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Validation of COOLOD-N2 Code Through Benchmark Calculations of IEA-R1 Reactor

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ABSTRACT

IEA-R1 reactor core has been modeled in COOLOD-N2 code with the aim to validate and verify the code against the experiment data provided by International Atomic Energy Agency (IAEA) through coordinated research project (CRP). Fuel cladding temperatures at different locations of an instrumental fuel assembly (IFA) at different operating powers have been calculated under steady state condition by using the COOLOD-N2 code. The calculated temperatures are then verified against the temperatures recorded by thermo couples placed for those locations of IFA in 243 configuration of IEA-R1 reactor. Reasonable agreement has been found between the calculation and experiment for fuel clad temperature which in turn implies the validity of COOLOD-N2 code in the calculation of core thermal hydraulic parameters of research reactors under steady state condition.

1. Introduction

To promote quality of safety analysis of research reactor by computational simulation, International Atomic Energy Agency (IAEA) provide experimental data to the working teams through coordinated research project (CRP) to validate their computer codes. Being involved with CRP project during the period 2009-2012, COOLOD-N2 [1] code was used to perform benchmark calculations against the provided experimentally measured temperature values recorded by thermocouples placed at different positions of an instrumental fuel assembly (IFA) of IEA-R1 research reactor of Brazil with 243 configuration. The specifications of IEA-R1 reactor is delivered by Umbehaun [2] based on which following description on the reactor has been made.

The IEA-R1 research reactor is 5MW pool type reactor that uses MTR (material testing reactor) fuel elements. It is light water cooled and moderated, graphite and beryllium reflected research reactor. The reactor contains 20 standard fuel assemblies, four control fuel assemblies and a central irradiator, assembled in a square 5×5 matrix. Each standard fuel element contains 18 fuel plates which are assembled on two lateral support plates so forms 17 independent flow channels. Fig. 1 shows the configuration of IEA-R1 reactor core and Fig. 2 shows the simplified scheme of the reactor cooling system that consists of primary and secondary loops. During the continuous operation of the reactor at high power levels, generated heat removed from core to the cooling tower through the following auxiliary systems:

1. Forced circulation coolant system pumps pool water down through the fuel elements to remove the fission heat from the reactor core.
2. A water to water heat exchanger transfers the generated heat to a secondary water coolant system.
3. The secondary water carries heated water to the cooling tower which dissipates the heat to the atmosphere. Water from the cooling tower is re-circulated through the secondary system and returned to the reactor pool through the primary water coolant system.

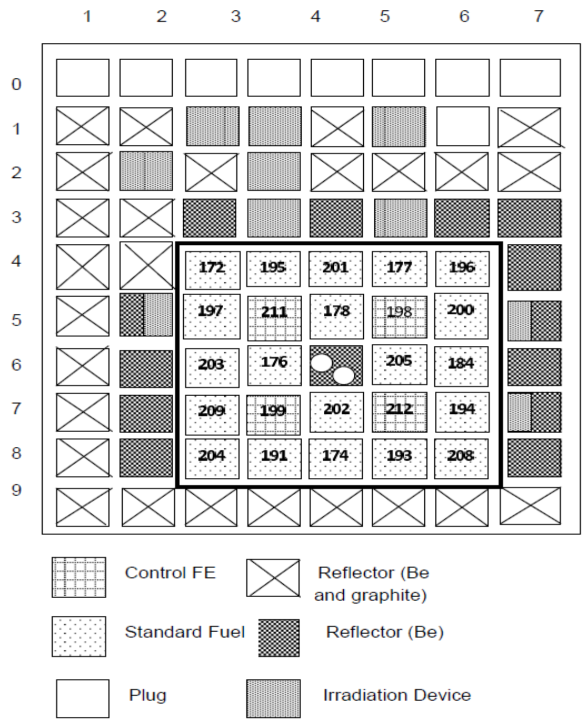

Fig. 1. Schematic diagram of IEA-R1 reactor core configuration.

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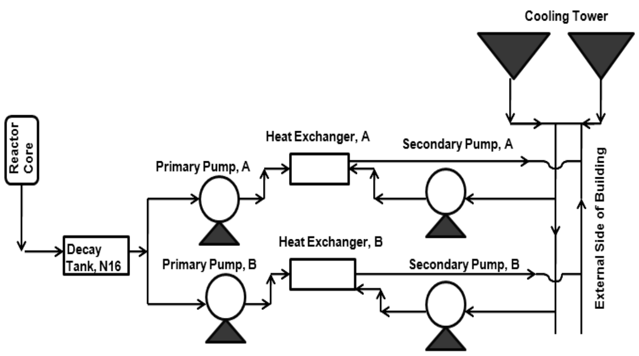

Fig. 2. Schematic line diagram of IEA-R1 reactor coling system.

