Chemical Engineering 512

Nuclear Reactor Transient Modeling

Lecture 17

Reactor Kinetics

Spiritual Thought

“They knew that they could trust God—even if things didn’t turn out the way they hoped. They knew that faith is more than mental assent, more than an acknowledgment that God lives. Faith is total trust in Him.

Faith is believing that although we do not understand all things, He does. Faith is knowing that although our power is limited, His is not. Faith in Jesus Christ consists of complete reliance on Him.

Knowing all this, it was not difficult for those three young Hebrews to make their decision. They would follow God; they would exercise faith in Him. He would deliver them, *but if not*—and we know the rest of the story.”

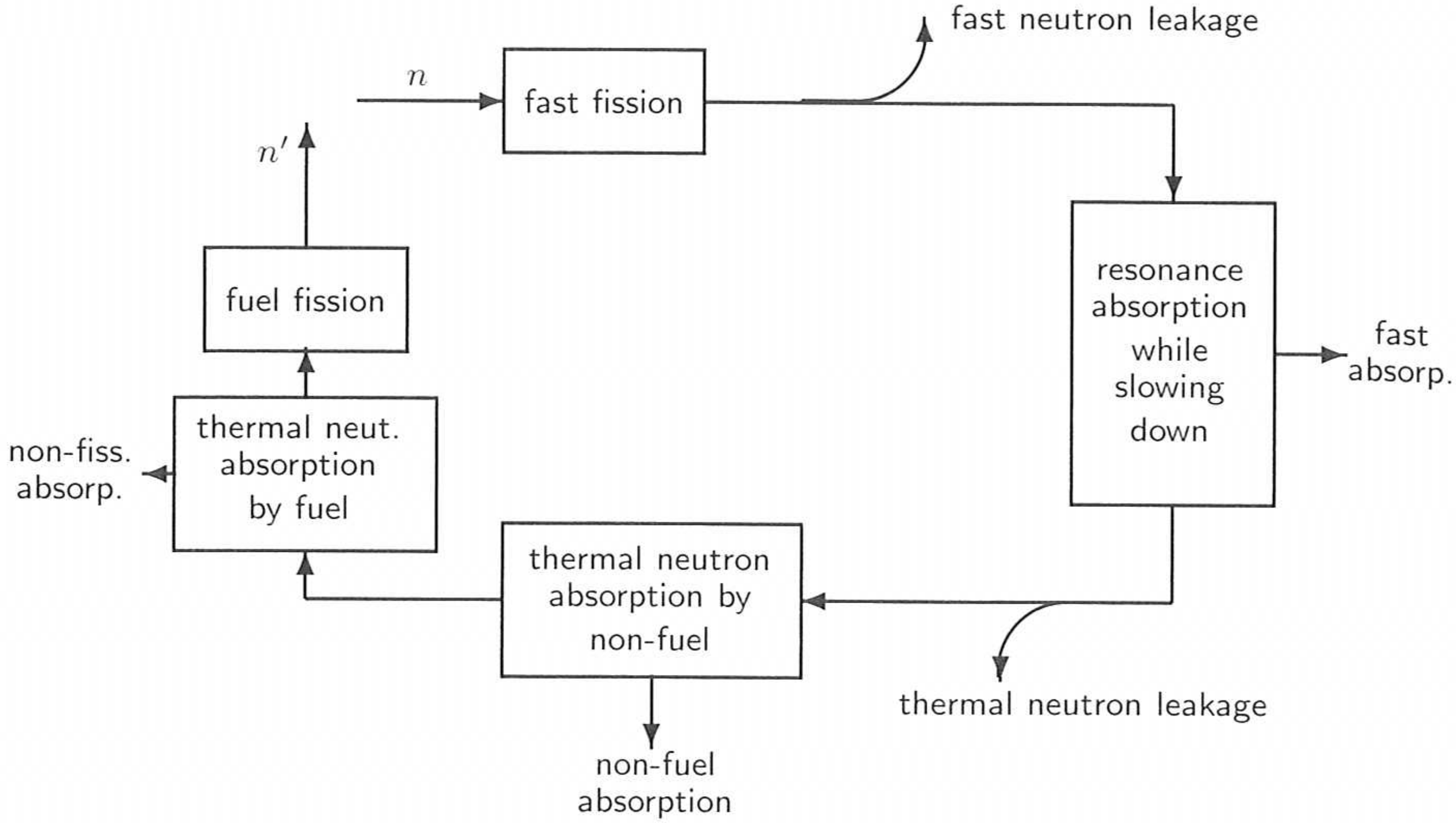
Dennis E. Simmons

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

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

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

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

$$P = \emptyset \sigma_f N_F V_F$$

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.

Power Changes

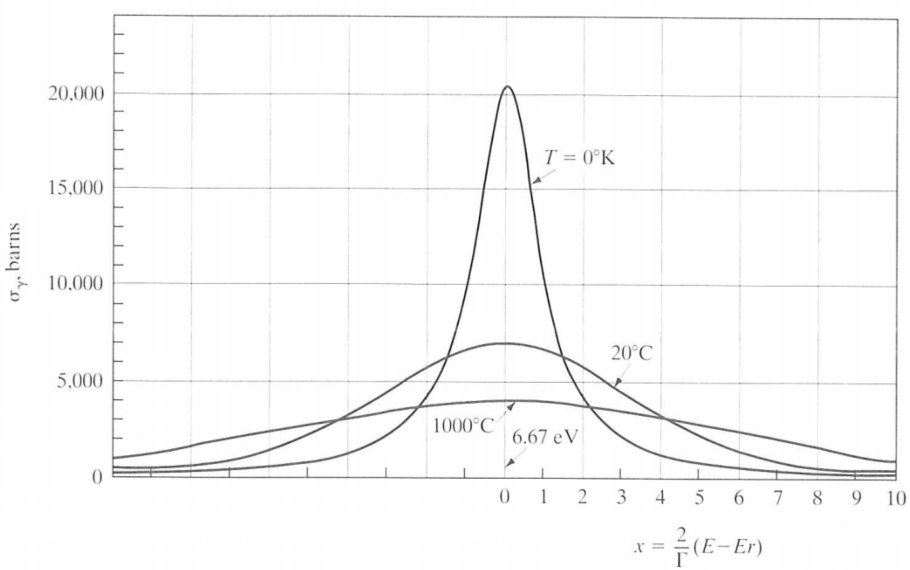
$$T = \frac{\beta\tau}{\delta k} = \frac{\beta\tau}{keff \cdot \rho} = \frac{\tau}{keff \cdot k(\$)} \sim \frac{\tau}{k(\$)}$$

- 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 Density Reactivity Table
  - – W1 – Moderator 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 9 Due 11/6/25