Name: ______________________

Take-home Final Exam for ENGR/ME 2101

December 2025

This Exam is due no later than Monday, December 8, 2025 by 6:00 pm

Problem weight indicated for each problem.

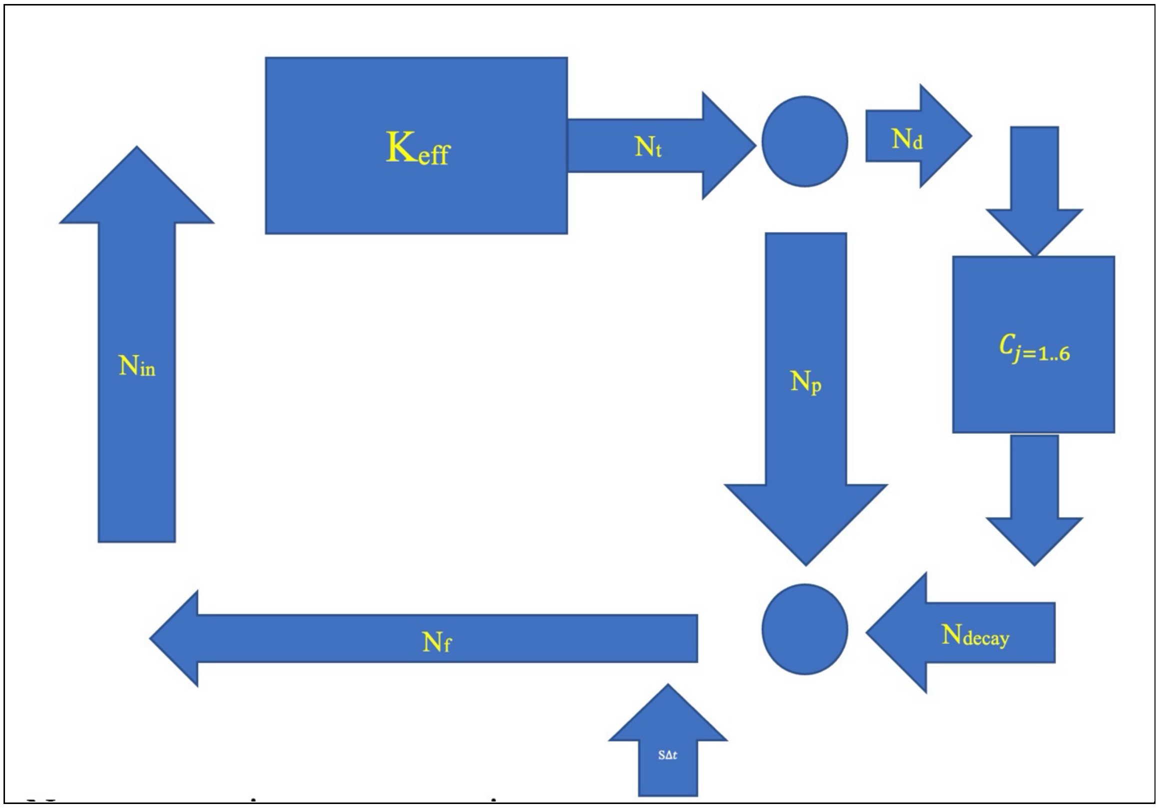
Instructions

1. Complete all questions
2. You may use any book, references, the internet, etc. that you wish. However, all work must be your own.
3. **Clearly** state any assumptions that you make.
4. **Clearly** identify any references that you use.
5. Please draw a box around your answer so the grader can find your answer.

Name: ______________________

Question 1 - Point Kinetics (15 Points)

Recall the fundamental model that we used to think about point reactor kinetics:



Here Δt is loosely the +time required for one prompt cycle. The other quantities remain as we have defined them.

a. What is meant here by the block labeled Keff. How can this block be represented in terms of basic physical quantities? (3 Points)

b. Demonstrate that the point reactor kinetics equations may be derived directly from this picture. (3 Points)

Name: ______________________

c. What is meant by the Prompt Jump Assumption and how can that assumption be related to this picture. (3 Points)

d. If a sudden change were made to Keff how would this system respond over time. Your answer should include the process that takes place over the first hundred, or so, milliseconds, followed by the longer-term response. (3 Points)

e. What is meant by the term “power turning” and how does that relate to this diagram? (3 Points)

