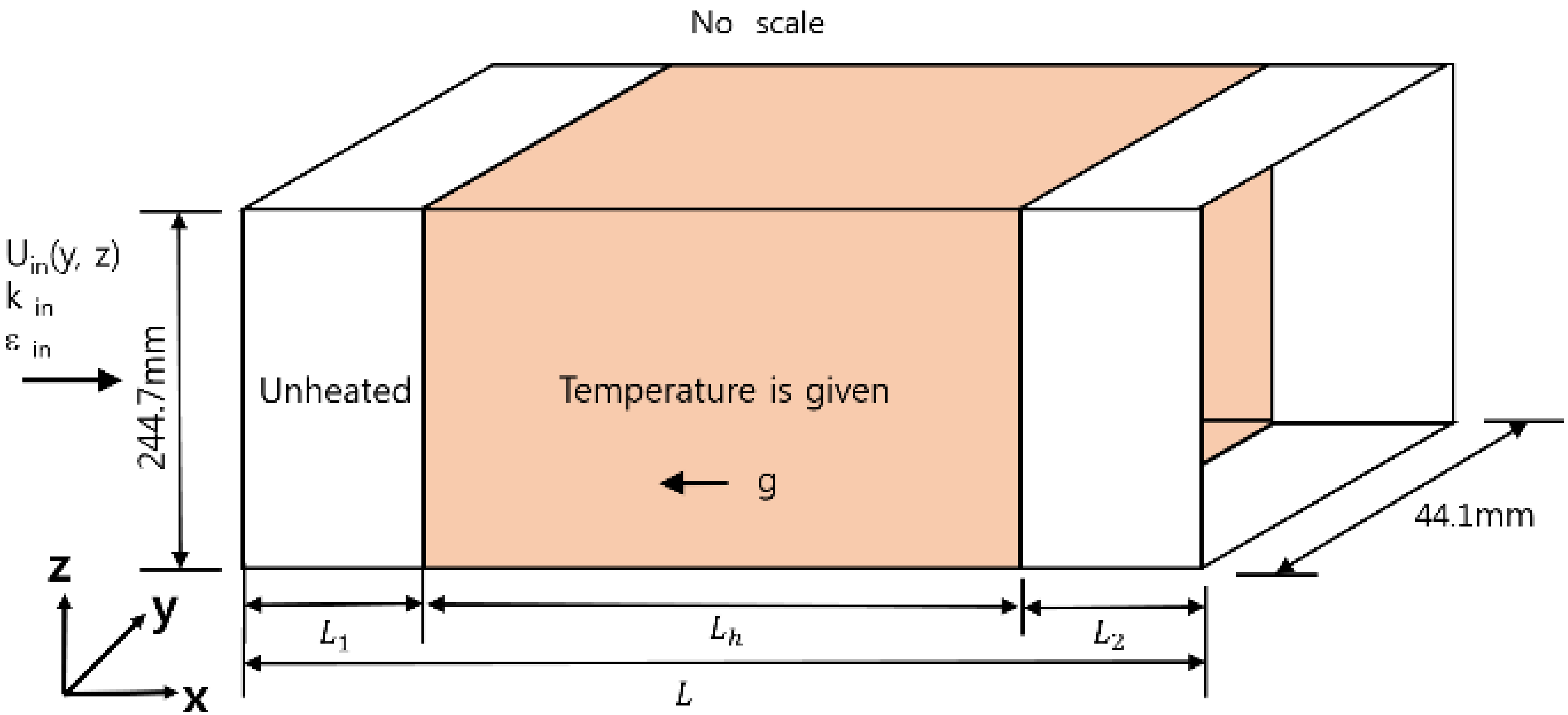


# Introduction

- I-NERI program
  - Comparative study of RCCS riser heat removal capability
  - Scale-down only in the vertical direction
    - KAERI, NACEF: ¼ scale
    - ANL, NSTF: ½ scale
    - U. of Wisconsin: ¼ scale
- Scaling analysis
  - Heat transfer coefficient
    - Forced convection: $h_R = \ell_R^{0.4}$
    - Natural convection: $h_R = 1$
    - Mixed convection: $h_R = ?$
- Unusual relations between NACEF and NSTF tests
- Necessity of numerical analysis was identified

