Recent Developments in PLTEMP/ANL V4.3 Code for Research Reactor Thermal Hydraulics Analysis

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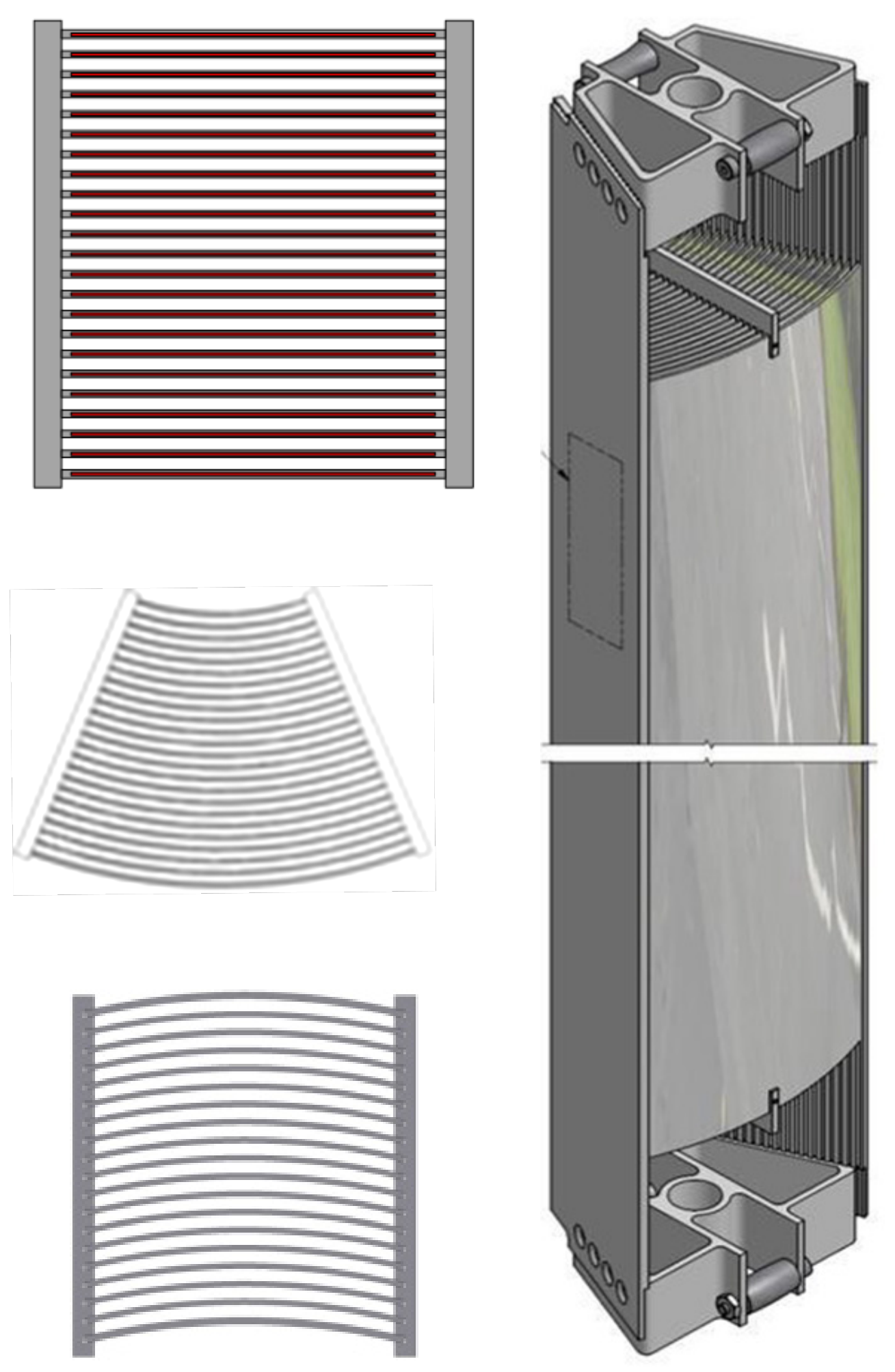
Introduction – PLTEMP/ANL Code

PLTEMP/ANL is a steady-state single-phase (liquid H_2O or D_2O) thermal hydraulics code to calculate temperature distribution and safety margins in research reactors whose cores contain fuel assemblies made of multiple fuel plates, nested fuel tubes, or fuel rods. The code has been used by Argonne National Laboratory and the research reactor community since 1980.

