Problem 1: Using the **xenon_gui** code, answer the following questions:

a. Roughly how long does it take to reach equilibrium Xe while running at full power (i.e. at 1 MW) starting from a xenon-free core? Is this time consistent with expectations based on the half-lives or mean lifetimes of I-135 and Xe-135? Explain…

b. What is the approximate equilibrium Xe reactivity in the UMLRR for 1 MW operation? How about 50 kW operation? Is it reasonable to assume negligible Xe feedback for P < 50 kW within the UMLRR?

c. Run the GUI with a scenario where the reactor is operated at 1 MW for 4 hours starting with no xenon in the system. How does the reactivity effect after 4 hours compare to the full equilibrium value? what about 50 kW operation?

d. Finally, use the GUI to simulate a sequence where the reactor is at full power for 8 hours and then is shutdown for 16 hours. Repeat this 8-hr on and 16-off sequence for several days until some quasi-equilibrium is reached. What is the maximum Xe reactivity for this operational scenario? How does this compare to the equilibrium worth if operating continuously at full power?

ⓐ Time to reach equilibrium: ~ 3 days $\simeq$ 70 - 75 hrs.

$T_{1/2}$ I-135 $\simeq$ 6.9 hr $T_{1/2}$ Xe-135 $\simeq$ 9.2 hr

behaves as $e^{-\lambda t}$ where $\lambda = \frac{\ln 2}{T_{1/2}}$

or e^{-t/τ_m}

$\tau_m = \frac{1}{\lambda}$ = mean lifetime

$= 1.44\, T_{1/2}$

$= 13.3$ hrs for Xe

$\therefore\ 5\,\tau_m \simeq 66.4$ hrs

and we expect equilibrium in roughly 5 mean lifetimes

Note that the dynamics is also strongly affected by the production due to fission and loss due to absorption. However, based on the $T_{1/2}$ for Xe-135, the estimate of ~ 3 days to reach equilibrium is quite reasonable

ⓑ $\rho_{eq} \simeq 2.3\ \%\,\Delta k/k$ at 1 MW   (almost 3\$!!!)

$\rho_{eq} \simeq 0.21\ \%\,\Delta k/k$ at 50 kW = 0.05 MW

At 50 kW, the max Xe reactivity is a factor of 10 less than at full power. However, 0.21 % $\Delta k/k$ is about

$$\frac{0.0021}{0.0078} = 0.27\,\$$$ ← which is still a fairly significant feedback reactivity (relative to Promp)

(d+e) However, over about 4 hrs of operations (which is typical of many tests within the UMLRR)

