Extension of the Validation Basis of Subchanflow by Using Measured Data From the IEA-R1 Research Reactor

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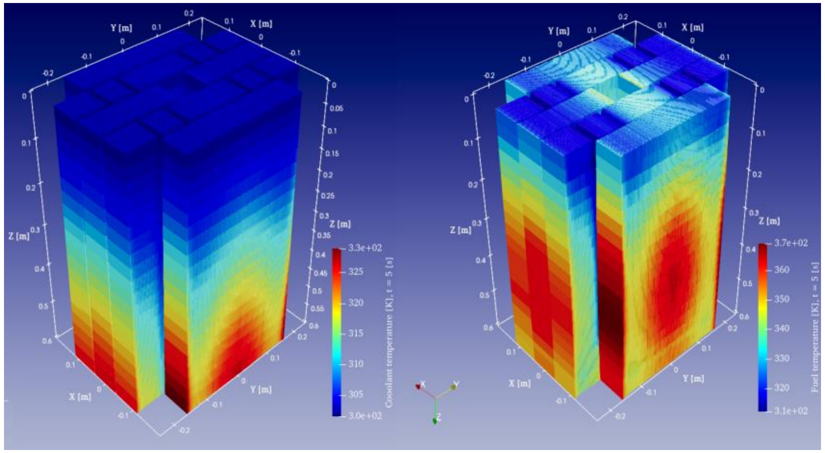

Presentation Outline

1. Introduction (& motivation)
2. Developed tools (SCF)
3. Verification:
   - IEA-R1 reactor description
   - Subchanflow Model
4. Results and discussion
5. Conclusions

1.1 Introduction

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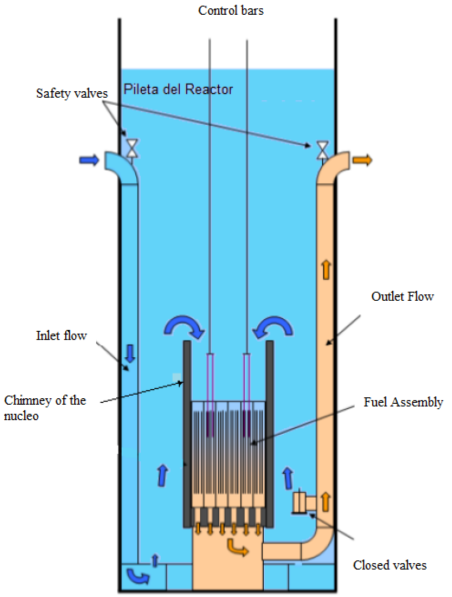
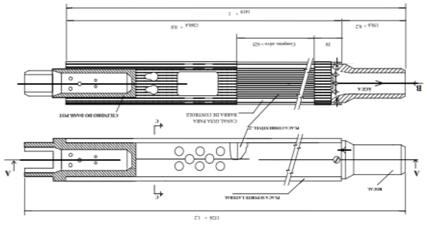
- According to IAEA to date 222 research reactors are operated and will open and build 24 reactors.
- The research reactor core are complex geometric and need analysis thermal-hydraulic and neutronics.
- Many researches use system codes and approximations geometric to simulated the research reactor MTR.
- During recent years a worldwide trend to develop high-fidelity approaches is observed.
- The majority of the high-fidelity code are focus to analysis the reactor power plants type PWR LWR BWR.
- Objective: Used High-fidelity approach to simulated the total MTR core to get local parameter (Plate by plate and plate/channel).



