Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 24

Exam 3 Review

Spiritual Thought

“During the 1940s and 1950s, an American prison warden, Clinton Duffy, was well known for his efforts to rehabilitate the men in his prison. Said one critic, ‘You should know that leopards don’t change their spots!’

Replied Warden Duffy, ‘You should know I don’t work with leopards. I work with men, and men change every day.’”

– President Thomas S. Monson

Chapter 10 (I)

- Chapter 10
  - Criticality
    - Six factor formula
    - Multiplication factor
    - Cross Sections
    - Neutron Life Cycle
  - Moderation
    - Common moderators
    - Most effective moderators
  - Bare Reactor
    - Flux profiles
    - Boundary conditions
    - Diffusion Equation Problems

Chapter 10 (II)

- Homogenous vs. heterogeneous
- Buckling
  - Geometric
  - Material
  - Constituents
  - How to size reactor
- Transient Reactor Behavior
  - Delayed neutrons
  - reactivity
  - δk
  - Reactor worth ($)
  - Reactor operation
  - Period and times

Chapter 10 (III)

- Poisons
  - Reactivity insertions
  - Reactivity “swing”
  - Reactor control methods
  - Long term reactivity changes and countermeasures
  - Changes in time
- Reactivity Coefficients
  - Doppler
  - Void (moderator expansion)
  - Axial Expansion
  - Radial Expansion
  - Control Rod Drive Expansion
  - Calculate change in reactivity based on given coefficients

Chapter 11 (I)

- Nuclear Energy Conversion
  - Key Components
  - General layout of nuclear plant systems
- Light Water Reactors
  - Components
  - Configurations
  - Design
  - Challenges
  - Operation
  - BWR vs PWR
- Operation Perturbations
  - Thermal Changes
  - Load Changes
  - Fuel Changes
  - Accidents

Chapter 11 (II)

- Gen IV Reactors
  - Know types
  - Benefits/Disadvantages
- Evolution of Nuclear Power
  - Generations
  - Characteristics
  - Other Non-LWR (non Gen IV)
- Fast Reactors
  - Breeder vs. Burner
  - Key Components
  - Challenges
  - World-wide use

Chapter 12

- heat output of radioactive isotopes.
- GPHS
  - Characteristics
  - Table 12.2
- RTGs
  - Types
  - Differences & Similarities
- Electricity generation at any point in the life of an RTG.
- Space reactor concepts

Example I

- Some people have decided that it's a good idea to enrich higher enrichment Uranium tails (0.2%), which is essentially free, so that you don't have to pay for natural uranium. The waste stream feed would be 0.05%, and they are final fuel uranium would be 4.95% U235 enrichment. What is the SWU/kg for this process?
- The cost of Uranium and SWU for natural uranium enrichment are \$39.5/lb and \$80/SWU. Is this plan cheaper than using natural uranium?

$$\frac{F}{P} = \frac{x_p - x_w}{x_f - x_w} \qquad \frac{W}{P} = \frac{x_p - x_f}{x_f - x_w}$$

$$V(x_i) = (2x_i - 1)ln\left(\frac{x_i}{1 - x_i}\right)$$

SWU/kg = $V\left(x_p\right) + \frac{W}{P} \cdot V(x_w) - \frac{F}{P} \cdot V(x_F)$

$$\frac{SWU}{kg} = 40.968 \qquad \frac{SWU}{kg} = 8.847$$

Example 2: Rod Ejection Accident

- A control rod is ejected from the core instantly adding \$0.0005 reactivity to the core. Assuming we want a temperature increase of no more than 10 ºC, what is the minimum overall reactivity feedback coefficient (in %mil/ºC)?

$\$.0005 = x \cdot 10^\circ C = \frac{\$.0005}{10^\circ C} = \frac{\$.00005}{^\circ C} \left| \frac{10000\, pcm}{1\$} \right. = \frac{5\ \%mil}{^\circ C}$

- If water contributes 1 %mil/ºC of negative feedback, how much should the fuel provide?

$5\% = \Delta\rho_{water} + \Delta\rho$

$\boxed{\Delta\rho_{Boron} = 5 - 1 = 4\ \%mil/^\circ C}$

Example – Homogeneous, ^{239}Pu

- Pure ^{239}Pu fuel and reactor is a water-moderated($\frac{N^{NF}}{N^F}$=1), water-cooled bare infinite cylinder. How large of radius for criticality?
  - $\boldsymbol{\epsilon p \eta f P_{NL}^{f} P_{L}^{th} = 1 = k_{eff}}$
  - $\boldsymbol{\epsilon p \approx 1}$ (pure fuel makes $\boldsymbol{p}$ close to 1 and $\boldsymbol{\epsilon}$ slightly greater than 1)
  - $\boldsymbol{\eta = 2.11}$ (Fuel property – Table 10.1)
  - $\boldsymbol{f = (749+271)/\left[(749+271) + 2\left(0.333 + \frac{0.00019}{2}\right)\left(\frac{N^{NF}}{N^F}\right)\right]}$ = 0.999
  - $\boldsymbol{P_{NL}^{th} = \frac{1}{L^2 B_c^2} = \frac{1}{L_M^2(1-f)B_c^2} = \frac{1}{2.85^2(0.001)\left(\frac{2.405}{R}\right)^2}}$
  - $\boldsymbol{P_{NL}^{f} = \exp(-B_c^2\tau) = \exp\left(-\left(\frac{2.405}{R}\right)^2 27\right)}$
  - $\boldsymbol{\epsilon p \eta f P_{NL}^{f} P_{L}^{th} = 1 = 1(2.11)f \frac{\exp\left(-\left(\frac{2.405}{R}\right)^2 27\right)}{2.85^2(1-f)\left(\frac{2.405}{R}\right)^2}}$ $= 68.8\boldsymbol{R}^2 \boldsymbol{\frac{N^F}{N^{NF}} exp(-\frac{156.6}{R^2})}$

Example: NPP Load Follow

A few years ago in Missouri, a law was passed that indicated any nuclear power plant that didn't decrease production when wind power came online would be charged \$0.19/kWhr if they didn't ramp down power to give priority to wind generation. However, the NRC limits the reactivity worth insertion for reactors in terms of control rod steps. In this case, let's assume the limit is -2%-mil per hour (assume the reactor just reaches a new steady state due to reactivity feedbacks each hour) to avoid reactivity instabilities. How long would it take one of these reactors to drop to 95% capacity when the wind starts blowing?

$$T = \frac{\tau}{\rho(\$)} = \frac{12.72s}{-.00002} = -636000s$$

$$t = T \cdot \ln\left(\frac{P(x)}{P_o}\right) = -636000\mathrm{s}\,\ln(.95) = 9.06\ hr$$