Evaluation of CHF correlation Model Performance in MATRA for Various Rod Bundle Geometries

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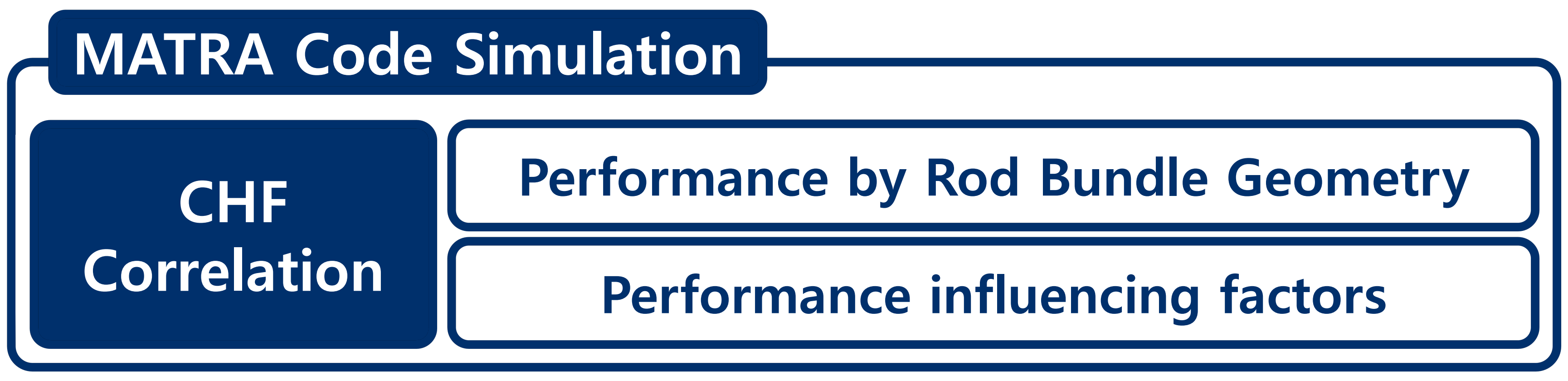
1. Introduction

- **Critical Heat Flux (CHF)** is a key thermal design parameter determining heat transfer and thermal margin in a reactor core. To predict this, various CHF correlations have been developed based on experimental data.
- However, because CHF in a fuel assembly is governed by multiple variables, **current CHF correlations are highly dependent on specific geometries** and radial/axial power distributions [1].
- To develop an enhanced CHF prediction model, **the performance of pre-existing CHF correlations** and **their influencing factors** were analyzed using the MATRA code according to fuel assembly designs and thermal-hydraulic conditions.