Typical research reactor

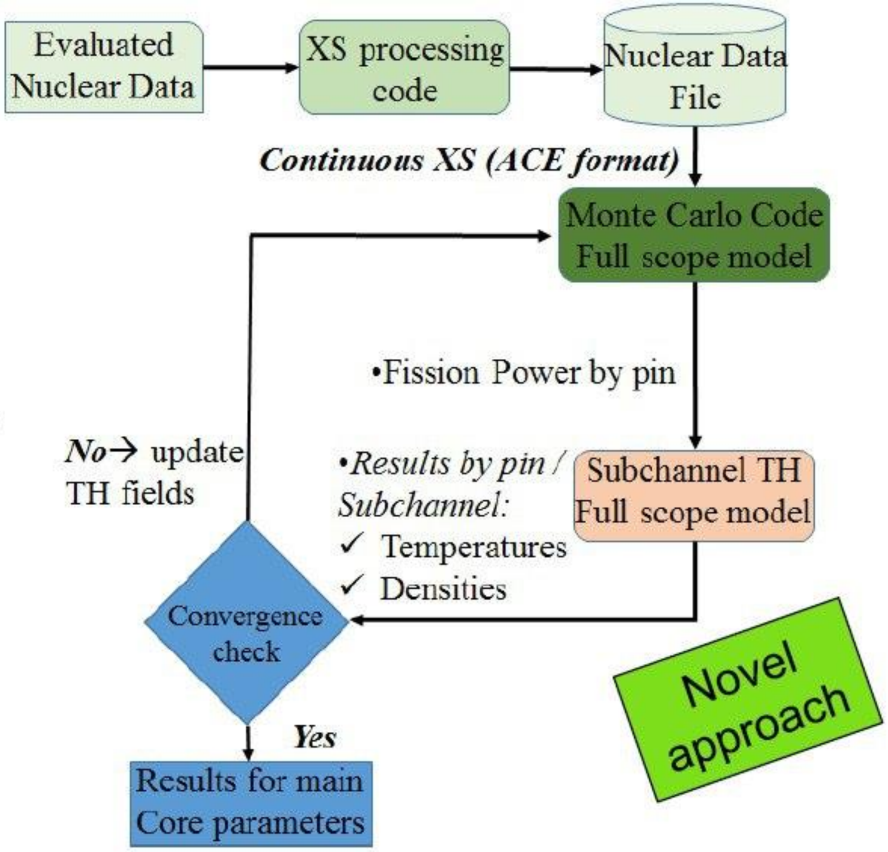


Fuel Assemblies

1.2 Introduction

The high-fidelity proposal

- Avoid the cell core approach and equivalents geometric.
- Coupling calculations using Serpent 2, Monte Carlo code, and the new version of **SubChanFlow** thermo-hydraulic code.
- Control and transient bars can move during dynamic simulations for reactivity insertion.



Novel approach (Ferraro D., 2020)

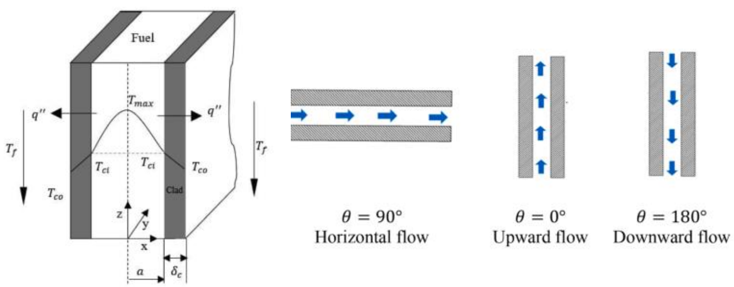
2.1 Developed tools

Subchanflow

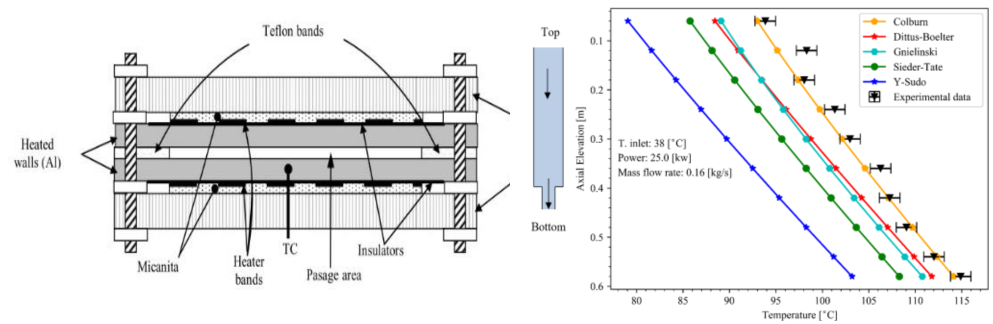
- Extension of SubChanFlow code:
  - Especial correlations for channels rectangular narrows.
  - Add module of heat conduction for plates.
  - Downward fluid.
  - Validation of new feature of SubChanFlow using experiments data (RA-6 device).
- Update the Internal coupling Serpen2/SubChanFlow version 2019 presents by H2020 McSAFE project.