Typical Assemblies Modeled →



PLTEMP/ANL Code Capabilities

- The scope of a PLTEMP/ANL problem can be:
  - A single fuel plate surrounded by two coolant channels
  - Several fuel plates and their coolant channels
  - One or more fuel assemblies
  - The entire core including unheated bypass-flow paths
  - The cladding can have longitudinal fins
  - An assembly of several nested coaxial fuel tubes with a central fuel rod, with or without longitudinal fins
- Each fuel plate can have 5 layers or 3 layers.
- The coolant can be light or heavy water single-phase liquid.
- The code can determine the flow rate in each channel based on a driving pressure drop or use input flow rate values.
- The code can determine the natural circulation flow rate in each channel
- Power density distribution in fuel meat can be specified by fuel plate.
- Heat generation due to gamma heating in the coolant, the fuel plate cladding, and the interlayer can be modeled.
- The code determines steady-state temperature distribution in each fuel plate and coolant channel.
- The calculation of temperature distribution can include azimuthal conduction.
- The code calculates margins to onset of nucleate boiling, excursive flow instability, and critical heat flux using several correlations & Groeneveld tables.
- The code uses hot channel factors (3 systematic and 5 statistical) to account for manufacturing tolerances & modeling uncertainties.
- The code can search for a reactor power that meets a user-specified criterion, such as a minimum CHFR of 1.
- Limitation: Constant thermal properties of fuel meat, cladding, interlayer (between fuel meat and cladding)

Three Recent Developments

1. Implemented IAPWS-IF97 Light Water Coolant Properties
2. Full 3-Dimensional Heat Conduction (Including Boundary Conditions) in All Fuel Plates of an Assembly
3. Modeling of Eddy-Induced Coolant Mixing in Coolant Channels

1. Comparison of Between the NIST and the IAPWS-IF97 Light Water Properties, over 4 to 336 °C

P, bar	Percent Difference				
	Enthalpy	Th Cond	Cp	Density	Dy. Visc.
1	0.0192	0.0096	0.0531	0.0016	0.0036
5	0.0194	0.0065	0.0801	0.0015	0.0026
10	0.0191	0.0079	0.0817	0.0014	0.0036
20	0.0189	0.0084	0.0810	0.0013	0.0047
50	0.0185	0.0078	0.1070	0.0013	0.0060
100	0.0189	0.0100	0.1082	0.0018	0.0048
145	0.0188	0.0073	0.1101	0.00232	0.0042
Max →	0.0194	0.0100	0.1101	0.0023	0.0060

2. Method of 3-D Heat Conduction in a Fuel Assembly

- Temperature distribution is calculated in an assembly in the 3-dimensional region (i.e., the solution region) of all coolant channels and all fuel plates, over the plate width including the two unfueled edges and the entire plate height including the upper and lower unfueled plate lengths.
- The solution region is divided into a user-specified number (several thousands to several millions) of control volumes (CVs) for each of which a *heat conservation equation* is written using the thermal resistance of the CV to the six neighboring CVs and the convective heat transport in a coolant channel CV.
- The *heat conservation equations* are solved by the Gauss-Seidel numerical iteration line-by-line method and the reactor safety margins (ONBR, OFIR, and CHFR) are calculated using the solution obtained.
- The solutions obtained by the code for test problems of different types were verified by comparison with the solutions obtained independently by MATLAB scripts.