MATRA Code Simulation

CHF Correlation

Performance by Rod Bundle Geometry

Performance influencing factors

2. Method

CHF Correlation

B&W-2
W-3
WRB-1

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Rod array

5x5 standard
5x5 cruciform
5x5 with big rod

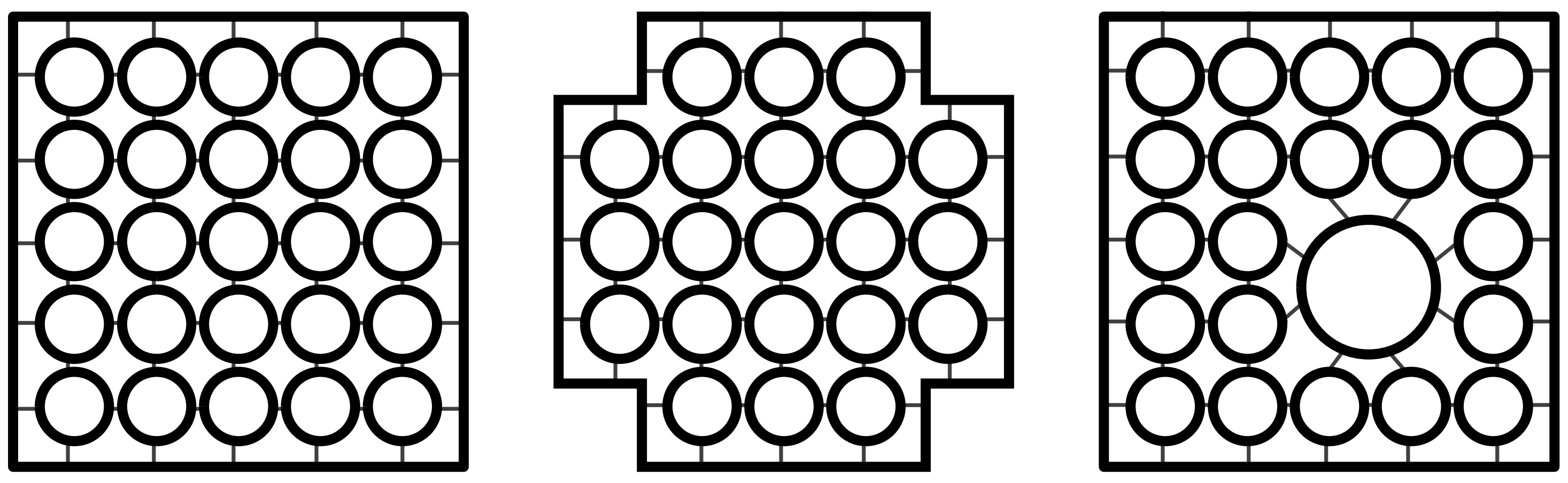


Fig 1. Geometries of rod configuration

- CHF database collected by EPRI [2], total 3,104 experimental data of three fuel assembly geometries were analyzed by MATRA.
- The simulations were performed using the iteration on power function.

Variables	Range
Inlet mass velocity	67.81 ~ 6046 $[kg/m^2 \cdot s]$
Inlet temperature	303.1 ~ 445.2 $[K]$
Exit pressure	1.345 ~ 16.79 $[MPa]$
Rod diameter	9.5 ~ 11.18 $[mm]$
Rod length	1219 ~ 4267 $[mm]$
Rod to rod gap	1.75 ~ 4.06 $[mm]$
Axial geometry slice gap	29 ~ 101.6 $[mm]$
Axial power profile (ratio)	Uniform, Non-uniform (0.296 ~ 1.63)

Table I. Inlet conditions of selected CHF database

Thermal-hydraulic analysis	Correlation models
Subcooled void fraction	Homogeneous model
Bulk void fraction	Chexal-Lellouche model
Two-phase friction multiplier	Homogeneous model
Type of void draft correction factor	KAERI (Independent of flow regime)

Table II. Models employed to compute the parameters related to the two-phase flow