Institution/Reactor	Pressure (MPa)	Correlation	Reynolds/Prandtl	Name/Ref
ORNL/HFIR	0.1-3.95	$Nu = 0.027Re^{0.8}Pr^{\frac{1}{3}}(\mu_b/\mu_w)^{0.14}$ The bulk-to-wall viscosity factor, 1.02	$1.14\times10^4 < Re < 1.65\times10^5$ $1.7 \le Pr \le 2.8$	Sieder-Tate / (Gambill & Bundy, 1961)
MIT/MITR	~0.1	$Nu = 0.023Re^{0.8}Pr^{1/3}$	$6.5\times10^3 < Re < 20\times10^3$ $0.71 \le Pr \le 5.7$	Colburn / (Spurgeon, 1969)
JAERI/JRR-3	~0.1	$Nu = 0.023Re^{0.8}Pr^{0.4}$	$500 < Re < 50\times10^3$	Dittus-Boelter / (Sudo, Miyata, Ikawa, & Kaminaga, 1985)
JAERI/JRR-3	~0.1	$Nu = \frac{0.0296Re^{0.8}Pr}{[1+1.54Pr^{-\frac{1}{4}}Re^{-0.1}(Pr-1)]}$	$2200 < Re < 16\times10^3$ $3 \le Pr \le 6$	Y. Sudo / (Sudo, Kaminaga, & Minazoe, 1990)
ORNL/HFIR	~0.13	$Nu = \frac{(f/8)(Re-1000)Pr}{[1+12.7(f/8)^{1/4}(Pr^{2/3}-1)]}$	$2100 < Re < 5\times10^6$ $2.2 \le Pr \le 5.4$	Gnielinski / (Bodey, 2014)

Heat transfer correlation used to MTR reactor



Fuel element (left) and fluid direction (right)(J.C. Almachi 2022)