# Computational Domain



# Initial and Boundary Conditions

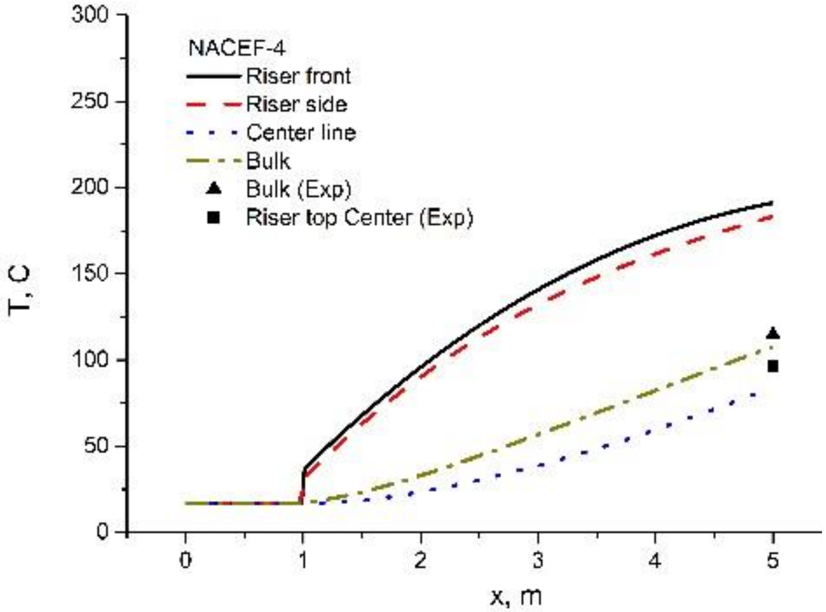
| | KAERI | | ANL | |
|---|---|---|---|---|
| **Case** | $Pl_R = 1$ | $Ri_R = 1$ | $Pl_R = 1$ | $Ri_R = 1$ |
| **ID** | NACEF-4 | NACEF-5 | NSTF-2 | NSTF-1 |
| $u_{in}$, **m/s** | 0.98 | 1.8 | 1.46 | 2.35 |
| $T_{in}$, **K** | 290 | 290 | 290.8 | 295.5 |
| $Re_{in}$ | 4455 | 8167 | 7219 | 11210 |
| $L_1$, **m** | 1.0 | | 0.17 | |
| $L_h$, **m** | 4.0 | | 6.83 | |
| $L_2$, **m** | 0.0 | | 0.40 | |

| | | | | |
|---|---|---|---|---|
| **Turbulence model** | **RNG-TL** | **MK** | **RKE-TL** | **RKE-TL** |

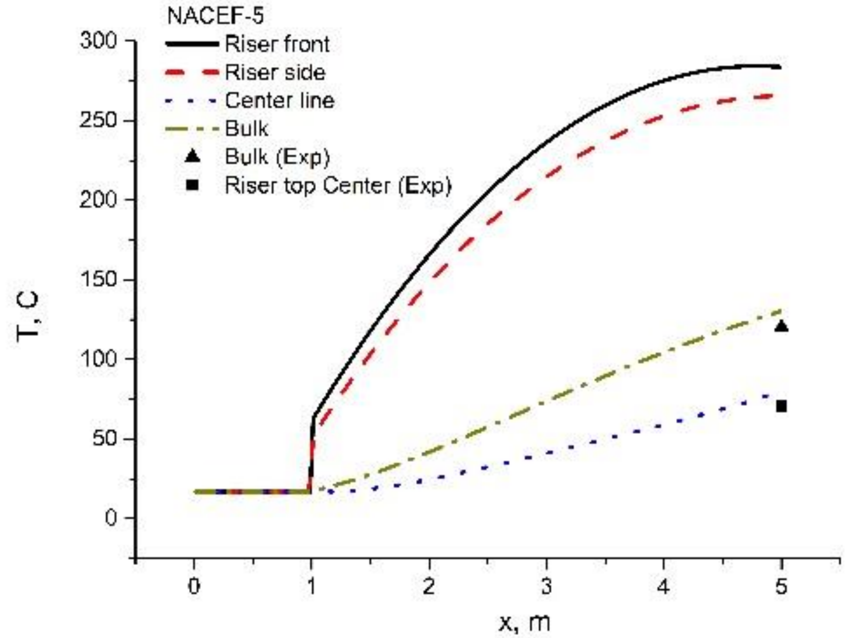
# Computational Method

- 3-D FVM
- SIMPLE algorithm
- Grid numbers (x x y x z)
  - NACEF: 200 x 40 x 100
  - NSTF: 270 x 40 x 100
- $y^+ < 0.5$
- $k_{in} = 1.5 u_{in}^2 Ti^2$ and $\varepsilon = 10^2 k$, $Ti$=0.1%
- Boundary condition for energy eq. : T(z) from experiment

