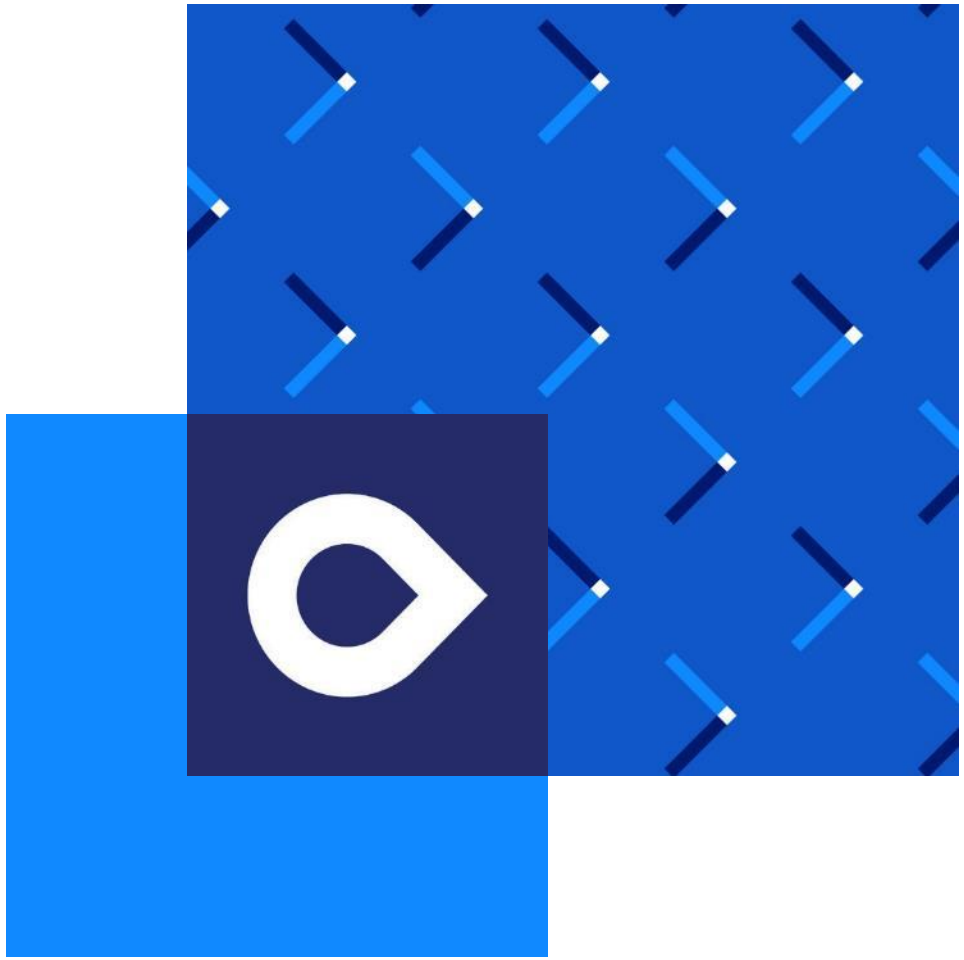
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VERA-440: Verification and Validation Approach and its Application to selected Tests and Benchmark Calculation

Matthias Roppel & Özlem Aktaş Özülüş

October 20-21

pwr PRAGUE 2026



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2. Mechanical assembly testing
3. COBRA-FLX & ALTHAMC12 Subchannel Code Benchmark

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1.

Verification and Validation Approach

Overview

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Verification and Validation Approach

Requirements

High-level requirements are expressed by stakeholders and have translated into specific, measurable criteria or derived requirements.

Design

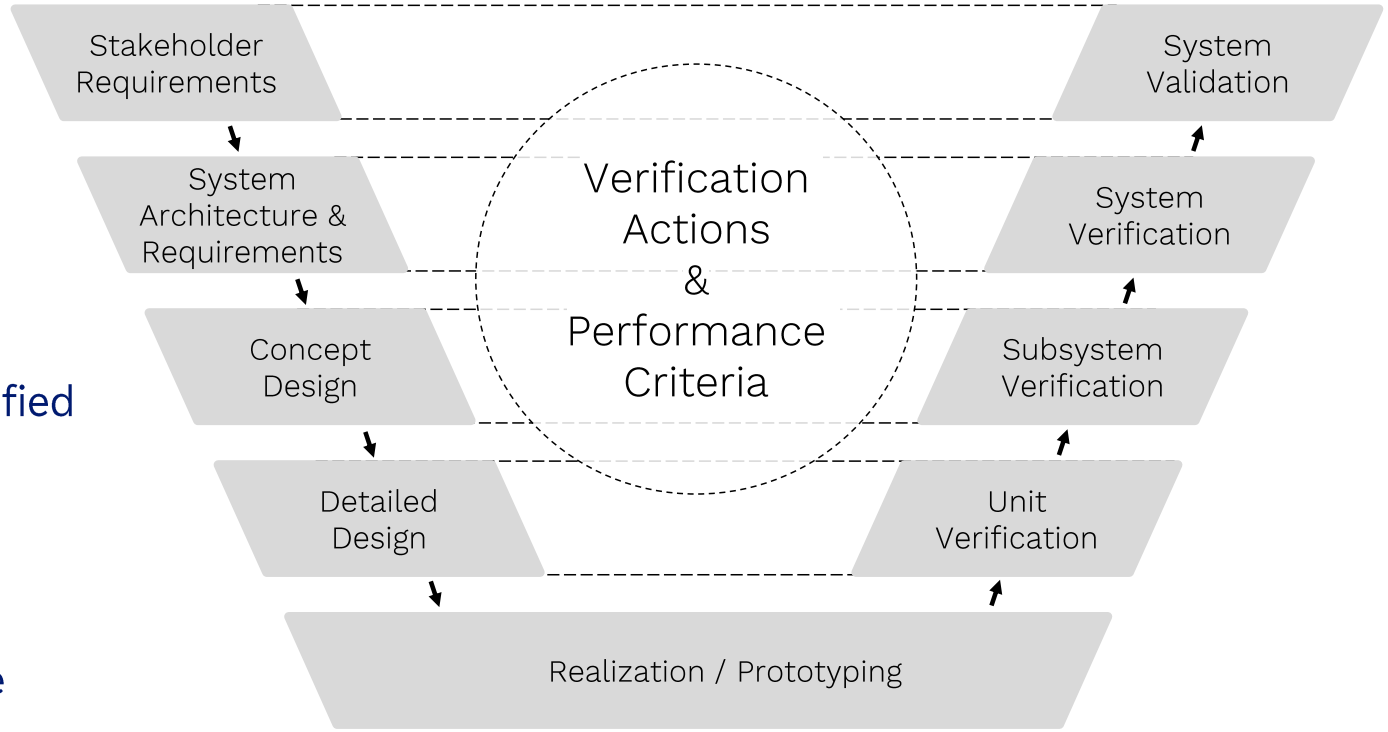
Design defines the architecture, components, interfaces, and interactions.

Verification

Verification demonstrates compliance with specified requirements through analyses, tests and inspections.

Validation

Validation demonstrated that the product or the applied models are suitable for their intended purpose.



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Verification Approach

Top Nozzle

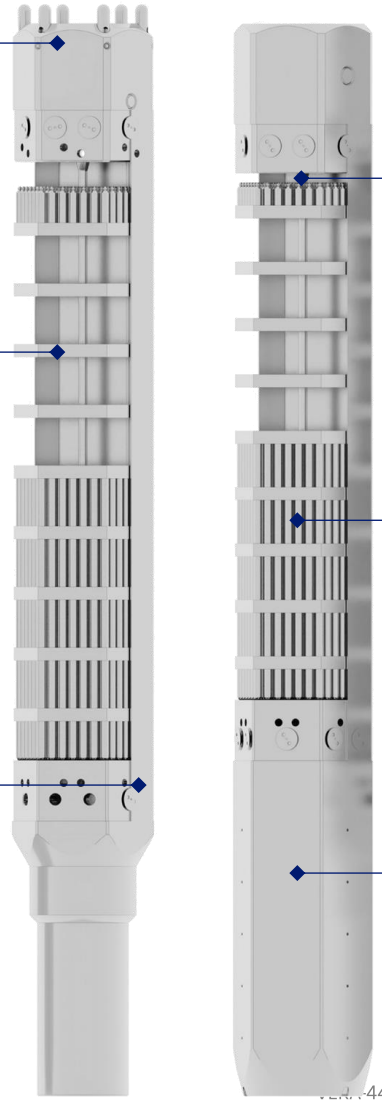
- Hold-down test and analyses
- Pressure loss analyses
- Load tests and analyses

Spacer Grid

- Material qualification
- Rod contact zone and clamping
- Rod fretting resistance
- Pressure loss analyses
- Buckling testing
- Central tube connections tests

Shroud

- Material qualification
- Shroud load test
- Nozzle connection load test
- Creep behavior analyses



Central Tube

- Material qualification
- Load analyses
- Insertion check
- Connections load tests

Fuel Rod

- Material qualification
- Mechanical design justification
- Insertion check

Bottom Nozzle

- Pressure loss analyses
- Body and tie plate strength
- Connections loads

Assembly

- Mixing and CHF testing
  Framatome, KATHY loop
- Pressure loss coefficient Tests
  ŠKODA JS a.s., KAZEX Test Loop
- Follower fuel assembly drop test
  ŠKODA JS a.s., KAZEX Test Loop
- Endurance test
  CEA Cadarache, HERMES-P loop
- Dynamic behavior test
  Framatome, SHP-1 test bench
- Flow-induced vibration tests
  Framatome, PETER loop
- Transportation test
- Accident analyses
- Neutronic analyses (burnups, etc.)