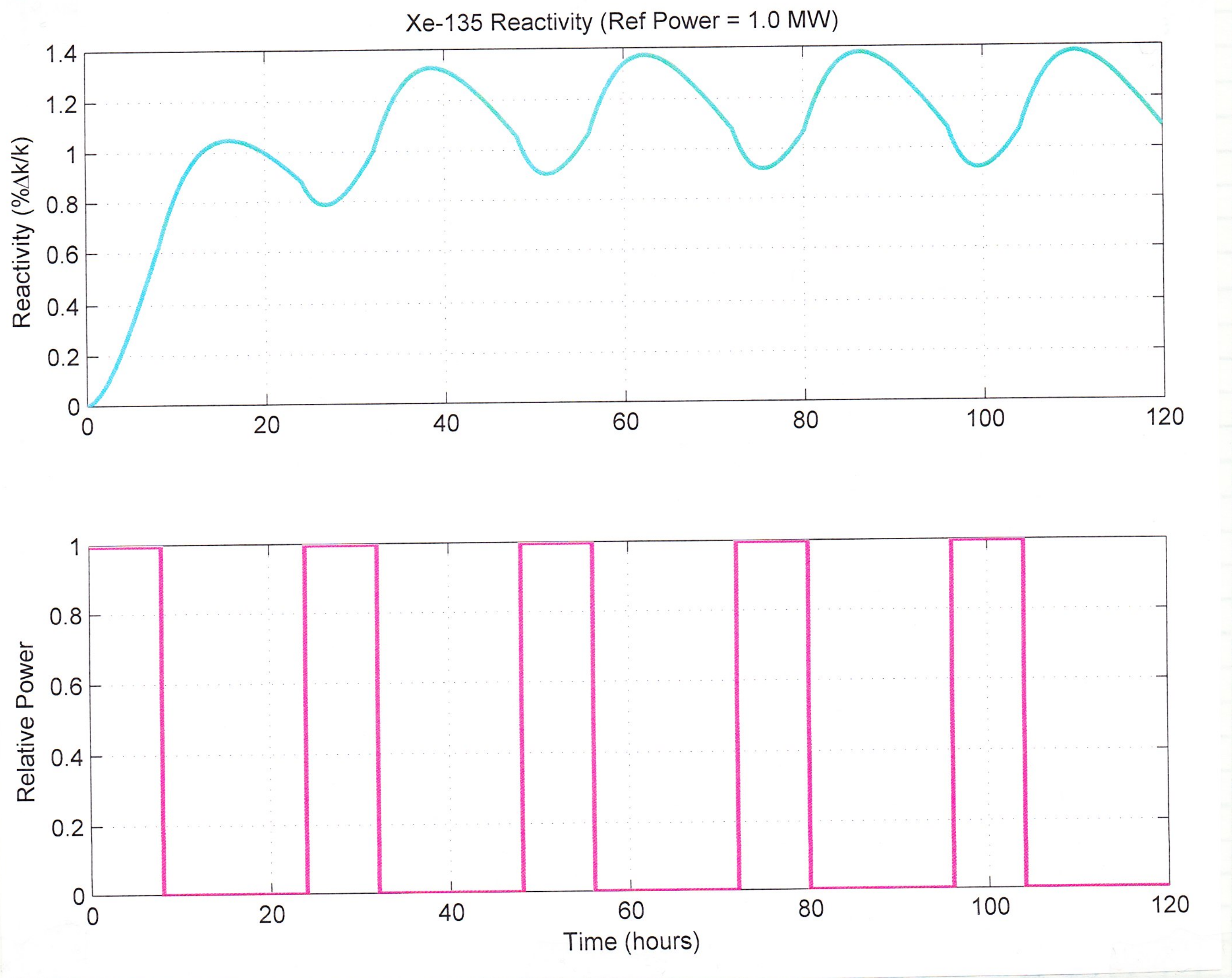
1 MW $\rho_{max} = 0.23\ \%\Delta k/k \cong 0.30\ \$$ ⟵ ⟶ Δz_{RB10} = requires re-bank

This is clearly important

50 kW $\rho_{mx} = \underline{0.0125\ \%\Delta k/k} \simeq \underline{0.016\ \$}$ $\underline{\Delta z_{RB10} = 0.6''}$

This is relatively small, but not negligible...

(c) Note that, for normal operation of the UMLRR, the max ρ of 2.3 %Δk/k is never observed. As seen in the simulation below, for an 8-hr shift per day, the max ρ is closer to 1.4 %Δk/k. Thus, this is a more reasonable upper limit for the max Xe reactivity in the UMLRR under normal operating conditions...



Note: Text here has been modified somewhat...

Problem 2: Using the **sstemp_umlrr_gui** code, answer the following questions assuming that the coolant inlet temperature is fixed at 25 °C:

a. For steady-state forced convection operation at 1 MW with 1650 gpm of flow, what are the expected maximum coolant, clad, and fuel temperatures in an average fuel channel and plate configuration? For this same situation, estimate rough averages for the fuel and coolant temperature (just from visual observation of the temperature profiles)? Finally, based on the data collected here, estimate the change in the average fuel and coolant temperatures when going from zero power to full power.

b. Using your results from Part a, estimate the negative temperature reactivity feedback that is inserted in going from zero power to full power within the UMLRR. Also approximate the relative reactivity contribution of the fuel and coolant feedbacks. In these calculations, assume the following reactivity coefficients:

$$\alpha_{Tf} = -7.7e\text{-}5\ \Delta k/k/^{o}C \qquad \alpha_{Tc} = -4.37e\text{-}5\ \Delta k/k/^{o}C$$

c. Now, re-do Parts a and b for the case of natural convection flow with P = ~~100~~ 50 kW. Compare your results for free convection with those for forced convection flow.

d. Based on your comparisons in Problem 2 Part c and your analyses from Problem 1, discuss how experiments that focus on temperature and xenon feedback effects would differ in their ability to highlight certain effects. That is, do forced and natural convection experiments highlight the various feedback components equally well? Explain…