Name: ______________________

Question 2 (10 Points)

A reactor is critical at 10^{-6} % power. Consider $\lambda_{eff} = 0.1 \ \text{sec}^{-1}$
Which step reactivity shown below is the best estimate to get the reactor power to 10 % power in 50 minutes? (Neglect reactivity feedback). Show your calculation that supports the answer you chose.

a) 0.01 β

b) 0.044 β

c) 0.051 β

d) 0.12 β

e) 0.36 β

Name: ______________________

Question 3 (10 Points)

A pressurized water reactor is in steady state operating at 100% steam load. Its moderator temperature coefficient is $\alpha_w = -10$ pcm/°F and we may ignore fuel temperature feedback and boron. Assume that rod control is in manual with no rod motion. The initial value of Tave is 587 degrees F.

a) What is controlling reactor power? Explain why this must be the case. (3 points)

b) A control rod worth -100 pcm drops into the core. What is the power level after the plant returns to steady state? (Assume that the reactor does not trip.) (3 points)

c) What is the temperature of the reactor coolant (Tave) after the plant stabilizes? (2 points)

d) What effect will this have on steam pressure? (2 point)

Question 4 (10 Points)

Assume that a very large (greater than β) positive reactivity addition occurs in a critical pressurized water reactor. Explain the resulting power trajectory and explain how one would analyze the transient to determine its consequences. Include an explanation of the impact of fuel type on this transient. (10 point)

Name: ______________________

Question 5 (5 Points)

a) How is xenon-135 created in a reactor? How is it destroyed? (2 points)

b) Two identically designed reactors have been operating continuously for one year—one reactor at 100% power, the second at 25% power. How does the xenon-135 concentration compare in the two reactors? How does the samarium-149 concentration compare in the two reactors? Explain. (2 points)

c) From an operational perspective, which presents the larger challenge, xenon or samarium? List at least three factors supporting your answer. (1 points)

Name: ______________________

Question 6

A PWR is operating at 80% of full power with manual rod control. It has been determined that power production is excessive in the lower half of the core.

a. Which one of the following actions will shift power production toward the upper half of the core? (Assume no additional operator actions.) (5 points)

- Increasing power to 100%
- Withdrawing control rods
- Borating the reactor coolant system
- Diluting the reactor coolant system

b. As reactor power is increased in a single pass core, the tendency for power shift to lower in the core is real. What causes this to happen and why does a low enrichment core controlling with boron in the coolant not see as pronounced a shift? (5 points)

Name: ______________________

Question 7

A pressurized water reactor is operating early in life on its first core. The reactor is fueled with low enrichment U-235.

a) The reactor is critical at 10^{-5} % power in the intermediate range. A step insertion of +50 pcm of reactivity occurs. Using a one delayed precursor group model and the prompt-jump approximation, write an equation describing reactor power as a function of time. Use appropriate numerical values for the kinetics parameters. Ignore temperature feedback effects in this part of question. (3 points)

b) Justify the choices for the kinetics parameters that you used in part a). (2 points)

c) When will power stop increasing? Explain. (3 points)

d) What would change in your calculation if we were at end of life for the core and the reactivity addition was +200 pcm. Explain (2 points)

Name: ______________________

Question 8 (10 Points)

a) Now reconsider the problem described in Question 7. What weakness does the one delayed-group model bring to your solution? Explain the significance of this weakness with respect to calculations made with this approach.

b) Develop a set of equations in matrix form which may be used to provide power as a function of time using the prompt jump assumption and a six-group delayed neutron model. Show how all matrixes and vectors associated with this solution would be defined. (6 Points)

c) Assess any weakness in the prompt jump assumption used in this problem. Would you expect this assumption to create errors rivaling the errors caused by the single delayed-group assumption? (1 Point)

Name: ______________________

Question 9

a) A plant started up is done following a refueling outage of 25 days. The plant achieved criticality at 100 steps on Bank D with a boron concentration of 1200 ppm. The plant proceeded to 100% power and operated there for 3 days. Then a trip occurred due to an I&C technician error.