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2.

Mechanical assembly testing

Endurance test and Follower fuel assembly drop test

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Endurance test

Hermes-P Loop, CEA Cadarache

Objectives

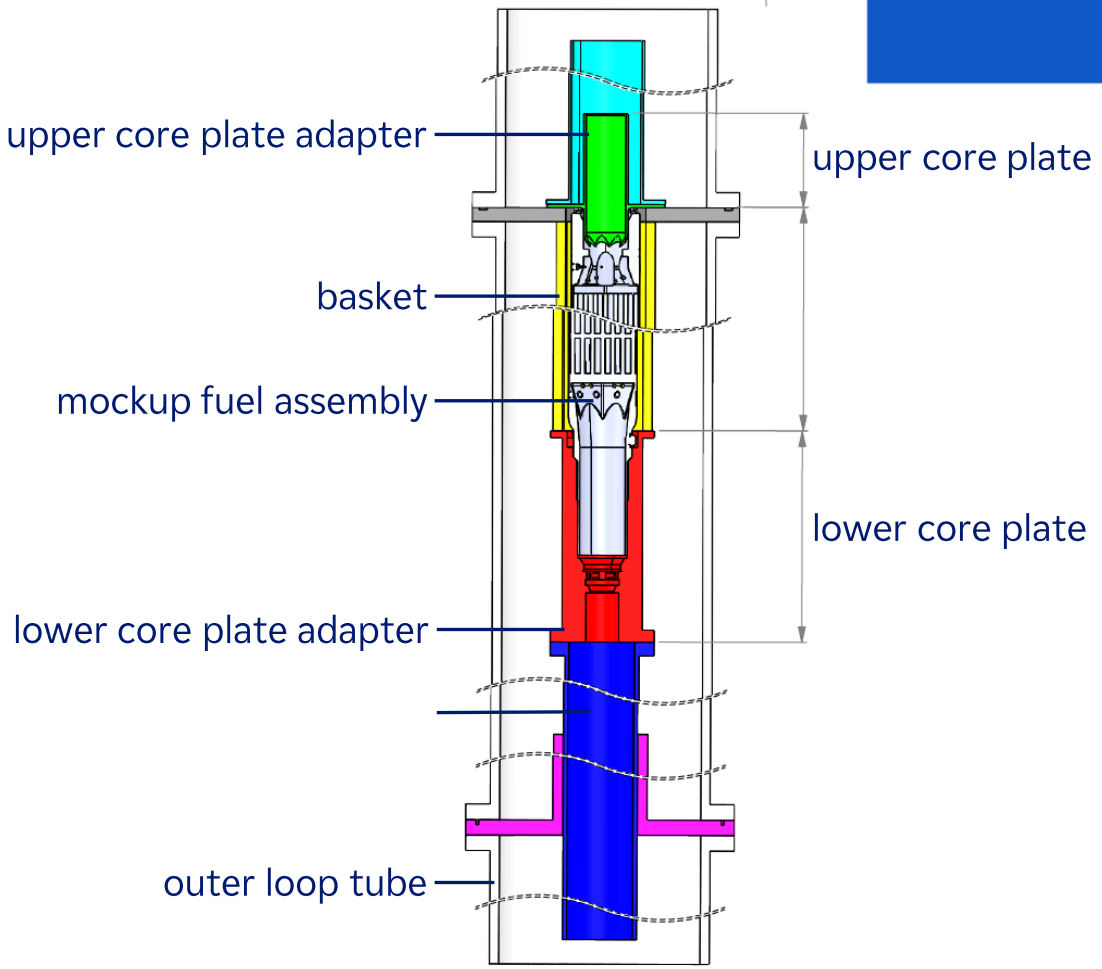
- Assessment of fuel rod fretting wear
- Verification of spacer grid support integrity

Description

A mockup fuel assembly, including upper and lower core plate adapters, will be installed in the Hermes-P loop. The 1000-hour test will be conducted under reactor-simulated conditions regarding temperature, pressure, and flow rate to assess the fretting and wear behavior.

Maximum loop capabilities

Maximum Pressure	15.5 MPa
Maximum water temperature	320°C
Water flow	800 m^3/h



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Follower fuel assembly drop test

KAZEX Test Loop, ŠKODA JS a.s.

Objectives

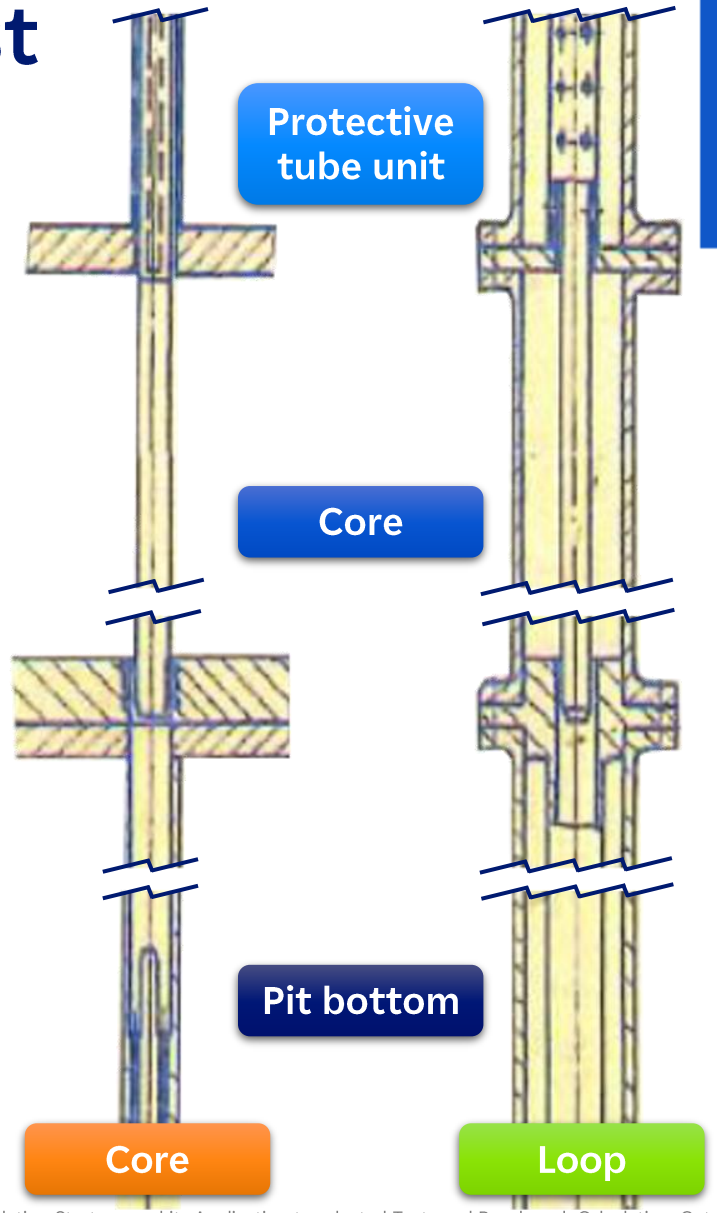
- Characterization of drop dynamics
- Assessment of hydraulic damping performance

Description

The campaign includes drop tests at different fluid temperatures and flow rates. The follower fuel assembly is released from its in-core position and descends over 2500mm into the below core position. Transient motion is monitored to determine drop time, position and velocity to characterize the hydraulic behavior.