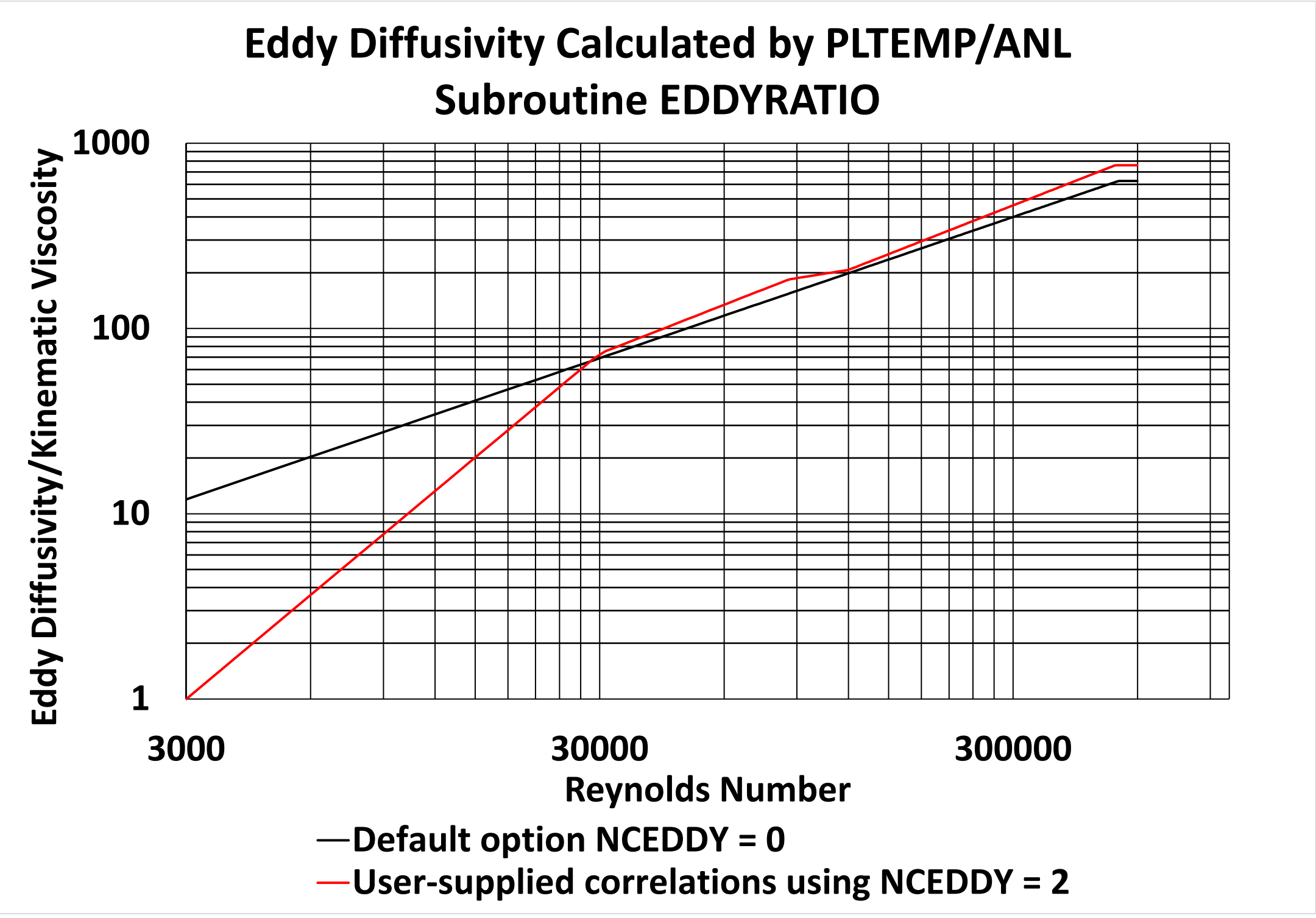
3. Eddy-Induced Coolant Mixing Along Channel Width

- The ratio of eddy diffusivity to kinematic viscosity (ratio ε_H/ν) of the coolant is calculated using the built-in correlation below (based on measured data of several publications) or a more general user-specified correlation.

