22.351 Systems Analysis of the Nuclear Fuel Cycle
Fall 2005

Lab #5: PWR Core Leakage Using MCNP Model
Solution

a) Neutron leakage from the core

Table 1 Neutron balance by cell from MCNP output

cell index	cell name	nuclides	atom fraction	total collisions	collisions * weight	wgt. lost to capture	wgt. gain by fission
1	1	92235.16c	1.01E-02	10364256	7.11E-01	1.06E-01	5.07E-01
		92234.86c	8.13E-05	36826	2.81E-03	1.83E-03	3.98E-05
		92238.16c	3.23E-01	40982167	3.43E+00	2.81E-01	2.99E-02
		8016.54c	6.67E-01	26263484	2.22E+00	1.72E-03	0.00E+00
2	2	8016.53c	1.00E+00	860	7.30E-05	5.66E-08	0.00E+00
3	3	8016.53c	7.10E-03	53296	4.49E-03	3.34E-06	0.00E+00
		24000.50c	1.75E-03	20531	1.73E-03	1.04E-04	0.00E+00
		26000.55c	3.41E-03	57681	4.60E-03	1.68E-04	0.00E+00
		40000.58c	9.77E-01	13142701	1.14E+00	8.49E-03	0.00E+00
		50000.40c	1.11E-02	130729	1.12E-02	4.89E-04	0.00E+00
4	4	1001.53c	6.67E-01	227731205	1.76E+01	3.85E-02	0.00E+00
		8016.53c	3.33E-01	22407394	1.89E+00	1.37E-03	0.00E+00
5	5	1001.53c	6.67E-01	26635888	2.06E+00	4.88E-03	0.00E+00
		8016.53c	3.33E-01	2505035	2.11E-01	1.45E-04	0.00E+00
6	6	8016.53c	7.10E-03	5453	4.57E-04	2.20E-07	0.00E+00
		24000.50c	1.75E-03	2177	1.82E-04	1.26E-05	0.00E+00
		26000.55c	3.41E-03	6116	4.88E-04	2.02E-05	0.00E+00
		40000.58c	9.77E-01	1330070	1.15E-01	9.35E-04	0.00E+00
		50000.40c	1.11E-02	13293	1.13E-03	5.45E-05	0.00E+00
7	7	1001.53c	6.67E-01	10326501	7.99E-01	1.86E-03	0.00E+00
		8016.53c	3.33E-01	983039	8.28E-02	5.79E-05	0.00E+00
10	10	1001.53c	6.67E-01	3351292	2.59E-01	5.64E-04	0.00E+00
		8016.53c	3.33E-01	330815	2.79E-02	2.06E-05	0.00E+00
11	11	1001.53c	6.67E-01	0	0.00E+00	0.00E+00	0.00E+00
		8016.53c	3.33E-01	0	0.00E+00	0.00E+00	0.00E+00
	Cells outside the core						
13	13	1001.53c	6.67E-01	38995625	2.15E+00	9.85E-03	0.00E+00
		8016.53c	3.33E-01	2116510	1.26E-01	3.87E-05	0.00E+00
14	14	14000.60c	1.00E-02	1053	7.16E-05	9.63E-07	0.00E+00
		24000.50c	1.85E-01	43077	2.61E-03	3.05E-04	0.00E+00
		25055.60c	2.00E-02	9864	6.81E-04	1.45E-04	0.00E+00
		26000.55c	6.75E-01	266117	1.45E-02	9.08E-04	0.00E+00
		28000.50c	1.10E-01	71478	3.92E-03	2.69E-04	0.00E+00
15	15	1001.53c	6.67E-01	2722847	1.74E-01	7.52E-04	0.00E+00
		8016.53c	3.33E-01	159659	1.11E-02	4.67E-06	0.00E+00
16	16	1001.53c	6.67E-01	2739838	1.75E-01	7.57E-04	0.00E+00
		8016.53c	3.33E-01	160314	1.11E-02	4.44E-06	0.00E+00
	Captures out of core		cells 13-16			**1.30E-02**	

Table 1 gives neutron balance in each cell. Neutrons that leak out of the core are either captured in the cells outside the core or leak out of the modeled system. Fraction of neutrons that are captured outside the core can be obtained from the neutron balance output table as shown in Table 1 to be 0.013.

Neutrons escaped from the system are given in the problem summary table in MCNP output, as shown below:

```
neutron loss              tracks      weight        energy
                    (per source particle)

escape                     49204    3.8139E-03    3.4166E-03
```

Thus, fraction of neutrons escaped is 0.00314. The total neutron leakage from the core is thus 0.013 + 0.00314 = 0.016, i.e., 1.6%. This is smaller leakage than typical value of 3% for PWRs, especially in view of uniform enrichment over the entire core. The reason for this is oversimplified modeling of structure around the core. Steel structures on the bottom and top of the core are not modeled at all and these contribute to neutron captures significantly more than water.

b) Coolant temperature coefficient

Reactivity of the reference case (Core average temperature and density of 309.95°C and 0.705g/cc, respectively) is

$$\rho_{nom} = \frac{k_{eff-nom} - 1}{k_{eff-nom}} = \frac{1.3169 - 1}{1.3169} = 0.2406 \pm 0.0002$$

Core average density at 10°C higher core average temperature (319.95°C) keeping the system pressure constant (15.5MPa) is 0.680g/cc. To obtain reactivity at this lower density, water density in all core regions in the MCNP input has to be adjusted to smaller values. The following lines were changed:

```
 4  4 -0.680     +3  u=1  imp:n=1  tmp=5.0246e-8   $ coolant, 593.1K
 5  4 -0.680     -4  u=2  imp:n=1  tmp=5.0246e-8   $ coolant inside
 7  4 -0.680     +5  u=2  imp:n=1  tmp=5.0246e-8   $ coolant outside
10  4 -0.680  (10:-11:12:-13)  u=4  imp:n=1  tmp=5.0246e-8
11  4 -0.680  -14 15 -16 17  u=5  imp:n=1  lat=1  fill=-8:8 -8:8 0:0
```

Running MCNP with the modified file yields k_{eff}=1.31076±0.0002, yielding reactivity

$$\rho_{up} = \frac{k_{eff-up} - 1}{k_{eff-up}} = \frac{1.3169 - 1}{1.3169} = 0.2371 \pm 0.0002$$

Coolant temperature coefficient is then

$$\frac{\partial \rho}{\partial T} = \frac{(0.2371 - 0.2406)10^5}{319.95 - 309.95} = -40 \pm 2\, pcm / K$$

This compares well with typical value of 38pcm/K at BOL with no soluble boron.