ACTIVITY

OBJECTIVES

At the conclusion of this course the trainee will be able to:

1. Define the units of activity, the Becquerel, and the Curie.

2. Define the half-life and discuss activity in terms of half lives.

3. State the activity relationship $A_t = A_o(\frac{1}{2})^n$ and solve simple activity and half-life calculations.

ACTIVITY

The activity of a radioactive material is measured in terms of the number of nuclei which decay per unit of time. This can be expressed in a number of ways. The simplest is perhaps to express it as "disintegrations per second" or dps. In the SI system this unit is called the becquerel (Bq). The becquerel *is defined as being one radioactive disintegration (decay) per* second. Another unit, widely used, is the curie. One curie is equal to 3.7×10^{10} Bq, which is the activity of 1 g of radium-226.

The Law of Radioactive Decay

A pure radioactive substance decays at a fixed fractional rate, i.e., in each second a constant fraction of the total amount present decays. Thus we can see that the activity, the actual number of atoms decaying per unit time, is proportional to the amount of the substance.

If we consider a particular sample of a radio-nuclide, the continual decay will diminish the quantity of the sample and so the activity will also diminish. This process will continue until the radiactive material is gone. Figure 4.1 is a plot of the quantity of the sample Q against time.

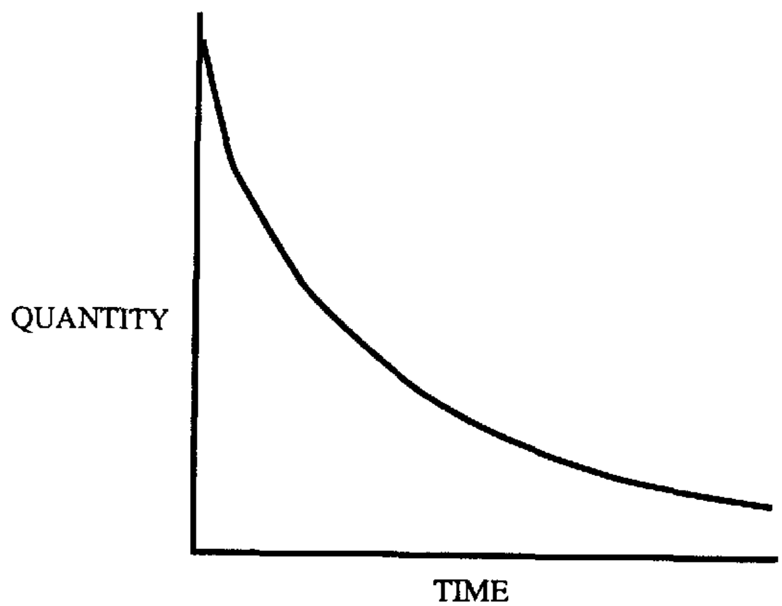

Figure 4.1: Quantity v Time for a Radionuclide

We have already seen that the activity is proportional to the quantity of the radioactive substance so we can also plot the activity A against time (Figure 4.2).