Maximum loop capabilities

Maximum Pressure	12.5 MPa
Maximum water temperature	300°C
Water flow (300°C)	130 m^3/h



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3.

COBRA-FLX and ALTHAMC12 Subchannel Code Benchmark

Özlem Aktaş Özülüş (Framatome GmbH)
Štěpán Foral (TES s.r.o.)

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Introduction

Objectives

- Code-to-code comparison between COBRA-FLX and ALTHAMC12 subchannel codes for open-literature, measured data sets with relevancy to VVER-440 conditions
- Verification of proper implementation of CHF correlations in COBRA-FLX
- Assessment of compatibility between the two codes and potential discrepancies
- Foster collaboration, knowledge exchange and best practice sharing



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COBRA-FLX

- COBRA-FLX Developed and Used by Framatome for decades
- NRC Approval received in January 2013[1]
- Framatome Standard Subchannel Code for PWR and VVER for CHF testing evaluation, correlation development, TH subchannel safety analyses
- Flexible meshing: Square or Triangular Lattice, variable meshing size
- Code Benchmark for VVER-1000 relevant data sets done in 2021[2]

ALTHAMC12

COBRA-IIIC

- ALTHAMC12 code developed by the Czech company ALVEL
- Subchannel code intended for safety analyses in normal and abnormal operations
- Optimized for triangular (VVER) rod array in terms of TH models
- Already tested in the TES s.r.o. company against several benchmarks. Submission for code licensing at SUJB planned in 2027

[1] ANP-10311NP-A, Revision 0, "COBRA-FLX: A Core Thermal-Hydraulic Analysis Code", January 2013
[2] "Framatome VVER codes and methods strategy roll out for VVER-1000 fuel assemblies", VVER 2022 Conference, Prag.

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Overview of the Experimental Data Sets

Data Set	Heated/unheated rod no.	Rod Diameter	Rod Pitch	Heated Length	Data Points no.	Radial Peaking Factor	Axial Peak. Factor	Pressure Range	Mass flux range
	[-]	[mm]	[mm]	[mm]	[-]	[-]	[-]	[Mpa]	[kg/m^{2}s]
1	36/1	9	12.2	2500	63	1	1	2.2 - 6.2	220 - 1670
2	19/0	9	12.2	2500	54	1	1	0.8 - 7	428 - 2852
3	7/0	9.1	12.8	800	25	1	1	6.8 - 6.8	205 - 353
4	7/0	9	12.2	1000	88	1	1	10.5 - 19.4	82 - 3230
5	7/0	9	12.2	1800	40	1	1	10.6 - 19.3	730 - 3057
6	7/0	9.1	12.2	2500	72	1	1	10.6 - 19.2	534 - 2500
7	7/0	9	12.2	2500	19	1	1	12.4 - 17.3	711 - 2223
8	7/0	9.1	12.2	2500	46	1	1.56	10.6 - 17.2	505 - 2004
9	7/0	9	12.2	2500	59	1	1	8.2 - 9.1	880 - 3240
10	19/0	9	12.2	2500	40	1	1	9.3 - 10.3	1487 - 3807
11	36/1	9	12.2	2500	59	1	1	7.8 - 9.7	1531 - 3210
12	7/0	9.1	12.6	2500	9	1	1	12.3 - 12.4	2038 - 2537
13	7/0	9.1	12.6	1750	92	1	1	12.2 - 13.9	1500 - 3050
14	7/0	9.1	12.75	1750	32	1	1	13.7 - 15.7	2000 - 3500
15	19/0	10.7	15.14	1524	12	1.15	1	10.3 - 10.3	1348 - 4078
16	15/4	9	12.2	2500	62	1.83	1	6.4 - 8.9	1023 - 3234

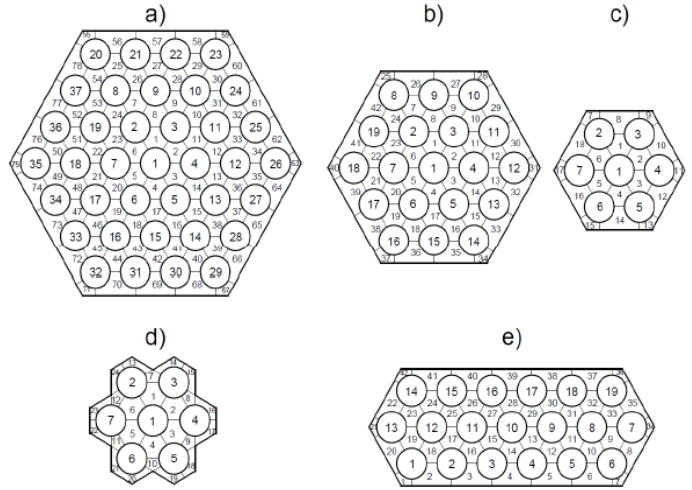


Figure 1 Cross section of a) 37-rod bundles, b) 19-rod bundles, c) 7-rod bundles, d) DS3 rod bundle, and DS16 rod bundle.

a	
b	
c	
d	
e	

- Open source literature[1]

[1] FORAL, Š.; KATOVSKÝ, K.; SUK, L.; POLÁŠEK, R. VALIDATION OF THE ALTHAMC12 SUBCHANNEL CODE. In ATH 2020 - International Topical Meeting on Advances in Thermal Hydraulics. Proceedings of ANS. 555 North Kensington Avenue La Grange Park, Illinois 60526 U.S.A.: American Nuclear Society, 2021. p. 768-781. ISBN: 9780894487774.

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CHF Correlations

- Two correlations used for benchmarking
- PG-S correlation
  - Heat balance correlation
  - Applicable in wide range
- OKB3 (Bezrukov) correlation
  - Local type correlation
  - Developed for triangular pitch

Applicability range of the PG-S[1] and OKB3(Bezrukov)[2] Correlations

Parameter	PG-S	OKB
p [MPa]	0.28 – 18.73	7.45 – 16.7
G [$kg.m^{-2}.s^{-1}$]	34 – 7478	700 – 3800
x_{in} [-]	-1.14 – 0.44	-
x_{loc} [-]	-0.34 – 1.0	-0.07 – 0.4
L_{heat} [m]	0.4 – 7	1.7 – 3.5

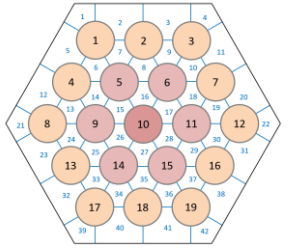
[1] Pernica, R and Cizek, J. "General correlation for prediction of critical heat flux ratio in water cooled channels.", NURETH-7 Conference, New York, Sep. 10-15, 1995.
[2] Bezrukov J.A. et al., Experimental Investigations and Statistical Analysis of Boiling Crisis Data for VVER Rod Bundle. Thermal Engineering, No. 2, in Russian. pp. 80-82. (1976).