The plant is started up 10 hours after the trip. It went critical at 100 steps on Bank D. T_{ave} was 557 degrees for both start-ups. Which of the following best describes the boron concentration when the plant achieved criticality? (5 points)

1) 1200 ppm

2) Greater than 1200 ppm

3) Less than 1200 ppm

4) Cannot be determined.

Explain your answer.

b) The plant returns to 100% power. 30 days later, the plant goes to 50% power for unplanned turbine maintenance. The down power transient takes 30 minutes. The maintenance will take five days. The operators have been instructed to maintain control rods fully withdrawn from the core. Describe the required changes in boron concentration over the over this three-day period. (5 points)

Name: ______________________

Question 10 (10 Points)

You have been assigned to act as a member of an investigating board to assess an event at a nuclear research reactor plant. Both the plant operators, and a digital event recorder, observed an unusual rise in power resulting in an ordered plant shutdown. This plant has low enrichment fuel; T_{hot} is a measure in the reactor outlet plenum; T_{cold} is a measure in the reactor inlet plenum. T_{ave} is just an average of those two values. The unexplained transient happened at a steady state 5% power. The Plant Engineer ordered the plant shutdown at 800 seconds into the initial transient.

One digital recorder provided an indication of an instantaneous startup rate of **781.88 dpm** at the moment of the initial transient. The normal plant chart recording equipment and meters can only provide startup rate indication in the range (-10 dpm, 10 dpm).

You are the investigating engineer, the lead of the investigation is somebody from outside the industry, but he provides you a great deal of encouragement and he stresses that you must believe all data until you show yourself that it is simply not realistic. The lead asks you to make an initial assessment based on the graphs that he has obtained. These plots come from the online chart recording equipment that remained installed after special testing. Other analysis of the pressure transient has indicated that boiling has probably not occurred during this event. See the recorded graphic shown on the next page.

Early measurement has determined that the event was initiated at 5 seconds on the accompanying plot and that the peak power happened at time 17.2 seconds, or 12.2 seconds after event initiation. A plant computer provided a plot or lambda effective and its time derivative provided with the plot on the next page.

a) <u>Based on your initial look at these graphs, what has happened to this reactor?</u> The plant was in steady state with no operator actions. (2 points)

b) What would you assume about the plant if the initial SUR of 781.88 dpm were correct? (2 points)

1. <u>Calculate the reactivity that could cause this value during the first few milliseconds</u> <u>of the transient.</u> (The neutron generation time is Λ = 2.6E-4 seconds. The effective delayed neutron fraction is β = 650E-5). Hint: Consider the full reactor kinetics equations without using the prompt jump assumption. Also assume that nearly no time

has passed between the transient and the SUR measurement.

2. Why does the rise rate in power decrease so rapidly after the initiation of the transient?

a) The lead is wondering about the validity of some of the documented plant data. He asks you to estimate the moderator temperature coefficient based on the near steady state chart data just prior to the shutdown at 800 seconds on the charts. [If you were unable to do part a., assume a reactivity of 1.1β. (This is not the correct value.)] (2 points)