(a) forced flow: 1 mw 1650 gpm $T_{in} = 25 C$

max T_c 28.8 °C max T_{clad} = 35.7 °C max T_f = 36.3 °C

mean T_c = 26.9 °C mean T_f = 33.7 °C

at zero power $T_c = T_f = T_{in} = 25$ °C

$\therefore$ $\boxed{\Delta T_c = 1.9\ °C}$ $\boxed{\Delta T_f = 8.7\ °C}$ } for P = 0 mw to P = 1 mw

(b) now for $\alpha_{Tc} = -4.37\times10^{-5}\ \frac{\Delta k/k}{°C}$ | $\alpha_{Tf} = -7.7\times10^{-5}\ \frac{\Delta k/k}{°C}$

$\rho_{Tc} = -8.3\times10^{-5}\ \Delta k/k$ | $\rho_{Tf} = -6.7\times10^{-4}\ \Delta k/k$

$= -0.0083\ \%\Delta k/k$ | $= -0.067\ \%\Delta k/k$

fractional contribution (0.11) | (0.89) ↖ clearly the dominant effect in forced flow mode

$\boxed{\text{Total } \rho_{Temp} \simeq -0.075\ \frac{\%\Delta k}{k}}$

$\boxed{\Delta z_{RB10} = 3.6''}$

ⓒ in natural convection mode

max T_c = 37.8 °c max t_{clad} = 38.7 °c max t_f = 38.8 °c

mean T_c = 31.4 °c mean T_f = 33.7 °c

at $P = 0$, $T_c = t_f = T_{in} = 25$ °c

$\therefore \boxed{\Delta T_c = 6.4 \text{ °c}}$ $\boxed{\Delta T_f = 8.73 \text{ °C}}$

and with

$\alpha_{Tc} = -4.37 \times 10^{-5} \frac{\Delta K/K}{°c}$ | $\alpha_{Tf} = -7.7 \times 10^{-5} \frac{\Delta K/K}{°c}$

$\rho_{Tc} = -2.80 \times 10^{-4} \ \Delta k/K$ | $\rho_{Tf} = -6.70 \times 10^{-4} \ \Delta K/K$

$= -0.028 \ \frac{\% \Delta k/K}{°c}$ | $= -0.067 \ \frac{\% \Delta K/K}{°c}$

fractional contribution 0.29 0.71

the fuel temp is still dominant but now the coolant temperature change plays an important role as well

28 - 30% of total temp. feedback

Total $\rho_{temp} \simeq -0.095 \ \% \Delta k/K$

$\Delta Z_{RB10} \simeq 4.7''$

Note that the total feedback for nat conv at $P = 50$ kW is MORE that in forced flow at $P = 1$ MW

ⓓ The main point here is to compare the various feedback effects: xenon, coolant temp, fuel temp

① Xenon clearly has the largest negative reactivity effect. At long times that exceed 72 hrs, the equil. worth is very large at full power and it is not trivial at low power.

However, for short term operations (i.e < 4 hrs)

at 1MW $\boxed{\rho^{Xe}_{max} = -0.23 \ \% \Delta k/K}$ This is dominant!!!

at $t = 4$ hrs

at 50kW $\rho^{Xe}_{max} = -0.0125 \ \% \Delta k/K$ This is important but not dominant

② For forced flow, the temp. effect is relatively small even at full power. The fuel temp feedback accounts for about 88-90% of the total temp. effect.

~ 10-12 % → $\rho_{Tc} = -0.008 \ \% \Delta k/K$

$\Rightarrow \boxed{\rho_{Temp} = -0.075 \ \% \Delta k/K}$ compare

$\rho_{Tf} = -0.067 \ \% \Delta k/K$

③ for natural convection flow at 50kW, the Temperature feedback is more important than for forced flow at 1MW, because of the reduced flow rate and larger coolant temp.

~28-30% → $\rho_{T_c} = -0.028$ %Δk/k

$\Rightarrow \boxed{\rho_{temp} = -0.095 \text{ \%}\Delta k/k}$

$\rho_{T_f} = -0.067$ %Δk/k

This is about 7-8 times larger than the Xe effect at about 4 hrs, but the Xe contribution continues to grow with time

