NUCE 2101: Final Exam

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Problem 1

Part A

K_{eff} is the effective growth or decay of the neutron population based on the prompt reactions. This block can be represented by basic physical quantities by using the six factor formula:

$$k_{eff} = \eta f p \varepsilon P_{FNL} P_{TNL}$$

where:

- η is the thermal neutron fission factor
- f is the thermal neutron absorption factor
- p is the resonance escape probability
- ε is the fast fission neutron production factor
- P_{FNL} is the fast non-leakage probability
- P_{TNL} is the thermal non-leakage probability

Part B

We start with a set of equations representing our neutron populations:

$$N_{in} = N_f$$
$$N_f = N_p + N_{decay} + S\Delta t$$
$$N_t = N_d + N_p$$
$$N_t = K_{eff} N_{in}$$

Now, how are these related? Well, the total number of neutrons is split between the neutrons that are prompt neutrons and those that are destined to become delayed neutrons. We can represent the fraction between the two as:

$$N_t = (1-\beta) K_{eff} N_{in} + \sum_{i=1}^{6} \lambda_i C_i \Delta t + S\Delta t$$

where

$$N_d = \sum_{i=1}^{6} K_{eff} \beta_i N_{in}$$

and

$$N_p = (1-\beta) K_{eff} N_{in}$$

Then we find the change in neutron population:

$$N_f - N_i = (1-\beta) K_{eff} N_i + \sum_{i=1}^{6} \lambda_i C_i \Delta t + S\Delta t - N_i$$

and take the 'derivative':

$$\frac{N_f - N_i}{\Delta t} = \frac{(1 - \frac{1}{K_{eff}} - \beta)K_{eff}N_i}{\Delta t} + \sum_{i=1}^{6} \lambda_i C_i + S$$

then after a little more substitution found in Fundamental Kinetics Ideas:

$$\dot{N}(t) = \frac{(\rho - \beta)N(t)}{\Lambda} + \sum_{i=1}^{6} \lambda_i C_i + S$$

and not forgetting our precursors:

$$\dot{C}_i(t) = \frac{\beta_i}{\Lambda} N(t) - \lambda_i C_i$$

Part C

The prompt jump assumption assumes that the speed of the prompt cycle is so fast that we can effectively ignore the dynamics of the prompt neutron effects. It is equivalent to us only using the outside loop, and not considering additions from N_p.

Part D

First, the number of prompt neutrons would increase dramatically. This would happen over the first hundreds of milliseconds. Then, over a much longer time horizon (seconds, minutes), the delayed number of neutrons would increase as the precursors catch up to the reactivity increase.

Part E

Power turning has to do with start-up rate and the rate at which the total neutron population is changing. For this diagram, turning means that $\dot{N}_f$ changes sign.

Problem 2

We can use the startup rate equation assuming $\dot{\lambda}_{eff}, S = 0$ to solve this problem:

$$SUR = 26.06[dpm - sec]\frac{\dot{\rho} + \lambda_{eff}\rho}{\beta - \rho}$$

To get from $10^{-6}\%$ to $10^{1}\%$ power in 50 minutes, we can find that:

$$SUR = \frac{1 - (-6)}{50} \frac{\text{decades}}{\text{minutes}} = 0.14\text{DPM}$$

We then plug in our values (assume $\dot{\rho} = 0$ with a step change):

$$0.14 = 26.06[dpm - sec]\frac{0 + 0.1\rho}{\beta - \rho}$$

$$0.14\beta - 0.14\rho = 2.606\rho$$

$$\boxed{\rho = 0.0509\beta}$$

Thus the correct answer is C.

Problem 3

Part A

The moderator temperature coefficient must be controlling power. With all other factors constant, the moderator temperature coefficient is the only thing adding negative reactivity to the system.

Part B

$$\rho_{net} = \frac{\partial \rho_{net}}{\partial T}dT + \frac{\partial \rho_{net}}{\partial H}dH + \frac{\partial \rho_{net}}{\partial Poison}dPoison + \frac{\partial \rho_{net}}{\partial Power}dPower$$

But with ingoring fuel temperature feedback and no boron effects,

$$\rho_{net} = -10[\frac{\text{pcm}}{^\circ F}]dT + \frac{\partial \rho_{net}}{\partial H}dH$$

Given that there is no poison or fuel temperature feedback, and steam demand does not change, reactor power will stay the same after the control rod drops into the core. Only moderator temperature can change reactivity in this problem.

Part C

$$0 = -10[\frac{\text{pcm}}{^\circ F}]dT - 100[pcm]$$

$$dT = \frac{100[pcm]}{-10[\frac{\text{pcm}}{^\circ F}]}$$

$$dT = -10^\circ F$$

$$\boxed{T_{final} = 577^\circ F}$$

Part D

Power will remain the same, and therefore steam pressure should remain the same as well.

Problem 4

The power trajectory would be exponentially positive as the reactor would become prompt critical. One would analyze the transient by using a robot to examine the reactor soup after the steam bomb goes off in the containment.

But being serious, one may examine the power transient by evaluating ρ over time using the partial addition formula we used in the last problem. Because the reactor is prompt critical, we can essentially ignore the delayed neutrons. The point kinetic equations can also be used, but honestly a decent approximation will be a first order exponential growth with time constant derived from the prompt neutron lifetime.

For a high enrichment fuel, the growth of the curve will be impeded by basically nothing. Fuel and moderator temperature effects will be minimal. For a low enrichment fuel, moderator temperature and fuel temperature effects will slow the exponential growth as temperature increases, but depending on reactor design, will not prevent catastrophic failure.

Problem 5

Part A

Part B

Part C