NUCE 2101: Exam 2

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Problem 3

Part A

Python Code

```python
import numpy as np

# Problem 3A
## Using formulas from Fundamental Kinetics Ideas R17 Page 51
DRW = 10  # pcm/step
STEPS = 8
LAMBDA_EFF = 0.1  # hz

# ASSUMING AFTER ROD PULL COMPLETE, RHO_DOT = 0
RHO_DOT = 0
BETA = 640  # pcm

# FIND RHO AFTER ROD PULL
rho = DRW * STEPS  # pcm

sur = 26.06 * (RHO_DOT + LAMBDA_EFF * rho) / (BETA - rho)

print(f"The Start Up Rate is: {sur:.3f}")
```

Solution

Given:

- Differential Rod Worth (DRW) = 10 pcm/step
- Number of steps = 8
- $\lambda_{eff} = 0.1$ Hz
- $\dot{\rho} = 0$ (after rod pull complete)
- $\beta = 640$ pcm

Reactivity after rod pull:

$$\rho = \text{DRW} \times \text{STEPS} = 10 \times 8 = 80 \text{ pcm}$$

Start-up rate calculation:

$$\text{SUR} = \frac{26.06 \times (\dot{\rho} + \lambda_{eff} \times \rho)}{\beta - \rho} = \frac{26.06 \times (0 + 0.1 \times 80)}{640 - 80}$$

$$\boxed{\text{Start Up Rate} = 0.373 \text{ DPM}}$$

Part B

Negative reactivity feedback due to temperature would cause this power level off. I would expect that the average reactor temperature would have increased from the low power state significantly. I would also expect xenon concentration would have increased, but would not have been the culprit in power leveling off.

Part C

Python Code

```
# Problem 3C
import sympy as sm

D_POWER = 2.5  # %
D_T_AVG = 4  # degrees
HEAT_UP_RATE = 0.15  # F/s
ALPHA_F = 10  # pcm/%power

rho_rod = rho

# The heat up rate introduces a rho_dot, so SUR becomes 0 at the
    peak power.
alpha_w_sym = sm.Symbol("alpha_w")
rho_dot = alpha_w_sym * HEAT_UP_RATE
rho_net = alpha_w_sym * D_T_AVG + rho_rod + ALPHA_F * D_POWER

# At peak power, SUR = 0, which means: rho_dot + lambda_eff *
    rho_net = 0
# (the numerator must be zero)
equation = rho_dot + LAMBDA_EFF * rho_net

# Solve for alpha_w
alpha_w_solution = sm.solve(equation, alpha_w_sym)[0]
alpha_w = float(alpha_w_solution)

print(f"The water temperature reactivity coefficient is: {alpha_w:.3
    f} pcm/F")
```

Solution

Given:

- Power change at peak: $\Delta P = 2.5\%$
- Average temperature change at peak: $\Delta T_{avg} = 4°\text{F}$
- Heat-up rate: $\dot{T} = 0.15$ °F/s
- Fuel temperature coefficient: $\alpha_f = 10$ pcm/%power
- Rod reactivity: $\rho_{rod} = 80$ pcm (from Part A)
- $\lambda_{eff} = 0.1$ Hz

At peak power, the start-up rate becomes zero (SUR = 0), but temperature is still rising. This is the key insight: the numerator of the SUR equation must equal zero:

$$\dot{\rho} + \lambda_{eff} \times \rho_{net} = 0$$

The temperature rise creates a reactivity change rate:

$$\dot{\rho} = \alpha_w \times \dot{T} = \alpha_w \times 0.15$$

The net reactivity at the peak is:

$$\rho_{net} = \alpha_w \Delta T_{avg} + \rho_{rod} + \alpha_f \Delta P = \alpha_w \times 4 + 80 + 10 \times 2.5$$

Substituting into the SUR = 0 condition:

$$\alpha_w \times 0.15 + 0.1 \times (\alpha_w \times 4 + 80 + 25) = 0$$

$$0.15\alpha_w + 0.4\alpha_w + 10.5 = 0$$

$$0.55\alpha_w = -10.5$$

$$\boxed{\alpha_w = -19.091 \text{ pcm/}^\circ\text{F}}$$

Part D

Solution

At final equilibrium when the transient is complete:

- Temperature stops changing: $\dot{T} = 0 \Rightarrow \dot{\rho} = 0$
- Start-up rate returns to zero: SUR = 0
- Net reactivity must be zero: $\rho_{net} = 0$

Since $\dot{\rho} = 0$ at equilibrium, the SUR equation requires:

$$\text{SUR} = \frac{26.06 \times (0 + \lambda_{eff} \times \rho_{net})}{\beta - \rho_{net}} = 0$$

This is satisfied when $\rho_{net} = 0$:

$$\alpha_w T_{final} + \rho_{rod} + \alpha_f P_{final} = 0$$

However, without knowing the heat removal characteristics (i.e., the relationship between power generation and temperature at thermal equilibrium with ambient losses), we cannot solve for exact values of T_{final} and P_{final}.

Qualitative Analysis:

The transient behavior proceeds as follows:

1. **At the peak** ($\Delta T = 4$°F, $\Delta P = 2.5\%$): SUR = 0, but temperature is still rising at 0.15 °F/s
2. **After the peak**: Temperature continues to rise $\Rightarrow$ more negative reactivity is added $\Rightarrow$ power decreases from its maximum
3. **At final equilibrium**: Temperature plateaus when heat generation equals ambient heat removal

Therefore:

$$\boxed{T_{final} > 4^{\circ}\text{F} \quad \text{and} \quad P_{final} < 2.5\%}$$

The final power is lower than the peak power, but the final temperature is higher than the peak temperature. The peak power at 2.5% is a transient maximum, not the steady-state equilibrium value.

Problem 6

Part A

Core design that prohibits adequate transfer of power between core regions will increase the likelihood of oscillations. In our notes for 'Simplified Parallel Coupled Reactors', we summarized this communication between reactor regions as a parameter g. Designs that have connections between areas with small g will suffer from worse oscillations. I would presume reactors that have large aspect ratios would suffer more from oscillations, as it would be harder for different ends of the reactor core to 'communicate' with one another.

Part B

These oscillations will cause damage to the fuel and reactor over time. The reactor is presumably not designed to carry such high power loads in localized regions of the reactor, as opposed to a balanced power load across the entire reactor core.

Part C

Oscillations might impact core protection or safety analysis by obscuring the actual reactivity or temperature values inside the reactor core. Without proper care to obtain good measurements, a reactor operator could not be aware that certain oscillating areas of the core are exceeding temperature and local power limits, all the while the reactor as a whole may appear as if it's behaving normally. The result is that while coolant flow in and out of the reactor maintain normal temperature, oscillating fuel rods may actually be pushing beyond designed limits, and compromising their cladding, performance, or other important characteristics..