Improvements to Thermal Hydraulics-Models and Methods for MTR-Type Reactors

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Introduction

- For research reactor analysis, largely 1D thermal-hydraulics models are used because they are simple to apply and technically defendable.
- Improvements to methods and models can reduce modeling uncertainties and thereby allow greater reactor performance with no reduction in predicted safety margins.
- These improvements in the thermal-hydraulics models potentially expand the design space, making additional designs feasible, which, in turn, may achieve better fuel utilization and proliferation resistance in the designs.

Introduction

- Using the OPAL reactor as a benchmark, ANL and INVAP collaborated to improve methods and models in several areas:
  - Asymmetric cooling of fuel plates
  - Direct heat deposition in coolant and cladding
  - Azimuthal conduction effects
- Two thermal-hydraulics codes were used
  - PLTEMP/ANL (Argonne National Laboratory)
  - TERMIC-MP (INVAP)

Codes Description

PLTEMP/ANL

- A program that obtains a steady-state flow and temperature solution for a nuclear reactor core, or for a single fuel assembly.
- It is based on an evolutionary sequence of codes originally used for plate temperatures, hence “PLTEMP”, developed at Argonne National Laboratory over several decades.

TERMIC-MP

- A steady-state code to perform core TH design using plate-type fuel assemblies
- Originally developed by CNEA in the 80´s and upgraded by INVAP
- As a result of the interactions with ANL, TERMIC-MP was developed based on the TERMIC code

Codes Comparison

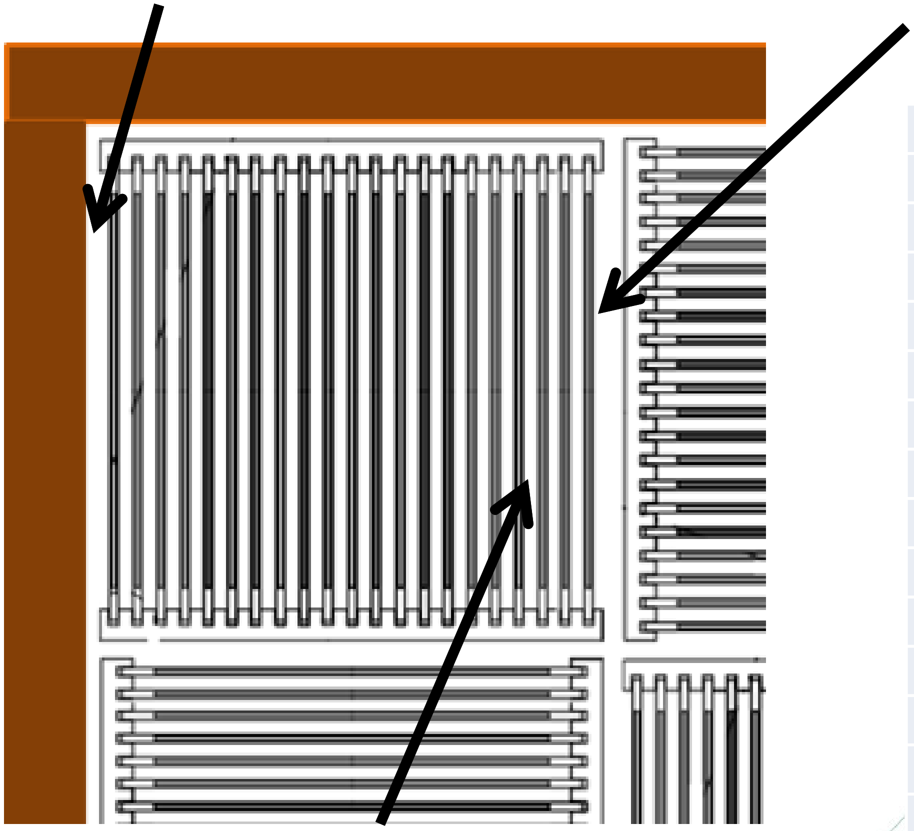
Capability	PLTEMP/ANL	TERMIC-MP
Plate type FA	✓ (flat/curved)	✓ (flat)
Coolant and flow direction (upward/downward)	✓ (H_2O/ (D_2O)	✓ (H_2O)
Single FP model	✓	✓
Complete FA model	✓	✓
Complete core model	✓	X
Axial conduction model	X	X
Azimuthal conduction model	✓	X
Power distribution in each FP	✓	✓
Distributed heat generation (meat/clad/coolant)	✓	✓
Uncertainties treatment	✓	✓
Margins to ONB/DNB/FI	✓	✓
Heat transfer correlations (includes Petukhov)	✓	✓
DNB correlations (includes Mirshak)	✓	✓
FI correlations (Whittle & Forgan)	✓	✓ (French form.)
ONB correlations (Bergles & Rohsenow)	✓	✓
Power level search	✓	✓ (ONB, DNB)