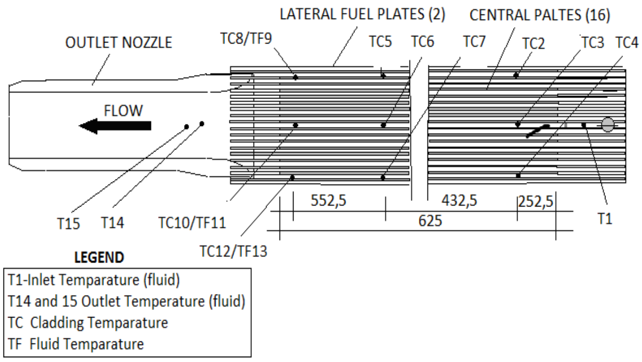

Fig. 3. Instrumental Fuel Assembly (IFA) with thermocouples.

From the configuration, as shown by Fig. 1, IFA can be identified by number 208. Fig. 3 shows the position of thermocouples in the IFA. To know more about the reason to access these thermocouples, Umbehaun's report [2] could be referred. The IFA has been divided into three regions. Each region consists of six fuel plates. The lateral region close to reflector elements is reflector side fuel plates, other lateral region close to fuel elements side is fuel element side plates. Between these, the central region lies. Except 5 positions, thermocouples at the rest 09 positions measure clad temperature. Reflector side thermocouples are TC2, TC5 and TC8 located at 252.3mm, 432.5 mm and 552.5 mm, respectively from the entrance of the channel. Similarly, TC3, TC6 and TC10 are central side and TC4, TC7 and TC12 are fuel element side thermo couples placed at 252.3 mm, 432.5 mm and 552.5 mm, respectively from the entrance of the channel. Reactor design specifications are summarized in Table 1 while the radial and average axial peaking factors of the fuel plates are taken from Umbehaun's report [2].

2. Analytical Method in COOLOD-N2 Code

COOLOD code was originally developed in Japan Atomic Energy Research Institute (JAERI) for steady state thermal hydraulic analysis under natural convection cooling of research reactors with plate type fuels. Later, the code was modified to COOLOD-N code by incorporating a heat transfer package based on heat transfer correlations

Table 1. Design parameters of IEA-R1 research reactor.

Reactor Parameters	Data
Steady State Power Level (MW)	5
Fuel Enrichment	20%
Number of Fuel Element in the Core	24
a) Standard Fuel Element	20
b) Control Fuel Element	4
Fuel Type	U_3O_8 –Al
Maximum Inlet Temperature (^{0}C)	40
Number of Fuel Plates in:	
a) Standard Fuel Element	18
b) Control Fuel Element	12
Thickness of the Plates (mm)	
a) Fuel	0.76
b) Clad	0.38
c) Total Thickness	1.52
Total Width of the plates (mm)	67.1
Fuel Meat Dimensions (mm)	0.76 x 62.6 x 600
Thickness of Water Channel (mm)	2.89
Inlet Pressure	1.7 bar
Average Velocity of Coolant (m/s)	1.92
Radial Peaking Factor	0.85

obtained during heat transfer experiments of the upgraded JRR-3 core. The updated code now holds capability to conduct steady state analysis for both forced and natural convection cooling for both plate typed and rod typed fuel reactors. Heat generation in fuel meat along the radial direction is considered constant and one dimensional heat conduction model is taken into account. An axial fuel plate temperature distribution is calculated from local bulk temperatures of the coolant and axial peaking factors. Fig. 4 shows calculation model of temperature distribution in fuel plates where T_b expresses coolant bulk temperature, T_w and T_{WB} denote clad outer and inner sureface temperature, respectyively and T_{BU} and T_{U0} present fuel meat surface and fuel maxixmum temperature, respectively. However, manual of COOLOD-N2 code [1] is referred to have datail of modelling with equations of the parameters, T_b T_w T_{WB} T_{BU} and $T_{U0,}$ respectively.

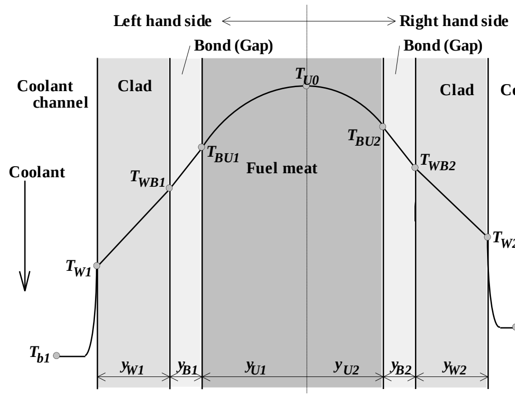

Fig. 4. Fuel plate temperature calculation model.

