(30%) 1) A PWR has operating characteristics given below for Beginning Of Cycle (BOC) and End Of Cycle (EOC), where the reactivity parameters are referenced to Hot Zero Power (HZP), i.e. the system is at temperature corresponding to $(\text{Rx Pwr})_{\text{REL}} = 0$ (560 F). The control rods are in four banks and insert reactivity linearly with position as they move out, i.e. at “full out” they insert zero reactivity and at “full in” they insert their full worth. The control rods move in steps, with a 100 step overlap and 228 steps corresponding to full out. You can assume the banks move out in order A, B, C, D, and insert in reverse order, i.e. D, C, B, A. Reactor operations can be complicated by the buildup and decay of the fission product Xe-135, which can reach equilibrium conditions in a matter of days, and decays away after reactor shutdown.

**Problem Parameters**

**BOC**
- Core Excess Reactivity: 12387 pcm
- Moderator Temperature Coefficient: -11.8 pcm/F
- Doppler Only Power Coefficient: -9.8 pcm/\% Power

**EOC**
- Moderator Temperature Coefficient: -33.4 pcm/F
- Doppler Only Power Coefficient: -13.7 pcm/\% Power

- Equilibrium Xenon Worth: -2653 pcm
- Soluble Boron Coefficient: -7 pcm/ppm
- Control Bank A Worth: 582 pcm
- Control Bank B Worth: 973 pcm
- Control Bank C Worth: 1171 pcm
- Control Bank D Worth: 893 pcm

You can assume the moderator temperature as a function of power is given by

$$ T_{\text{ave}} = 560 + 30 \times (\text{Rx Pwr})_{\text{REL}} $$

a) Determine the necessary boron concentration for the reactor to be critical at 100% power, BOC with All Rods Out (ARO), prior to Xe build up, i.e. Xe concentration equal zero.

b) What would be the necessary boron concentration at these conditions, once Xe has reached its equilibrium value?

c) At EOC, with zero boron, what would be the excess reactivity necessary for the reactor to be able to operate at 100% power, ARO and equilibrium Xe?

d) With this excess reactivity, would the control rods have sufficient worth to maintain criticality at EOC, HZP and zero boron prior to Xe buildup?

(30%) 2) The pressurizer in problem 1 has a total volume of 1800 ft$^3$. The pressurizer level program is linear with $T_{\text{ave}}$, such that at HZP conditions, the programmed level is 33%, and at 100% power the programmed level is 66%. The reactor is initially at 100% power and executes a reduction in power to 80%. Assuming an initial primary side liquid mass inventory of 595,000 lbm (not including the pressurizer), how much mass inventory must be charged/let down to maintain the pressurizer level at its programmed value? You can assume a constant system
pressure of 2250 psia, and the liquid temperature in the pressurizer is that of a saturated liquid at the system pressure. You can assume over the temperature and pressure range of interest

\[ \rho_f = 37.1 \text{ lbm/ft}^3 \]

\[ \rho(T) = 46.2 - 0.1067(T - 560) \text{ lbm/ft}^3 \]

(30%) 3) A PWR with Once Through Steam Generators (OTSGs) is operating at nominal full power, ARO, when a controller malfunction results in the feed control valves failing to their full open position. Assuming the valves remain in this position, the reactor does not trip and all other control systems operate in their normal automatic mode, indicate all control system actions using logic flow diagrams (arrows as in the notes and lectures). You can assume all control valves have sufficient capacity to accommodate this upset and the steam generators do not overfill.

(10%) 4) Provide brief answers to the following questions

a) What is the difference between a directly and an indirectly controlled parameter?

b) Why is Steam Generator Level not a directly controlled parameter in OTSGs?

c) How is steam pressure controlled (either directly or indirectly) in UTSGs? What about OTSGs?

d) How does feed pump size change the flow rate within UTSGs?

e) What determines the speed setpoint for the turbine/generator?