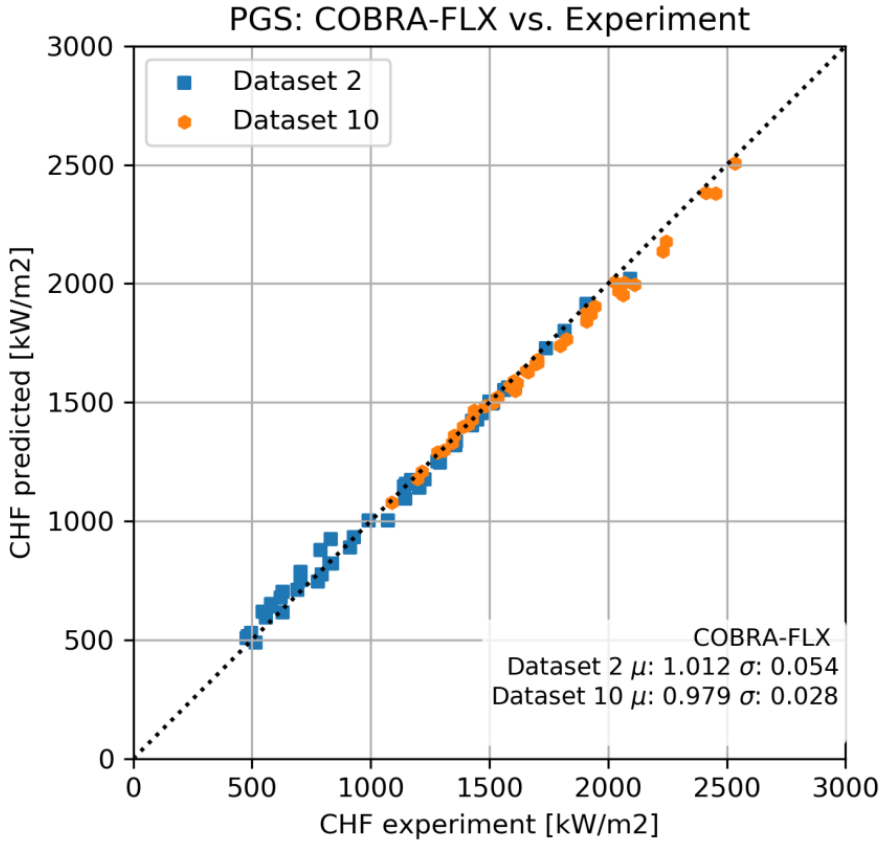
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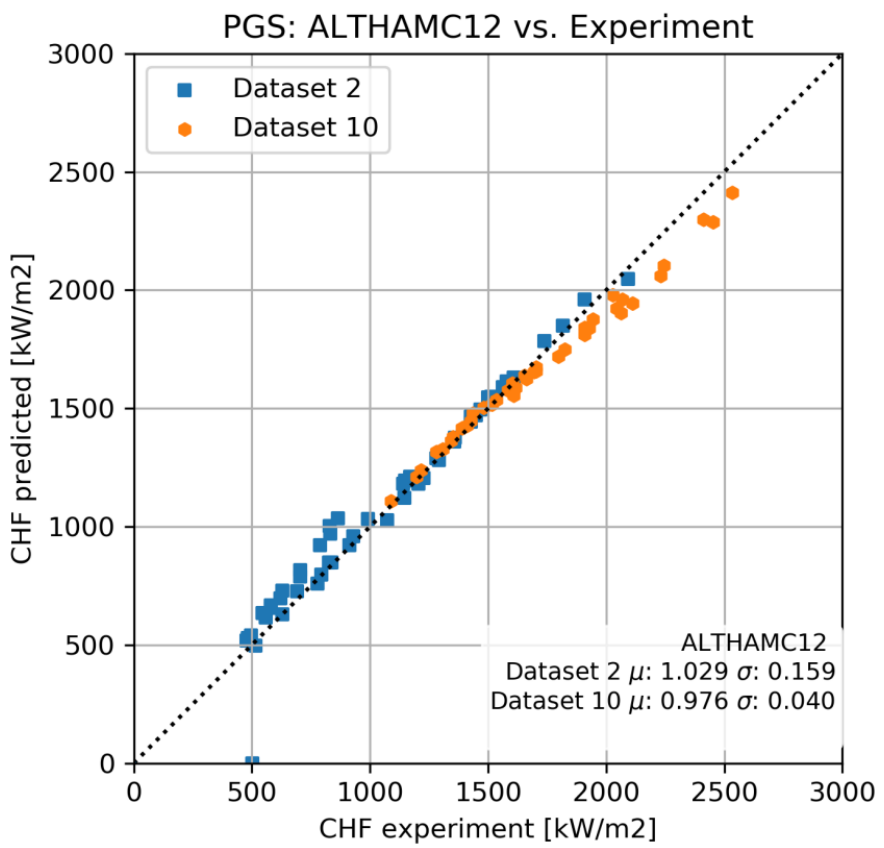
Results

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19 Rods Bundle Results – Data Sets 2, 10
PG-S Correlation



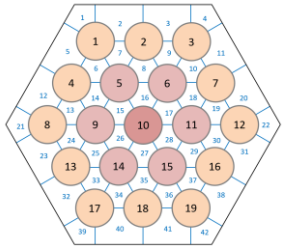




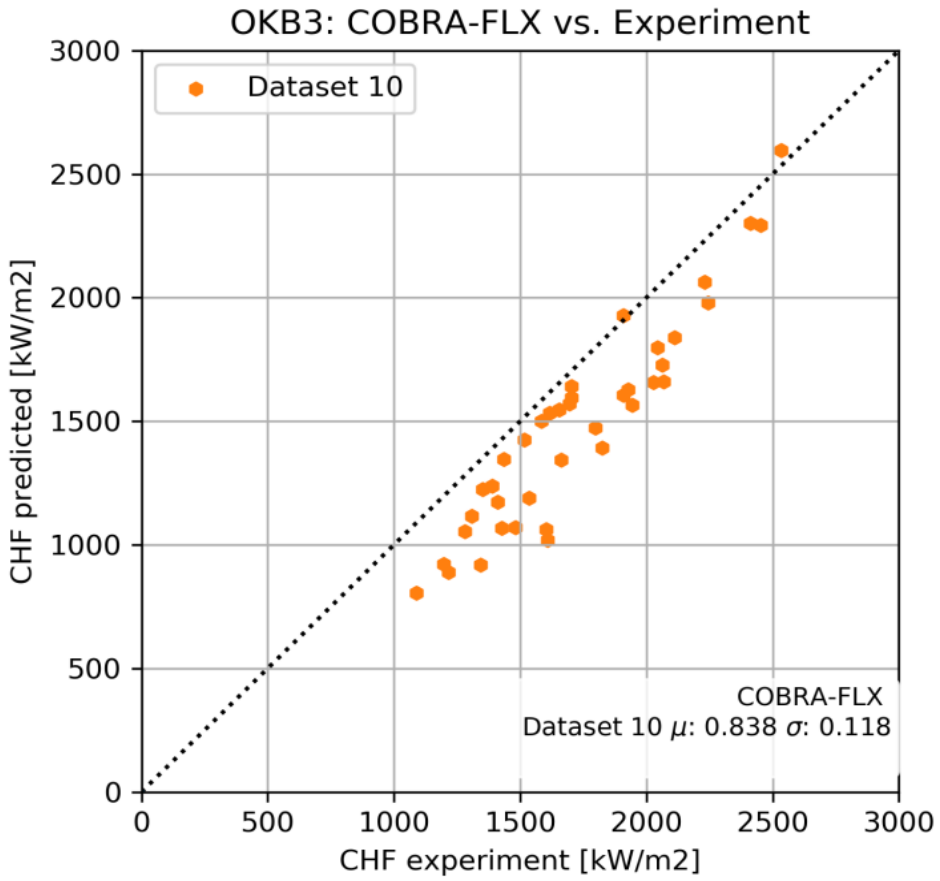
Very good agreement between predicted and measured CHF

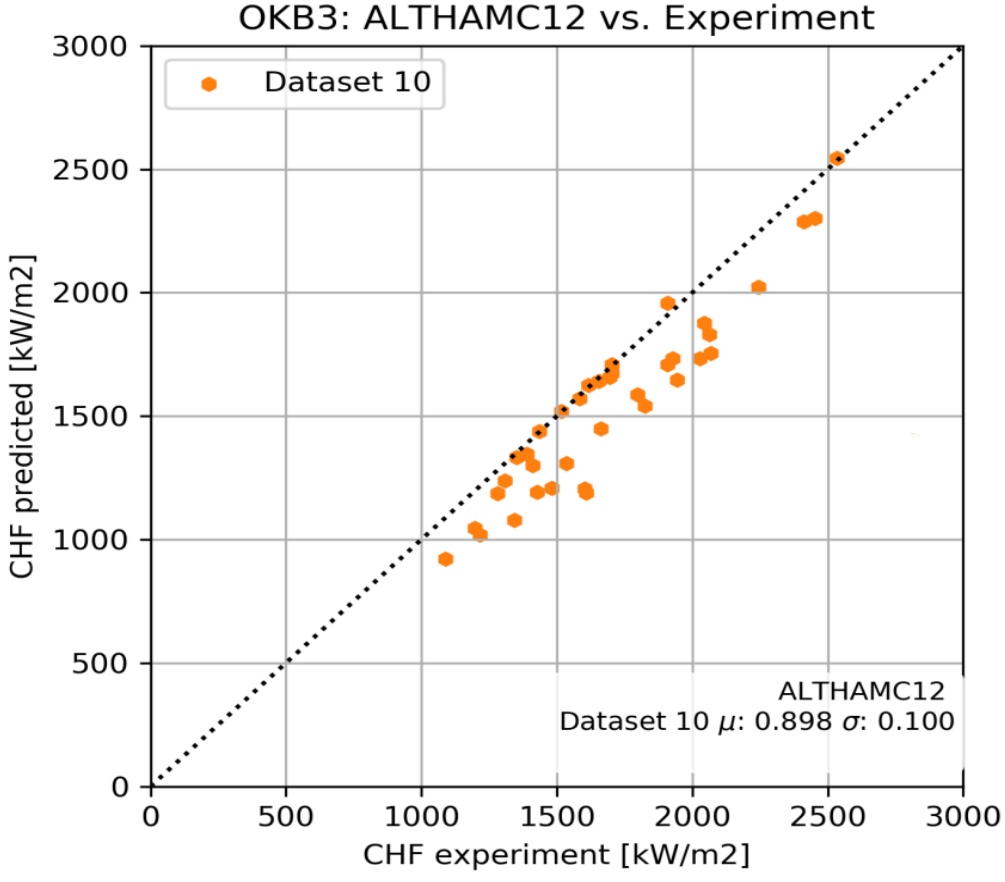
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19 Rods Bundle Results – Data Sets 2, 10
OKB3 (Bezrukov) Correlation