3. Results and Discussions

The thermal hydraulic analysis of IEA-R1 research has been carried out to verify the fuel cladding temperature calculation model through comparing the calculated temperature with the recorded temperatures by thermocouples. The active height of the fuel assembly is 600 mm which was subdivided into 10 regions each correspond to 60 mm. Axial peaking factors in average for fuel plates of three regions are mapped in Fig. 5. Using the specification provided in Table 1, COOLOD code has calculated the temperature at the desired locations of fuel clad of three different regions. Tables 2, 3 and 4 summarize the calculated and experimental values of peak clad temperatures for fuel element side, reflector side and central side fuel plates, respectively.

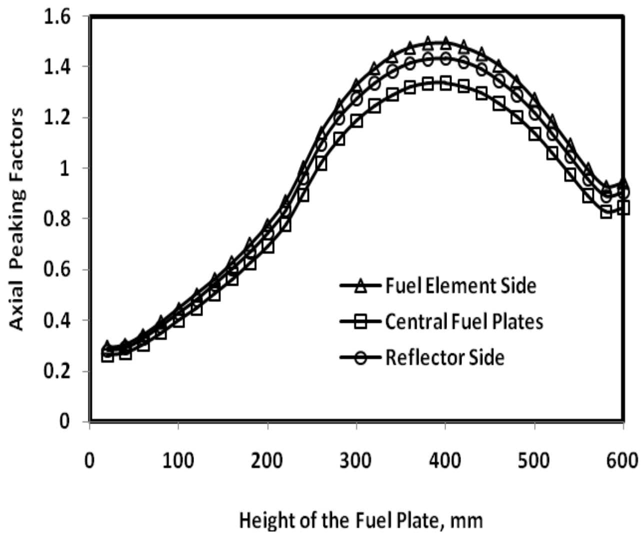

Fig. 5. Average of axial peaking factors of fuel plates in three regions.

Tables 2 and 3 show good agreement between code and experiment wherever with the maximum error are found to

Table 2. Comparison between calculated and experimental measured temperature (^{O}C) for fuel element side plates

Power MW	Thermo couples	Fuel Element Side		
		Experiment	COOLOD	Error (%)
5	TC4	49.57	48.92	1.31
	TC7	55.85	55.80	0.09
	TC12	----	52.50	----
4	TC4	47.29	46.15	2.41
	TC7	53.02	52.50	0.98
	TC12	----	49.50	----
4.5	TC4	45.27	44.50	1.70
	TC7	50.51	49.73	1.54
	TC12	----	46.50	----

Table 3. Comparison between calculated and experimental measured temperature (^{O}C) for reflector side.

Power MW	Thermo couples	Reflector Side		
		Experiment	COOLOD	Error (%)
5	TC2	48.72	50.55	- 3.75
	TC5	54.56	52.69	3.42
	TC8	50.69	49.38	2.58
4	TC2	46.47	47.89	-3.05
	TC5	51.78	49.10	5.17
	TC8	48.22	46.50	3.56
4.5	TC2	44.41	45.95	-3.46
	TC5	49.25	47.10	4.36
	TC8	45.99	44.42	3.41

lie in the order of 2.41% in Table 2 and about 5% in Table 3. Table 4, instead, shows relatively large difference between calculation and experiment. It is seen although the calculated values vary within 10% with experimental values for TC6 position, but for TC3, the calculated values found to be exceeded about 27% of experimental values.

The large difference, especially for TC3 positions, may be the consideration of large value of radial peaking factors, 0.85 which might not be suitable for centrally position fuel plates.

Table 4. Comparison between calculated and experimental measured temperature (^{O}C) for central position.

Power MW	Thermo couples	Central Position		
		Experiment	COOLOD	Error (%)
5	TC3	40.30	51.32	- 27.34
	TC6	47.01	51.10	- 8.70
	TC10	----	49.50	-----
4	TC3	38.68	46.32	- 19.75
	TC6	44.87	46.80	- 4.30
	TC10	----	44.53	------
4.5	TC3	37.28	46.30	- 24.19
	TC6	42.95	46.15	- 7.45
	TC10	--	44.50	--

Hence, apart from conservative estimates for TC3 and also for TC6 thermocouples at central position, it is seen the calculated and experimental values of temperature for most of the positions of thermocouples vary within 5%. Based on these verifications of results, it is seen, in general, that

COOLOD-N2 code is well suited to perform steady state analysis of research reactor with good approximations.

Acknowledgement

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