# Numerical Results

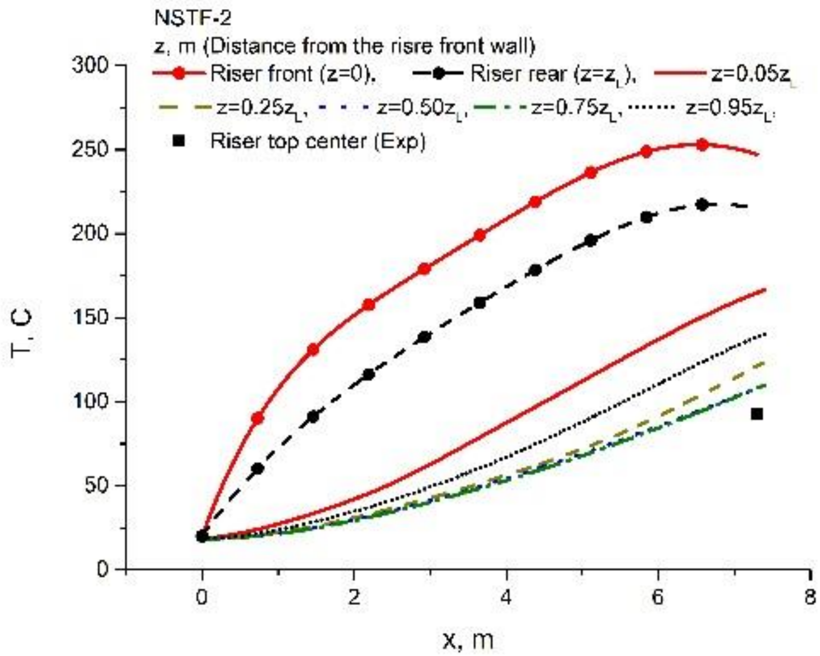



$Pl_R = 1$, NACEF-4

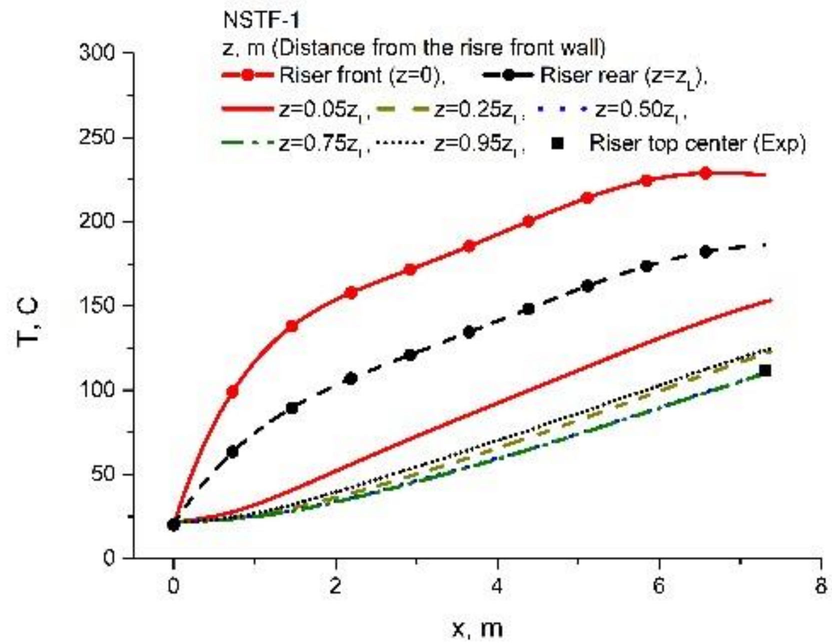



$Ri_R = 1$, NACEF-5

# Numerical Results




$Pl_R = 1$, NSTF-2




$Ri_R = 1$, NSTF-1

Note: The lines for *z*=0.5 $Z_L$ and 0.75 $Z_L$ were nearly overlapped.

