Exam 2
Nuclear Engineering 2101
Fall 2025

Instructions

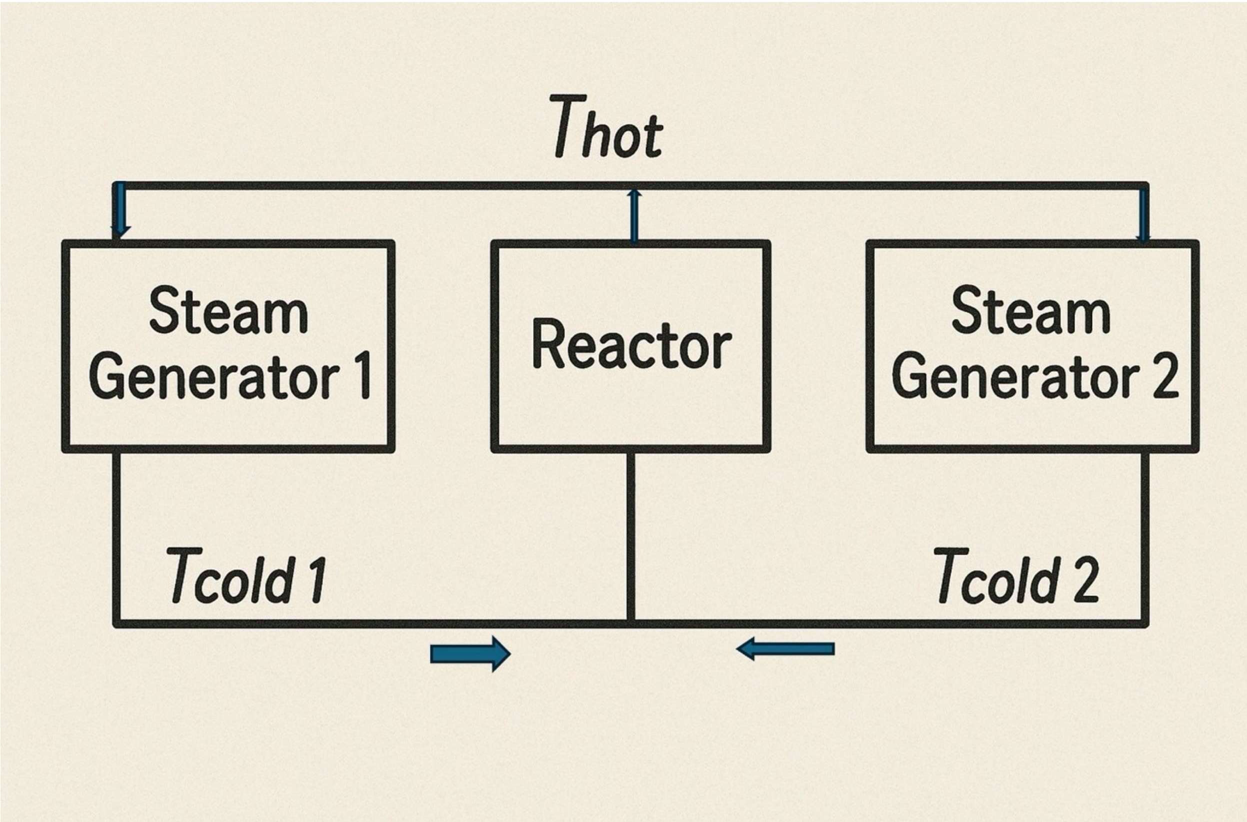
Complete all questions.

You may use any books, references, and the internet. We do ask that you not provide us answers provided by use of artificial intelligence sites. Use of computer programming is encouraged.   In any place where we ask for a graph or plot, that may be a hand drawing or a computed result. Either may receive full credit. If numerical results related to the graph are required, the problem will so state. Otherwise, where computation is asked for, assume that numerical results are required.

Where possible show your work including computer programs. Any language is acceptable so long as you provide adequate commentary to explain the function of the program.

Do not try to answer these questions using only this test document. Use your own paper. Your calculations should be clearly organized to facilitate the reading and grading or your exam. Where possible, show your results in terms of algebraic quantities prior to making computation and providing your numerical results.

