Chemical Engineering 512

Nuclear Reactor Transient Modeling

Lecture 19

Reactor Kinetics

Spiritual Thought

D&C 121:41-42

41 No power or influence can or ought to be maintained by virtue of the priesthood, only by persuasion, by long-suffering, by gentleness and meekness, and by love unfeigned;

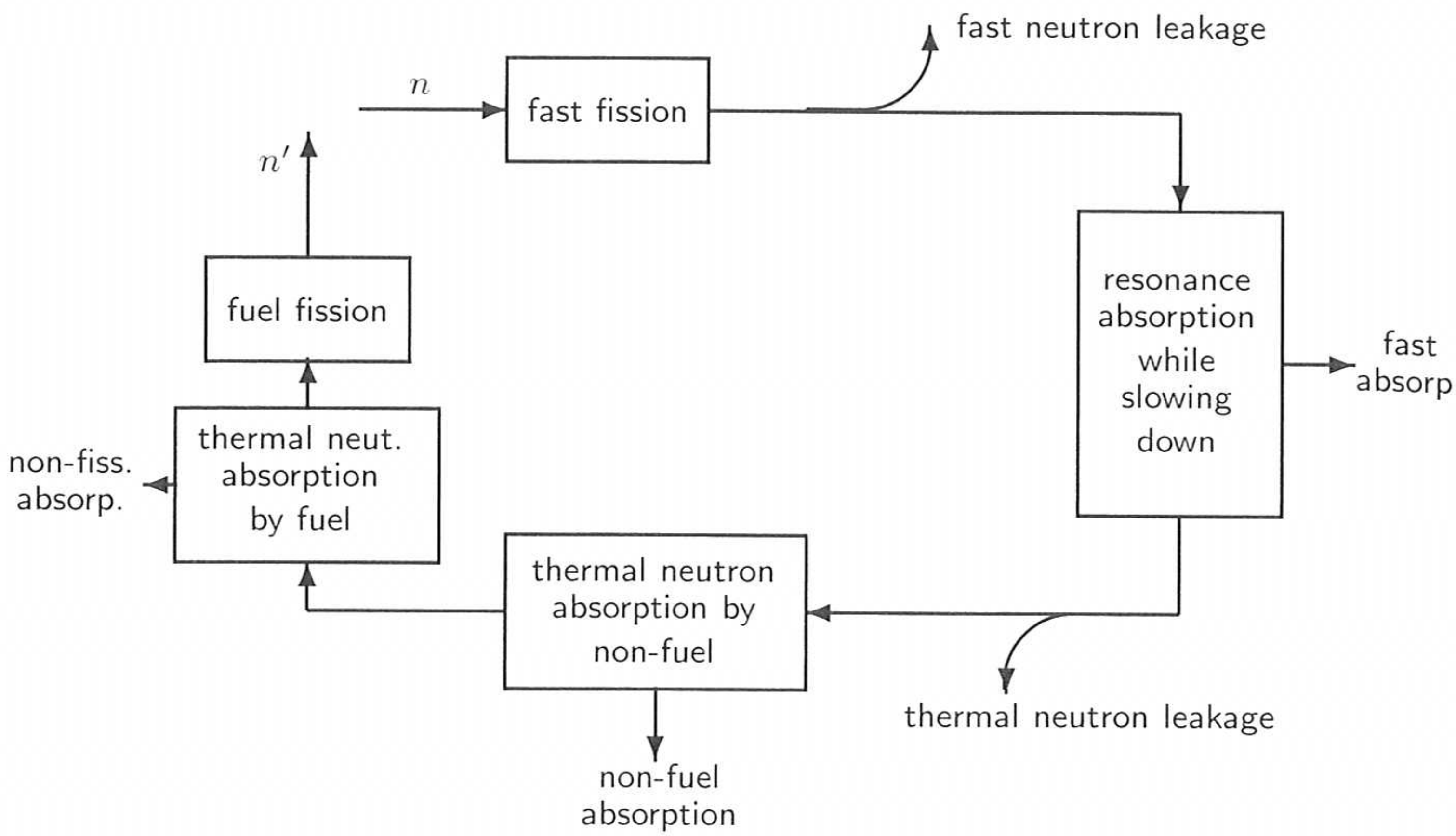
42 By kindness, and pure knowledge, which shall greatly enlarge the soul without hypocrisy, and without guile–"

Objectives

- Learn basics of reactor kinetics
- Learn how to input kinetics into RELAP5-3D
- Practice inputting kinetics into RELAP5-3D
- Talk about how to apply this to an existing RELAP5-3D model

Fast Neutron Life Cycle

- What happens to fast neutrons?



