22.251 Systems Analysis of the Nuclear Fuel Cycle

Fall 2009

Lab Exercise #5 Investigation of potential uprate of a PWR core using VIPRE

In this exercise you will learn how to use VIPRE in a subchannel analysis of a PWR core. Given the boundary conditions, VIPRE calculates the coolant velocity and temperature distribution and the temperature of the structures in space and time dependent form within the reactor core. Furthermore, it includes a module to calculate the margin for the boiling crisis. We will use VIPRE to investigate the possibility of power uprate in PWRs. The analysis will include steady state and transient scenarios. Note that the power uprate problem is a multi-physics one. Here, we would like to emphasize the thermal-hydraulics and structural aspects of it.

1. Given data: Parameters of a typical Westinghouse PWR core with 17×17 fuel assemblies are given in Table-1. Pin power distribution (normalized to core average linear heat rate) in a hot fuel assembly is given in Figure-1 and normalized fuel assembly distribution is shown in Figure-2. Note that core power distribution is symmetrical; hence only 1/8 of the core can be modeled. Assume chopped cosine with peak-to-average ratio of 1.55 for the axial power profile.

Table 1. Operating parameters and selected characteristics of a typical Westinghouse PWR

Parameter	**4-loop PWR**
1. Core	
Reactor thermal power (MWth)	3411
Power generated directly in coolant (%)	2.6
Power generated in the fuel (%)	97.4
Radial power factor ($F_{\Delta h}$)	1.65
Allowable core total peaking factor (F_Q)	2.5
2. Primary Coolant	
System pressure (MPa)	15.51
Core inlet temperature (°C)	292.7
Average temperature rise in reactor (°C)	33.4
Total core flow rate (Mg/s)	18.63
Effective core flow rate for heat removal (Mg/s)	17.7
3. Fuel Rods	
Total number	50,952
Fuel density (% of theoretical)	94
Fuel pellet diameter (mm)	8.19
Fuel rod diameter (mm)	9.5
Cladding thickness (mm)	0.57
Cladding material	Zircaloy-4
Active fuel height (m)	3.66
4. Fuel Assemblies	
Number of assemblies	193
Number of heated rods per assembly	264
Fuel rod pitch (mm)	12.6
Fuel assembly pitch (mm)	215
Number of grids per assembly	7
Fuel assembly effective flow area (m^2)	0.02458
Location of first spacer grid above beginning of heated length (m)	0.3048
Grid spacing (m)	0.508
Grid type	L-grid with mixing vanes
Number of control rod thimbles per assembly	24
Number of instrument tubes	1
Guide tube outer diameter (mm)	12.243

