2.5 Radiation

Aside from the emission of neutrons (that may be referred to as *neutron radiation*), nuclear fission and radioactive decay also result in the emission of various additional forms of radiation:

- Alpha radiation is the emission of two protons and two neutrons, an *alpha particle* being identical in composition to a nucleus of helium. It is emitted, for example, in the decay of ^{235}U to ^{231}Th.
- Beta radiation is the emission of small charged particles, namely electrons and other similarly small particles. It is emitted, for example, in the decay of ^{239}Np to ^{239}Pu.
- Gamma radiation is the emission of short wavelength electromagnetic radiation in the form of photons. It is emitted, for example, during fission or radiative capture in ^{235}U.

Since all of the above radiation emissions are associated with the decay of an isotope, a measure of radioactivity is the number of disintegrations per second, given by $\lambda N(t)$. One disintegration per second is known as *one becquerel* ($1\ Bq$) and is related to the more traditional unit of a *curie* (Ci) by $1\ Ci = 3.7\times 10^{10}\ Bq$. Comment on typical magnitudes of radioactivity is appropriate here. Room air has a typical radioactivity of $10^{-12}\ Ci/l$ or about $10^{-8}\ Ci/kg$. Typical radiation treatments for cancer range up to about $10^4\ Ci$ and the activity in the core of a typical thermal reactor just after it has been shut down is about $1.5\times 10^9\ Ci$.

Though they are beyond the scope of this text, the effects of radiation on materials (see, for example, Foster and Wright 1977, Cameron 1982) or on biological tissue (see, for example, Lewis 1977, Murray 1993) are clearly important and therefore it is useful to establish some measures of the changes in a material or tissue brought about by exposure to radiation. These measures will clearly be a function not only of the strength and type of radiation but also of the nature of the material (or tissue) exposed to that radiation. A number of such measures are used:

- One *roentgen* (R), a traditional unit for x-rays and gamma radiation, is defined in terms of the ionization produced in air and is equivalent to the deposition in air of $87\ ergs/g$.
- To address the fact that the absorption of radiation in biological tissue differs from the ionization in air, the *rad* (rad) was introduced as a measure of the radiation energy absorbed per unit mass ($1\ rad = 100\ ergs/g$). One *gray* (Gr) is $100\ rads$ and $1\ Gr = 1\ J/kg$.
- To address the fact that the damage done depends on the type of radiation, the *roentgen-equivalent-man* (or *rem* for short) was introduced and defined to be the dose (energy) of $250\ keV$ x-rays that would produce the same damage or effect as the dose (energy) of the radiation being measured.

Thus 1 *rem* is the equivalent dose of 250 keV x-rays that would produce the same effect as 1 *rad* of the radiation being measured. Similarly one *sievert* (Sv) is equivalent to 1 Gr.

- The ratio of the number of *rems* to the number of *rads* is called the *quality factor* . Clearly then x-rays (and gamma radiation) have a quality factor of unity. In comparison, the quality factor for alpha radiation and fission fragments is 20 while that for neutrons varies from 5 to 20 depending on the neutron energy.

The biological effects of radiation are beyond the scope of this text (see, for example, Lewis 1977 or Murray 1993). It is sufficient for present purposes to observe that the potential damage that might be caused by the nuclear fuel before, during and after use in a nuclear reactor requires that the fuel (and other components of a reactor that may have been irradiated within the core and its immediate surroundings) be confined within a secure containment system for as long as the destructive levels of that radiation continue. Such assurance is only achieved by a system that is necessarily comprised of multiple systems and multiple levels of containment.