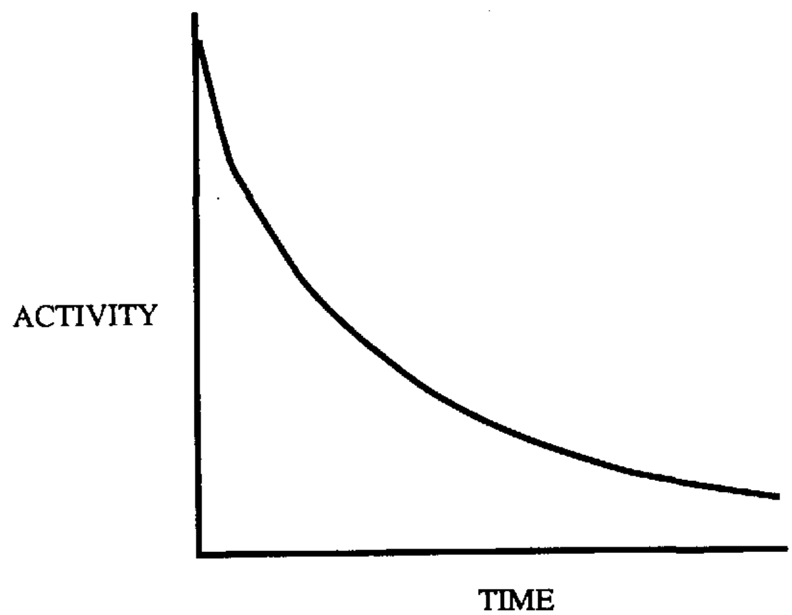

Figure 4.2: Activity v Time for a Radionuclide

These two graphs (Figures 4.1 and 4.2) are mathematically identical and only differ in that they have different vertical scales. In practice we prefer to use the second form because activity is the quantity usually measured and indeed activity is what we are most often interested in. By contrast we seldom can measure, and often don't care about the actual quantity of the radioactive substance. For example the activity of the moderator, quoted in curies per kilogram, is very important information but tells us nothing directly about the number of tritium atoms in the moderator.

Half-life

If we plot graphs of activity vs time (Figure 4.3) for different radioactive materials we find that they have different rates of change. To distinguish between the different rates we use the concept of the half-life (Figure 4.4). The half-life ($T_{\frac{1}{2}}$) is the time interval that it takes for the activity of a specimen to fall to half of its original value, i.e., the time interval between activity Ao and activity $\frac{A_o}{2}$. For an exponential decay curve (which these are) it does not matter where we start with Ao. For any starting point on the curve the time to $\frac{A_o}{2}$ will be the same (Figure 4.4).