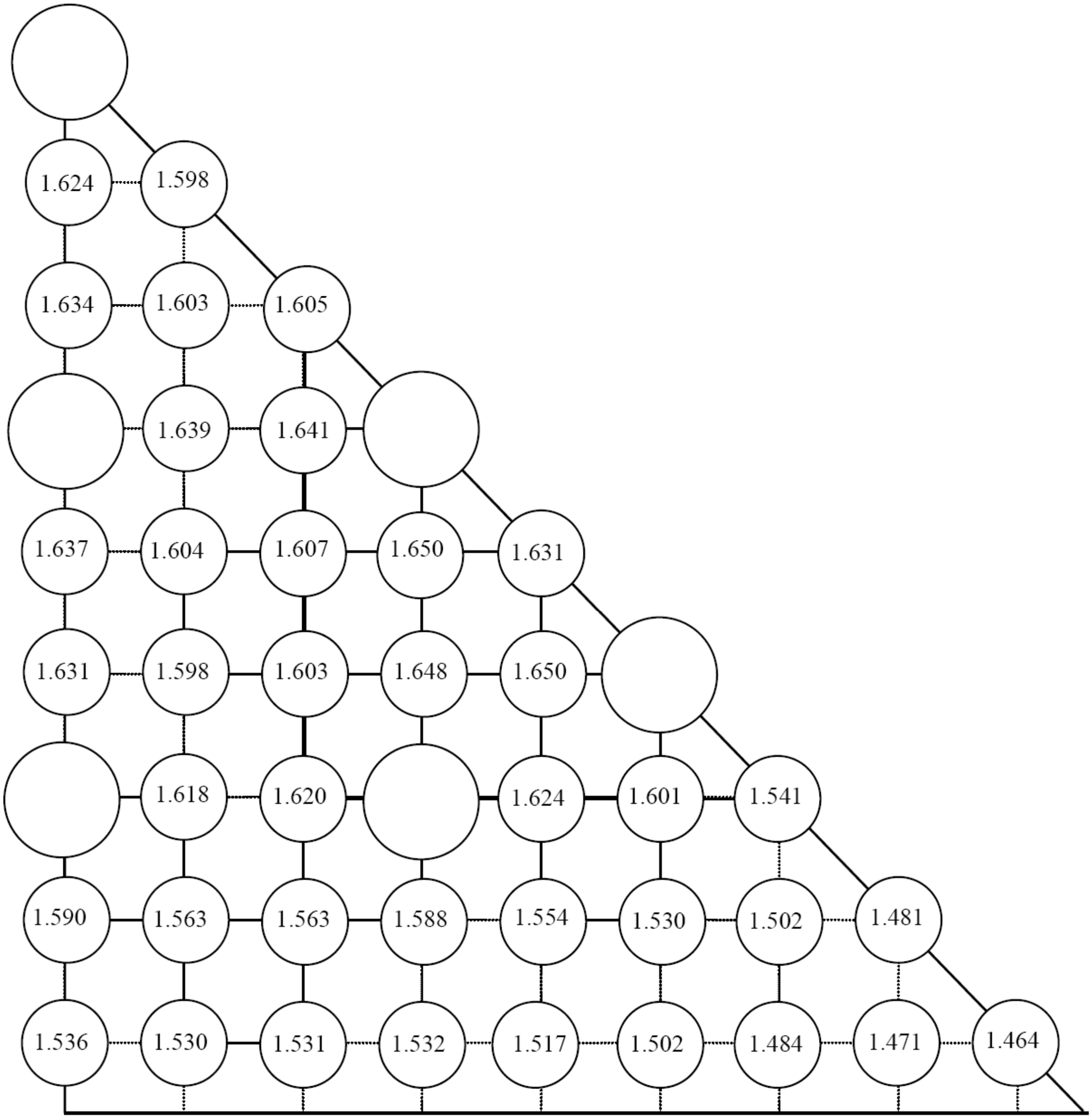

Figure 1 Typical pin power distribution in the hot fuel assembly of a PWR core

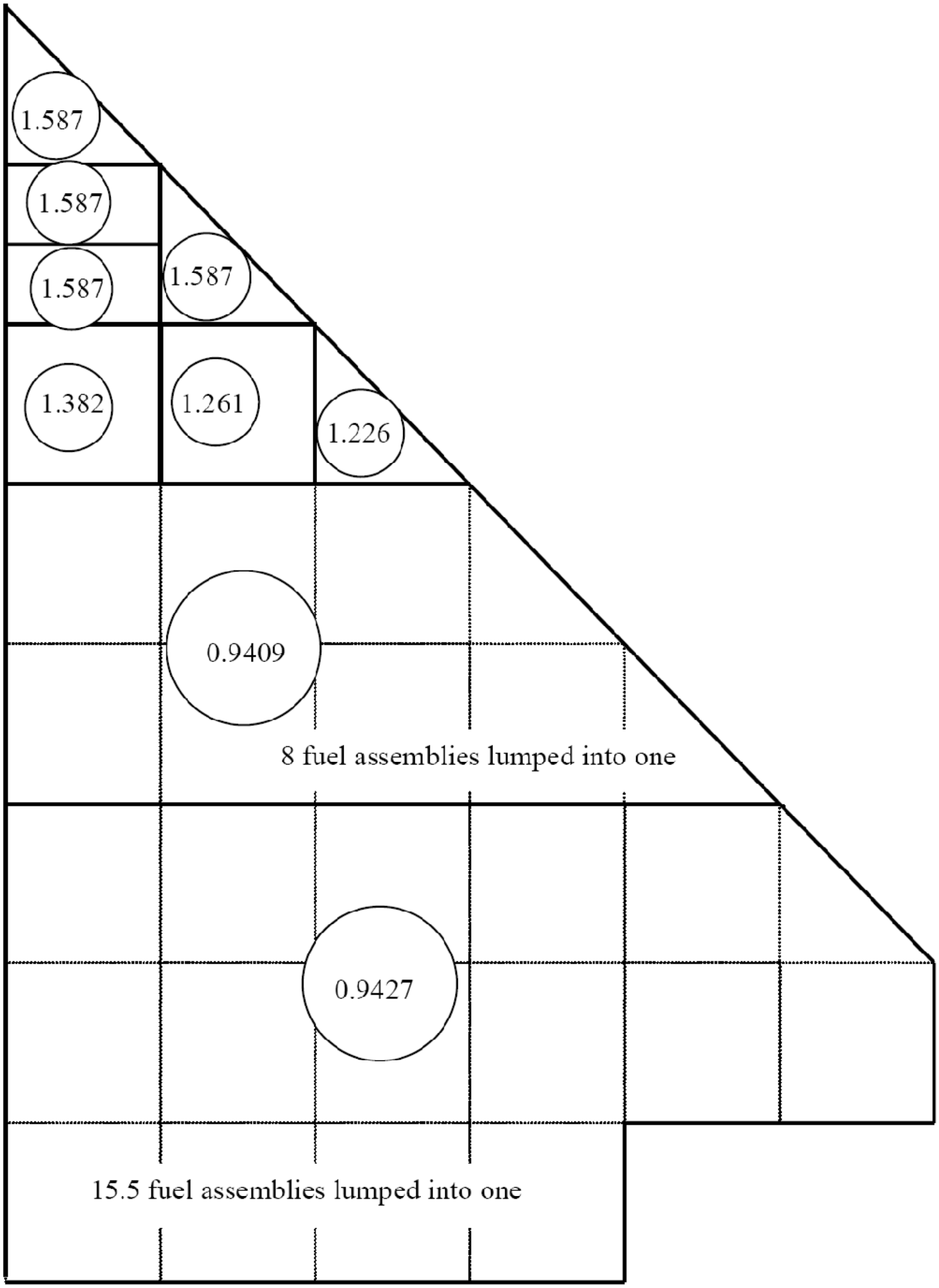

Figure 2 Fuel assembly power distribution in a typical PWR core

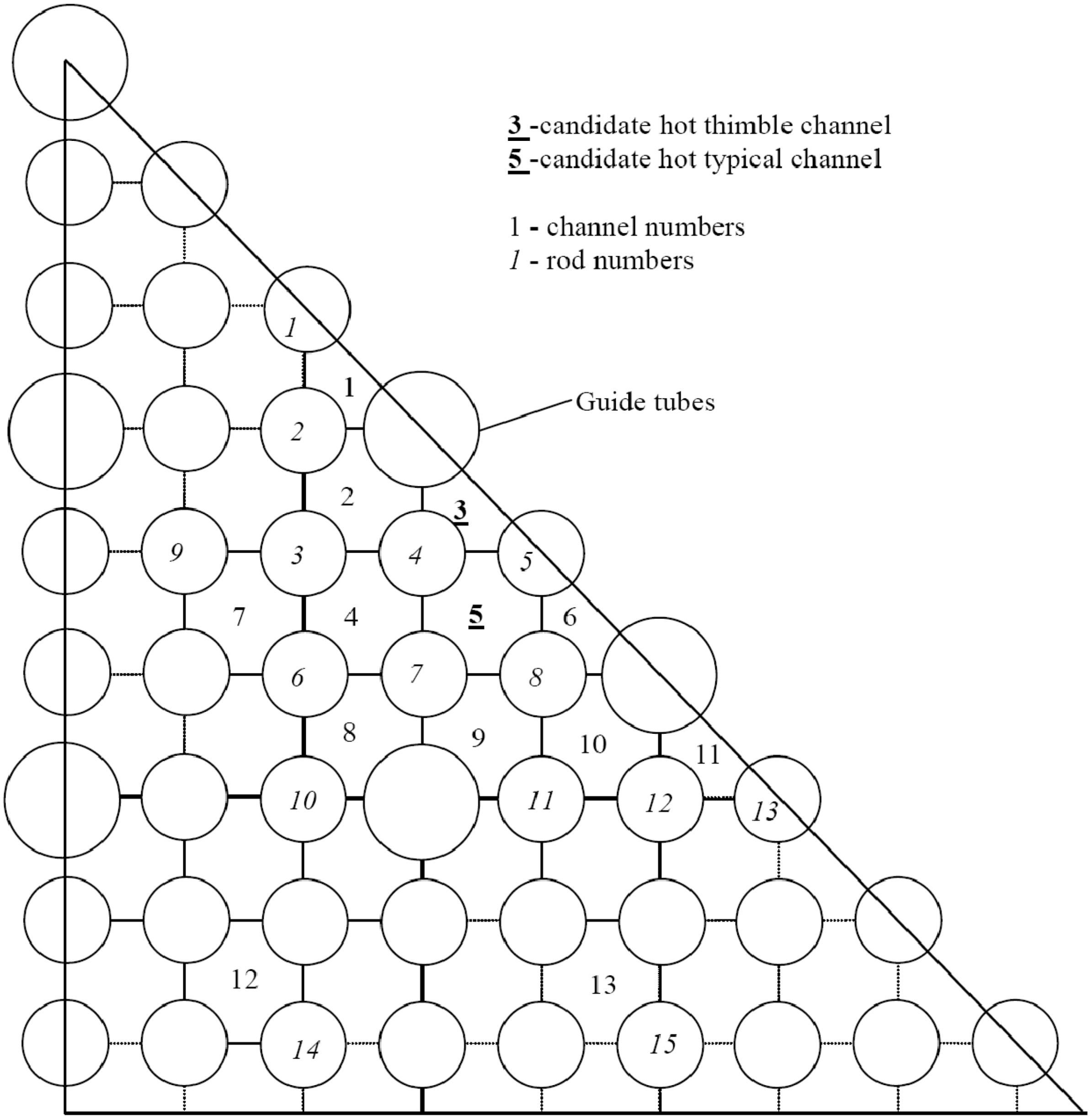

Figure 3 Channel and rod numbering scheme for 1/8th model of the hot fuel assembly

VIPRE provides the capability to lump more subchannels into one channel to reduce the computational requirements. This practice has been shown to provide accurate results at substantial savings of CPU as long as sufficient modeling details are maintained in the vicinity of the hot subchannel. This method has been employed in the PWR core model in this exercise. For example, channel 7 is lumped into 11 subchannels, channel represents 9 subchannels and channel

21 lumps a large number of 4698 subchannels. The total number of channels used in the reference PWR model is 21, each divided into 48 axial nodes.