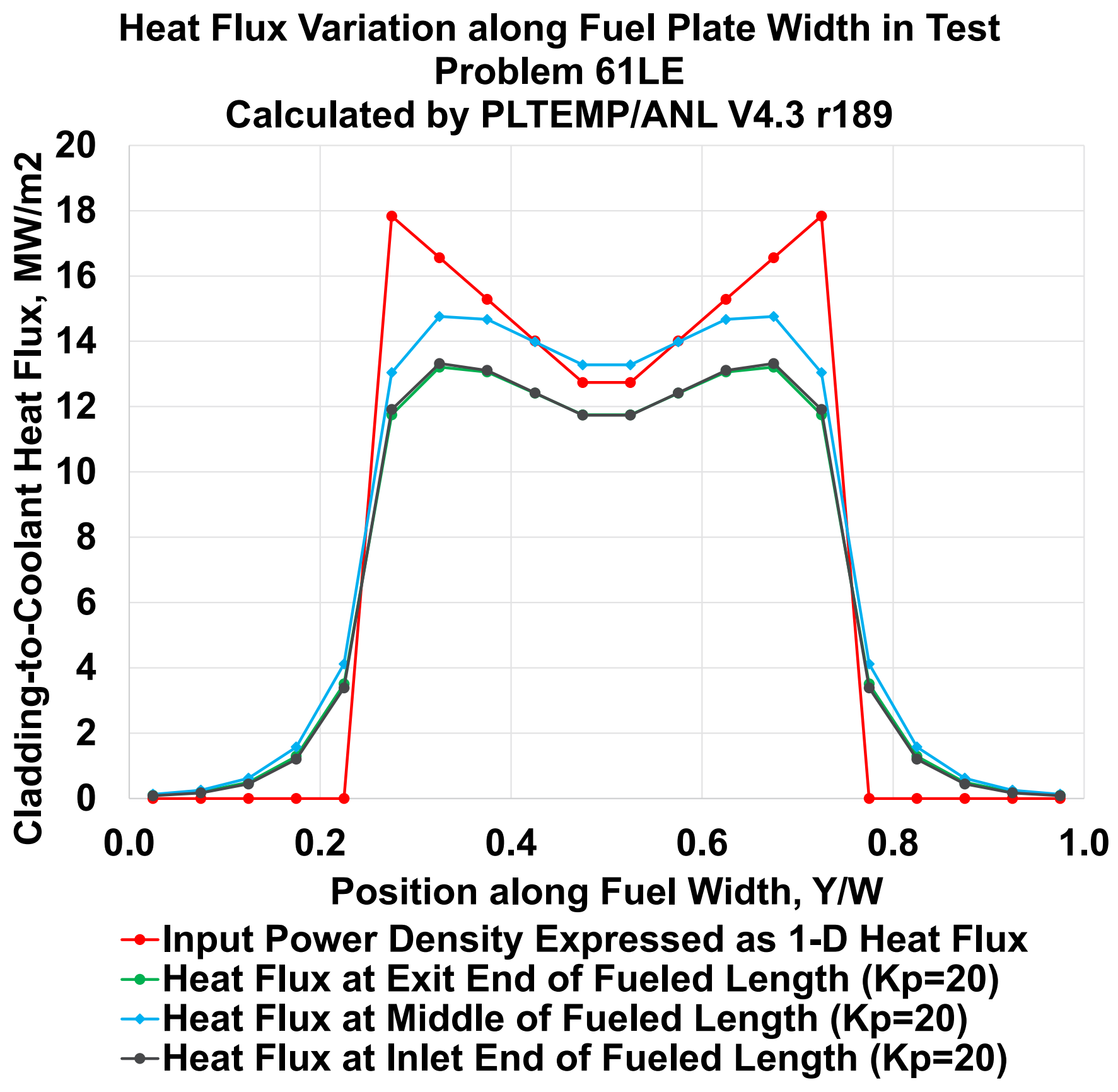
$$\frac{\varepsilon_H}{\nu} = 0.0268\ \mathrm{Re}^{0.762} \ ,\ \text{for plate geometry}$$