Model Description

OPAL fuel assembly

External channel
Gap = 0.2925 cm / V = 890 cm/s

External channel between FAs
Gap = 0.2425 cm / V = 800 cm/s



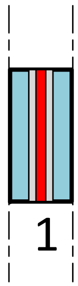
Internal channel
Gap = 0.245 cm / V = 860 cm/s

Uncertainties

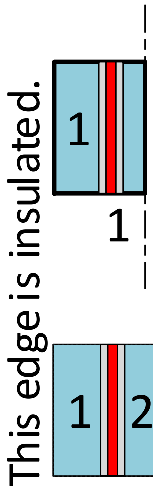
Statistical uncertainties	
Inlet temperature	0.5°C
Uranium loading	2%
Operational power	2%
Active surface	5%
Channel gap	10%
Channel velocity	10%
MCNP power distribution	10%
Uranium homogeneity	10%
Meat thickness	10%
Atmospheric pressure	4%
Pool water level	1%
Friction correlation	5%
Systematic uncertainties	
Heat transfer correlation	10%
Inlet temperature	1°C

Improvements: Asymmetric Cooling

Top Views

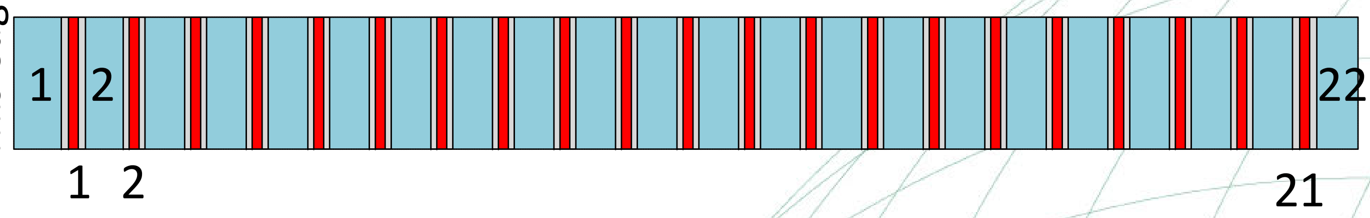


Case 1: 1 stripe of plate 1 with a symmetric half of channel 2 of each side



Case 2: Same as case 1 except channel 1 is full thickness & heated from only one side

Case 3: 1 Stripe of an entire 21-plate assembly



In all three cases:

- Only a single stripe of the fuel plate or assembly (1/8th of the fuel meat width)
- Axial power distribution provided by a neutronic code
- 20 axial nodes were adequate

Improvements: Asymmetric Cooling

Key Thermal Margins with Uncertainties

- ONBR = ONB ratio = (ONB power) / (Nominal power)
- DNBR = DNB ratio = (DNB power) / (Nominal power)
- FIR = FI ratio = (FI power) / (Nominal power)

	PLTEMP/ANL			TERMIC-MP		
	ONBR	DNBR	FIR	ONBR	DNBR	FIR
Case 1 (Sym.)	2.197	3.533	3.807	2.212	3.539	3.951
Case 2	2.255	3.609	4.051	2.301	3.789	4.206
Case 3 (entire FA)	2.264	3.629	4.023	2.298	3.803	4.157

- ✓ Cases 2 and 3 take advantage of 1-sided heating and greater flow in the external channel
- ✓ Small differences between Cases 2 and 3
- ✓ Differences in the thermal margins between PLTEMP\ANL and TERMIC-MP < 5%

Improvement: Direct Power Deposition to Coolant and Clad

- Depositing all power directly into the fuel meat is the typical approach and conservative.
- A fraction of the power is deposited into the clad and the coolant modifying Case 2 (single plate with asymmetric cooling) to form Case 4.
  - 96.63% fuel meat
  - 0.35% left clad + 0.35% right clad
  - 1.335% left coolant channel + 1.335% right coolant channel

} 100%

	PLTEMP/ANL			TERMIC-MP		
	ONBR	DNBR	FIR	ONBR	DNBR	FIR
Case 2	2.255	3.609	4.051	2.301	3.789	4.206
Case 4	2.309	3.693	4.053	2.358	3.881	4.207