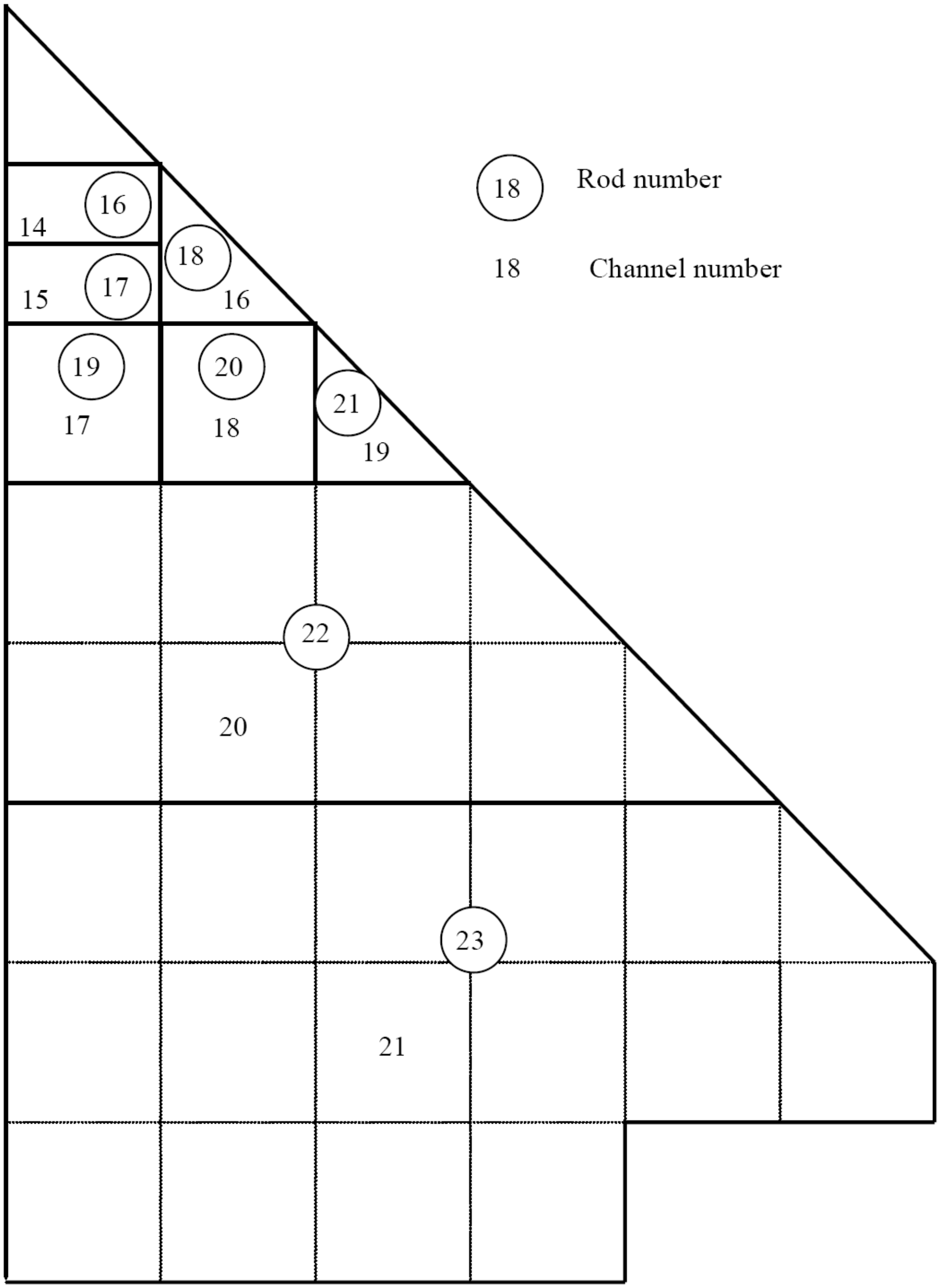

Figure 4 Channel and rod numbering scheme for 1/8th core model

Tasks:

1. Study the input file given for the steady state, the above data and figures and VIPRE manual to familiarize yourself with the structure and logic of the VIPRE input. Make sure the table and the input descriptions are matching. Print MDNBR, hot subchannel exit quality, peak fuel temperature, peak clad outer temperature and core pressure drop for the steady state case. (20 points)
2. Evaluate the possibility of power density increase of this core by keeping the total core power to total core flow ratio and coolant inlet temperature constant. Find the permissible power uprate to satisfy the limitations given in Table-1. (20 Points)
3. How would you modify the core to allow for room for further power density increase while keeping the coolant inlet temperature and power to flow ratio constant? You may use VIPRE for this part to an extent possible. You may also do simple hand calculations and/or just a qualitative description of your ideas (10 points).

Table-1: Limiting values

Property	Limiting Value
Max. Allowed Pumping Power*	20 MW
MDNBR (Steady state)	1.3
Peak Fuel Temperature (Steady-state) (ºC) **	1400

* You may define the pumping power in a simple way multiplication of the core pressure drop (Pa) and volumetric flow rate (m^3/s). Assume the process is isentropic.
** The maximum allowed fuel temperature at steady state is limited by the fission gas release behavior of the fuel. Excessive fission gas release may lead to pressurization of the plenum and the cladding lift off risk in steady state and LOCA scenarios; hence, limits the achievable burnup.

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