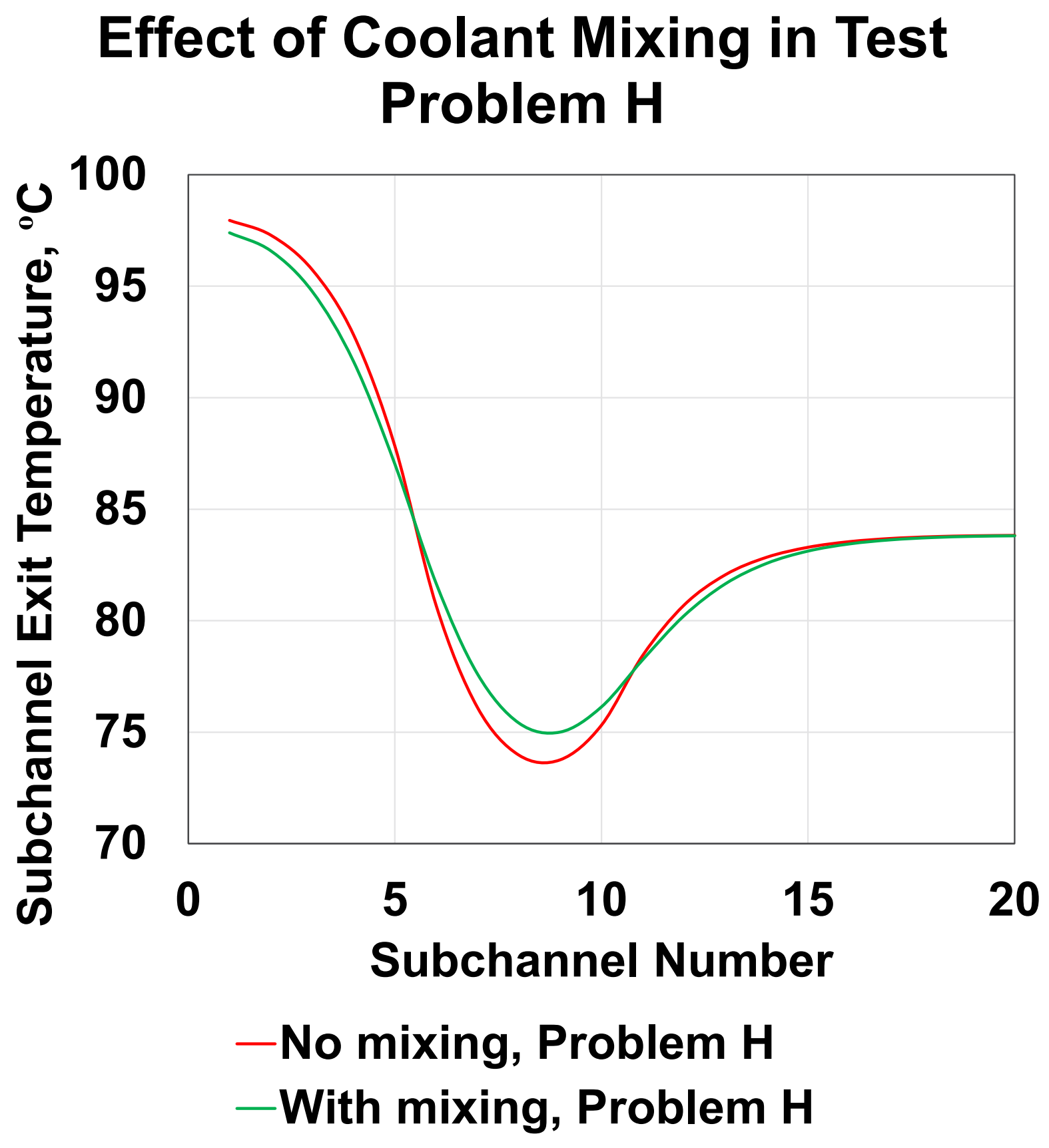
- The coolant's total thermal conductivity K_{total} (due to the thermal motion of molecules and the eddy-induced mass & heat exchange) in the channel lateral direction is calculated (by the following equation) and used to calculate the coolant temperature distribution