Data Set 2 out of applicability range

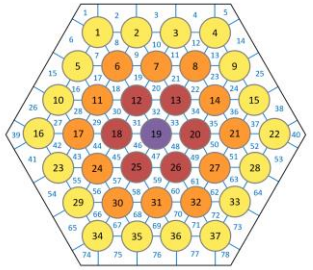


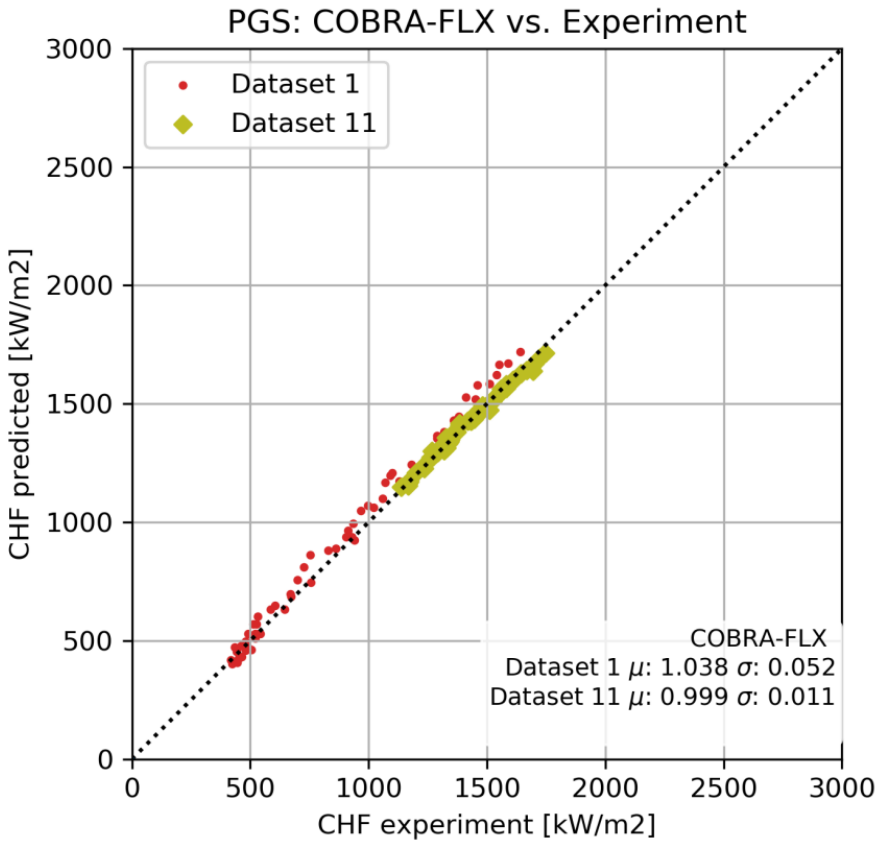


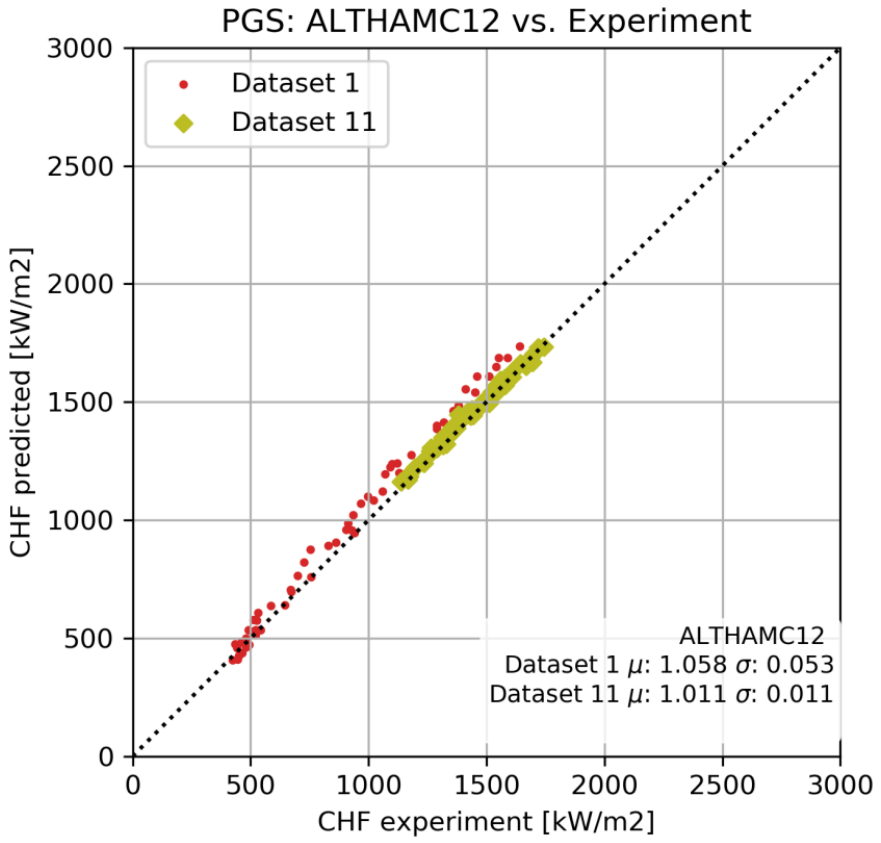
Best estimate agreement with tendency to be conservative

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37 Rods Bundle Results – Data Set 1, 11
PG-S Correlation



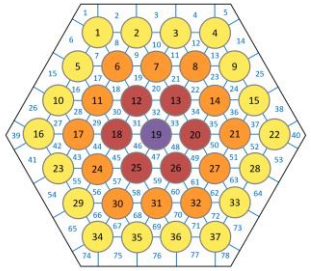




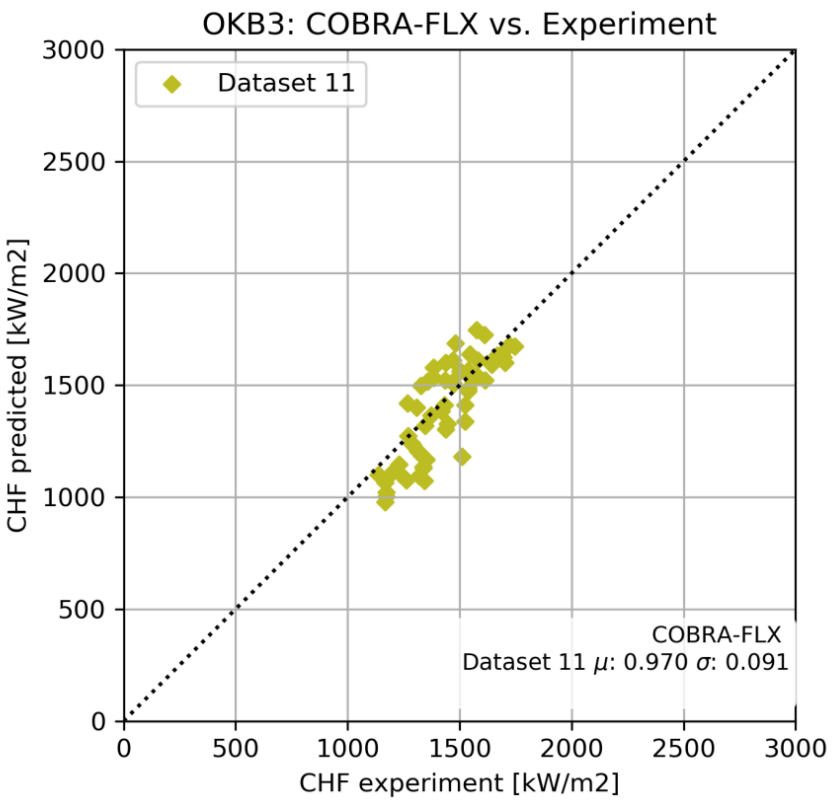
Very good agreement between predicted and measured CHF

