REACTIVITY

Reactivity is a measure of the departure of a reactor from criticality. The reactivity is related to the value of k_{eff}. Reactivity is a useful concept to predict how the neutron population of a reactor will change over time.

EO 1.8 **Given the number of neutrons in a reactor core and the effective multiplication factor, CALCULATE the number of neutrons present after any number of generations.**

EO 1.9 **DEFINE the term reactivity.**

EO 1.10 **CONVERT between reactivity and the associated value of k_{eff}.**

EO 1.11 **CONVERT measures of reactivity between the following units:**

a. **$\Delta k/k$** **c.** **$10^{-4}\ \Delta k/k$**
b. **$\% \Delta k/k$** **d.** **Percent millirho (pcm)**

EO 1.12 **EXPLAIN the relationship between reactivity coefficients and reactivity defects.**

Application of the Effective Multiplication Factor

When k_{eff} remains constant from generation to generation, it is possible to determine the number of neutrons beginning any particular generation by knowing only the value of k_{eff} and the number of neutrons starting the first generation. If N_o neutrons start the first generation, then $N_o(k_{eff})$ neutrons start the second generation. Equation (3-4) can be used to calculate the number of neutrons after the completion of "n" generations.

$$N_n = N_o \left(k_{eff}\right)^n \tag{3-4}$$

Example:

The number of neutrons in the core at time zero is 1000 and k_{eff} = 1.002. Calculate the number of neutrons after 50 generations.

Solution:

Use Equation (3-4) to calculate the number of neutrons.

$$N_n = N_o \left(k_{eff}\right)^n$$

$$N_{50} = 1000 \text{ neutrons } \left(1.002\right)^{50}$$

$$= 1105 \text{ neutrons}$$

Reactivity

If there are N_o neutrons in the preceding generation, then there are $N_o(k_{eff})$ neutrons in the present generation. The numerical change in neutron population is $(N_o k_{eff} - N_o)$. The gain or loss in neutron population $(N_o k_{eff} - N_o)$, expressed as a fraction of the present generation $(N_o k_{eff})$, is shown below.

$$\frac{N_o \, k_{eff} - N_o}{N_o \, k_{eff}}$$

This relationship represents the fractional change in neutron population per generation and is referred to as *reactivity* (ρ). Cancelling out the term N_o from the numerator and denominator, the reactivity is determined as shown in the equation below.

$$\rho = \frac{k_{eff} - 1}{k_{eff}} \tag{3-5}$$

From Equation (3-5) it may be seen that ρ may be positive, zero, or negative, depending upon the value of k_{eff}. The larger the absolute value of reactivity in the reactor core, the further the reactor is from criticality. It may be convenient to think of reactivity as a measure of a reactor's departure from criticality.

Example:

Calculate the reactivity in the reactor core when k_{eff} is equal to 1.002 and 0.998.

Solution:

The reactivity for each case is determined by substituting the value of k_{eff} into Equation (3-5).

$$\rho = \frac{k_{eff} - 1}{k_{eff}} \qquad\qquad \rho = \frac{k_{eff} - 1}{k_{eff}}$$

$$= \frac{1.002 - 1}{1.002} \qquad\qquad = \frac{0.998 - 1}{0.998}$$

$$= 0.001996 \qquad\qquad = -0.0020$$

Units of Reactivity

Reactivity is a dimensionless number. It does not have dimensions of time, length, mass, or any combination of these dimensions. It is simply a ratio of two quantities that are dimensionless. As shown in the calculation in the previous example, the value of reactivity is often a small decimal value. In order to make this value easier to express, artificial units are defined.

By definition, the value for reactivity that results directly from the calculation of Equation (3-5) is in units of $\Delta k/k$. Alternative units for reactivity are $\%\Delta k/k$ and pcm (percent millirho). The conversions between these units of reactivity are shown below.

$$1\% \ \frac{\Delta k}{k} = 0.01 \ \frac{\Delta k}{k}$$

$$1 \ \text{pcm} = 0.00001 \ \frac{\Delta k}{k}$$

Another unit of reactivity that is used at some reactors is equivalent to 10^{-4} $\Delta k/k$. This unit of reactivity does not have a unique name. Special units for reactivity that do have unique names are dollars and cents. These units and their applications will be described in a later chapter.