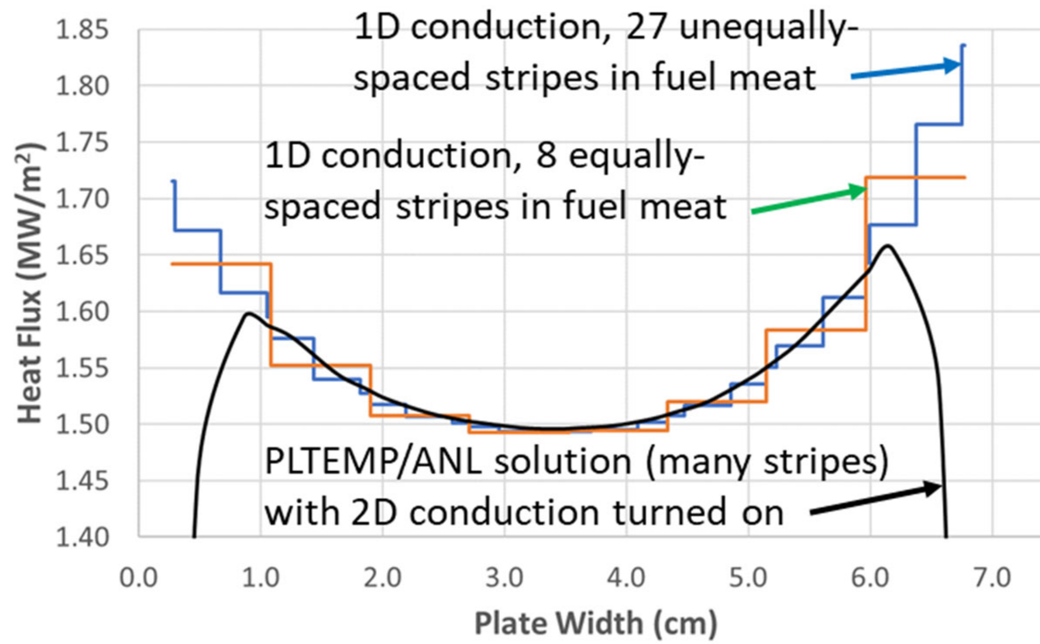
Conservativeness degree (**Case 4 – Case 2**) / **Case 2** < 3%

- Direct heat deposition into the coolant lowers the q''_{clad} meaning larger ONB and DNB ratios
- No effect on FIR, total heat into the coolant did not change by moving the power from the meat to the clad and the coolant
- Differences in the thermal margins between PLTEMP\ANL and TERMIC-MP are < 5%

Improvements: Azimuthal Conduction

- For 1-D heat conduction, q" (W/m^2) is proportional to q''' (W/m^3).

- q''' is peaked at the edges of the fuel meat.



- **Blue** curve (1D – 27 unequal stripes) closely approximates these peaks.
- **Black** curve (PLTEMP/ANL azimuthal heat conduction option) shows that the peak q" **<<** than 1D analysis predicts. This is due to heat conduction into the unfueled plate edges.
- **Orange** curve bounds the actual (2D) peak q".

Thus, the computationally simpler and more efficient 1D analysis with 8-equal stripes is completely defendable and reduces the excess conservatism caused by doing 1D analysis with 27 unequal stripes.

Improvements: Azimuthal Conduction

Case	PLTEMP/ANL		
	ONBR	DNBR	FIR
27-stripes	1.892	2.955	2.675
8-stripes	2.034	3.183	3.008
(27-stripes)-(8-stripes)/ (27-stripes), %	7.5%	7.7%	12.5%

- Using 8 equally-spaces stripes in the fuel meat instead of 27 unequally-spaced stripes in the 1-D PLTEMP/ANL analysis, widens the following predicted margins:
  - ONB power – 7.5%
  - DNB power – 7.7%
  - FIR power – 12.5%
- Similar results are expected for (1-D) TERMIC-MP analysis.

Summary

ANL, using PLTEMP/ANL, and INVAP, using TERMIC-MP, after the good comparison of results presented in a previous work, studied the impact of asymmetric cooling, direct power deposition into the clad and coolant, and azimuthal conduction, arriving to the following conclusions:

- Asymmetric cooling takes advantage of 1-sided heating and greater flow in the external channel giving a better representation of the fuel assembly
- Direct power deposition into clad and coolant has a direct effect in the cladding heat flux which results in the increase of ONB and DNB ratios
- A calculation with azimuthal conduction showed that 1D models with proper discretization of the plate width can bound the peak heat fluxes in the 2D model without excessive conservatism and with much less modeling complexity and computation.
- Improvements to the methods and models can expand the design space and enable better fuel utilization and proliferation resistance in the design.

Questions?

Thank you for your attention

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