2.8.1 Thermal reactors and Moderator

An alternative that avoids the costly and difficult enrichment process and eliminates the need to handle weapons grade uranium is hinged on a characteristic of the absorption cross-section of ^{238}U whose form was shown in figure 1. This has

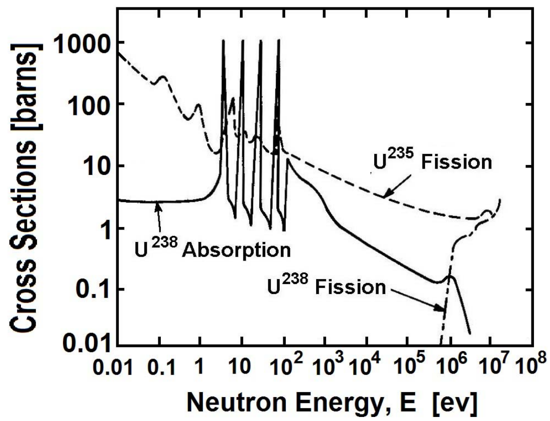

Figure 1: Qualitative representations of how the fission cross-sections for ^{235}U and ^{238}U as well as the absorption cross-section for ^{238}U vary with the neutron energy.

strong peaks at intermediate neutron energies, the so-called *capture resonances*, so that many neutrons, slowed down by scattering, are absorbed by the ^{238}U before they can reach low or *thermal* energies. This is important because, as shown in figure 1, ^{235}U has a very high fission cross-section at thermal energies and this potential source of fast neutrons is attenuated because so few neutrons can pass through the resonance barrier. Note that neutrons that are in the process of being slowed down are termed *epithermal neutrons*.

However, if it were possible to remove the fast neutrons from the reactor, slow them down to thermal energies and then reintroduce them to the core, the reactivity of the reactor could be increased to critical or supercritical levels. In practice, this can be done by including in the reactor a substance that slows down the neutrons without absorbing them. These slowed down neutrons then diffuse back into the uranium and thus perpetuate the chain reaction. This special substance is known as the *moderator* and it transpires that both water and carbon make good moderators. Such a reactor is called a *thermal* reactor since its criticality is heavily dependent on the flux of low energy, thermal neutrons. Virtually all the nuclear reactors used today for power generation are thermal reactors and this monograph will therefore emphasize this type of reactor.

To summarize, a conventional thermal reactor core comprises the following components:

- Natural or slightly enriched uranium fuel, usually in the form of an oxide and encased in fuel rods to prevent the escape of dangerous fission products.

- Moderator, usually water (sometimes heavy water) or carbon.
- Control rods made of material that is highly absorbent of neutrons so that the insertion or withdrawal of the rods can be used to control the reactivity of the core.
- A cooling system to remove the heat, the energy produced. In many reactors water serves as both the coolant and the moderator.

A variety of thermal reactors have been developed and used to produce power in the world. These comprise three basic types:

1. Light water reactors (LWRs) are by far the most common type used for power generation and include the common pressurized water reactors (PWRs) and boiling water reactors (BWRs) (see sections 4.3.1 and 4.3.3). They use regular water (so called *light* water) as both the coolant and the moderator but need somewhat enriched uranium fuel (about 2% ^{235}U).
2. Heavy water reactors (HWRs) use natural, unenriched uranium fuel and achieve the needed increase in reactivity by using deuterium oxide (*heavy* water) as the moderator and coolant rather than light water. The Canadian CANDU reactor is the best known example of this type.
3. Gas-cooled reactors (GCRs) in which the primary coolant loop utilizes a gas (for example carbon dioxide or helium) rather than water. Typically these use graphite as the moderator. Examples are the high temperature gas-cooled reactor (HTGR) and the advanced gas-cooled reactor (AGR) manufactured respectively in the USA and UK.

This list focuses on the large thermal reactors for power generation. There is a much greater variety of design in the smaller reactors used for research and for power-sources in vehicles such as submarines, space probes, etc. The various types of thermal reactors will be examined in more detail in chapter 4.