2.4.2 Decay in a nuclear reactor

In the unnatural environment of a nuclear reactor, the high neutron flux causes the formation of a number of unstable isotopes. These decay to other unstable isotopes and the chain thus followed can be long and complex before finally coming to an end with the formation of stable elements and isotopes. A full catalog of these decay chains is beyond the scope of this book but several important examples should be given.

First note that the decay of ^{235}U (half life 4.47×10^9 years) results in ^{231}Th which, after 25.5 hours, emits radiation and becomes ^{231}Pa. This decays with a half life of 3.28×10^4 years to ^{227}Ac and the chain continues with many intermediate stages eventually resulting in the stable lead isotope, ^{207}Pb. Many of these intermediate stages involve the series of elements with atomic numbers from 89 to 103 that are known as *actinides*. They feature prominently in the decay of a nuclear reactor and in the processing of the reactor waste.

One of the most important isotopes produced in a nuclear reactor is the unstable element plutonium, ^{239}Pu, formed when a ^{238}U atom absorbs a neutron. Plutonium does not occur in nature because it has a relatively short half life (2.44×10^4 years). Because of this short half life it is highly radioactive, decaying back to ^{235}U that then decays as described above.

This process of decay has a number of important consequences. First, the thermal energy generated by the decay adds to the heat generated within a nuclear reactor. Thus, although the primary source of heat is the energy transmitted to the molecules of the core as a result of nuclear fission and neutron flux, the additional heat generated by decay is an important secondary contribution. This heat source is referred to as *decay heat*.

However there is an important additional consequence for although the primary fission contribution vanishes when the reactor is shut down (when the control rods are inserted) and the neutron flux subsides, the radioactive decay continues to generate heat for some substantial time following shutdown. The decrease in heat generation occurs quite rapidly after shutdown; thus the reactor heat production decreases to 6.5% after one second, 3.3% after one minute, 1.4% after one hour, 0.55% after one day, and 0.023% after one year. Though these numbers may seem small they represent a substantial degree of heating and coolant must be circulated through the core to prevent excessive heating that might even result in core meltdown. The production of decay heat also means that fuel rods removed from the core must be placed in a cooled environment (usually a water tank) for some time in order to avoid overheating.