Multiplication Factor

$$k_{eff} \equiv \frac{neutrons\ at\ point\ in\ cycle}{neutrons\ at\ same\ point\ in\ previous\ generation}$$

$$k_{eff} = \frac{n'}{n}$$

$$k_{eff} = \epsilon p \eta f P_{NL}^{f} P_{NL}^{th}$$

Reactivity and Worth

$$\rho \equiv \frac{k_{eff} - 1}{k_{eff}} = \frac{\delta k}{k_{eff}}$$

reactivity ρ and δk

$$k(\$) \equiv \frac{\rho}{\beta}$$

β is delayed neutron fraction
worth can be measured in units of $k(\$)$ or k

- cents?
- Percent Mil?

Delayed Neutrons

TABLE 3.5 DELAYED NEUTRON DATA FOR THERMAL FISSION IN ^{235}U*

Group	Half-Life (sec)	Decay Constant (l_i, sec^{-1})	Energy (ke V)	Yield, Neutrons per Fission	Fraction (β_i)
1	55.72	0.0124	250	0.00052	0.000215
2	22.72	0.0305	560	0.00346	0.001424
3	6.22	0.111	405	0.00310	0.001274
4	2.30	0.301	450	0.00624	0.002568
5	0.610	1.14	—	0.00182	0.000748
6	0.230	3.01	—	0.00066	0.000273
					Total yield: 0.0158
					Total delayed fraction (β): 0.0065

*Based in part on G. R. Keepin, *Physics of Nuclear Kinetics*, Reading, Mass.: Addison-Wesley, 1965.

For 1-group model, $T_{\frac{1}{2}}$ for ^{235}U is about 8.87 s and τ is about 12.8 s.

Simple Kinetics Model

$$\Delta n(t) \equiv \ell_p \frac{dn(t)}{dt} = (k_{eff} - 1)n(t)$$

$$\frac{dn(t)}{dt} = \frac{k_{eff} - 1}{\ell_p} n(t)$$

$$\Rightarrow n(t) = n(0) \exp\left(\frac{k_{eff} - 1}{\ell_p} t\right)$$

- For ^{235}U
  - ℓ_p= 2.1x10^{-4} s
  - $k_{eff} - 1 = 0.001$
  - and $t = 1s$,
- n/n^0 = 117 (22,027 if $\ell' = 10^{-4}$ as in text)
- Far too rapid to control!!!

Reactors with delayed neutrons

Delayed neutrons: β is fraction of total neutrons

$$\bar{\ell}_p = (1-\beta)\ell_p + \beta\left(\ell_p + \tau\right) \approx \ell_p + \beta\tau$$

τ is lifetime of delayed neutrons = $\dfrac{T_{1/2}}{\ln 2} \approx 12.8\ s$

For $\delta k \ll \beta$

$$\frac{n(t)}{n_0} = \exp\left(\frac{k_{eff}-1}{\bar{\ell}_p}\right) = \exp\left(\frac{t}{T}\right)$$

$$T = \frac{\bar{\ell}_p}{k_{dff}-1} = \frac{\beta\tau}{\delta k}$$

- For ^{235}U, T = 83 s, k_{eff}-1 = 0.001,
- n/n^0 = 1.012
- This can be controlled!

Reactivity Equation Solutions

$$T = \frac{\bar{l}}{k_{eff} - 1} = \frac{\bar{l}}{\delta k} = \frac{\beta\tau}{\delta k} =$$

Reactor period - The time required for a neutron population to change by a factor of e

$$k_{eff} = 1 + \delta k = 1 + \frac{\beta\tau}{T}$$

$\tau =$ Lifetime of delayed neutrons ~12.8s (U235)

$$T = \frac{\beta\tau}{\delta k} = \frac{\beta\tau}{k_{eff} - 1} = \frac{\beta\tau}{k_{eff}\rho} = \frac{\tau}{k_{eff}\rho(\$)} \approx \frac{\tau}{\rho(\$)}$$

$$\phi(t) = exp\left(\frac{t}{T}\right)$$

Remember, Flux is proportional to power….

