427.00-12

REACTIVITY EFFECTS OF TEMPERATURE CHANGES

THIS SECTION IS NOT REQUIRED FOR MECHANICAL MAINTAINERS

OBJECTIVES

At the conclusion of this lesson the trainee will be able to:

1. Define:
    a) temperature coefficient of reactivity
    b) void coefficient
    c) power coefficient
2. Explain why and how reactivity changes when the temperature of the fuel changes.
3. Explain why a negative temperature coefficient is desirable.

REACTIVITY EFFECTS OF TEMPERATURE CHANGES

The NRX Experiment

In 1949, the NRX reactor at the Chalk River Nuclear Laboratory was allowed to "run away". NRX is a heavy water moderated experimental reactor which uses control rods for reactor regulation. The heavy water level was set 3 cm above the height at which the reactor would be critical at low power with the rods withdrawn. The reactor power was allowed to increase unchecked, and the manner in which it increased is rather unexpected (see Figure 12.1).

The power initially increased. However, it did not increase indefinitely as you might have expected. As the temperature of the fuel rods increased, the reactivity decreased and this caused the rate of power increase to slow down. Later the reactivity decreased at a faster rate as the heavy water got warmer. The total decrease in reactivity was enough to make the reactor sub-critical, and the end result was that the power reached a maximum value and then started to decrease.

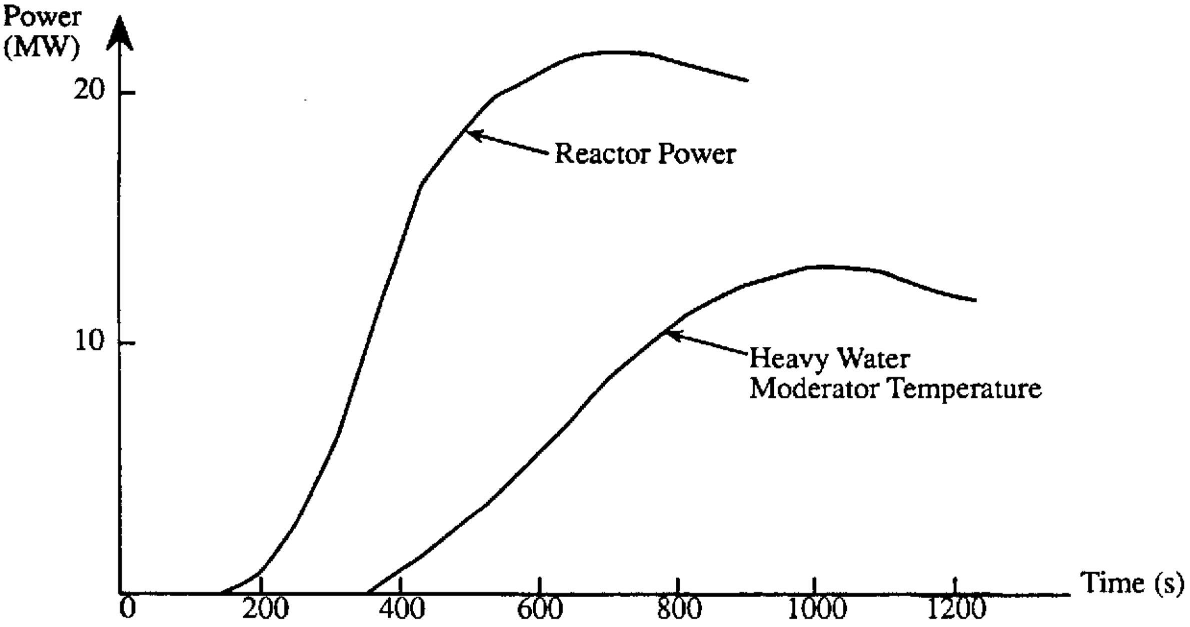

Figure 12.1: The NRX Experiment

Thus for small positive reactivity insertions the reactor is self-regulating because the temperature increases reduce reactivity, preventing the power from continuing to increase. In this experiment the initial excess reactivity was quite small. If more reactivity had been inserted initially it is quite possible that the power would have continued to rise. The point of this example is not to demonstrate that reactor power would never increase continuously (it well might), but to show that there is a loss in reactivity due to the increase in the temperatures of fuel and heavy water.

The temperature coefficient of reactivity is defined as the change in reactivity per unit increase in temperature. Its units are mk/°C. This coefficient may be positive or negative. In the example just described, it was negative because an increase in temperature led to a loss of reactivity.

Temperature changes occur, more or less independently, in the fuel, the heat transport system and the moderator, and there will therefore be a temperature coefficient of reactivity associated with each of these. It is very desirable for the overall temperature coefficient of a reactor to be negative to provide the self-regulating feature illustrated by NRX.

In this course only the effects caused by the temperature changes in the fuel will be examined in detail.

