22.251 Systems Analysis of the Nuclear Fuel Cycle
Fall 2005
Lab exercise #6 Investigation of potential uprate of a PWR core using VIPRE
Due: Friday December 2,2005

In this exercise you will learn how to use VIPRE in a subchannel analysis of a PWR core to investigate the effect of various parameters on the Minimum DNBR (MDNBR).

1. Given data. The parameters of a typical Westinghouse PWR core with 17x17 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 1and 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

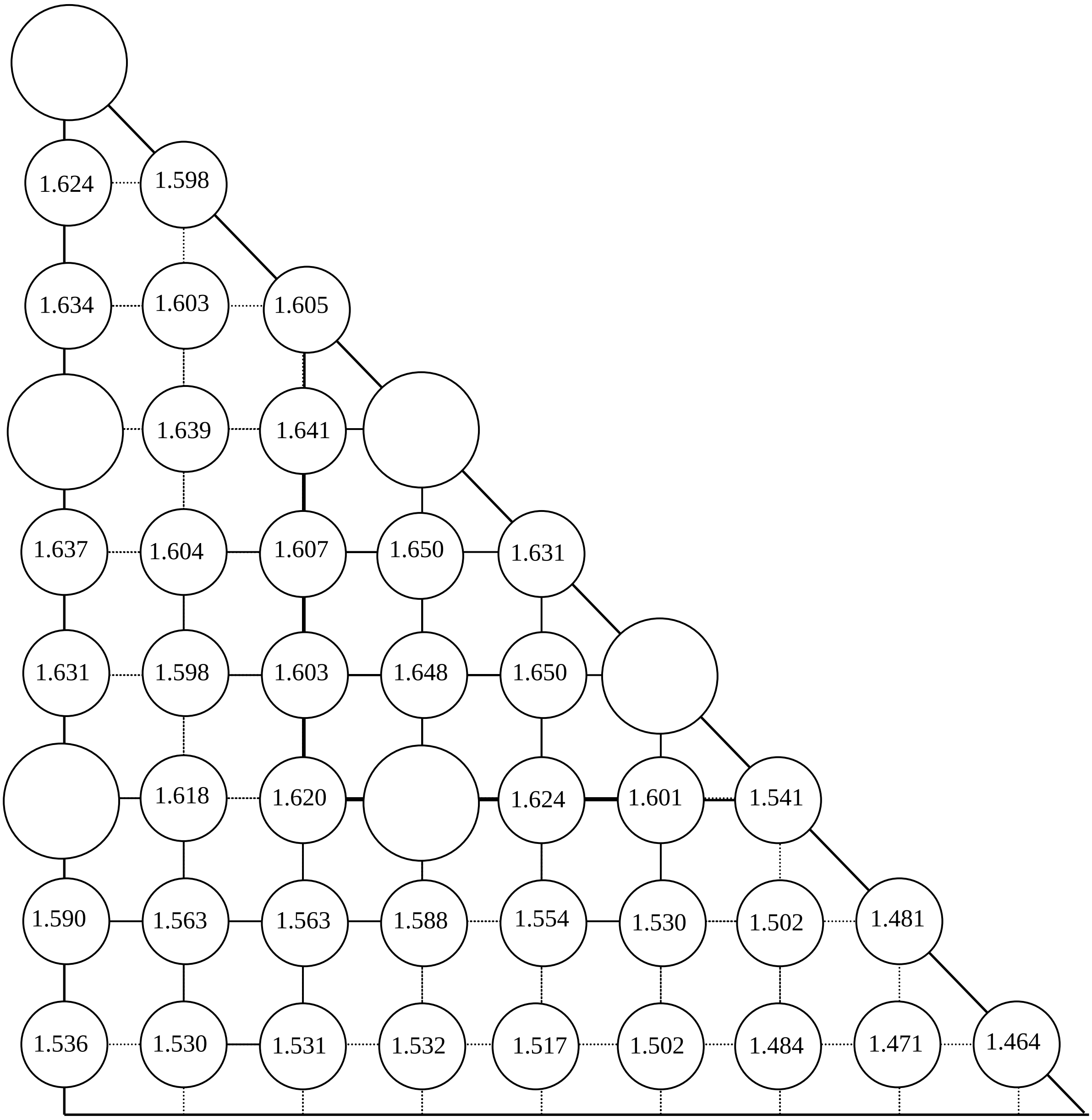

Figure 1 Typical pin power distribution in the hot fuel assembly of a PWR core

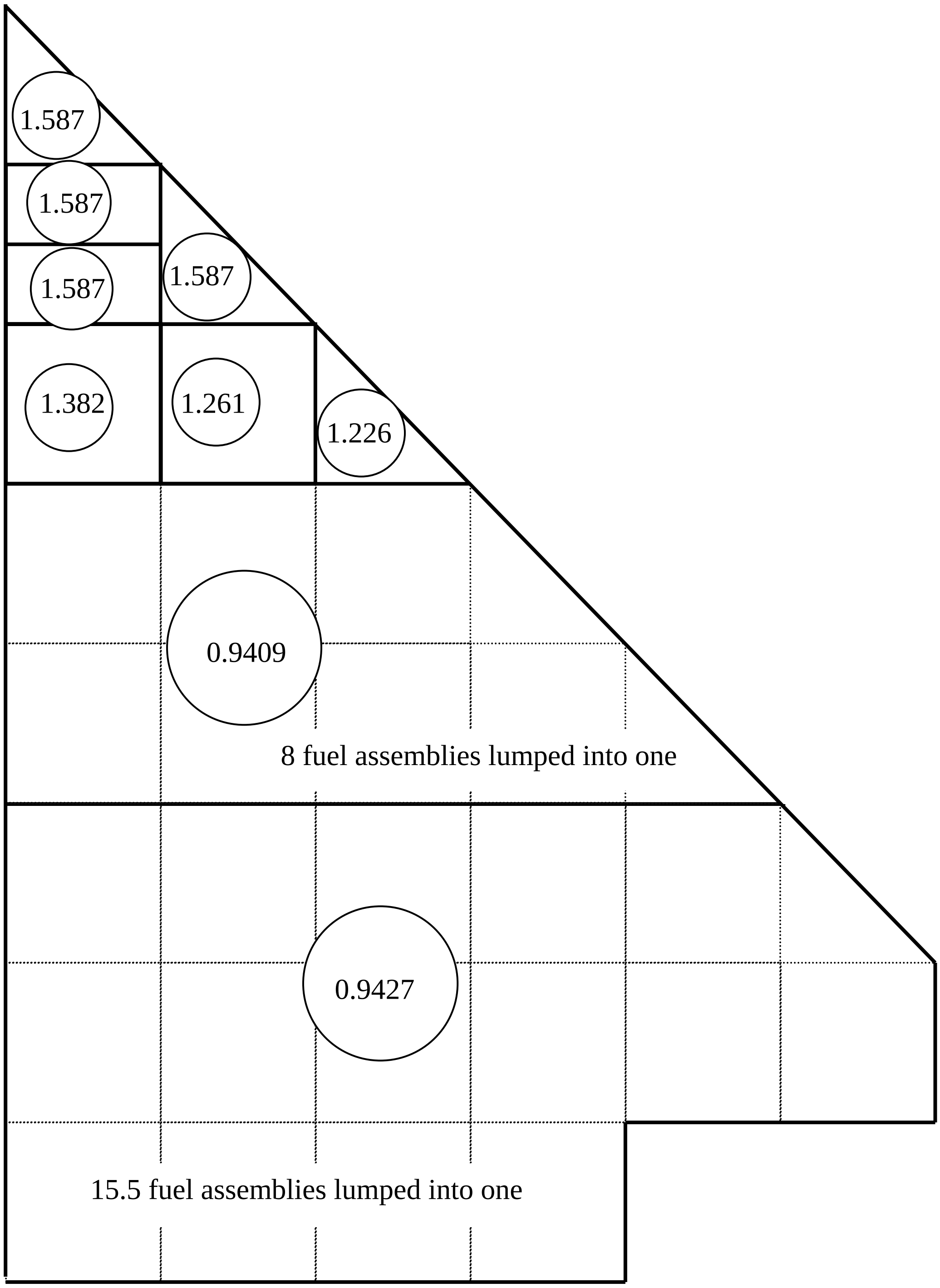

Figure 2 Fuel assembly power distribution in a typical PWR core

2. VIPRE model. The VIPRE input file for the above core configuration has been prepared and is available at 22.251 mightyalpha account – see section 4 (instructions to run VIPRE). To help you to get oriented in the input file, the channel and rod numbering scheme used to generate VIPRE geometry cards is shown in Figures 3 and 4.

