17 Neutron Life Cycle

A typical neutron, from birth as a prompt fission neutron to absorption in the fuel, survives for about 0.001 s (the neutron lifetime) in a CANDU. During this short lifetime, it travels about 25 cm while slowing and then 30 cm while diffusing, before the fuel absorbs it.

On this journey, it typically scatters 120 or 130 times, 36 times to thermalize. If a neutron is not absorbed in the fuel then one of the earlier interactions absorbs it, or it may escape into the shielding. Figure 17.1 give a pictorial view of the most likely fates of a neutron. The remainder of this module examines each of the possible fates a neutron faces.

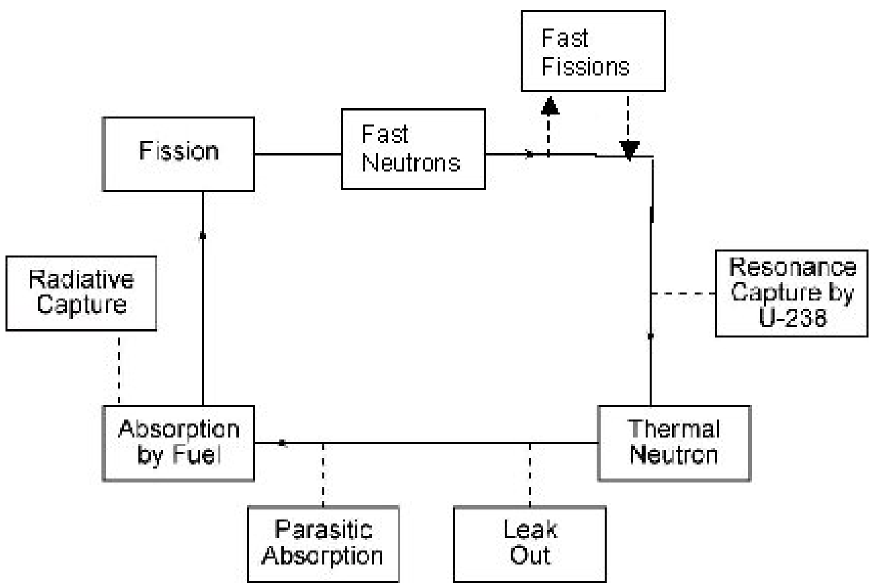

Figure 17.1
Neutron Life Cycle

14.1 Absorption by Equilibrium Fuel

Natural uranium UO_2 fuel, after the reactor has operated for a while, contains U-235, U-238, various isotopes of plutonium, and a variety of fission products. The overall composition of the fuel changes very little with operation because we continually remove old fuel and replace it with fresh.

Over 50% of the thermal neutrons absorbed by equilibrium fuel simply undergo radiative capture. The remaining thermal neutrons (almost 50%) cause fission of U-235 or Pu-239. The net result is that we get about 1.2 fast neutrons per thermal neutron absorbed by the fuel. That is, if 100 thermal neutrons enter the fuel we get 120 fast neutrons in return.

17.1 Fast Fission

An exact accounting of neutron absorption in the fuel includes interactions between fast neutrons (> 2 MeV) and U-238. U-238 cannot fission with a thermal neutron, but U-238 fission can occur with fast neutrons (*fast fission*). This rare process would be completely insignificant but for the fact that our core contains such a large quantity of U-238. Fast fission increases the number of fast neutrons a little from those produced by thermal fission alone.

By far the most significant effect of U-238 in the core is resonance capture. This is important enough to require a new heading.

17.2 Resonance Capture

U-238 has several extremely high absorption peaks in the energy range of about 10 eV to 1 keV, with cross-sections as high as 6,000 barns. Most neutrons that return to the fuel while in this energy range are absorbed.

This is the single largest loss of neutrons in a CANDU; about 10% of the fast neutrons undergo resonance capture while thermalizing.

17.3 Parasitic Absorption

A thermal neutron absorbed by something other than U-235 is unavailable to cause fission. Any of the following can absorb thermal neutrons:

- Fuel sheath
- Coolant, moderator and reflector
- Pressure tubes and calandria tubes
- In-core guide tubes and in-core measuring devices
- Various rods and control zone compartments

In total, the materials on this list absorb about 7.5% of the neutrons, most of them in the moderator and the pressure tubes.

17.4 Leakage

While traveling approximately 40 cm from birth to death a neutron may reach the boundary of the reactor and leak out, never to return.

In a CANDU, leakage accounts for the loss of about 2.5% of the neutrons.

Essentially three things affect leakage: size of the reactor, shape of the reactor, and what happens at the boundary. The designer can adjust these effects, as described below, to reduce leakage into the shielding.

17.5 Size and Shape

Figure 17.2 shows three spherical reactors. If some neutrons travel 50 cm, a neutron born at any location in reactor ‘A' has a possibility of escaping. As we increase the size of the reactor to ‘B', the neutrons born inside the dotted circle normally won't leak before they are captured. By increasing the size again to ‘C' a still smaller percentage of the neutrons can leak out.