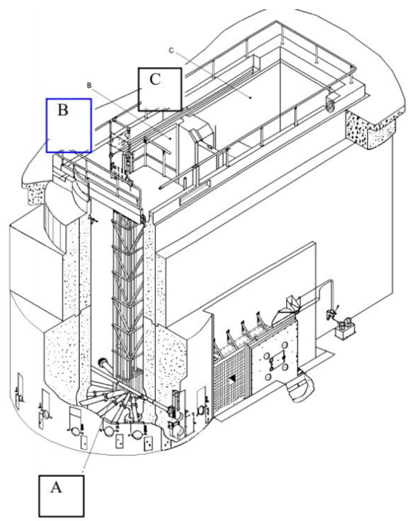


Ra-6 experimental facility

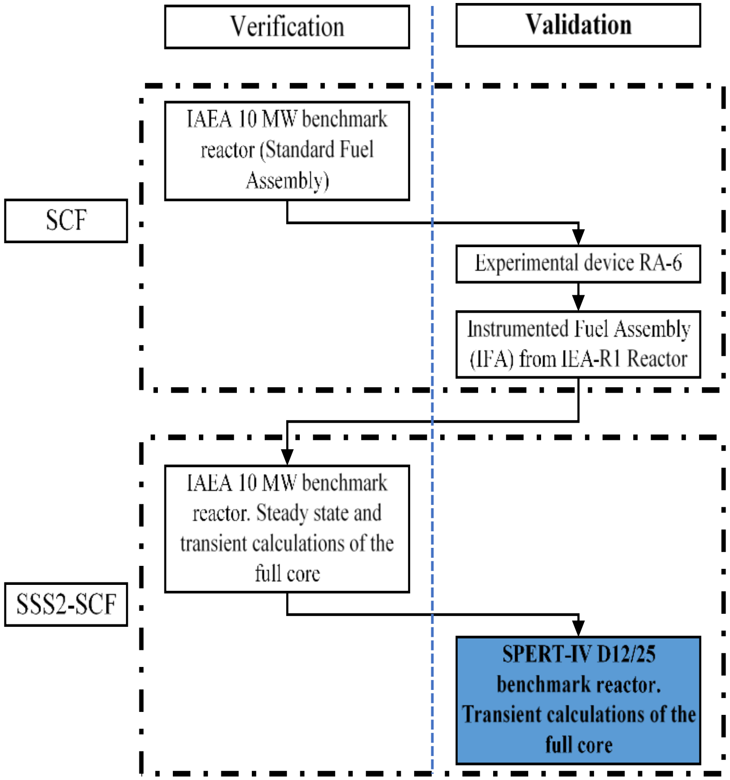
3.1 Verification & Validation

State-of-the-art

- New code features and implementations must meet the following requirements:
  - Verification and validation are mandatory for regulatory and industrial applications.
  - In this work the validation approach is using.
- The IEA-R1 reactor is used, why?
  - The experimental data are public.
  - Experimental data have been used to validate other thermal-hydraulic codes.



IEA-R1 reactor (J. R. Maiorino, 2000)

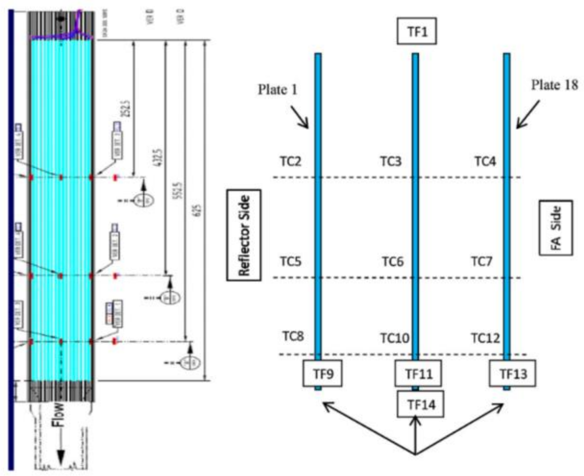


Strategy for validate SCF and Serpent

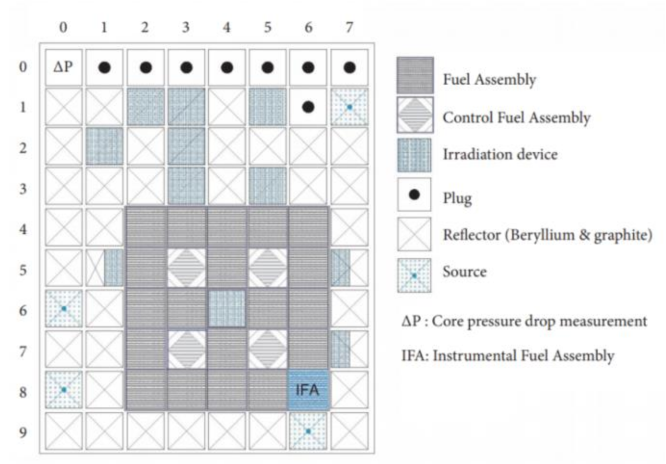
3.2 Verification & Validation

IEA-R1 reactor

- The geometric characteristics, initial conditions, and materials are taken from:
  - ”IAEA Technical Report Series 480 Vienna 2015“
- The core configuration consists of:
  - 20 Standard Fuel Assemblies (SFA) with 18 plates.
  - 4 Control Fuel Assemblies (CFA) with 10 plates.
- The IFA has 18 fuel plates distributed at a distance of 2.89 mm, forming 17 internal channels and two around whose value corresponds to half a channel. It has 14 thermocouples distributed in three regions:



Location of thermocouples (P.E. Umbehaun 2015)



Radial core IEA-R1 (P.E. Umbehaun 2015)

Parameter	Units	Test 1	Test 2
Pressure outlet	Pa	162165	162165
Power (IFA)	W	128000	147610
Temperature inlet	^{o}C	32.69	31.67
Inlet flow rate (IFA)	Kg/s	6.27	6.27

Main operation conditions of IEA-R1 (A. Hainoum, 2014)

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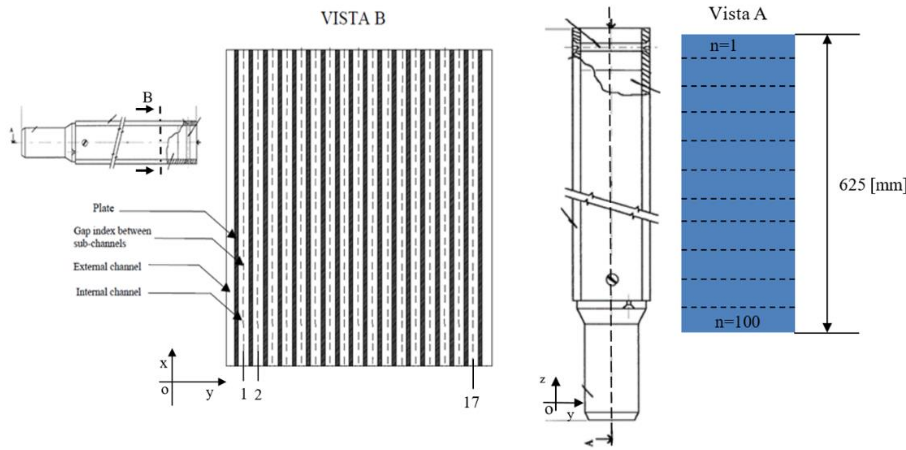
3.3 Verification & Validation

Thermo-Hydraulic models

- Subchanflow model IFA
  - Steady-state power and coolant flow.
  - Pressure losses due to acceleration of elevation is considered negligible.
  - A very detailed 3D model IFA at plate-by-plate level was created.
  - Axially, each plate is subdivided into 100 zones
  - Each water channel (17 in total) is represented by a subchannel with 100 axial cells.
  - 3 and 2 cells are used in the x-direction for the fuel and cladding.



Coolant representation, figure adapted from (P.E. Umbehaun 2015)

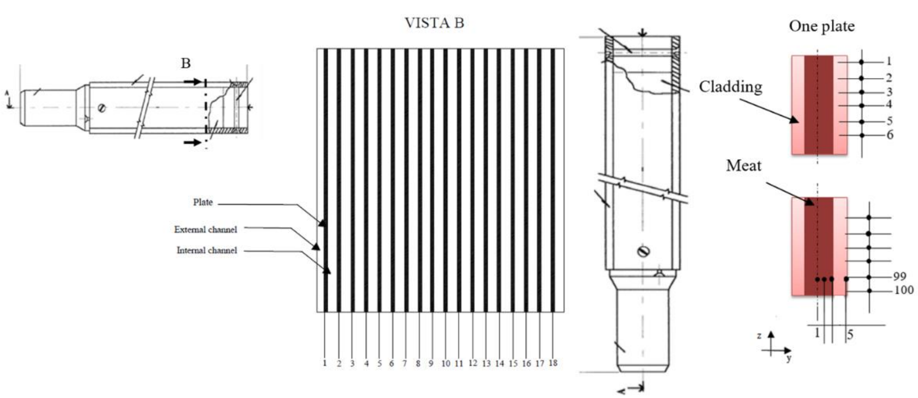


Plate representation, figure adapted from (P.E. Umbehaun 2015)

3.4 Verification & Validation

Empirical Correlations

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- Two correlations are used:
  - The friction factors recommended by (IAEA-Tecdoc-233, 1980).
  - The heat transfer correlation developed for the research reactor JRR-3 proposed by (Y. Sudo, 1990).
    - The Channels and Plates of the JRR-3 reactor have comparable dimensions and spacing.

