22.251 Systems Analysis of the Nuclear Fuel Cycle
Fall 2005

Lab #5: PWR Core Leakage and Safety Coefficient Using MCNP Model

A standard Westinghouse 4-loop PWR core (1/8th symmetry) was modeled with MCNP. Core average conditions were assumed, i.e., the coolant temperature as 583.1 K and the fuel temperature as 900 K. The thermal hydraulic feedback was ignored. The core parameters are listed in Table 1. The cross sectional view of the core is shown in Figure 1. There are also axial reflectors at the bottom/top of the core.

Two major challenges in the core criticality calculation are (1) appropriate sampling; (2) fundamental mode source distribution. It will be verified in MCNP that at least one fission source neutron was generated in every cell containing fissionable material. One of practical commercial core design objectives is to minimize the power peaking. Hence, the neutron importance at various locations of large commercial cores doesn't vary too much (on the same order of magnitude). Sampling of the fissionable material is not an issue for MCNP calculations if a sufficient number of neutron histories are tracked. However, the fundamental-mode spatial distribution is not a trivial task. The convergence might be very slow, particularly for large, thermal, low-leakage systems. This requires a long preparation calculation of equilibrium source distributions. A general guide of producing the well converged source file (srctp) is to use small number of neutrons per cycle at first, then increase that number step by step to large neutrons per cycle. This has been done and you are given converged source file, MySrc, in addition to MCNP input.

(a) Using this MCNP model and source file, calculate the PWR core leakage, i.e., percent of neutrons that escape the core. Note that the leakage refers to neutrons leaking out of the core.

(b) Modify the given input to calculate coolant temperature coefficient $\partial\rho/\partial T\ [pcm/K]$ in the vicinity of the operating point represented by reference MCNP input file. Hint: You will need to perform an additional run with modified MCNP input by altering water density in the core region. Make sure to use a temperature difference that produces a reactivity difference between the two points that is larger than MCNP statistical error. Also, make sure that you start the new run using the same srctp file as before to eliminate uncertainties due to different initial source distribution.

Table 1. Operating parameters for a typical Westinghouse 4-loop PWR.

Operating Parameter	Value
1. Plant	
Number of primary loops	4
Total heat output of the core (MWth)	3411
Total plant thermal efficiency (%)	34
Electrical output of plant (MWe)	1150
Energy deposited in the fuel (%)	97.4
Energy deposited in the moderator (%)	2.6
2. Core	
Core barrel inside diameter/outer diameter (m)	3.76/3.87
Mass of fuel UO_2 (MT)	101.0
Mass of fuel as U (MTU)	88.2
Mass of cladding material (MT)	23.1
Rated power density (kW/liter-core)	104.5
Specific power (kW/kgU)	38.7
Average linear heat generation rate (kW/ft)	5.6
Core volume (m^3)	32.6
3. Primary coolant	
System pressure (MPa)	15.51
Total core flow rate (Mg/sec)	18.63
Effective core flow rate for heat removal (Mg/sec)	17.7
Rated coolant mass flux ($kg/m^2 \cdot sec$)	2087.6
Core inlet temperature (°C)	292.7
4. Fuel rods	
Total number	50,952
Fuel density (% of theoretical)	94
Pellet diameter (mm)	8.19
Pellet height (mm)	13.4
Fuel-clad radial gap width (μm)	82
Cladding material	Zircaloy-4
Cladding thickness (mm)	0.57
Clad outer diameter (mm)	9.5
Active fuel height (m)	3.66
5. Fuel assemblies (17×17 square lattice)	
Number of assemblies	193
Number of fuel rods per assembly	264
Number of grids per assembly	7
Pin-to-pin pitch (mm)	12.6
Assembly pitch (mm)	215
6. Rod cluster control assemblies (RCCA)	
Neutron absorbing material	Ag(80)-In(15)-Cd(5)
Cladding material	Stainless Steel (SS) 304
Cladding thickness (mm)	0.46
Number of RCCA clusters	53

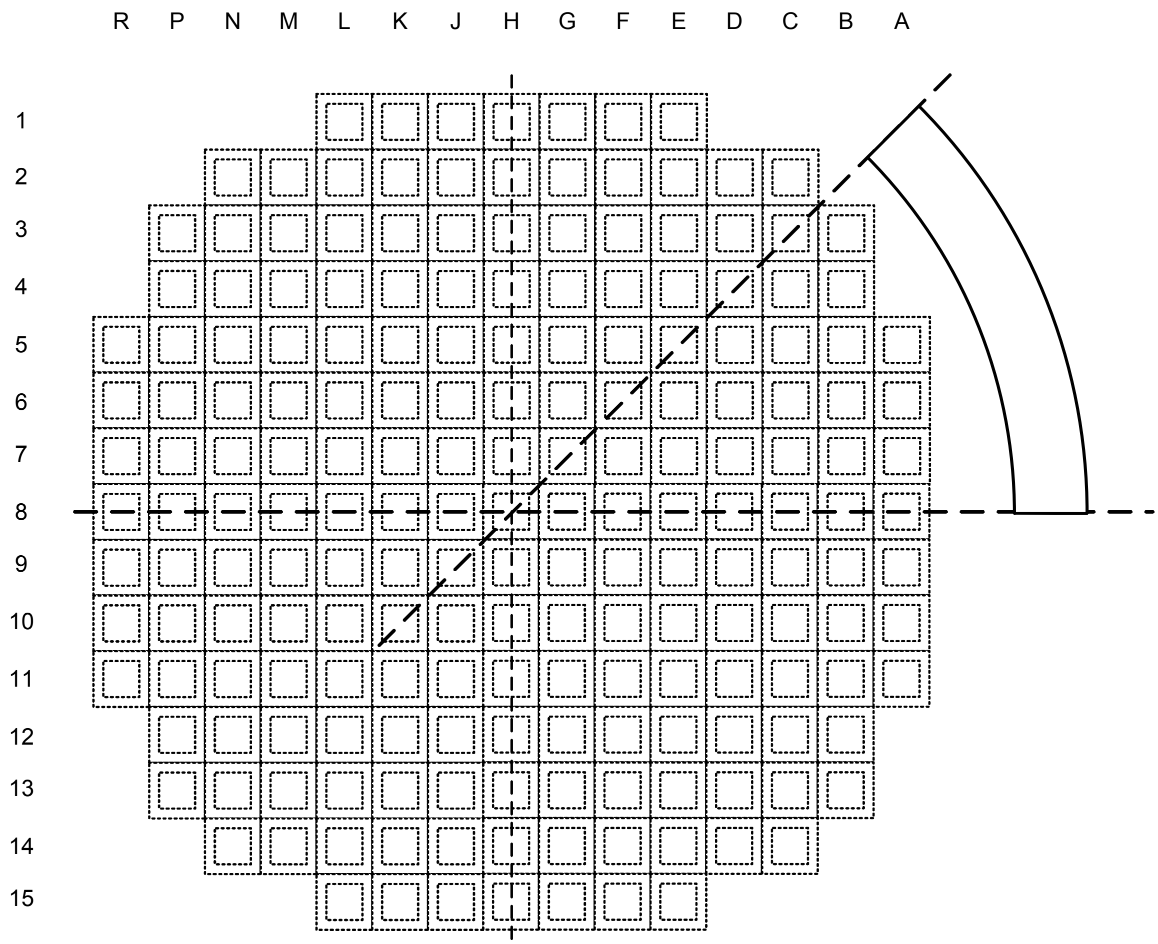

Figure 1. Cross sectional view of PWR core model (1/8th symmetry).