$$C \cdot P(t) = exp\left(\frac{t}{T}\right) \qquad \frac{t}{T} = exp\left(\frac{P(t) \cdot C}{P(0) \cdot C}\right) \qquad \frac{t}{T} = exp\left(\frac{P(t)}{P(0)}\right)$$

Power Changes

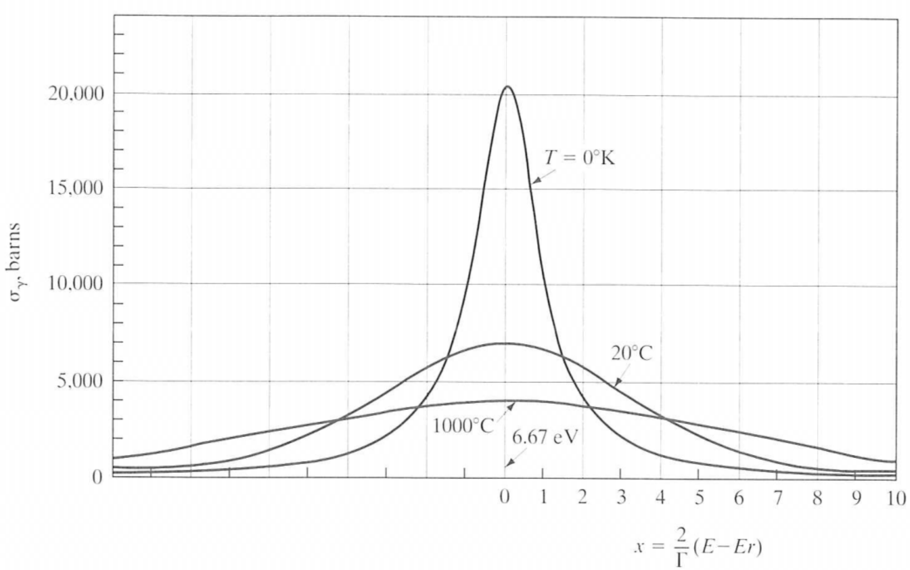
$$T = \frac{\beta\tau}{\delta k} = \frac{\beta\tau}{keff \cdot \rho} = \frac{\tau}{keff \cdot k(\$)} \sim \frac{\tau}{k(\$)}$$

- T = Reactor Period (units of time)
  - Time required to increase reactor power (or neutron flux) by 2.72
- Integrate solution with specific values (initial time power to final time/power

$$\frac{t}{T} = ln\left[\frac{P(t)}{P(0)}\right]$$

Temperature Dependence

$$\alpha_T = \frac{d\rho}{dT} = \frac{d}{dT}\left(\frac{k-1}{k}\right) = \frac{1}{k^2}\frac{dk}{dT} \cong \frac{1}{k}\frac{dk}{dT}$$



Breit-Wigner describes absorption profile at 0 K but Doppler effect broadens peaks, with little change in area, at higher temperatures.

$$\sigma_\gamma(E) = \frac{\lambda_r^2 g}{4\pi}\frac{\Gamma_n\Gamma_\gamma}{(E-E_r)^2 + \frac{\Gamma^2}{4}}$$

- *α_T = temperature reactivity feedback coefficient*
- *If α_T* > 0,
  - Unstable
  - increases and decreases in temperature run away to meltdown or shutdown without operator response.
- *If α_T* < 0,
  - Stable
  - Increases and decreases in temperature self regulate and the reactor stabilizes.
- Different α's for fuel/moderator
  - Different timescales
    - Fuel is most rapid
    - α_{prompt}
- NRC requires negative α_{prompt} values for licenses

Feedback Types

- Flowering
- Axial Expansion
- Radial Expansion
- Coolant
- Doppler

Kinetics Type

Point

- Core-average fluid conditions, weighting factors, feedback coefficients are used
- Power distribution does not change with time
- Can preform quick calculations

Nodal

- Initial conditions calculated by model and are nodalized
- Power distribution is calculated based on time
- Takes much longer to calculate these equations yet leads to more realistic results

Feedback Type

Separable

- Moderator Density
- Moderator Temperature
- Fuel Temperature

- Changes in one of these DO NOT effect the others

Table

- Moderator Density
- Moderator Temperature
- Fuel Temperature

- Changes in these DO effect each other

Kinetics RELAP Input Cards

- 30000000 – Type Card
- 30000001 – Reactor Kinetics Information
- 30000002 – Fission Product Decay Information
- 300004NN – Power History Data

