2.4.1 Half-Life

A fundamental process that effects the behavior of a nuclear reactor and the treatment of its waste is the radioactive decay of the atomic constituents of the fuel, the fuel by-products and the containment structures. All the heavier, naturally-occurring elements of the earth and other planets were formed by fusion in the enormous thermonuclear furnace that eventually resulted in the formation of our planet and, indeed, are part of any cataclysmic astronomical event like a supernova. Only such an event could have produced the incredible temperatures (of order 10^9 $^\circ C$ that are required for such fusion. Many of the heavier elements and isotopes formed in that event are unstable in the sense that they decay over time, fissioning into lighter elements and, at the same time, releasing radiation and/or neutrons. This release leads directly to the generation of heat through collisions (or interactions with the surrounding material) in which the kinetic energy associated with the radiation/neutrons is converted to thermal motions of the molecules of the surrounding material.

However the rates at which these heavier elements decay differ greatly from element to element and from isotope to isotope. The rate of decay is quoted in terms of a half-life, τ, namely the length of time required for one half of the material to be transformed and one half to remain in its original state. Note that $\tau = 0.693/\xi$ where ξ is known as the radioactive decay constant. It describes the rate of decay of the number of original nuclei of a particular isotope, $N(t)$, according to

$$-\frac{dN(t)}{dt} = \xi N(t) \tag{1}$$

Isotopes with extremely long half lives, like ^{238}U (whose half life is 4.47×10^9 years), are therefore almost stable and, in a given period of time, exhibit very few (if any) fission events and consequently generate very little thermal energy. Rare elements with short half lives like ^{107}Pd may have existed at one time but have now disappeared from the earth. In between are isotopes like ^{235}U (half life like 7.04×10^8 years) that are now much rarer than their longer-lived cousins, in this case ^{238}U.