1. Consider a two-loop reactor. Each loop contains a steam generator, and a pump. We will assume that each steam generator plus its cold loop has the same water mass and flow rate. The reactor and equal size hot branches may be lumped into a single water volume. We will ignore the loop transport times. (16 Points)



When the reactor is operating at 100% and each steam generator is removing heat (by steam flow not shown) equal of 100% of its rated load, the system is balanced. With a constant average temperature. Let's define the fraction in the reactor and its hot leg piping as the Reactor Water Mass Fraction (RWMF) as μ.

Base Heat Capacity	C_0 = 33.33 [%-sec/°F]	
Base Time Constant	Tau = 0.75 [sec/(%-sec/°F)] C_0	
Reactor Time Constant	$\tau_r = \mu \tau_0$	
Reactor Heat Capacity	$C_r = \mu C_0$	
SteamGenerator Water Time Constant	$(1-\mu)\tau_0/2$	

Steam Generator Heat Capacity	$C_s = (1-\mu) C_0 / 2$	
Initial Steady State Temperature	Tcold_1 = Tcold_2 = T_hot = 450 °F	

a. Develop differential equations showing the rate of change of each of T_{hot}, $T_{cold\_1,}$ and T_{cold_2} as a function of the temperatures, the reactor power, P_r, and the steam generator powers, $\dot{Q}_1$ and $\dot{Q}_2$. Let's establish that power flowing out of the steam generators is positive. So, these will need to appear in the differential equations with minus signs.

b. Develop an expression for the $\Delta T_1 = T_{hot} - T_{cold_1}$ and $\Delta T_2 = T_{hot} - T_{cold_2}$. Note we do not need to be drawing the same steam flow from the steam generators, but we will assume that the net power is balanced and that the system is in steady state.

c. Use energy conservation to develop an expression for the average reactor temperature defined as follows: $T_{ave} = \frac{T_{hot} + \frac{T_{cold_1} + T_{cold_2}}{2}}{2} = T_{hot}/2 + \frac{T_{cold_1} + T_{cold_2}}{4}$.

d. Create a plot (zero to 30 sec) of $T_{hot}, T_{cold_1}, T_{cold2}, T_{ave}$ for the following cases: The Reactor Water Mass Fraction is 0.5, 0.75 with both steam generators equally loaded. Also create a plot with The Reactor Water Mass Fraction is 0.5, 0.75 but the steam generators unequally loaded, $\dot{Q}_1 = 120\% \wedge \dot{Q}_2 = 80\%$.

Note: Feel free to use any differential equation solver that you like for this or an iteration such as a central difference. (You're "A" matrix (as in $\frac{dT}{dt} = AT + B$) should be singular and this will lead to challenges using our typical exponential solution method. This problem can be averted as we did in the class notes, but this case would require significant effort using that approach)

2. Consider a liquid material containing fissile nuclei in adequate concentration that criticality is a concern in its storage. Suppose the physics experts have provided the following material properties for this material in a simple two group form. (18 Points)

Quantity	Fast Group	Thermal Group
Diffusion Constant, D	1.4	0.35
Absorption, Σ_a	$0.010\, cm^{-1}$	$0.080\ cm^{-1}$
Scattering removal from fast group to thermal group. $\Sigma_s^{1\to 2}$	$0.050\, cm^{-1}$	N/A
Scattering from thermal group to fast group, $\Sigma_s^{2\to 1}$	$0\, cm^{-1}$	$0\, cm^{-1}$
Neutrons per fission times the fission cross section, $v\,\Sigma_f$	$0.000\, cm^{-1}$	$0.125\, cm^{-1}$
Neutron group distribution, χ	1	0
Average group velocity, v	$1.8\,x\,10^9\, cm/sec$	$2.2\,x\,10^7\, cm/sec$

a) What would be the K_∞ for this material?

b) What would be the fast and thermal diffusion lengths $L_s \wedge L_{fast}$?

c) What is the equation for the buckling for a rectangular solid geometry? Assume the flux goes to zero at the edges of the trough. Assume sides L_x, L_y, L_z.

d) Consider a trough with a width of 150 cm and a length of 200 cm. At what height in the trough would you estimate that a liquid material with these parameters would become critical? (Use two group theory for this)

e) Suppose the liquid is being added fast enough that the liquid could reach prompt criticality. At what height would you expect this to happen? Assume $\beta = 640\,x\,10^{-5}$.

f) Suppose a group of people are working near this trough. Also assume the flux is not really zero at the edges of the trough. Could presence of the people impact our critical height? If so, how would it impact the critical height?