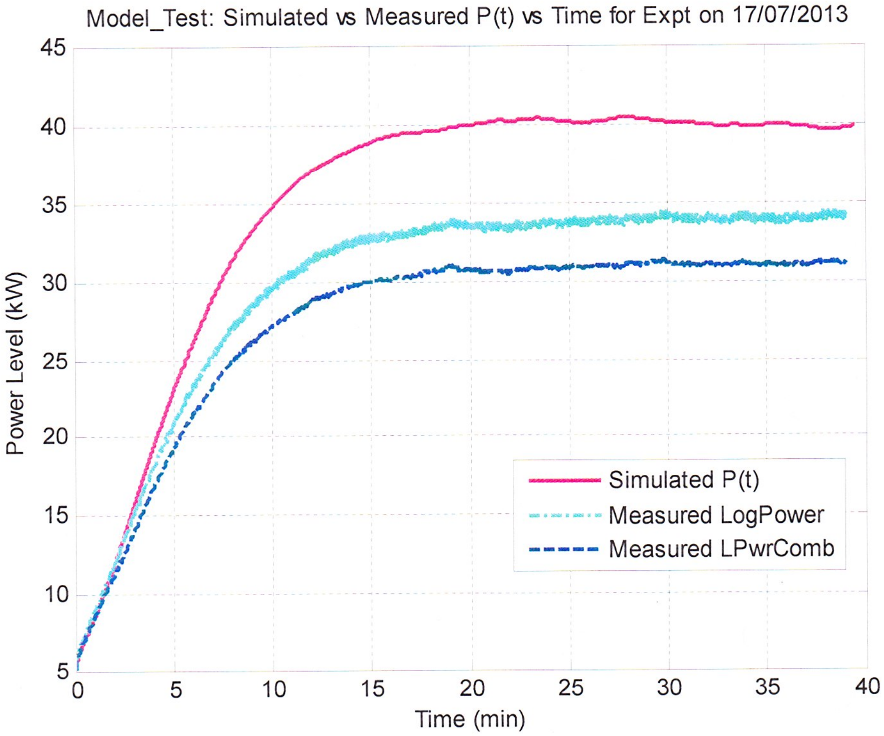
Conclusions:

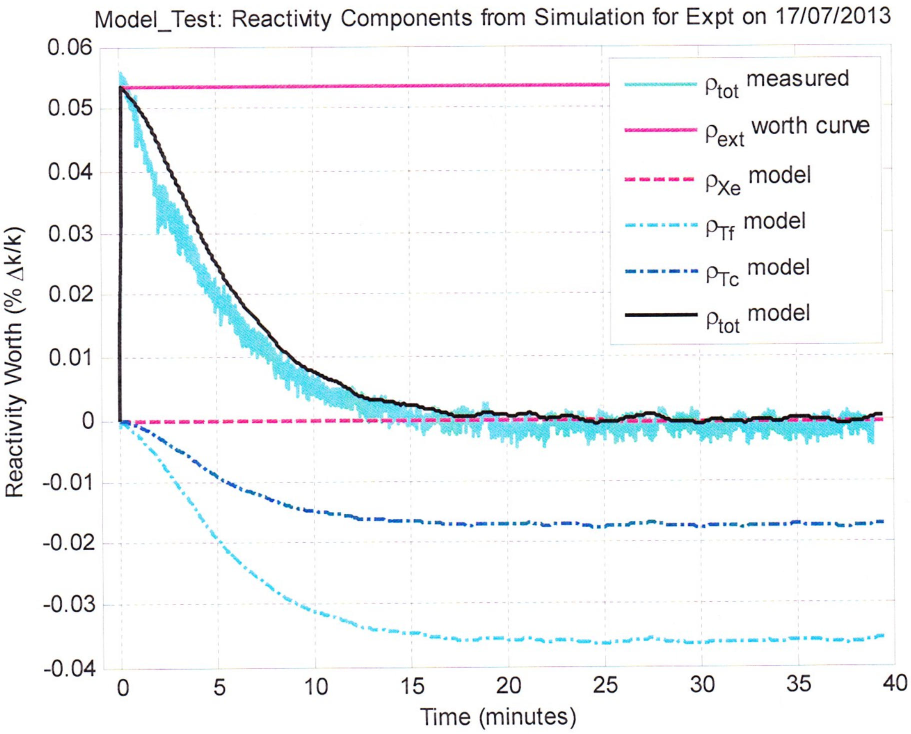
① to separate temp effects from xenon
→ run in natural convection mode for only a few hours or less with P < 50kW

→ in forced convection, the very early portion of the transient is dominated by temp effects, but Xe quickly takes over (after just 10-20 minutes)

② The coolant temperature effect is small in forced flow mode. Thus, to see the impact of this component, we need to run in natural convection mode.

Natural Convection Results





Forced Convection Results