3. Results and Discussion

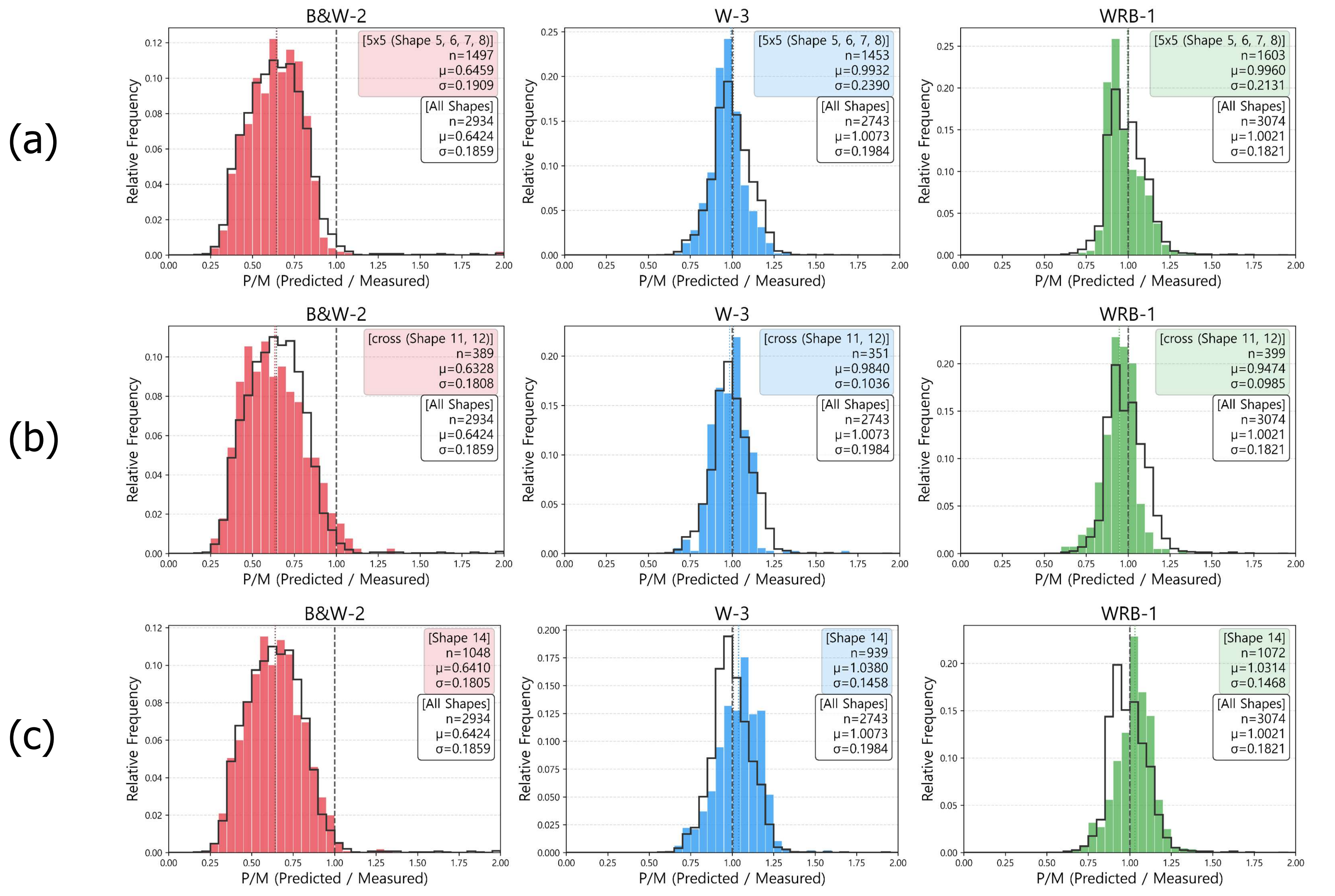
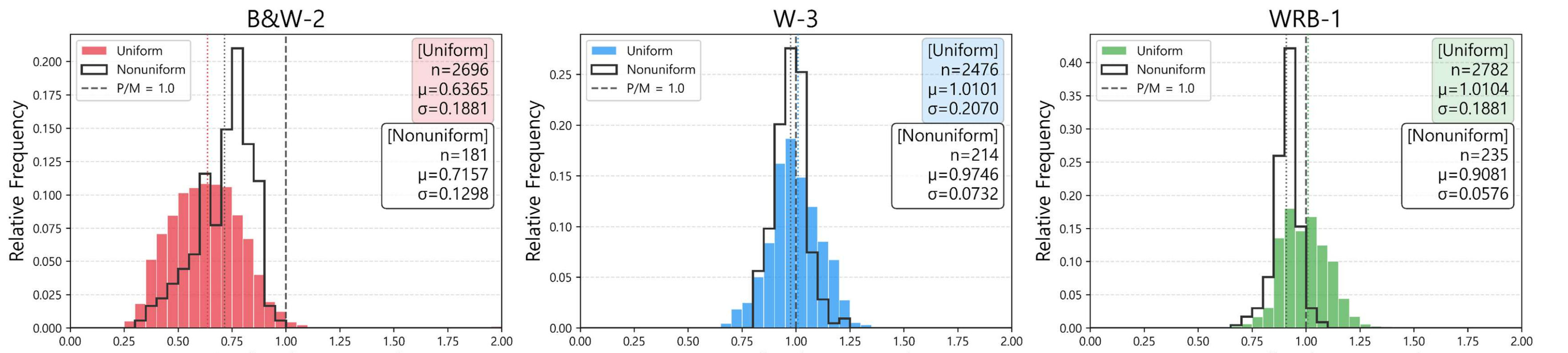
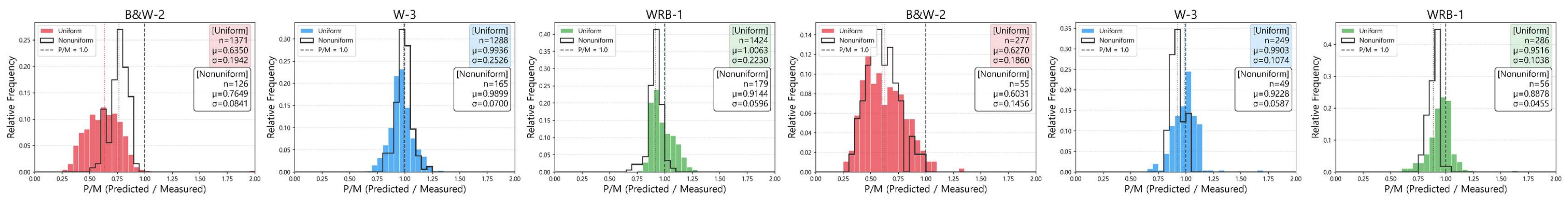