3. During physics testing, a technician has measured the differential rod worth (DRW) (reactivity added per inch) near the critical position in a low power physics test. This yielded a DRW of 10 pcm/step. For this problem, the effective delayed neutron decay constant, $\lambda_{eff} = 0.1\, sec^{-1}$. We will accept that this will remain fixed. (20 Points)

    a. What steady SUR would you expect for an <u>8-step</u> outward rod motion assuming that we are below the point of adding heat?

    b. Power is allowed to rise above the point of adding heat and power levels off. What would have caused this leveling and what primary plant parameters would you expect to see changed other than power level? State both parameter name and direction of the change. Assume there are no other things happening at the same time.

    c. The physics testing data acquisition system finds that power increased to a peak and then leveled off at a lower level. The fuel reactivity is known to be $\alpha_F = \frac{10\ pcm}{\%power}$. The following data was noted at the peak power:

Peak Power Level	2.5%
Change in Tave	4 degrees
Heat up Rate	$0.15\, F/sec$

    Based on this information compute the coefficient of reactivity for the water temperature α_w. Assume that the equation derived from the one delayed group (constant λ_{eff}), prompt jump assumption approach is adequate for this problem.

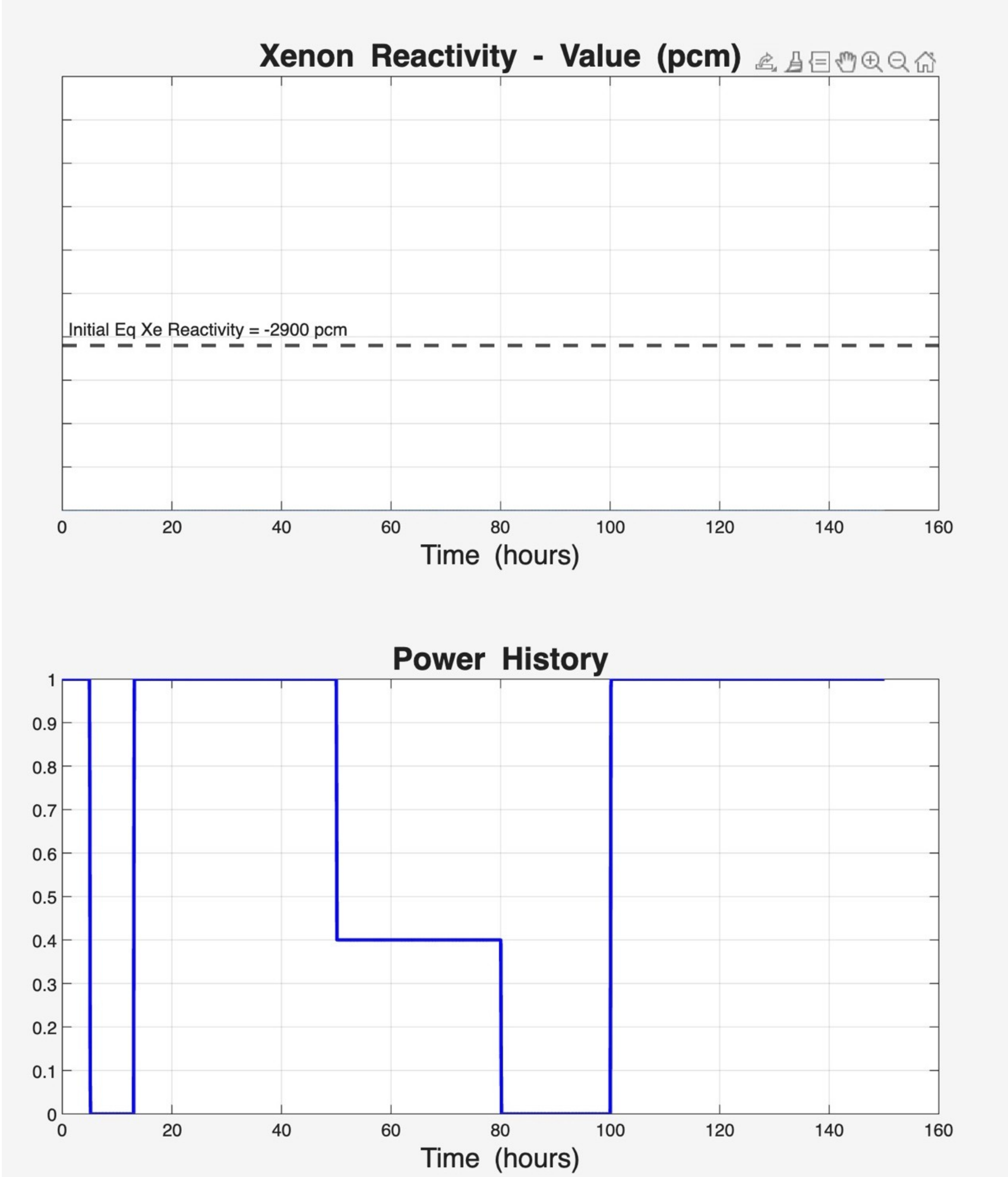
d. When the transient is complete and barring other effects, what would you expect the final power and average temperature to be? Assume that ambient losses ensure that the system will regain a zero reactivity.