30000000 – Type Card

- W1(A) – Kinetics Type (nodal or point)
- W2(A) – Feedback Type

30000001 – Reactor Kinetics Information

- W1(A) – Fission product decay type
- W2(R) – Total reactor power
- W3(R) – Initial reactivity
- W4(R) – Delayed neutron fraction over prompt neutron lifetime
- W5(R) – Fission product yield factor
- W6(R) – ^{239}U yield factor
- W7(R) – Fissions per initial fissile atom
- W8(R) – Reactor operating time
- W9(R) – Units for W8

- W1(A) – Fission product type
- W2(R) – Energy release per fission
- W3-W10 – As needed based upon W1

300004NN – Power History Data

- W1(R) – Reactor power
- W2(R) – Time duration
- W3(A) – Time duration units

- If not inputted, infinite operation at previously input total reactor power is assumed.

Separable Option

- 300005NN Desnity Reactivity Table
  - W1 – Modertor Density
  - W2 – Reactivity
- 300006NN Doppler Reactivity Table
  - W1 Fuel Temperature
  - W2 – Reactivity

Example

- Download Lecture 22.i
- Fill in the blanks based upon the following
  - Kinetics Type - Separable
  - Delayed Neutron Fraction (β) – 0.0056
  - Prompt neutron lifetime – 0.000025s
  - Doppler reactivity coefficient – $((-0.0000158^{o}F^{-1})/\beta)*(\Delta T)$
  - Moderator Density Reactivity
    - Convert reactivity to $
    - Hint: $ = %/β

Density (lb/ft^3)	Reactivity (%)
4.7	-68.5
14.0	-30.0
23.4	-14.1
35.1	-4.8
46.8	0.0
56.2	3.0

Answer

```
*               KineticsType          FeedbackType
30000000        point                 separabl
*               Decay       Power       React       NFrac     YFact     U239
30000001        gamma-ac    3600.e6     0.0         224.0     1.0       0.48
*               Type
30000002        ans79-1
*               Table/ContVarNum
30000011        2
*                 Denisty Reactivity Table
*               ModeratorDensity          Reactivity
30000501        4.7                       -122.3
30000502        14.0                      -53.6
30000503        23.4                      -25.2
30000504        35.1                      -8.57
30000505        46.8                      0.0
30000506        56.2                      5.36
*                 Doppler Reactivity Table
*               Temperature               Reactivity
30000601        200.                      5.08
30000602        2000.                     0.0
30000603        5000.                     -8.46
*
```

Connecting To a Heat Structure

```
*************************************************************************
*                                                                       *
*                          Heat Structures                              *
*                                                                       *
*************************************************************************
*
*           AxialHS  RadMesh  GeoType  SSFlag  LeftBound  Reflood
11000000    6        8        2        1       5.74       0
*           MeshLocation     MeshFormat
11000100    0                1
*           NumOfIntervals   RightCoordinate
11000101    7                6.5
*           CompositionNum   IntervalNum
11000201    5                7
*           SourceValue      IntervalNum
11000301    1000.            7
*           InitialTemp      MeshPointNum
11000401    500.             8
*           BoundaryVol/Table  Incr  BCType  SACode  SA/Factor  HSNum
11000501    150010000          0     1       1       10.0       6
*           BoundaryVol/Table  Incr  BCType  SACode  SA/Factor  HSNum
11000601    0                  0     0       1       10.0       6
*           SourceType  Pf        LeftBoundMult   RightBoundMult   HSNum
11000701    1000        0.001791  0.0             0.0              6
*           WordFormat
11000800    0
*           HydDiam  HLFor  HLRev  GSLFor  GSLRev  GLCFor  GLCRev  Boil  HSNum
11000801    0.0      3.0    3.0    0.0     0.0     0.0     0.0     1.0   6
*           WordFormat
11000900    0
*           HydDiam  HLFor  HLRev  GSLFor  GSLRev  GLCFor  GLCRev  Boil  HSNum
11000901    0.0      3.0    3.0    0.0     0.0     0.0     0.0     1.0   6
*
```

Assignment

- Homework 10 Due 11/14/23