HOMEWORK # 7

Self-controllability a gas cooled fast reactor (GFR)

As discussed in lecture #7, it is more challenging to design a GFR to achieve the same level of safety as that of the Integral Fast Reactor (IFR), which in all possible accidents without scram can attain inherent shutdown while not exceeding temperature limits on structural materials. In this problem, you will use a quasi-steady reactivity balance method to partially answer the question of whether or not this is feasible from the neutronic point of view, specifically in view of positive coolant void worth. Assume the following:

1. The proposed 600 MWth GFR core has the following characteristics
   Coolant – helium, direct Brayton power cycle

Inlet temperature	480°C
Outlet temperature	850°C
Pressure	7 MPa
Active core length	1.4 m
Geometry	pins in hexagonal lattice
Fuel	U-Pu-N
Total number of fuel pins	39897
Fuel pellet diameter	5.5 mm
Thickness of SiC cladding	0.5 mm
Fuel pin outer diameter	6.5 mm
Pin pitch	9.9 mm

2. The GFR decay heat removal system has been designed to be capable of removing decay power by natural circulation of helium between the core and emergency cooling heat exchangers placed 10m above the core. To make this possible, both the reactor vessel and the power conversion unit are enclosed in a close guard containment capable of holding a pressure up to 25 bars after depressurization of the primary system.

3. Reactor physics parameters you will need are as follows:

Doppler coefficient	-0.10 ¢/K
Fuel thermal expansion coefficient	-0.04 ¢/K
Core radial expansion coefficient	-0.09 ¢/K
Control rod driveline expansion coef.	~0
Coolant temperature coefficient	~0
Coolant void worth	$0.5 (between nominal pressure and final pressure of 25 bars)

4. Assume that in decay heat natural circulation mode after LOCA the core inlet temperature is the same as during normal operation.
   Further assume;

conductivity of nitride fuel	15 W/m-K.
SiC cladding conductivity	10 W/m-K (irradiated SiC)
conductance of helium filled gap	8000 W/m^2-K

Use correlation Nu=0.023*$Re^{0.8}$*$Pr^{0.4}$ for heat transfer coefficient
Helium thermal conductivity = 0.348 W/m-K
Helium density = 3.58 kg/m^3
Helium heat capacity = 5190 J/kg-K
Helium viscosity = 4.4×10^{-5} Pa-s

Use the following structural limit
SiC cladding 1600°C

Tasks:

1. Read the paper by Wade and Chang "The integral Fast Reactor Concept: Physics of Operation and Safety" pg. 507 – 513 and study the method of analysis of core physics of inherent shutdown for IFR. The ΔT_f used to evaluate reactivity ratio coefficient, A, is not defined in the paper. It is a difference between core average fuel temperature (averaged over the whole core radially and axially and radially over the rod) and average coolant bulk temperature at core midplane.
   Get core average
   $$\Delta T_f = \left[\frac{1}{\pi R_{core}^2 H} \int_0^{Rcore} \int_{-H/2}^{H/2} 2\pi R T_{fo}(R,z)\, dR\, dz + \frac{1}{\pi R_{rod}^2} \int_0^{Rrod} 2\pi r [T(r) - \overline{T}_{fo}]\, dr \right] - \left[T_{in} + \frac{\Delta T_c}{2} \right]$$
   where T_{fo} is fuel pellet surface temperature, $\overline{T}_{fo}$ is core axially and radially averaged fuel surface temperature (first term in the large bracket) and T(r) is fuel temperature profile in the core-average channel, R_{rod} is fuel pellet outer diameter, H is core active height, R_{core} is core diameter, T_{in} is core inlet temperature and ΔT_c is core temperature rise at nominal conditions. Hint: You can obtain the same result using temperatures in the average channel having flat linear power at the axial midplane of the core.
2. Using the above method as a guide, apply its logic to derive the core design goals for inherent shutdown (similar as in Table II of Wade and Chang's paper) in terms of reactivity coefficient ratios A,B and control rod worth for the case of <u>loss of coolant without scram</u>. During the derivation the need for a maximum reactivity coefficient ratio of A/B will arise. This ratio can be derived from the requirements for an unprotected (without scram) loss of flow accident (ULOF). One can derive that to achieve inherent shutdown in ULOF, the A/B ratio needs to satisfy the following expression:
   $$\frac{A}{B} \le \left[\frac{1}{2} \left(\frac{\gamma \Delta T_{clad}^{\max}}{\Delta T_c} \right)^2 \right] + \left(\frac{\gamma \Delta T_{clad}^{\max}}{\Delta T_c} \right) - \frac{1}{2}$$
   where ΔT_c is the core temperature rise during normal operation, γ is a factor which accounts for uncertainties and simplifying assumptions of the analysis by reducing the average clad temperature limit (use γ=2/3) and $\Delta T_{clad}^{\max}$ is the difference between cladding failure temperature limit and core average cladding temperature during normal operation. This can again be found by using temperatures in the average channel having flat linear power at the axial midplane of the core. You can neglect peaking in view of the γ factor and assume that the difference between cladding temperature and coolant bulk temperature is about

the same for both normal operation and during decay heat removal. Once you know the above inequality is satisfied, you can substitute the right hand side for A/B in your expression for unprotected loss of coolant accident.

3. Can the proposed GFR achieve inherent shutdown in a LOCA without scram? If not what value of coolant void worth would be necessary to achieve inherent shutdown provided that other reactivity coefficients do not change?
4. Would the use of oxide fuel with significantly lower conductivity than nitride and more negative Doppler coefficient be beneficial in achieving inherent shutdown? Provide reasons behind your answer and support them by simple calculations using k=2 W/m-K for your UO_2 conductivity and -0.23¢/K for Doppler coefficient while keeping all other parameters the same.