4. A pressurized water reactor (with highly enriched fuel) is initially at a steady state of 25% steam load and with its temperature, pressure, pressurizer level, and other parameters as would be expected for this condition. The operators are directed to raise power (picking up electrical load) and they do so in a single motion over a short time raising steam flow to 50%. Initial Tave = 500°F, Th = = 510°F, Tc = = 490°F. Assume that the system does not have any automatic control forcing changes in the average temperature other than what the natural physics provides. (20 Points)
    a. Create a **chronological list** of the physical impacts on the primary system and the reactor itself that will cause power to rise to its final level and explain why it levels off at the new level of 50%. Provide detail on the impacts on temperatures and on six factors in Keff as the transient proceeds. As an example, here is what will get the ball rolling on the secondary side, you do the rest:
        - The turbine throttle is opened
        - This allows an increase in steam flow
        - This increase in steam flow will cause pressure in the steam generator to drop which leads to aggressive boiling in the steam generator.
        - This boiling will cool the steam generator water and this in turn cools the water on the primary side of the steam generator, Tc. The generator is maintaining saturation conditions.

    b. Provide a comparison of the final state of the primary parameters with the initial state. Include, Reactor Power, Tc, Th, and Tave in this discussion. Numerical values should be obtained.

    c. Now consider a reactor with low enrichment fuel, how will the final condition be different and what will be required to restore proper operation?

5. A pressurized water reactor has a power history shown below. (16 Points)
    a. Sketch the xenon-135 transient that will happen in the reactor in this condition. (Computed values are not required for this step, but if you desire you may develop or modify provided software to compute the transient).



b. The first shutdown happened at Time = 5 hours. Using the parameters shown below compute the time at which that peak happens, and the value of the xenon reactivity at the peak. (In your calculations be careful of your units, in particular, seconds vs hours).

I-135 fission yield	γ_I	5.7%
Xe-135 fission yield	γ_{Xe}	0.3%
I-135 decay constant (6.7 hour $t_{1/2}$)	λ_I	2.87e-05 sec^{-1}
Xe-135 decay constant (9.2 hour $t_{1/2}$)	λ_{Xe}	2.09e-05 sec^{-1}
Full Power Burnout Factor $\sigma_a^{Xe}\varphi_{th}^{100\%}$	R^{Max}	7.34e-05 sec^{-1}
Power Constant based on a Full Power Equilibrium Xe Reactivity of -2900 pcm	K	4.56 pcm x sec^{-1}

Notice p = 1 implies 100% power.

$A=\begin{bmatrix} -\lambda_I & 0 \\ \lambda_I & -\lambda_{Xe}-pR^{Max} \end{bmatrix}$	$B=pK\begin{bmatrix} \gamma_I \\ \gamma_{Xe} \end{bmatrix}$
$\frac{dX}{dt}=AX+B$	$X=\begin{bmatrix} N_I \\ N_{Xe} \end{bmatrix}$

6. We discussed the fact that xenon oscillations can disrupt operations and protection of nuclear reactors. We showed that for some cases a pressurized reactor might have radical oscillations such that virtually all the power is produced in a fraction of the overall core volume and that this fraction will vary significantly with time. (10 Points)

    a. What core design aspects will make oscillation likely?

    b. What problems will these oscillations make for an operator other than the
    fact that the operator may be precluded by rule from operating this way at all?

    c. How could these oscillations impact the core protection or safety analysis?