Fig 2. Prediction data histogram according to fuel rod assembly geometries
(a) 5x5 standard, (b) 5x5 cruciform, (c) 5x5 with big rod

- WRB-1 and W-3 demonstrated high accuracy (mean P/M ≈ 1.0), whereas B&W-2 consistently underpredicted CHF across all geometries.
- The consistent underprediction of B&W-2 is attributed to its inherent conservatism (lack of a turbulence correction factor), rather than pressure data limits [4].
- W-3 slightly outperformed WRB-1 in the cruciform geometry. This is attributed to the fact that W-3 incorporates the cold-wall factor $F_{CW} \propto \left(1 - \frac{D_{wetted}}{D_{heated}}\right)$ [5], which accounts for changes in geometric structure.



(a) Entire array

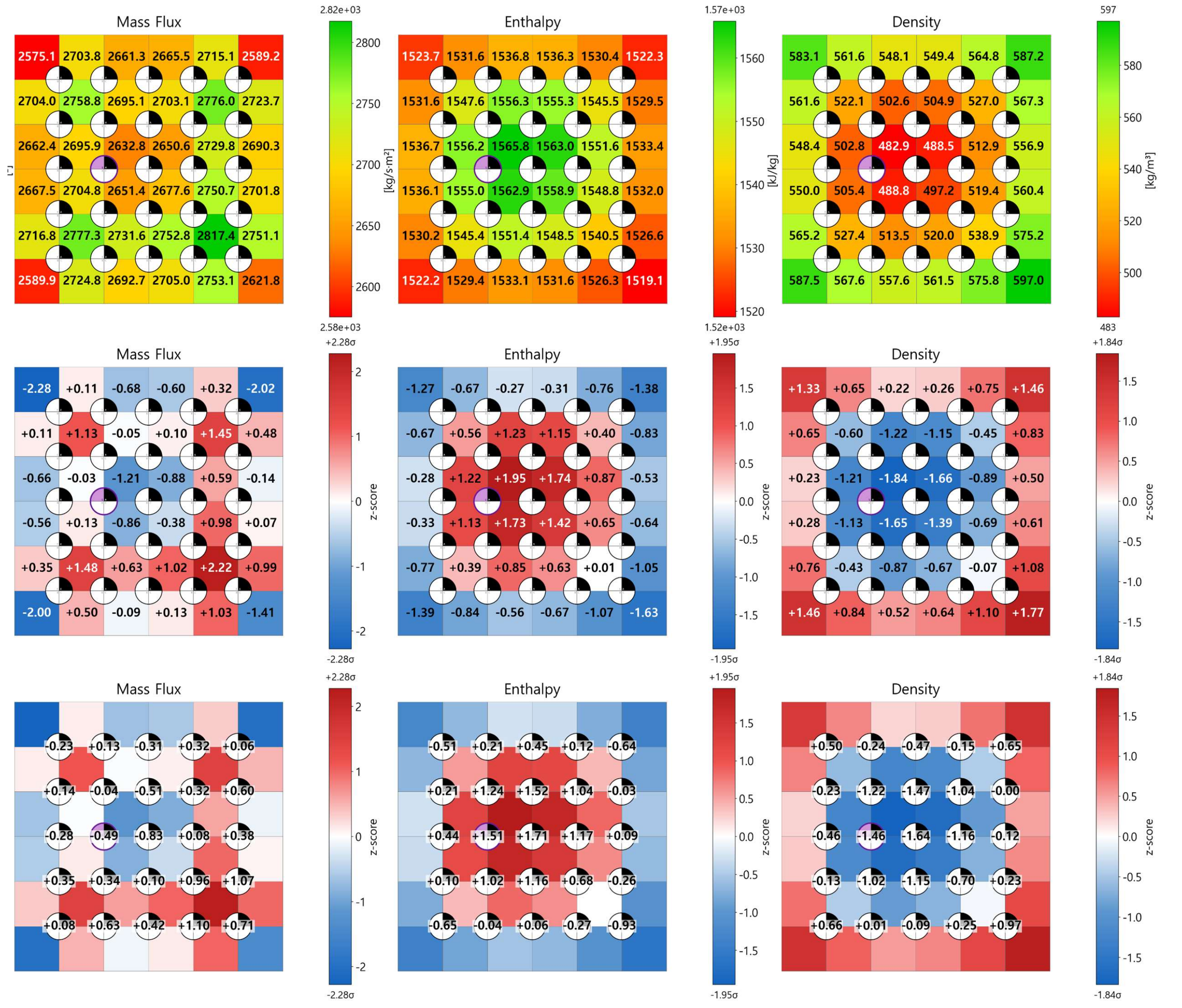


(b) 5x5 standard array

(c) 5x5 cruciform array

Fig 3. Prediction data histogram according to axial power distribution (vs Nonuniform)

- Nonuniform power distributions significantly improved prediction consistency for all models.
- Notably in B&W-2, geometric differences from atypical structures completely dominated over the effectiveness of axial power correction (F_{APk}) [3].