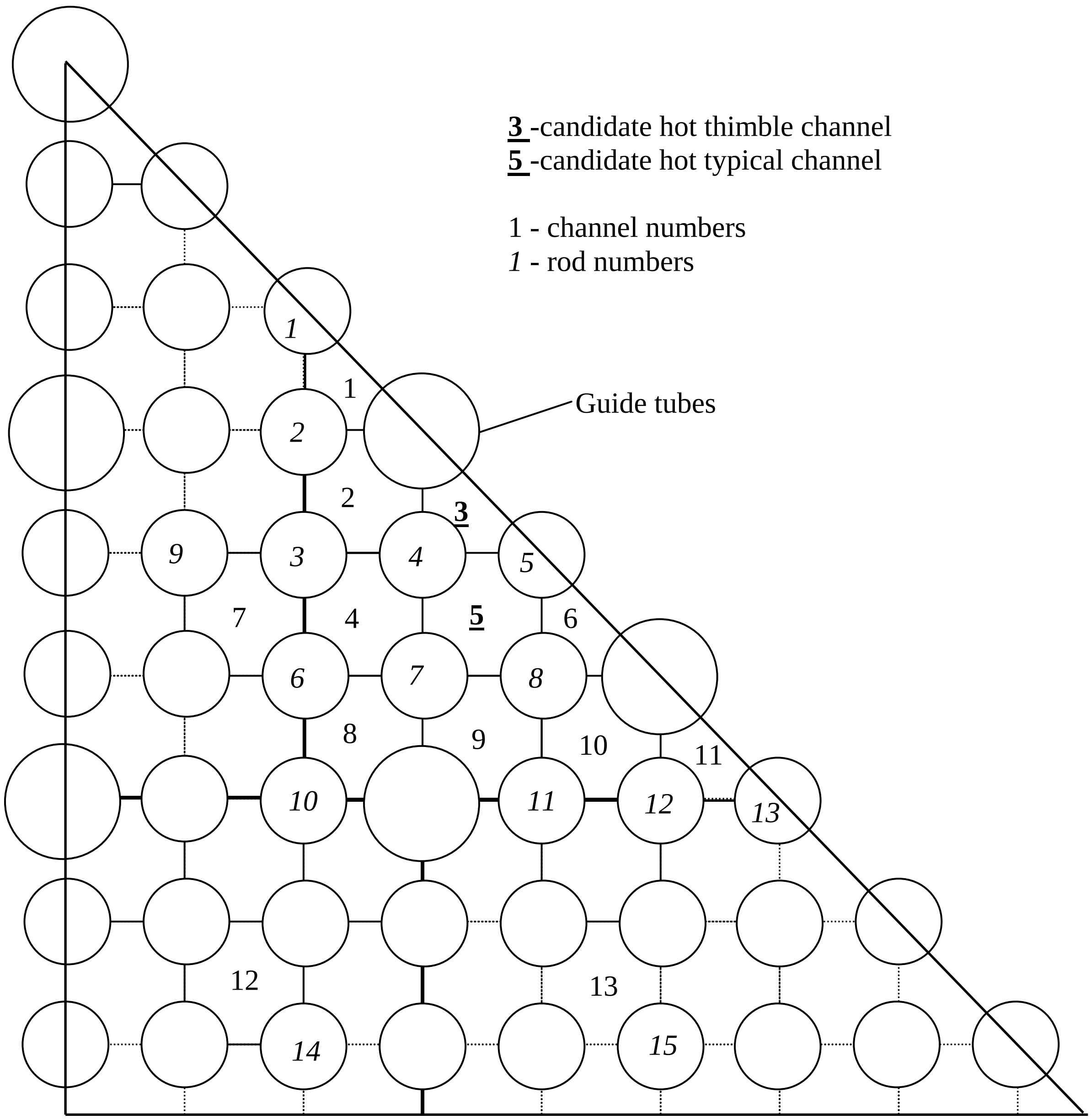

Figure 3 Channel and rod numbering scheme for 1/8th model of the hot fuel assembly

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 detail is 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.