Parameter	Correlations
Laminar pressure drop	$f = \frac{0.0791}{Re^{0.25}}$
Turbulent pressure drop	$f = 0.0460 Re^{-0.20}$
Heat transfer, Y-Sudo	$Nu = \frac{0.029 Re^{0.8} Pr}{[1+1.54 Pr^{-\frac{1}{4}} Re^{-0.1} (Pr-1)]}$

Pressure drop and heat transfer correlation for IEA-R1

4.1 Results and discussion

Comparison of the experimental data with SCF predictions

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- Global parameter predicted by the code SCF are:
  - Outlet temperature fluid
    - The difference of experimental temperature with that calculated by SCF is in the range of ± 0.02 ◦C.
  - Pressure drop (The experimental results with respect to the pressure drop were not rigorously studied in this set of tests, but their values can be used as a reference) (A. Hainoun, 2014),
    - the relative error as a percentage of the predicted pressure drop with respect to the measured one is about -4.43 %

Item	Experimental [^oC]	SCF [^oC]	Difference [^oC]
Test 1	37.60	37.58	0.02
Test 2	37.28	37.30	-0.02

Outlet temperature fluid

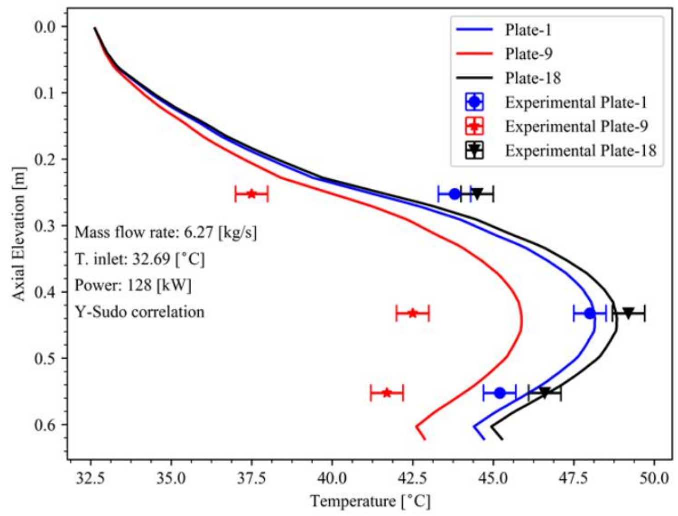
Item	Experimental [Pa]	SCF [Pa]	Error relative %
Test 1	7835	7488	-4.43
Test 2	7835	7481	-4.522

Global pressure drop, from (A. Hainoun, 2014)

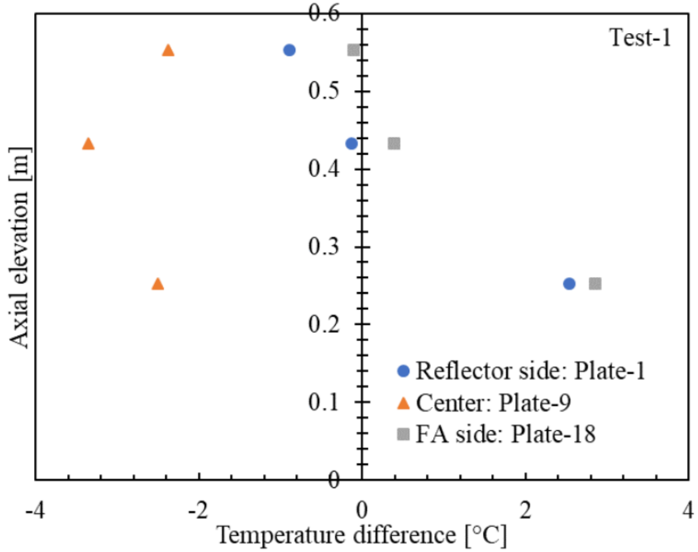
4.2 Results and discussion

Comparison of the experimental data with SCF predictions

- Local parameter predicted by code SCF for Test 1
  - Considering only the experimental results, it can be concluded that the largest temperatures were measured at the Plat-18 of the FA side, followed by plate 1 (reflector side) and the center plate 9.
  - The central plate-9 and FA side plate-18 have the highest temperature difference between the experimental and SCF simulated values, with values of -3.3 ◦C and 2.8 ◦C respectively.



