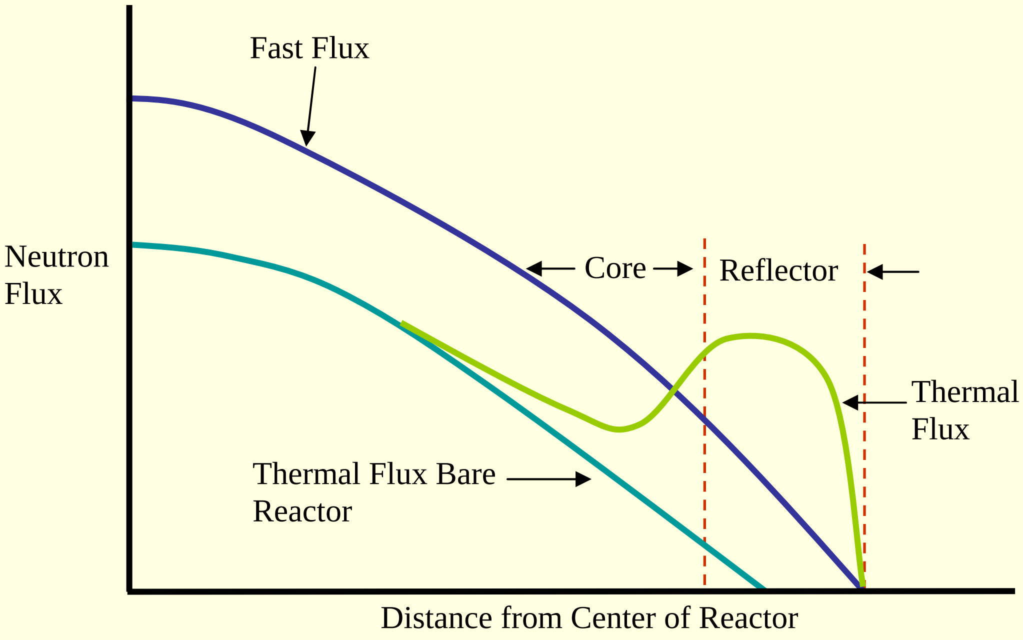
22.05 Reactor Physics - Part Twenty-Two

Application of the Two-Group Equations

1. Reflected Reactors:

One-group theory (or the one-velocity model depending on how it is called) was useful for analyzing bare cores. Two-group theory is useful for analyzing reflected cores because it allows separate calculations of the spatial shape of the fast and thermal fluxes. The figure below shows the results of one such calculation. Also, shown for purposes of comparison, is the thermal flux that would have existed if the core had been bare.



Fast and Thermal Fluxes in a Reflected Thermal Reactor and the Thermal Flux in an Unreflected Reactor

The following should be noted:

1. The shape of the fast flux is that of a cosine as is predicted from one-group theory.

2. The shape of the thermal flux in the bare reactor is the same as that of the fast flux. Again, this is as would be expected from one-group theory for a bare core.

3. The magnitude of the thermal flux in the bare reactor is less than that of the fast flux. This is also to be expected because the fuel has a higher cross-section for thermal neutron absorption and hence it depresses the thermal flux.

The observation that is perhaps unexpected is the next one. The two-group calculation of the actual thermal flux shows that it (the thermal flux) has a very different shape then that of its fast counterpart. It rises near the core-reflector boundary and peaks in the reflector. The shape of the peak is often called a "thermal ear" (evidently because the overall drawing of the flux looks like a head with two ears?) This peak occurs because fast neutrons leak from the core region to the reflector. The reflector consists of a medium, such as D_2O or graphite, that has a high scatter cross-section and a low absorption one. So, the fast neutrons thermalize in the reflector and scatter without significant absorption. So, they peak. Eventually, they leak back, as thermal neutrons, into the core.

A related consequence of these "thermal ears" is that the thermal flux is much flatter than the fast flux. This is important for fuel burnup, which occurs mainly as a result of thermal fissions. For economic reasons, one needs the fuel to deplete at a uniform rate throughout the core. Otherwise, some fuel would reach the peak burnup well before the core as a whole and this would necessitate a premature outage.

2. Reflector Savings:

The presence of a reflector decreases the critical dimensions of a reactor. The difference in the dimensions is called the "reflector savings."

3. Flux Shape Effects:

Accurate knowledge of the flux shape, in all directions, in a reactor is essential to safe operation. The attached figure illustrates one of the problems. Shown is the axial flux for three cases: homogeneous one-velocity calculation; control rod inserted; and control rod withdrawn. In all cases, the reactor is critical and the power is the same. The latter requirement means that the area under each curve has to be the same.

a) Case One – Flux is cosine shaped as is predicted from theory for a homogenous bare core.

b) Case Two – Flux is severely distorted. The region near the control rod is depressed because of the rod's high absorption cross-section. In order to produce sufficient power, the flux below the control rod is enhanced. Thus, a peak exists below the rod.

c) Case Three – The flux is still distorted but less so because the control rod is not inserted as far into the core.