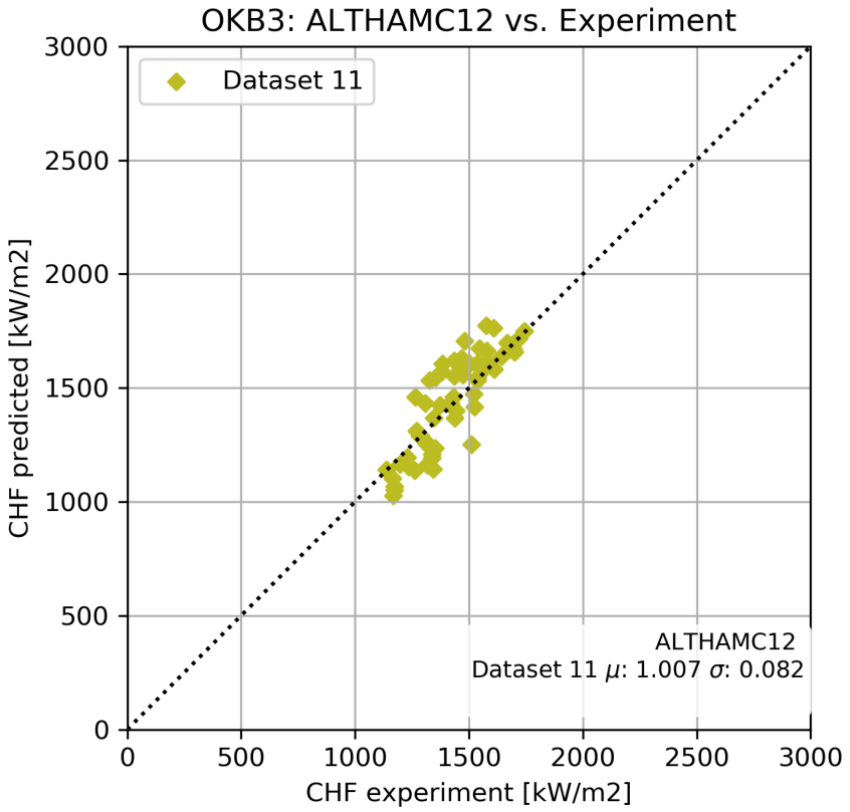
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37 Rods Bundle Results – Data Set 1, 11
OKB3 (Bezrukov) Correlation



Data Set 1 out of applicability range





Very good agreement between predicted and measured CHF

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Conclusion

- Generally, a very good agreement between COBRA-FLX and ALTHAMC12 is observed
- For PGS correlation very good agreement between predicted and measured CHF
- For OKB3 correlation also good agreement with tendency to be conservative
- Overall good agreement confirms that
  - PG-S and OKB3 correlations are correctly implemented in COBRA-FLX
  - COBRA-FLX and ALTHAMC12 are compatible



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Our approach ensures traceability from requirements definition to verification and validation activities. The completed, ongoing and planned verification actions represent key development milestones ensuring robustness and maturity of the VERA-440 design.



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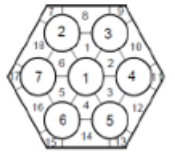


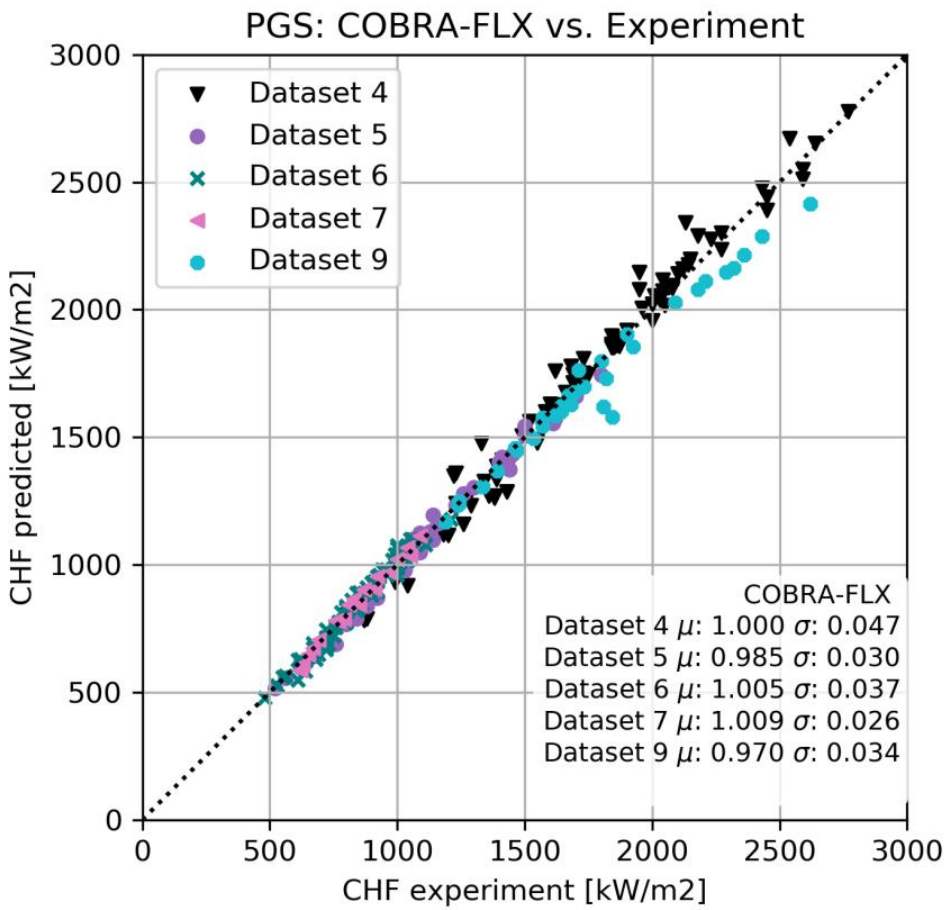
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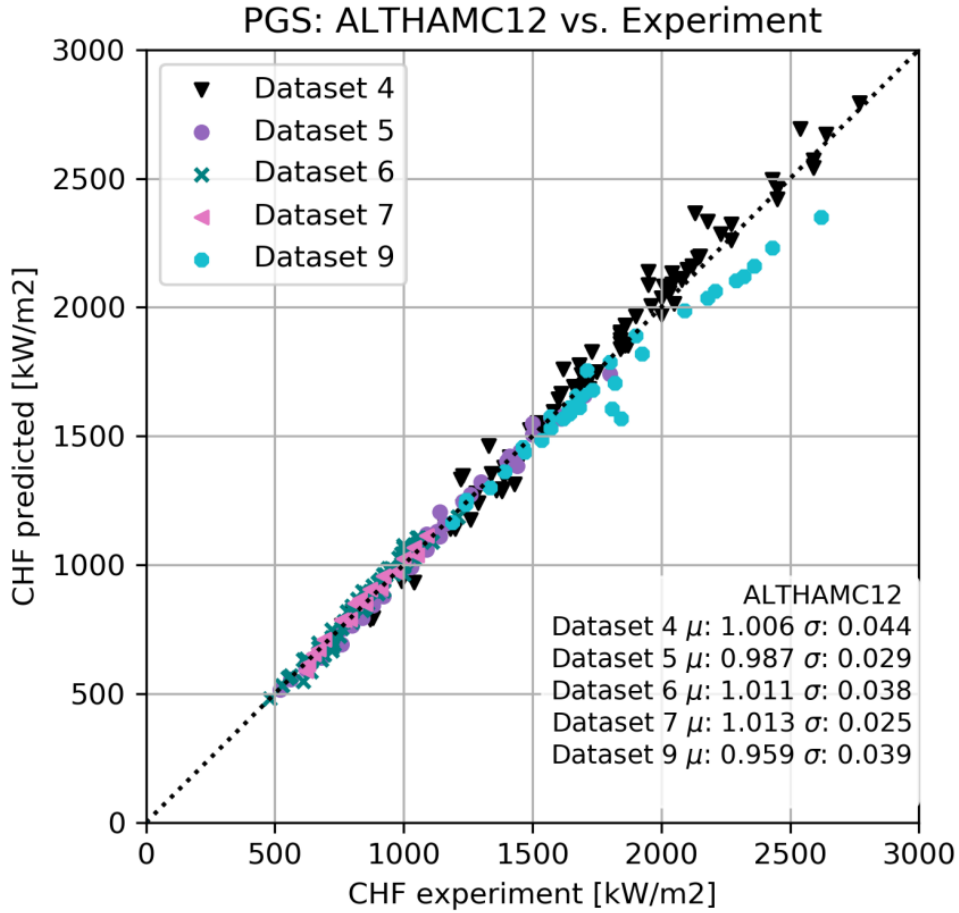
BACK-UP Slides