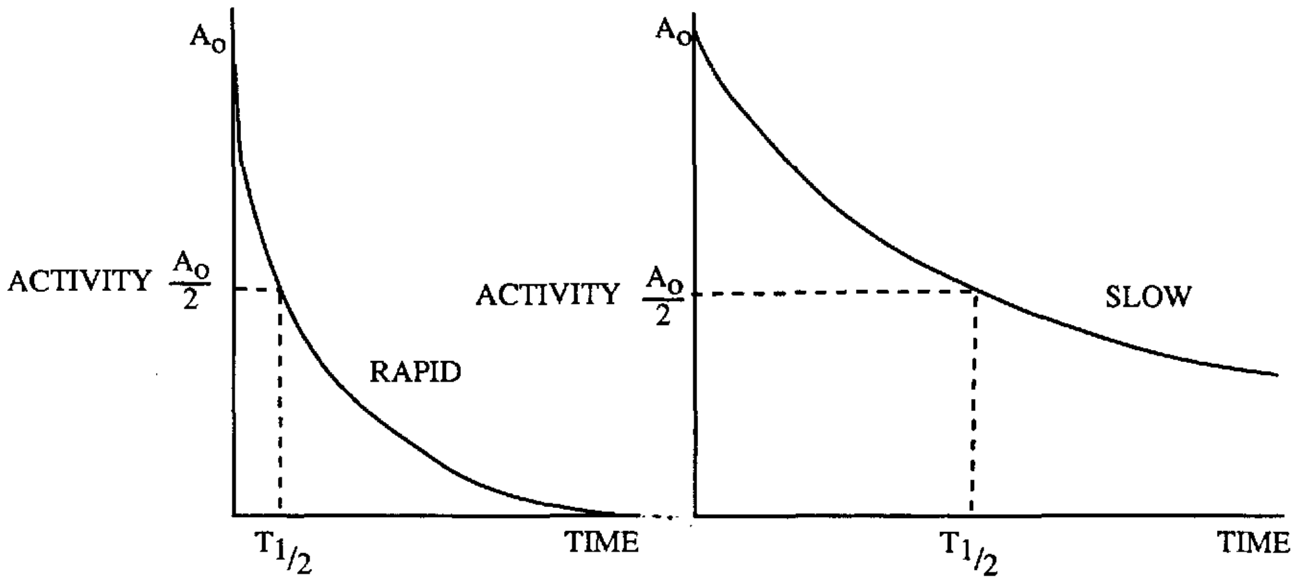

Figure 4.3 a&b:
Activity Plots for Two Different Radioactive Materials

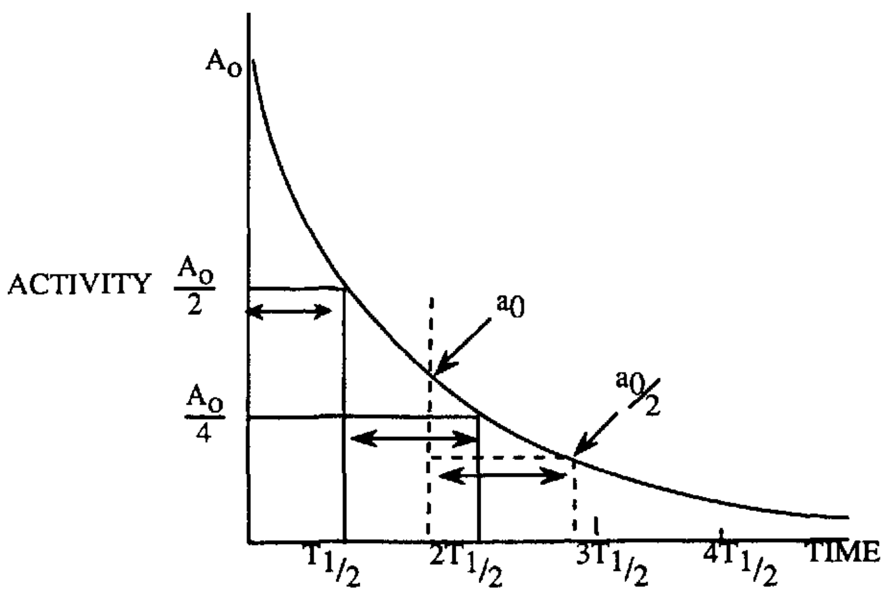

Figure 4.4: Activity and Half-life

The time from Ao to $\frac{Ao}{2}$ is the same as from $\frac{Ao}{2}$ to $\frac{Ao}{4}$. It also takes the same time from ao to $\frac{ao}{2}$. This leads to the formula

$A_t = Ao\ (\frac{1}{2})^n$ where n is the number of half lives,

i.e., $n = t/T_{\frac{1}{2}}$

In this relationship we usually take n to be an integer but it need not be.

Another form of the equation is

$$\frac{Ao}{A_t} = 2^n$$

Before reviewing the following examples try the end-of-chapter exercises. Many people find these calculations easier to do then to read about.

Examples

1. Suppose a radioactive substance has an activity of 6144 Bq (this is a high figure). How many half-lives will it take for the activity to fall to 6 Bq?

$$\frac{Ao}{At} = 2^n$$

$$\frac{6144}{6} = 2^n$$

$$1024 = 2^n$$

$$\therefore \quad n = 10$$

Answer

It will take 10 half-lives for the activity to fall from 6144 to 6 Bq.

2. What will the activity be 6 half-lives later for a radioactive substance which has an activity now of 192 Bq?

$$A_t = Ao\ (\tfrac{1}{2})^n$$

$$= 192\ (\tfrac{1}{2})^6 \text{ i.e. } (192 \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2})$$

or $$= \frac{192}{2^6} = \frac{192}{64}$$

$$= 3 \text{ Bq}$$

Answer

After 6 half-lives an original activity of 192 Bq falls to 3 Bq.

3. If the half-life in example 1. is 25 minutes what would be the time t?

$t = nT_{\frac{1}{2}}$

$= 10$ half-lives x 25 minutes per half-life

$= 250$ m

$= 4h\ 10\ m$

Range of Half-lives

Half-lives vary from very short (fractions of a second) to very long (billions of years). From an operational point of view these values are important in comparison to reactor life, operational times, outage times, fuel life, etc.

For example, fresh CANDU fuel is made with natural uranium. The half-life of U-238 is 4.5 billion years and for U-235 is 700 million years. Although both of these are decaying by α emission we never notice any change in their activity over the lifetime of the reactor. Thus we can say that fresh fuel will be the same no matter how long we keep it. By contrast, the half-life of N-16 (produced by activation in the reactor core) in only 7s and the activity changes faster than most of us can calculate.

In fuel that has been irradiated there are isotopes of uranium and neptunium that decay to make fissile plutonium. The beta decays of U-239 and Np-239 have half-lives of 23m and 2.3d respectively. Thus they convert into the fissile Pu-239 on a quite short time scale. The Pu-239 decays by α decay with a half-life of 25 thousand years so its quantity does not change due to α decay in the 1 to 2 years the fuel is in the reactor.

ASSIGNMENT

1. What is the relationship between disintegrations per second and the becquerel?

2. What is the usual way we express the characteristic rate of decay of a radionuclide?

3. Fe59 has a half-life of 45 days. If a sample has an activity of 1000 dps what will its activity be after one year.

4. The activity of a radioactive specimen is 2×10^7 DPS. After 20 days the activity is 2×10^4 dps. What is the half-life of this specimen? (Calculate to the nearest whole number of half-lives.)