Now, what are the consequences of these changes to the flux shape? Several of the more obvious are:

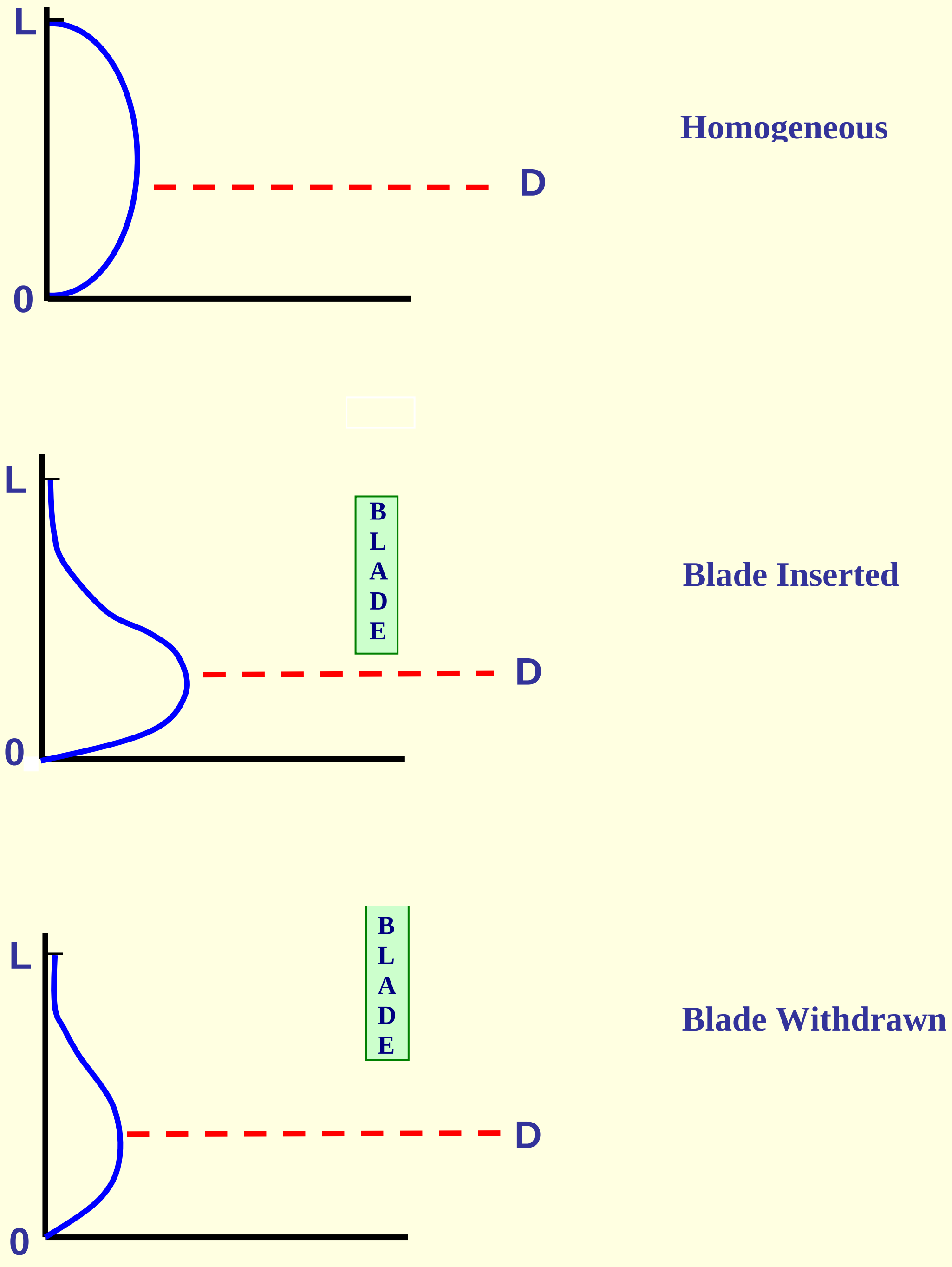
- The axial fuel burnup will not be uniform.
- The power distribution will not be uniform. Power density will peak in the regions where the flux peaks. This could in turn cause thermal-hydraulic safety limits to be approached locally even though, for the core as a whole, there is ample margin to those limits. In order to preclude such issues, reactor operators are required to ensure that the fraction of power generated in the upper and lower halves of the core is monitored and kept within specified limits.
- Monitoring of reactor power is made difficult.

Suppose that a detector is at a fixed location, noted as D in the figure. It senses a varying neutron count rate as the control rod position changes. Yet the power level (area under curve) is the same in all three cases. In order to avoid this problem:

- Detectors that are quite long are often used. These in effect integrate over the flux shape.
- Detectors are frequently calibrated against thermal power balances, which are called calorimetrics.

$$\text{Power} = \Sigma\, \dot{m} c_p \Delta T$$

Where $\dot{m}$ is flow rate, c_p is heat capacity, ΔT is difference between inlet and outlet temperatures. The summation is over all fluid flows that remove heat from the reactor. These include the primary, reflector, and shield coolant systems. (Note: One might logically ask why use detectors at all if calorimetrics are more accurate. The answer is that calorimetrics are only accurate when a plant is at thermal equilibrium. Power plants have enormous heat capacities. As a result, it can take days for a plant to attain thermal equilibrium following a power change. Detectors responses are, in contrast, on the order of a second or less.)



Effect of Axial Flux Shape