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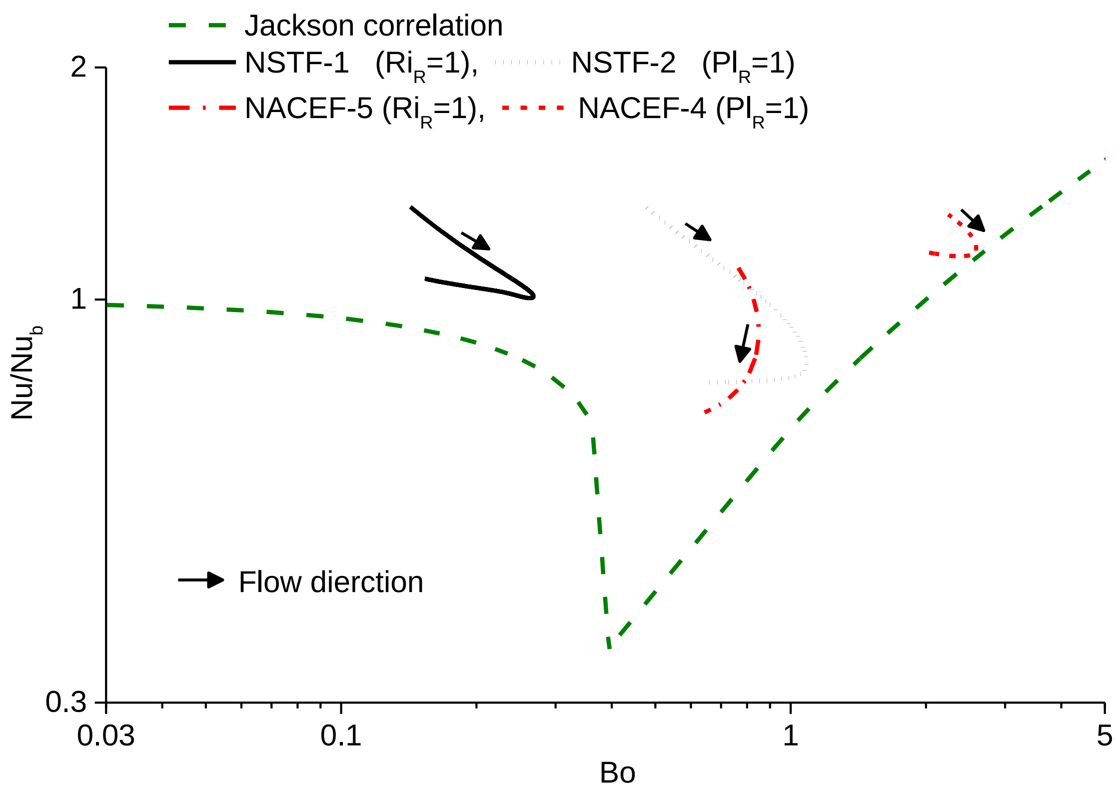
# Variation of Reduced Nusselt Number

- $Bo = Gr_b/(Re_b^{2.625} Pr_b^{0.4})$, $Gr = g\beta(T_w - T_b)D^3/\nu^2$, $Re = ud/\nu$
- $Nu_b$: evaluated by the Gnielinski correlation
- The results clearly requires a scaling based on Bo rather than Re.

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# Variation of Reduced Nusselt Number

| | | ANL | | KAERI | |
|---|---|---|---|---|---|
| **Case** | | NSTF-1 $Ri_R = 1$ | NSTF-2 $Pl_R = 1$ | NACEF-5 $Ri_R = 1$ | NACEF-4 $Pl_R = 1$ |
| $Nu/Nu_b$ | | 1.064 | 0.781 | 0.714 | 1.158 |
| ***Bo*** | Numerical | 0.154 | 0.635 | 0.643 | 1.939 |
| | Scaling Law | 0.222* | | 0.643 | |

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# Scaling Law

- Based on Symolon Correlation: $Bo_q = Gr_q / \left(Re_b^3 Pr_b^{0.5}\right)$
  - Temperature-based $Gr_q$ was used for convenience.
  - $$\left(Bo_q\right)_R = \frac{\left(Bo_q\right)_m}{\left(Bo_q\right)_p} = \begin{cases} \ell_R^{-2} \; for \; Ri_R = 1 \\ \ell_R^{-3} \; for \; Pl_R = 1 \end{cases}$$

- Nusselt number can be estimated from the SNU correlation.
  - $$\frac{Nu}{Nu_T} = \left\{ \begin{array}{l} \left[ \dfrac{\left(\dfrac{9.2320\times10^{-5}}{Bo_q}\right)^{4.0330}}{1+\left(\dfrac{9.2320\times10^{-5}}{Bo_q}\right)^{4.0330}} \right]^{4.7420} + \\ \left(0.4756 Bo_q^{0.3326}\right)^{4.7420} \end{array} \right\}^{0.2109}$$

# Conclusions

- Numerical simulation of buoyancy influenced flow field
  - Selection of turbulence model was very important.
  - Low-Re $k$-$\varepsilon$, RNG-TL, RKE-TL worked in our cases.

- When buoyancy is involved
  - The value of *Bo* should be checked whether heat transfer mode is mixed convection
  - Heat transfer coefficient estimation should be made via buoyancy parameter.

# Comment Resolutions

- The boundary conditions are not available for the prototype.
  - Attempts are being made to simulate whole part of RCCS (cavity + riser s +chimneys)
  - ANL's results are not promising
  - Due to the limitation of computation resources, KAERI is attempting to simulate only a part of system (cavity + risers)
- SNU is now developing a new correlations based on the correlation proposes by Symolon, which is generally overlaps on the Jackson correlation.

- Since we already know from the earlier experiences that the standard $k$-$\varepsilon$ model totally failed in the simulation of NACEF test, we did not even attempt to use it.
  - Unrealistic turbulence model did not result in a converged solution.