Temperature profiles on different plates Test 1

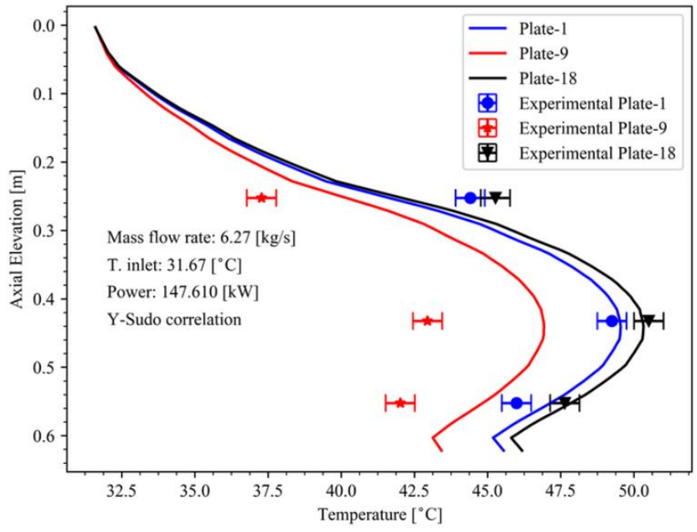


Cladding temperature difference, Test 1

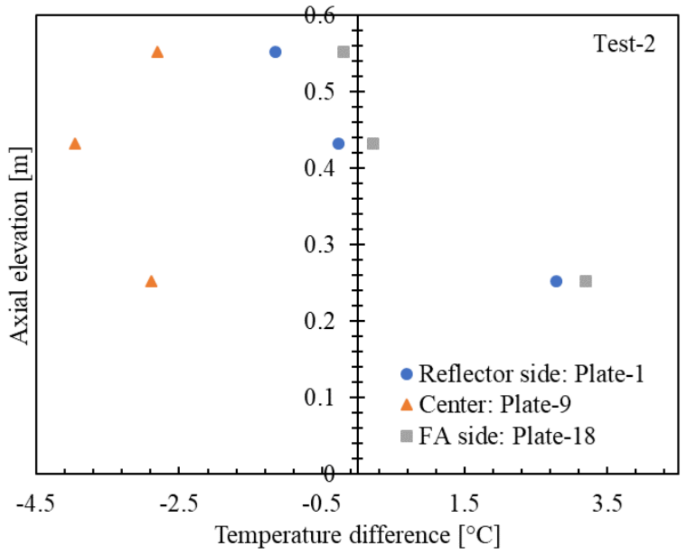
4.3 Results and discussion

Comparison of the experimental data with SCF predictions

- Local parameter predicted by code SCF for Test 2
  - To test 2, show the same behavior as in Test 1. The central plate has higher temperature difference values.
  - In this case, SCF overestimates all temperature values.
  - Based on the observation of both tests, it is obtained that the temperature values simulated by SCF in the lower part of the fuel assembly present a better temperature difference.



Temperature profiles on different plates Test 2



Cladding temperature difference, Test 2

5.1 Conclusions

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- The results obtained by SCF have been compared with the experimental values getting good results: the coolant temperature difference between the measured and predicted values is slight and ranges between ± 0.02 ◦C The results obtained by SCF have been compared with the experimental values getting good results: the coolant temperature difference between the measured and predicted values is slight and ranges between ± 0.02 ◦C.
- The performed investigations confirm the excellent prediction capability of Subchanflow regarding thermal hydraulic parameters of plate-type fuel used in MTR research reactors.

Acknowledgment

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