More than 3000 nuclides are known, of which approximately 2700 are radioactive, and the rest are stable. The majority of radionuclides are artificially produced in the cyclotron and reactor. Some short-lived radionuclides are available from the so-called radionuclide generators in which long-lived parents are loaded and decay to short-lived daughters. The following is a brief description of the sources of different radionuclides.

Cyclotron-Produced Radionuclides

In a cyclotron (Fig. 5.1), charged particles (S) such as protons, deuterons, $\alpha$-particles, $^3$He-particles, and so forth are accelerated in circular paths within the dees (A and B) under vacuum by means of an electromagnetic field. These accelerated particles can possess a few kiloelectron volts (keV) to several billion electron volts (BeV) of kinetic energy depending on the design of the cyclotron. Because charged particles move along the circular paths under the magnetic field with gradually increasing energy, the larger the radius of the particle trajectory, the higher the kinetic energy of the particle. The charged particles are deflected by a deflector (D) through a window (W) outside the cyclotron to form an external beam.

When targets of stable elements are irradiated by placing them in the external beam of the accelerated particles or in the internal beam at a given radius inside a cyclotron, the accelerated particles interact with the target nuclei, and nuclear reactions take place. In a nuclear reaction, the incident particle may leave the nucleus after interaction with a nucleon, leaving some of its energy in it, or it may be completely absorbed by the nucleus, depending on the energy of the incident particle. In either case, a nucleus with excitation energy is formed and the excitation energy is disposed of by the emission of nucleons (i.e., protons and neutrons). Particle emission is followed by $\gamma$-ray emission when the former is no longer energetically feasible. Depending on the energy deposited by the incident particle, several nucleons are emitted randomly from the irradiated target nucleus,
leading to the formation of different nuclides. As the energy of the irradiating particle is increased, more nucleons are emitted, and therefore a much wider variety of nuclides is produced.

Medical cyclotrons are compact cyclotrons that are used to produce routinely short-lived radionuclides, particularly those used in positron emission tomography. In these cyclotrons, protons, deuterons, and \( \alpha \)-particles of low-to-medium energy are available. These units are available commercially and can be installed in a relatively small space.

An example of a typical cyclotron-produced radionuclide is \(^{111}\text{In}\), which is produced by irradiating \(^{111}\text{Cd}\) with 12-MeV protons in a cyclotron. The nuclear reaction is written as follows:

\[
^{111}\text{Cd}(p, n)^{111}\text{In}
\]

where \(^{111}\text{Cd}\) is the target nuclide, the proton \( p \) is the irradiating particle, the neutron \( n \) is the emitted particle, and \(^{111}\text{In}\) is the product radionuclide. In this case, a second nucleon may not be emitted, because there is not enough energy left after the emission of the first neutron. The excitation energy that is not sufficient to emit any more nucleons will be dissipated by \( \gamma \)-ray emission.

As can be understood, radionuclides produced with atomic numbers different from those of the target isotopes do not contain any stable (“cold,” or “carrier”) isotope detectable by ordinary analytical methods, and such preparations are called carrier-free. In practice, however, it is impossible to have these preparations without the presence of any stable isotopes. Another term for these preparations is no-carrier-added (NCA), meaning that no stable isotope has been added purposely to the preparations.

The target material for irradiation must be pure and preferably monoisotopic or at least enriched isotopically to avoid the production of extraneous radionuclides. Because various isotopes of different elements may be produced in a target, it is necessary to isolate isotopes of a single element; this can be accomplished by appropriate chemical methods such as solvent extraction, precipitation, ion exchange, and distillation. Cyclotron-produced...