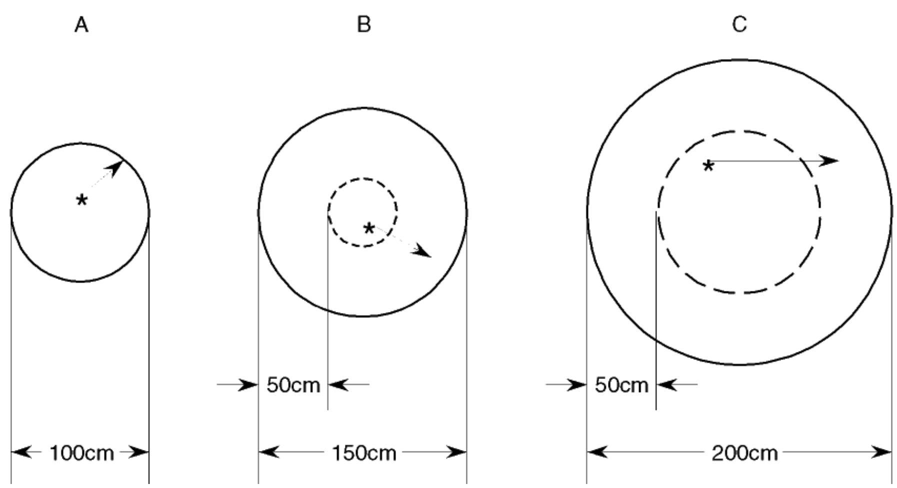

Figure 17.2
Effect of Size

Similar arguments can be made concerning the shape of a reactor. It can be shown that for a given volume of fuel and moderator a sphere always has the smallest leakage. A sphere is not a practical shape from an engineering point of view. Instead, we use a cylindrical reactor core that has the diameter slightly bigger than the length. The actual shape is a compromise between engineering and nuclear considerations.

17.6 Reflectors

The final thing that affects leakage is what happens to a neutron when it reaches the boundary. By surrounding the reactor with material that "bounces" some of the leaking neutrons back into the reactor, the loss due to leakage is reduced. We call this surrounding material a reflector.

An ideal reflector has a high probability of scattering neutrons and a low probability of absorbing them. These properties are shared with the moderator, so the reflector is merely an extension of the moderator as shown in Figure 17.3.

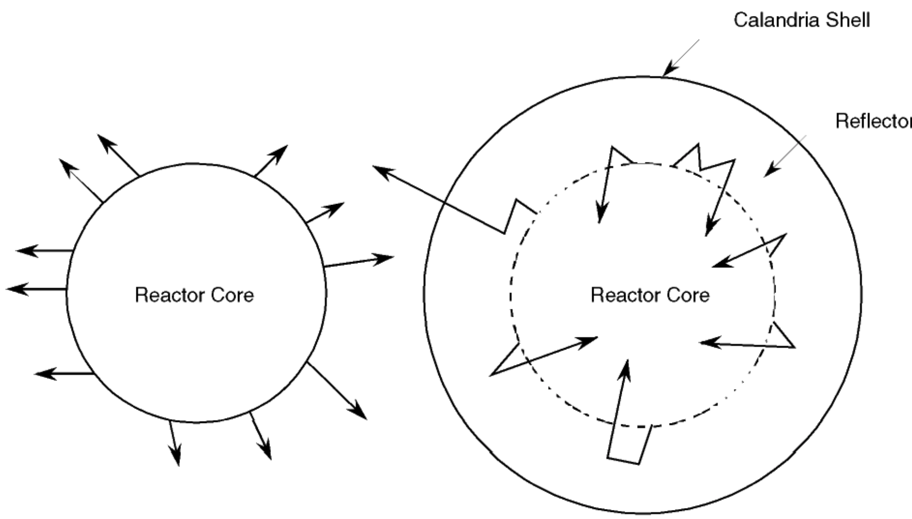

Figure 17.3
Reflector Location

The zone between the fuel region (indicated by the dotted line) and the calandria shell serves as the reflector.

Another effect of the reflector is that it assists with flux flattening. The neutrons that are stopped from leaking add to the flux in a region where flux is naturally low. This *flux flattening* allows bundles near the edge of the core to increase their contribution to the power output, without raising the power from bundles in the high flux region.

17.7 Overall Cycle

Roughly 20% of the neutrons are lost (10% by resonance capture, 7.5 % by parasitic absorption, and 2.5 % by leakage) and do not return to the fuel. About half of those remaining (i.e., 40%) cause fissions, and fission produces 2.5 neutrons, restoring the total to 100%.

Looked at another way, suppose 100 thermal neutrons are absorbed in the fuel. This produces a new generation of 120 fast neutrons, enhanced to 123 by fast fission. A loss of 23 neutrons rounds off to a 20% loss. This leaves 100 thermal neutrons to be absorbed in the fuel again, sustaining continuous energy production in the reactor. Parasitic absorption can be adjusted to hold power steady or to change the number of neutrons in the cycle so power can be increased or decreased.

17.8 Assignment

1. Sketch the neutron life cycle.
2. Discuss each of the possible fates of a neutron.
3. Why do our reactors have reflectors?