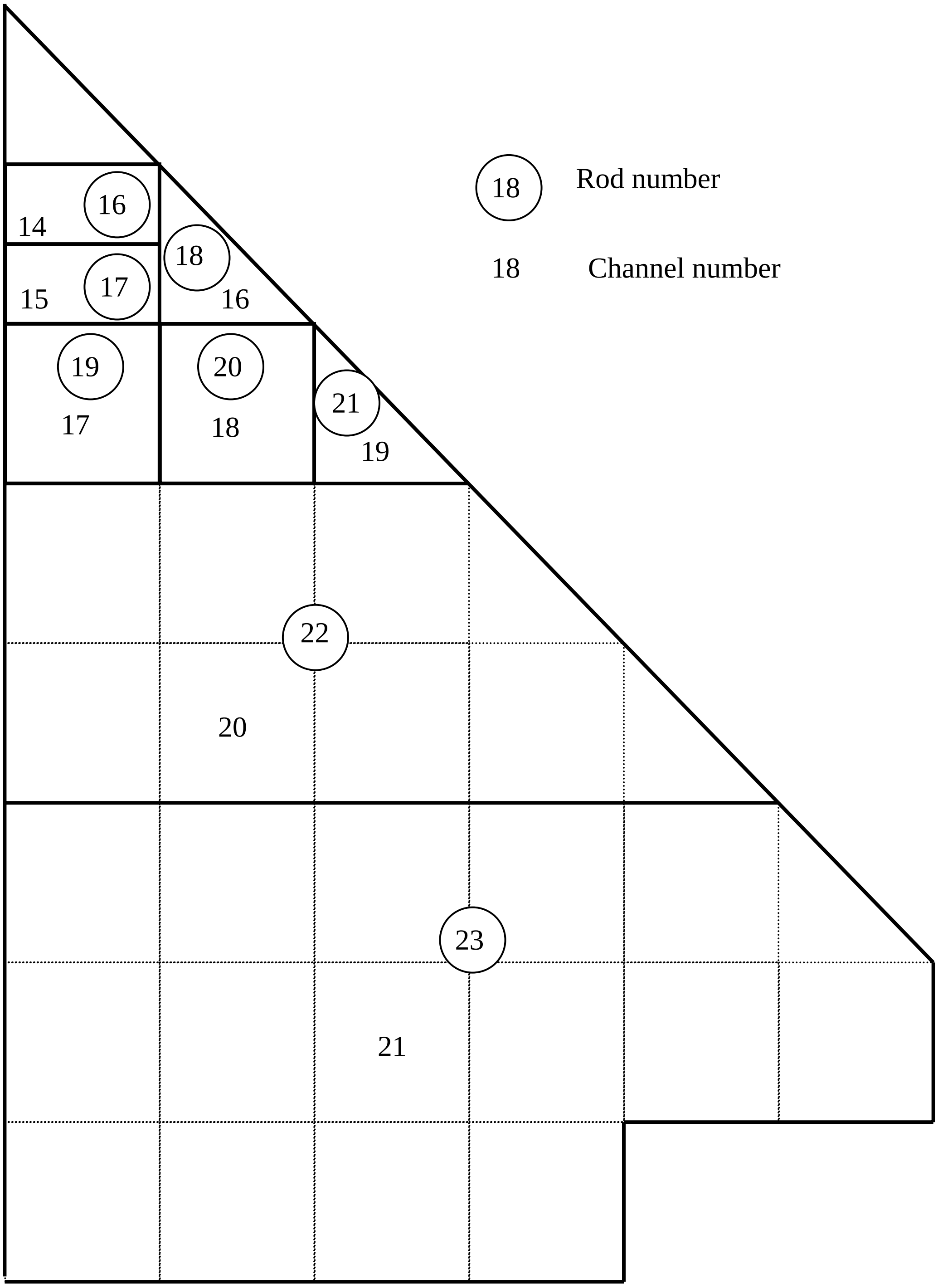

Figure 4 Channel and rod numbering scheme for 1/8th core model

3. Tasks

1. Study the input file using the above data and figures and the VIPRE manual to familiarize yourself with the structure and logic of the VIPRE input. Run the input and study the generated output file to get acquainted with the structure of VIPRE output so that you understand how the code works and where the results of interest (MDNBR, peak fuel temperature, convergence criteria) are located.
2. MDNBR needs to be satisfied for the full spectrum of transients and accidents. To avoid lengthy process of analyzing the full spectrum of transients, a shortcut is sometimes used to analyze the steady state at overpower condition. How large overpower was selected for

the core in the given input? The key parameters influencing MDNBR are core flow and core inlet temperature. What core flow and coolant inlet temperature are used in the given input? Explain why do you think these values are different from the data given in Table 1. Determine the two-phase flow quality of the hot channel.

3. Currently, many utilities are pursuing power uprate of LWRs. How much can you uprate the PWR core from Table 1 by changing core inlet temperature while keeping other parameters (geometry, flow rate, pressure, power distribution) fixed? Use the W-3L correlation for DNBR calculations and assume that the DNBR margin of the uprated core remains the same as for the reference core. Make sure that you do not exceed fuel melting point limit. What consequences of reduced core inlet temperature need to be evaluated considering the fact that the goal is to achieve maximum electrical power output? Estimate the net electrical power gain assuming that the reference plant has 33.5% efficiency and steam generator pressure is 5.7MPa.