(a) Distributions of local thermal-hydraulic parameters

(b) z-score

(c) Average z-score of 2x2 subchannels

Fig 4. Specific data of thermal-hydraulic parameters prediction results on at 5×5 standard array
(5x5 standard, P = 12.41MPa, T = 566.5 K, G= 2703 $kg/m^2 \cdot s$, Purple: Actual CHF rod)

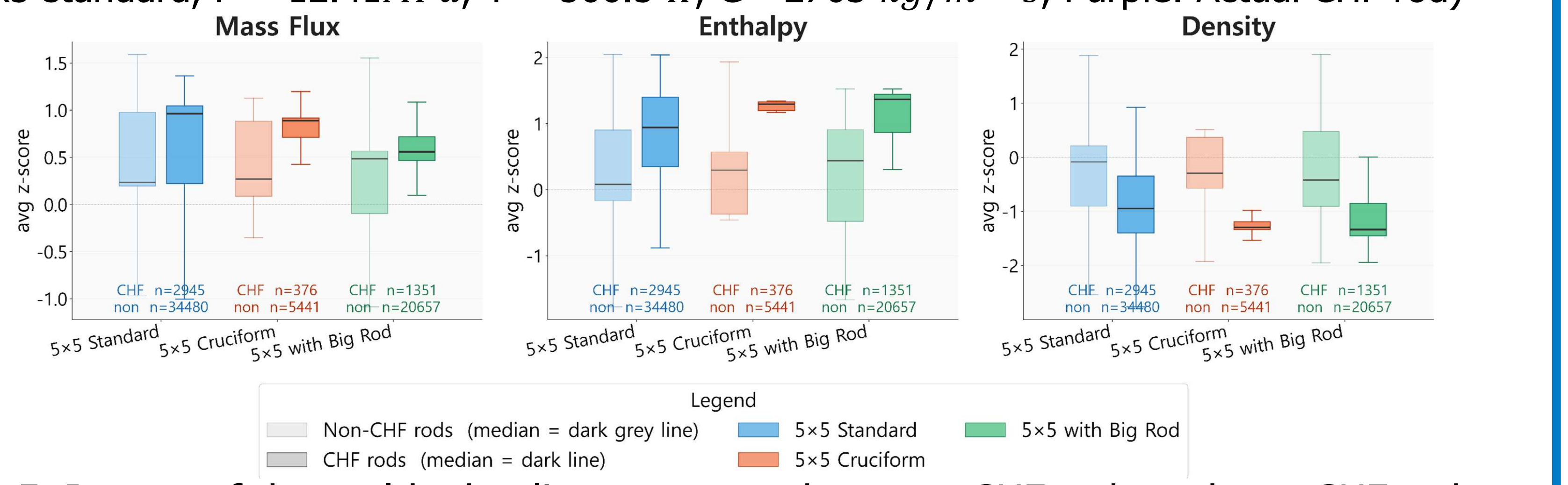


Fig 5. Impact of thermal-hydraulic parameters between CHF rods and non-CHF rods

- Enthalpy and density exhibit significant differences between CHF and non-CHF rods. Notably, in the 5x5 cruciform array, a margin of over 0.5 exists between the two distributions, indicating high sensitivity to these parameters.

4. Conclusion

WRB-1 and W-3 demonstrated high accuracy with mean predictions close to 1.0. Notably, in the atypical cruciform geometry, W-3 slightly outperformed WRB-1 by approximately 0.04 (mean prediction of 0.98). This is because the cold-wall factor F_{CW} is explicitly considered. For B&W-2, the nonuniform power correction led to significant improvements in the standard array but failed to do so in the atypical structure. This suggests that severe geometric distortion powerfully dominates the correlation's predictive performance in atypical geometries. Furthermore, local parameter analysis revealed that enthalpy is a primary discriminator for CHF in distorted geometries (z-score margin>0.5). Therefore, future enhanced CHF correlations must prioritize explicit geometric corrections and local enthalpy parameters.

References

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