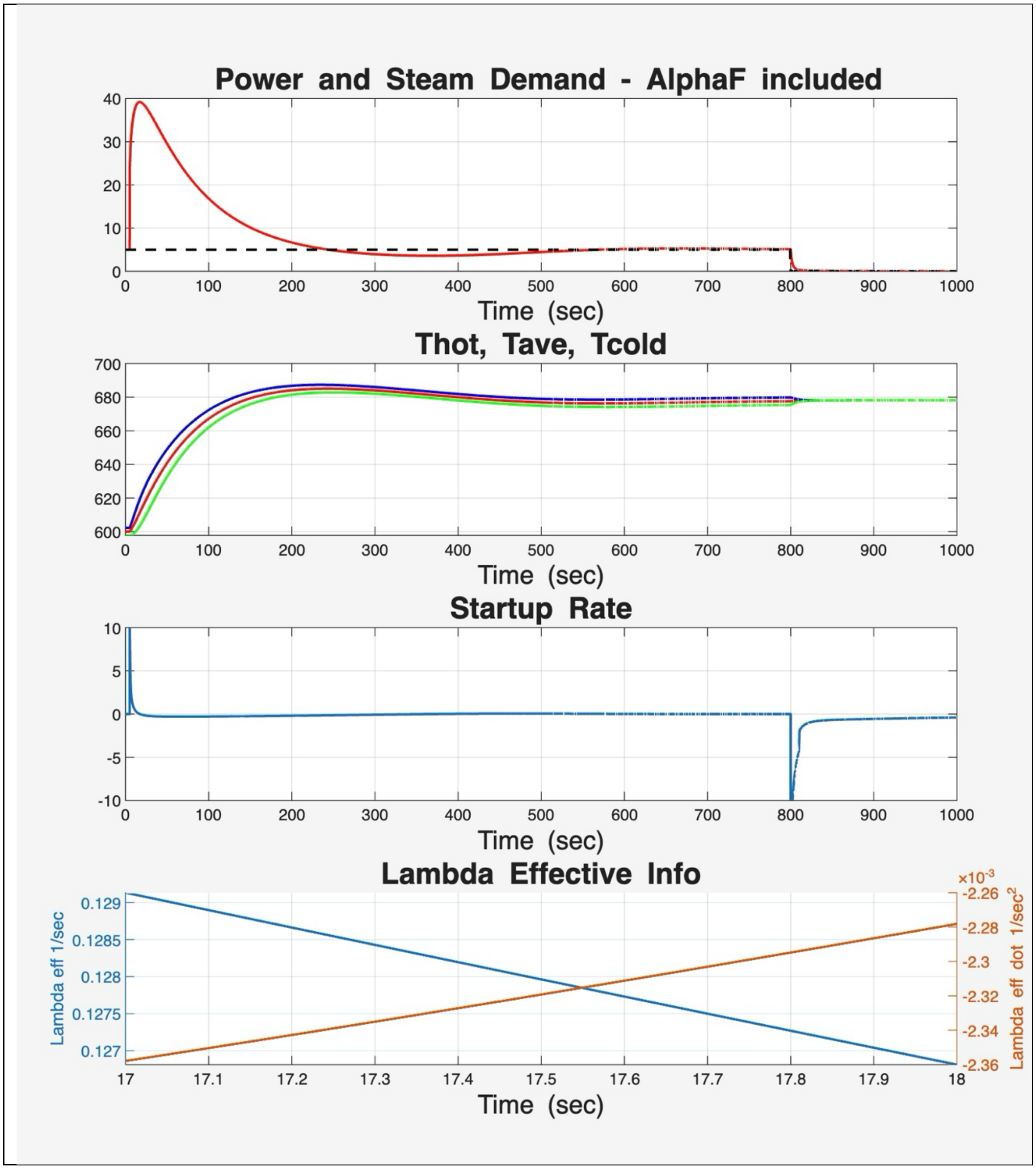
d) The lead asks you to help him understand the concept of power turning. He understands that the simple one delayed group approximation assumes a constant effective lambda. The plant information clearly shows that λ_{eff} is not constant here. Use the prompt jump approximation for power and precursor concentrations to develop a version of the power turning expression that may be used in the presence of non-zero rate of change of λ_{eff}. (Hint: use the one delayed group approximation but account for the changing λ_{eff}.) (2 points)

e) Now use your power turning expression to estimate the fuel temperature coefficient. You will need to estimate values of ΔT_{ave}, $d(\Delta T_{ave})/dt$, λ_{eff}, and $d\lambda_{eff}/dt$ from the graphs. The peak in power happened at the time 17.2 seconds. [If you were not able to solve part a or c, use a value of -10pcm/degree for the α_w and 1.1β as the initial reactivity, also if you were not able to solve part (d) use the simple power turning expression from class ignoring the change rate λ_{eff}.] (2 points)

f) What are your recommendations with respect to operation of this plant? What special monitoring would you require if there were a plan to restart? Would you recommend against a restart at all? (2 point)

In all cases provide full detail for all of your derivations and calculations. These would be critical to the report of an investigation such as this. They are also critical to showing your work on this exam.

Name: ______________________



Left scale is lambda effective. (0.127 to 1.129) 1/sec
Right scale is lambda effective dot. (-0.00236 to – 0.00226) 1/sec^2
Note: Time scale is unique to the last plot.
Power peak happened at time 17.2 seconds.
SUR is clamped at plus and minus 10 DPM.