Nuclear Reactor Physics Lecture Note (13)
-Neutron Spectrum (4) Heterogeneous Effect-

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9.5 Resonance absorption in finite diffusion and core heterogeneous effect

(1) Resonance absorption in finite dilution

Resonance escape probability in finite dilution

In the general case of finite dilution, the neutron flux is depressed for the energies in the neighborhood of the resonance. (Energy self-shielding effect)

Approximation method to calculate neutron spectrum with resonance absorber

1. Narrow Resonance (NR) approximation method
2. Narrow Resonance Infinite Mass absorber (NRIM) approximation method
   (Wide Resonance (WR) approximation method)

Doppler effcet on resonance escape probability

As temperature increases

- The resonance peak decreases
- Decreasing self-shielding and flux depression
- Increasing resonance absorption
- Decreasing of resonance escape probability
    - Negative reactivity effect by fuel temperature rise

(2) Core heterogeneous effect

(a) Resonance escape probability in heterogeneous lattice

If the fuel is lamped into a heterogeneous lattice, the resonance escape probability increases dramatically.

Reason :

Neutrons that are slowed down to resonance energies in the moderator are primarily absorbed in the outer regions of the fuel element.

- Spatial self-shielding effect

(b) Treatment of heterogeneous lattice by core homogenization

Reactor cores have a regular or periodic lattice structure in which one subelement or

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so-called unit cell is repeated throughout the core.

The scheme to treat heterogeneous lattice

① Performing a detailed calculation of the flux distribution in a given unit cell of the lattice assuming that there is zero net neutron current across the boundary of the cell

② The various multigroup cross sections characterizing materials in the cell are then spatial averaged over the cell using the flux distribution as weighting function

③ Characterizing the cell by effective group constants accounting for inhomogeneous flux distribution in the cell

- Replaces the actual unit cell by an equivalent homogeneous unit cell characterized by these effective cross sections

(c)Basic method for cell-averaging

Cell-averaged group constants

$$\langle \Sigma_g \rangle_{cell} \equiv \frac{\int_{E_g}^{E_{g-1}} dE \int_{V_{cell}} d^3r \Sigma(\mathbf{r}, E)\phi(\mathbf{r}, E)}{\int_{E_g}^{E_{g-1}} dE \int_{V_{cell}} d^3r \phi(\mathbf{r}, E)}$$

$\Sigma(\mathbf{r}, E)$ is constant within each region, so

$$\langle \Sigma_g \rangle_{cell} = \frac{V_M \int_{E_g}^{E_{g-1}} dE\, \Sigma^M(E)\bar{\phi}_M(E) + V_F \int_{E_g}^{E_{g-1}} dE \Sigma^F(E)\bar{\phi}_F(E)}{V_M \int_{E_g}^{E_{g-1}} dE\, \bar{\phi}_M(E) + V_F \int_{E_g}^{E_{g-1}} dE \bar{\phi}_F(E)}$$

where,

$$\bar{\phi}_M(E) = \frac{1}{V_M}\int_{V_M} d^3r \phi(\mathbf{r}, E) \qquad \text{M : moderator}$$

$$\bar{\phi}_F(E) = \frac{1}{V_F}\int_{V_F} d^3r \phi(\mathbf{r}, E) \qquad \text{F : fuel}$$

here we assume,

$$\phi(\mathbf{r}, E) = \phi(\mathbf{r})\psi(E)$$

then,

$$\langle \Sigma_g \rangle_{cell} = \frac{V_M \Sigma_g^M \bar{\phi}_M + V_F \Sigma_g^F \bar{\phi}_F}{V_M \bar{\phi}_M + V_F \bar{\phi}_F}$$

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$$= \frac{\Sigma_g^F + \Sigma_g^M (V_M/V_F)\zeta}{1 + (V_M/V_F)\zeta}$$

where,

$$\Sigma_g^F \equiv \frac{\int_{E_g}^{E_{g-1}} dE\, \Sigma^F(E)\psi(E)}{\int_{E_g}^{E_{g-1}} dE\psi(E)} \qquad \text{etc}$$

$$\bar{\phi}_F \equiv \frac{1}{V_F}\int_{V_F} d^3r\phi(\mathbf{r}) \qquad \text{etc}$$

$$\zeta \equiv \frac{\bar{\phi}_M}{\bar{\phi}_F} \qquad \text{cell} - \text{disadvantage factor}$$

cf. $f_s \equiv \frac{\bar{\phi}_F}{\bar{\phi}_{hom}}$

(self-shielding factor)

where

$\bar{\phi}_{hom}$: average flux in the cell which has been homogenized

Procedure (example)

① Calculating the neutron spectrum $\psi(E)$ for the homogeneous cell using infinite-medium spectrum code.

② The spectrum is used to calculate group constants for each region of the cell. (Σ_g^F and Σ_g^M)

③ One-speed spatial calculation of the cell disadvantage factor ζ is performed at an average energy characterizing the group of interest.

④ The region wise group constants Σ_g^M and Σ_g^F are combined using ζ to obtain the cell-averaged group constant $\langle\Sigma_g\rangle_{cell}$.

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