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7 Rods Bundle Results – Data Sets 4, 5, 6, 7, 9
PG-S Correlation



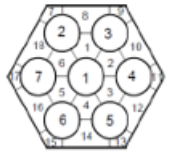


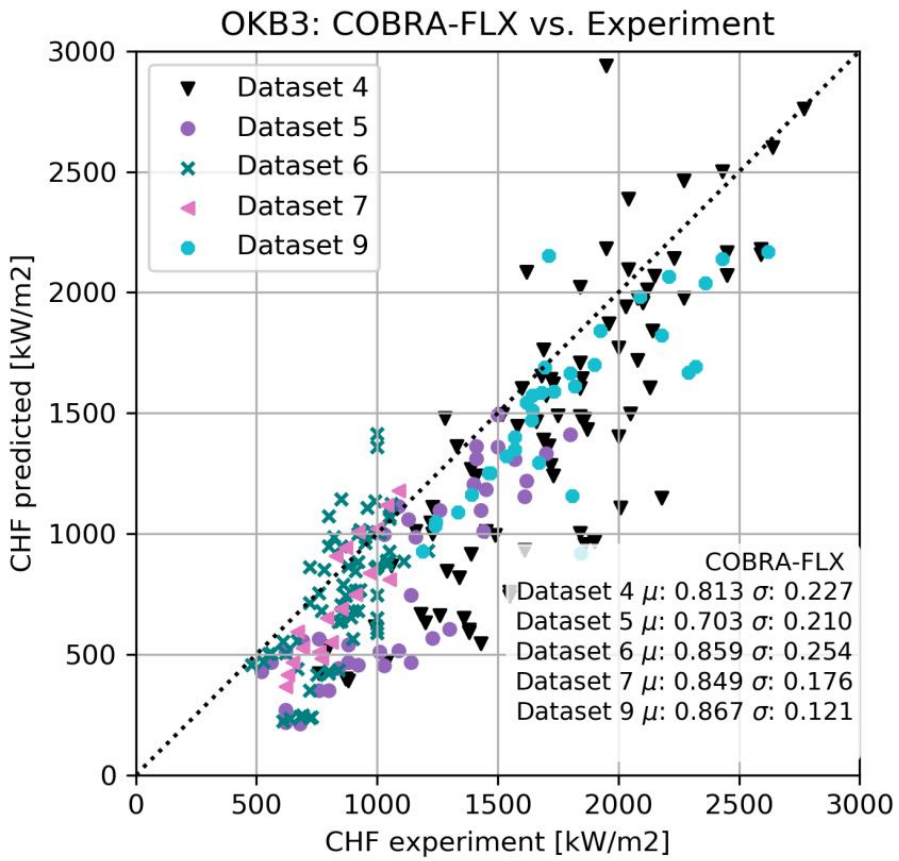


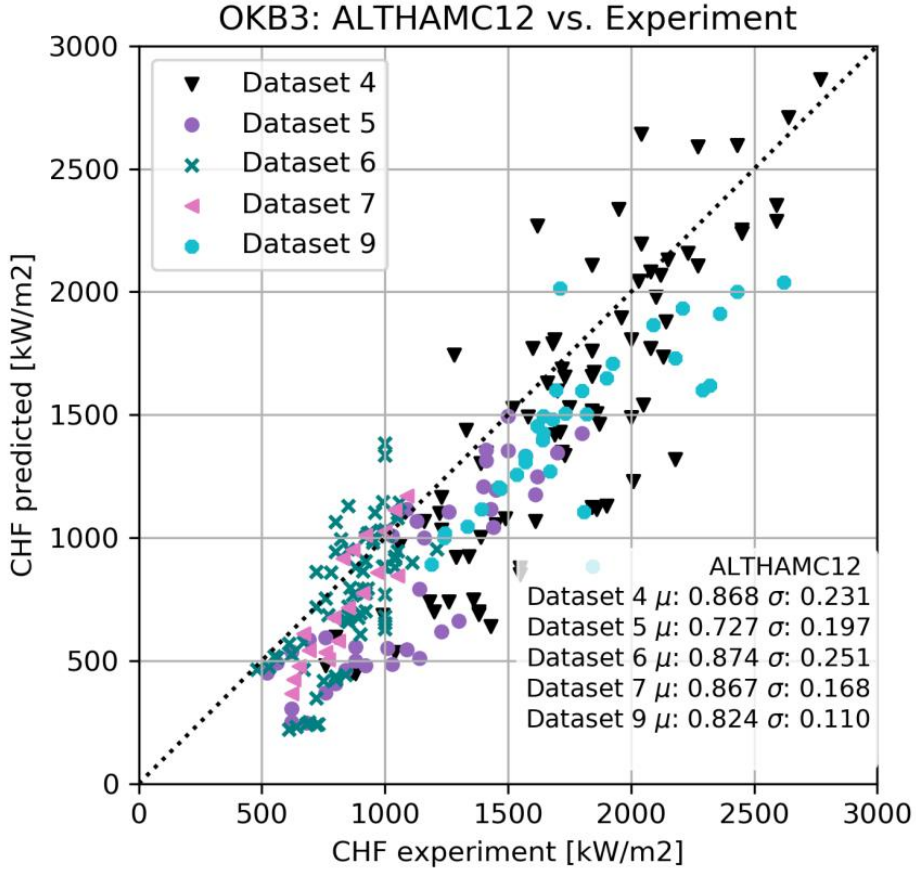
Very good agreement between predicted and measured CHF

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7 Rods Bundle Results – Data Sets 4, 5, 6, 7, 9
OKB3 Correlation