The total change in reactivity due to normal coolant temperature changes is small and an explanation of the effects causing it is beyond the scope of this course. Moderator temperature changes can cause reactivity changes but we generally control the moderator temperature constant. Furthermore, changes in moderator temperature occur at a relatively slow rate (because of the large amount of D_2O) and therefore the effects are not nearly as immediate as those in the fuel.

Fuel Temperature Coefficient of Reactivity

There are two primary causes of the fuel temperature coefficient:

1. Increasing fuel temperature causes increased resonance capture in U-238.

2. The ratio of fissions to absorptions in the fissile material changes with fuel temperature. (The direction and magnitude of change depend on whether the reactor is at fresh or equilibrium fuel).

Both of these effects will be examined.

Increased Resonance Absorption

In lesson 6 the presence of certain resonance absorption peaks in U-238 was discussed. The width and height of these peaks depend on the temperature of the U-238. Figure 12.2 shows one particular resonance peak at 20°C and 800°C. At the higher temperature, the peak is lower but covers a wider range of energies. Even the low peak is high enough that virtually any neutron within this energy range will be captured. Therefore, increasing the fuel temperature increases resonance absorption by increasing the range of energies which can be captured. Resonance absorption is always the most important fuel temperature effect.

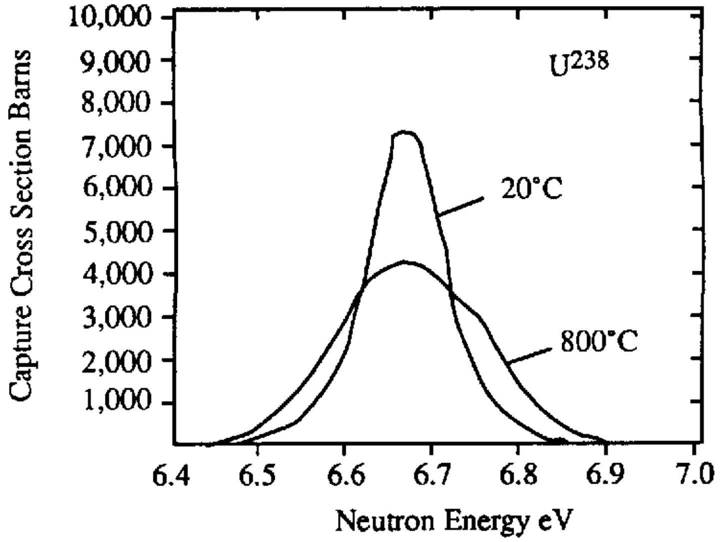

Figure 12.2: Resonance Broadening

Ratio of Fissions to Absorptions

In an earlier lesson the variation of neutron cross-section with temperature was discussed. Consequently the ratio of fissions to absorption $\frac{\sigma_f}{\sigma_a}$ may be expected to change if the speeds of the thermalized neutrons change. For U-235 this ratio goes down with increasing temperature. For Pu-239 the ratio increases. Thus, for fresh fuel where U-235 is the only fissile fuel, increasing the temperature tends to decrease reactivity. In equilibrium fuel where Pu-239 is a significant portion of the fissile material, increasing the fuel temperature tends to increase reactivity.

The overall change in reactivity is a combination of both these effects. The resonance absorption effect is always larger than the ratio effect. Clearly for fresh fuel, the fuel temperature coefficient of reactivity is negative, since both effects are negative. A typical value is -0.013 mk/°C. For equilibrium fuel, the effect of the plutonium partly cancels the resonance effect and reduces the magnitude of the fuel temperature coefficient to about -0.004 mk/°C.

Power Coefficient

Operationally the reactor power is measured and fuel temperature is not. It is convenient to define the "power coefficient", the overall effect of temperature increases. The power coefficient is defined as "the change in reactivity due to temperature effects when power is increased from 0% to 100%". A typical value for CANDU reactors is ≈-5 mk, a decrease in reactivity. The exact value depends on the reactor design and fuel condition. For Bruce NGS the values are about -9 mk for fresh fuel and -3.5 mk for equilibrium fuel.

Void Coefficient

If boiling occurs in a coolant channel, steam will gradually displace the coolant. This effect is called "voiding". If a channel is partially or totally voided there will be a number of reactivity effects. An exact discussion of most of the effects is beyond the level of this course. The void coefficient is defined as "the change in reactivity for 100% voiding of all coolant channels". It is always positive for our reactors. The actual value varies from reactor to reactor but is about +10 mk for the Bruce reactors.

10 mk is a very large positive reactivity. It should be noted that this definition is "theoretical" in that it is not ordinarily possible for all the coolant to flash rapidly to steam. Even on a large pipe break the rate of voiding is limited. The safety systems are designed to detect and stop the power rise before the +10 mk of reactivity is inserted.

ASSIGNMENT

1. Define:
    a) temperature coefficient,
    b) power coefficient,
    c) void coefficient.
2. Discuss the reasons why the fuel temperature coefficient is negative and why the magnitude is lower for equilibrium fuel than it is for fresh fuel.
3. Why is a negative temperature coefficient desirable?

J.E. Crist