Lecture 3
Reactor Kinetics and Control
Topics to Be Covered

• Time Dependent Diffusion Equation
• Prompt Neutrons
• Delayed Neutrons
• Point Kinetics Equation
• Reactivity
• Inhour Equation
• Feedback - Fuel-Doppler, Moderator, Power
• Reactor Control
Key Concepts

• Time Dependent Diffusion Equation
  – Rate of change = rate of production – rate of absorption – rate of leakage

• Prompt neutron $k_{eff}$

• Reactivity – $\rho = (k - 1)/k$

• Mean neutron generation time $l^* = 10^{-7} \text{ sec}$

• Reactor Period – $T = l^*/\rho$
  – *Time to increase power by factor of e*
Impact of Delayed Neutrons

- 99% of Neutrons are Prompt – released at time of fission
- Fission Products also release neutrons with some delay based on half life - Precursors
- 20 Precursors grouped into 6 groups with half lives ranging from 0.25 sec to 1 minute
- Delayed neutron fraction
  \[ \beta_i = \frac{\text{delayed neutrons from precursor group } C_i}{v} \]
# Delayed Neutrons

<table>
<thead>
<tr>
<th>Group</th>
<th>Half-life $T_{1/2}$ (s)</th>
<th>Delayed fraction $\beta_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55.0</td>
<td>0.00021</td>
</tr>
<tr>
<td>2</td>
<td>23.0</td>
<td>0.00142</td>
</tr>
<tr>
<td>3</td>
<td>6.2</td>
<td>0.00127</td>
</tr>
<tr>
<td>4</td>
<td>2.3</td>
<td>0.00257</td>
</tr>
<tr>
<td>5</td>
<td>0.61</td>
<td>0.00075</td>
</tr>
<tr>
<td>6</td>
<td>0.23</td>
<td>0.00027</td>
</tr>
<tr>
<td>Total</td>
<td>—</td>
<td>0.0065</td>
</tr>
</tbody>
</table>

Neutron Balance

• Prompt source
• Delayed source
• Time Dependent Neutron Balance Equation
Key Kinetics Equations

• Point Kinetics Equations

• Inhour Equation
### Average Delayed Neutron from Uranium and Plutonium

#### TABLE 5-3

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Delayed fraction $\beta$</th>
<th>Effective delayed fraction $B_{\text{eff}}^{\dagger}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{233}\text{U}$</td>
<td>0.0026</td>
<td>0.003</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>0.0065</td>
<td>0.0070</td>
</tr>
<tr>
<td>$^{239}\text{Pu}$</td>
<td>0.0021</td>
<td>0.0023</td>
</tr>
</tbody>
</table>

$^{\dagger}$Typical for LWR systems.

Delayed neutrons are produced at about $\frac{1}{2}$ the energy of prompt neutrons.

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Reactivity Insertions

• Reactor follows point kinetics equations
• Prompt jump – drop
• Asymptotic Period – considering delayed neutrons
• Prompt critical – transition to prompt from delayed control \( \rho = \beta \)
• Period of core used to start up reactor – 80 sec.
$S = \rho / \rho_0$

**GURE 5-1**

Time-dependent power behavior following various reactivity insertions representative of a reactor using slightly enriched uranium fuel. Figures © Hemisphere. All rights reserved. This content is excluded from our Creative Commons license. For more information, see [http://ocw.mit.edu/fairuse](http://ocw.mit.edu/fairuse).
Reactivity Feedbacks

- Fuel Temperature
  - Thermal expansion
  - Doppler
- Moderator/Coolant
- Fuel Motion – bowing
Reactivity Coefficients

• Fuel Temperature
• Moderator Temperature
• Moderator Density
• Void Coefficient
• Power Coefficient
Doppler Broadening

FIGURE 5-2
Effect of temperature on the effective shape of a resonance absorption cross section.
Reactivity Feedback

FIGURE 5-3
Reactivity feedback diagram.

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FIGURE 5-4
Response of the Peach Bottom HTGR to a 68°C decrease in helium inlet temperature (Adapted from *The Technology of Nuclear Reactor Safety*, T. J. Thompson and J. G. Beckerly (eds.), Vol. 1, by permission of The MIT Press, Cambridge, Massachusetts. Copyright © 1964 by the Massachusetts Institute of Technology.)
Reactor Control

• Inherent feedback mechanism
  – Fast – fuel
  – Slow – moderator

• Control Rods
  – Relatively fast but rod worth an issue
    - Rod ejection
    - Rapid withdrawal

• Soluable Boron – effect on Moderator Temp. Coefficient
Homework Assignment

• Knief Chapter 5
  – Problems: 1, 4, 6, 9

• Read Chapter 6 for next class