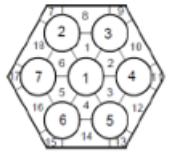


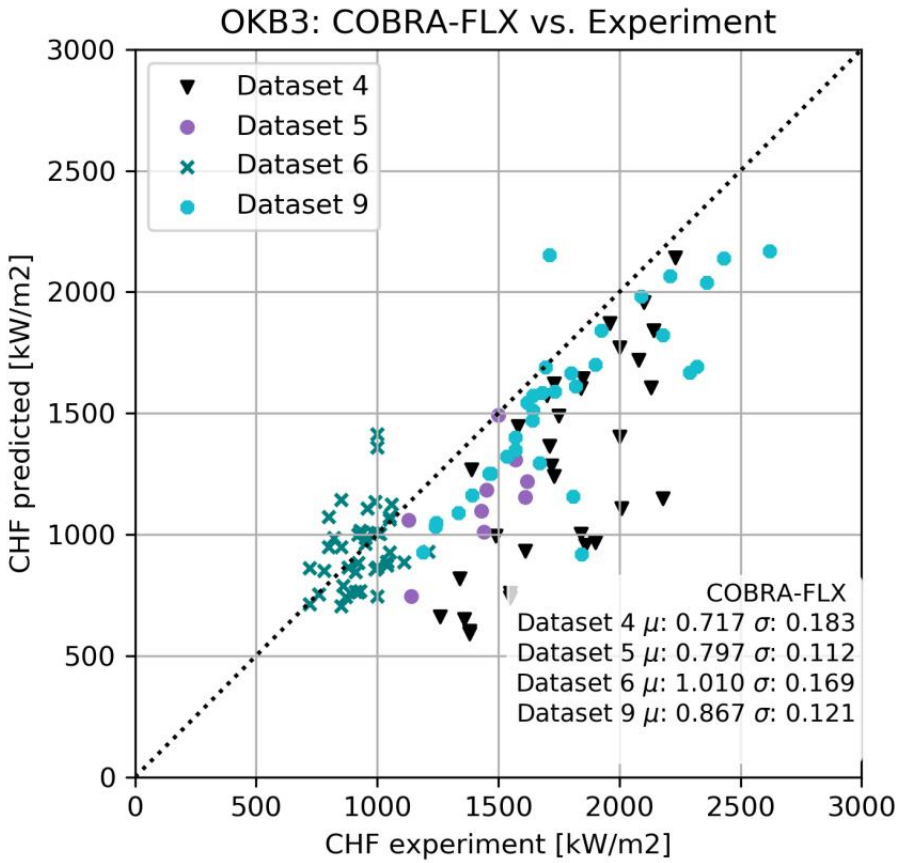


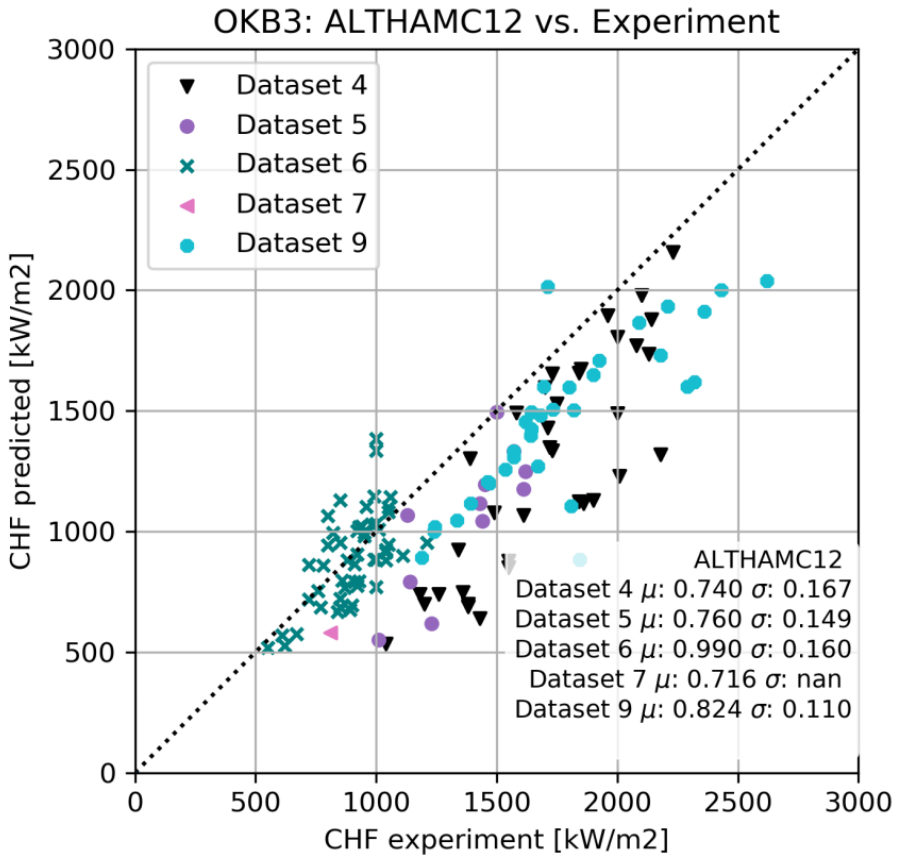


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7 Rods Bundle Results – Data Sets 4, 5, 6, 7, 9
OKB3 Correlation



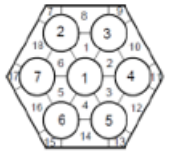


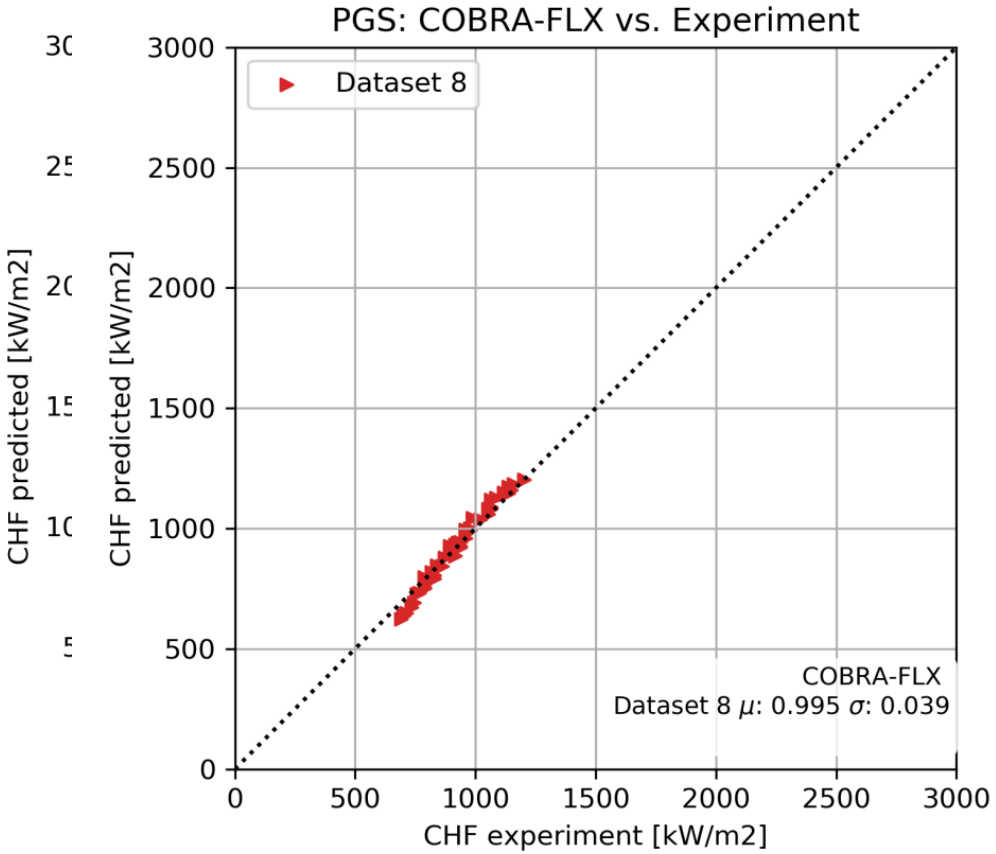


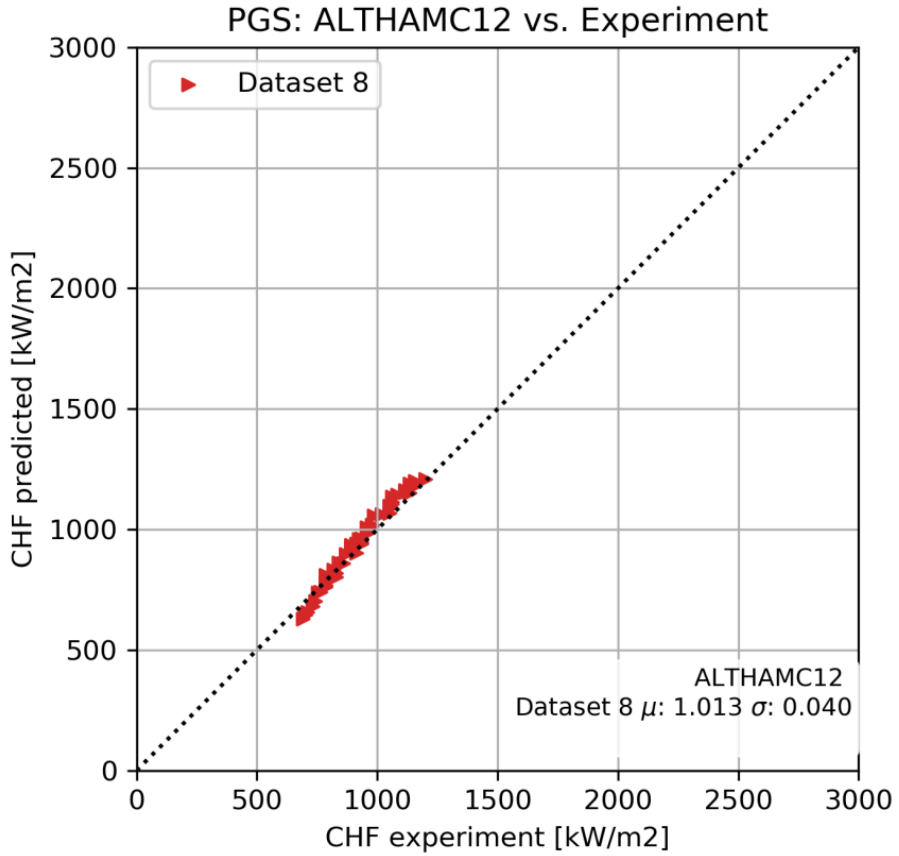
Best estimate agreement with tendency to be conservative

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7 Rods Bundle Results – Data Sets 8 – Cosine Axial Power Shape
PG-S Correlation







Very good agreement between predicted and measured CHF

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