4. How much can you uprate the PWR core from Table 1 by changing core flow rate while keeping other parameters (geometry, core inlet temperature, pressure, power distribution) fixed? Use the W-3L correlation for DNBR calculations and assume that the DNBR margin of the uprated core remains the same as for the reference core. Make sure that you do not exceed fuel melting point limit. What other important parameters (in addition of DNBR and fuel temperature) of the uprated core may be of concern and would require further analyses to make sure that the proposed uprate is feasible?

4. Instructions to run VIPRE

VIPRE is located on the ALPHA workstation mightyalpha and is accessible to all 22.251 course students through the 22.251 account from athena clusters or from PCs connected to the internet. Running VIPRE is simple. It requires only one input file and the typical running time per case should not exceed 1 minute. To run the code, follow the instructions below:

1. Log into 22.251 account and go to your directory

2. Copy reference input file pwrref.dat into your directory. The command is

   cp ../VIPRE/pwrref.dat myinput

3. Copy the script runvipre to run executable into your directory. Use the command

 cp ../VIPRE/runvipre runvipre

4. Enable execution of the script under your account by using the command

chmod +x runvipre

5. Make the test run with the reference input file, i.e. ./runvipre myinput.

VIPRE generates a number of output files, from which only the file “outptt” is important for your analyses and contains all output data that you need. Note that the script prior to executing VIPRE deletes all output files from previous VIPRE runs to prevent VIPRE crash due to file overwrite protection. Therefore, you will need to save the outptt file under a different name (if you want to preserve it) prior to running runvipre script again to avoid losing the data from an earlier run.

Use the reference input file (myinput) to modify required parameters for your sensitivity study. You will need to consult VIPRE manual, which is located in the computer room of NW12.