4.4 Heavy water reactors (HWRs)

An alternative thermal reactor design that uses natural rather than enriched uranium is the heavy water reactor (HWR). The principal representative of this class of reactors is the Canadian-built CANDU reactor (see, for example, Cameron 1982, Collier and Hewitt 1987) of which there are about 48 in commercial operation worldwide (in 2013). A schematic of the CANDU reactor is included in figure 1. The use of natural uranium fuel avoids the expense of the enrichment process. In an HWR the reactivity is maintained by using heavy water (D_2O) rather than light water as the moderator.

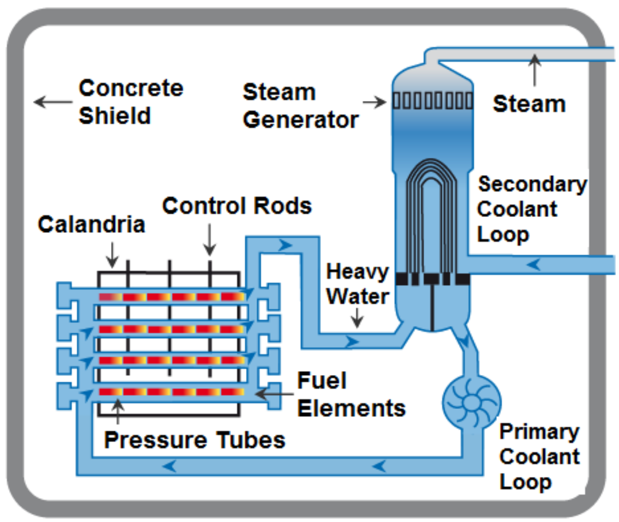

Figure 1: Schematic of the CANDU heavy water reactor. Adapted from WNA (2015b).

One of the unique features of the CANDU reactor is the refueling technique employed that is made possible by the natural uranium fuel. As depicted in figure 1, the fuel is contained in horizontal tubes and refueling is done continuously rather than in the batch process used in LWRs. Fueling machines inside the secondary containment push the natural uranium *fuel bundles* into the core and remove the spent fuel bundles at the other side of the reactor. The coolant, instead of being contained in a primary pressure vessel as in the LWRs, flows through the core in horizontal pressure tubes surrounding the fuel channels of which there are typically 380-480 in a CANDU reactor.

The cylindrical fuel bundles that are pushed through the core in the fuel channels are about 10 cm in diameter and 50 cm long. They consist of a zircaloy package of about $30-40$ zircaloy fuel tubes that contain the fuel in pellet form. In an older model there were twelve of these fuel bundles lying end-to-end within each fuel channel. Light water coolant flows through high-pressure tubes surrounding the fuel channels and these high-pressure coolant tubes are in turn surrounded by a *calandria tube* containing a thermally-insulating flow of carbon dioxide gas. All of this tube assembly is contained in a much larger, low-pressure tank known as the *calandria* that contains most of the heavy water moderator. The carbon dioxide flow placed between the light water coolant and the heavy water moderator is needed to prevent the hot coolant from boiling the moderator. Note that a cooling system is also needed for the heavy water moderator; this moderator mass represents a heat sink that provides an additional safety feature.

As described in section 2.8.1, the heavy water moderator is needed with natural uranium fuel because the heavy water absorbs a lesser fraction of the neutrons and thus allows a sustainable chain reaction. However, a larger presence of heavy water moderator is needed to slow the neutrons down to thermal energies (because the heavier deuterium molecule needs more collisions to slow down the neutrons) and therefore the CANDU reactor requires a larger thickness of moderator between the fuel bundles. This means a proportionately larger reactor core.

One of the disadvantages of the CANDU reactor is that it has a positive void coefficient (see section 7.1.2). In other words, steam formed by coolant boiling would cause an increase in the reactivity that, in turn, would generate more steam. However, the much larger and much cooler mass of moderator in the calandria would mitigate any potential disassembly. Other features of the design that improve the margin of safety include the basic fact that natural uranium fuel is not critical in the light water coolant and the fact that any distortion of the fuel bundles tends to reduce the reactivity. The CANDU reactor also contains a number of active and passive safety features. As well as the normal control rods, shut-off emergency control rods are held above the core by electromagnets and drop into the core if needed. Another high pressure safety system injects a neutron absorber into the calandria in the event of an emergency.