22.251 System Analysis of the Nuclear Fuel Cycle
Fall 2009
Homework Set #3

Problem 1. Consider three reactor types, a current large PWR, a proposed CANDU fueled with slightly enriched U (SEU), and a small modular pebble-bed HTGR, having the following characteristics:

	PWR	PBMR	CANDU-ACE
Thermal Power, MWe	1150	114	881
Electric Power, MWth	3411	265	2798
FUEL ENRICHMENT, w/o U-235	4.5	8.0	1.20
DISCHARGE BURNUP, MWd/kg	50	80	19.75
FUEL Management	3-BATCH	CONTINUOUS ON-LINE REFUELING	CONTINUOUS ON-LINE REFUELING

(a) Compare the uranium and separative work utilization, in MWde/kg U_{NAT} and MWde/kg SWU, for an enrichment plant tails of 0.25 w/o.

(b) Determine which fuel cycle is superior to the others among the PWR, PBMR and CANDU, and explain why the possible reasons behind this behavior.

Problem 2. This problem aims at examining the thermal hydraulic limits and their implications for the design of advanced fuels of LWRs

It is proposed to use a 13 x 13 internally and externally cooled annular fuel assembly design to replace the 17 x17 externally cooled fuel assembly in a typical Westinghouse PWR reactor. The power density in the original core is 100 kW/liter. The new fuel rod is assumed to operate with the same heat flux on both the external and internal surfaces. For simplicity, you may assume that the new fuel/clad gap thickness and clad thickness are equal to their values in the original solid fuel 17 by 17 assembly. Dimensions of the original assembly are given in the Table below.

2.1.a) If the external annular fuel rod diameter is 1.54 cm and the internal diameter of the annular fuel rod is 0.8cm, what is the enrichment of the fuel that will conserve the amount of U235 in the reload fuel if the current reactor uses 4.5% enrichment. This will allow the innovative fuel to operate at the same power density for roughly the same fuel cycle length. You may assume that the clad and gap thicknesses on the inside or outside of the annular fuel are the same and equal to those of the solid fuel.

2.1.b) Explain why the actual enrichment needed to operate at the same core power density for the same fuel cycle length will be higher than what was estimated in part 2.1.a.

2.2.a) If the heat flux is assumed constant on the outer and inner surfaces of the annular fuel rod, what is the heat flux at the cladding surface in the new fuel assembly when it operates with the same power density as the old fuel assembly?

2.2.b) At what conditions would the heat fluxes at the inner and outer surfaces become equal? Evaluate, qualitatively, the validity of this approach.

2.3.a) Can we increase the power density in the new core if we want to maintain the same Minimum Critical Heat Flux Ratio (MCHFR) as for the old fuel? The designer wishes to keep the power to coolant flow ratio in the core at its value in the old design. You may assume the Critical Heat Flux in subcooled and low quality flow boiling in water to be proportional to $G^{0.4}/De^{0.6}$, where G is the coolant mass flow rate per unit area and De is the equivalent hydraulic diameter. For this solution, you may deal with the whole assembly as a single hydraulic channel and the heat flux is identical on the outer and inner surfaces of the annular fuel rod.

2.3.b) Is assuming the whole assembly as a single hydraulic channel valid? Evaluate, qualitatively, the validity of this assumption.

2.4) Assuming that the fuel cycle length remained the same, what are the consequences of operating at higher power density in the new core for each of the following: (i) initial enrichment needed, (ii) the fast neutron fluence of the cladding at discharge (iii) The decay heat level in the discharged assembly?

Table 1: Assembly parameters for a Westinghouse 17X17 assembly

Assembly pitch (cm)	21.5
Lattice pin pitch (cm)	1.26
Fuel pellet radius (cm)	0.4096
Gap thickness (cm)	0.0082
Clad thickness (cm)	0.0572