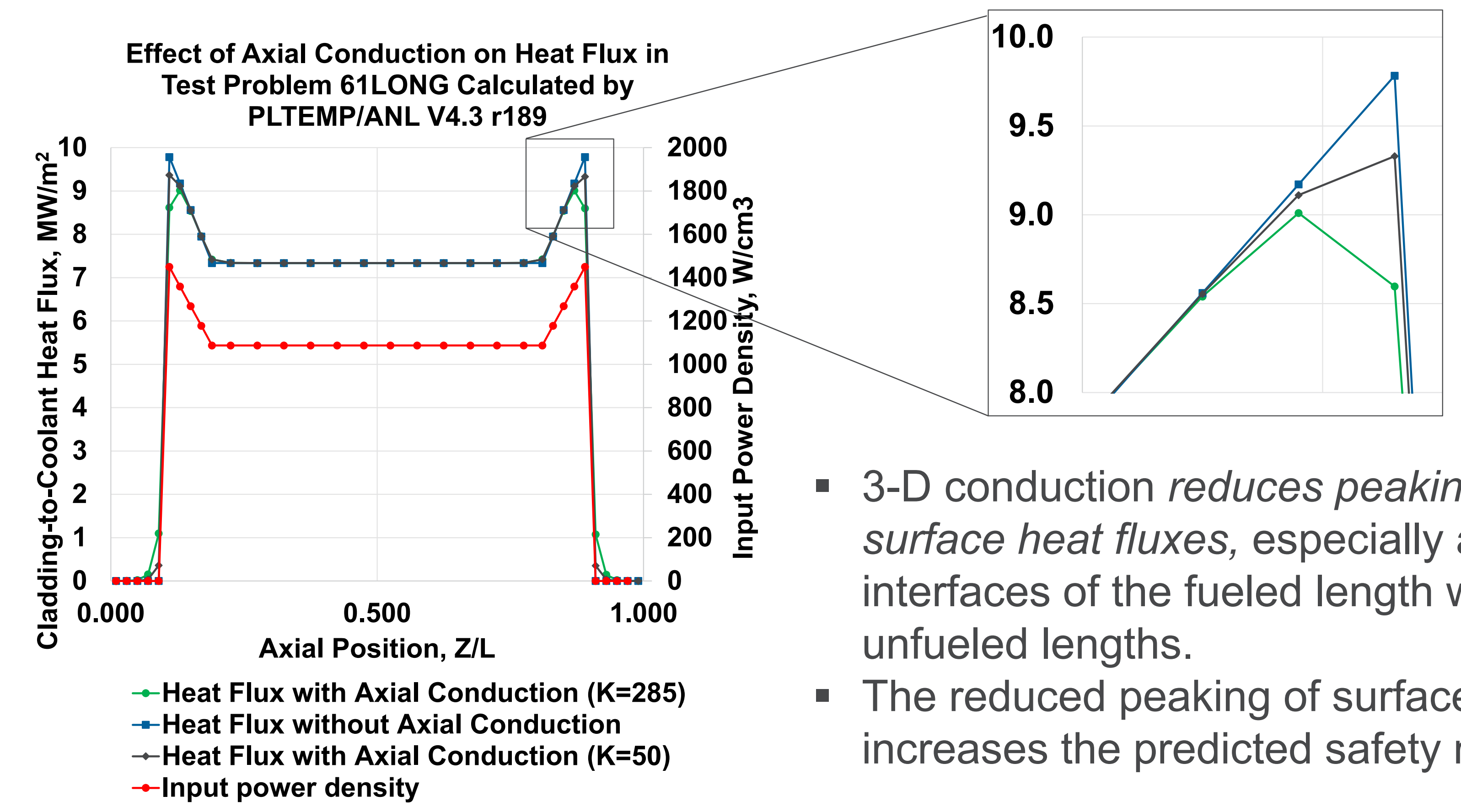
$$K_{total} = K\left(1 + \mathrm{Pr}\frac{\varepsilon_H}{\nu}\right)$$


Eddy Diffusivity Calculated by PLTEMP/ANL Subroutine EDDYRATIO

Sample 3-D Results and Discussion


Heat Flux Variation along Fuel Plate Width in Test Problem 61LE Calculated by PLTEMP/ANL V4.3 r189


Effect of Coolant Mixing in Test Problem H


Effect of Axial Conduction on Heat Flux in Test Problem 61LONG Calculated by PLTEMP/ANL V4.3 r189

- 3-D conduction *reduces peaking of plate surface heat fluxes,* especially at the interfaces of the fueled length with the unfueled lengths.
- The reduced peaking of surface heat flux increases the predicted safety margins.