Example:

Convert the values of reactivity listed below to the indicated units.

a. 0.000421 Δk/k = _____ pcm
b. 0.0085 Δk/k = _____ % Δk/k
c. 16 x 10^{-4} Δk/k = _____ Δk/k

Solution:

a. 42.1 pcm
b. 0.85% Δk/k
c. 0.0016 Δk/k

If the reactivity is known, the effective multiplication factor can be determined by solving Equation (3-5) for k_{eff} in terms of the reactivity. This results in the following relationship.

$$k_{eff} = \frac{1}{1 - \rho} \tag{3-6}$$

Reactivity must be in units of Δk/k for use in Equation (3-6).

Example:

Given a reactivity of -20.0 x 10^{-4} Δk/k, calculate k_{eff}.

Solution:

$$\begin{aligned} k_{eff} &= \frac{1}{1 - \rho} \\ &= \frac{1}{1 - (-20.0 \ \text{x} \ 10^{-4})} \\ &= 0.998 \end{aligned}$$

Reactivity Coefficients and Reactivity Defects

The amount of reactivity (ρ) in a reactor core determines what the neutron population, and consequently the reactor power, are doing at any given time. The reactivity can be effected by many factors (for example, fuel depletion, temperature, pressure, or poisons). The next several chapters discuss the factors affecting reactivity and how they are used to control or predict reactor behavior.

To quantify the effect that a variation in parameter (that is, increase in temperature, control rod insertion, increase in neutron poison) will have on the reactivity of the core, *reactivity coefficients* are used. Reactivity coefficients are the amount that the reactivity will change for a given change in the parameter. For instance, an increase in moderator temperature will cause a decrease in the reactivity of the core. The amount of reactivity change per degree change in the moderator temperature is the moderator temperature coefficient. Typical units for the moderator temperature coefficient are pcm/^{o}F. Reactivity coefficients are generally symbolized by α_x, where x represents some variable reactor parameter that affects reactivity. The definition of a reactivity coefficient in equation format is shown below.

$$\alpha_x = \frac{\Delta\rho}{\Delta x}$$

If the parameter x increases and positive reactivity is added, then α_x is positive. If the parameter x increases and negative reactivity is added, then α_x is negative.

Reactivity defects ($\Delta\rho$) are the total reactivity change caused by a variation in a parameter. Reactivity defects can be determined by multiplying the change in the parameter by the average value of the reactivity coefficient for that parameter. The equation below shows the general method for relating reactivity coefficients to reactivity defects.

$$\Delta\rho = \alpha_x \, \Delta x$$

Example:

The moderator temperature coefficient for a reactor is -8.2 pcm/^{o}F. Calculate the reactivity defect that results from a temperature decrease of 5^{o}F.

Solution:

$$\begin{aligned}\Delta\rho &= \alpha_T \, \Delta T \\ &= \left(-8.2 \ \frac{\text{pcm}}{{}^\circ\text{F}}\right)\left(-5 \ {}^\circ\text{F}\right) \\ &= 41 \ \text{pcm}\end{aligned}$$

The reactivity addition due to the temperature decrease was positive because of the negative temperature coefficient.

Summary

The important information in this chapter is summarized below.

Reactivity Summary

- The number of neutrons present in the core after a given number of generations is calculated using Equation (3-4).

$$N_n = N_o \left(k_{eff}\right)^n$$

- Reactivity is the fractional change in neutron population per generation.

- Reactivity and k_{eff} are represented in Equation (3-5) and Equation (3-6), respectively.

$$\rho = \frac{k_{eff} - 1}{k_{eff}} \qquad k_{eff} = \frac{1}{1 - \rho}$$

- The relationship between units of reactivity are listed below.

$$1\% \ \frac{\Delta k}{k} = 0.01 \ \frac{\Delta k}{k}$$

$$1 \ \text{pcm} = 0.00001 \ \frac{\Delta k}{k}$$

- A reactivity coefficient is the amount of change in reactivity per unit change in the parameter. A reactivity defect is the total reactivity change caused by a change in the parameter. The reactivity defect is the product of the reactivity coefficient and the magnitude of the parameter change.