phosphorus-32 and sulfur-35 are used, and in special cases, such as in vitamin B-12, cobalt-60 or cobalt-58 is the tracer atom. Tracers are also used for production and process development in the pharmaceutical industry. In process design, for example, tracers are used to study mixing efficiency, residence time in reactors, flow rates and patterns in columns, and towers for chromatography, absorption, racemization, etc. One firm reported that its process for a vitamin B-12 product could not have been properly designed without the engineering information obtained from tracer studies with the cobalt-60 labeled vitamin.

In the petroleum industry one of the most useful tracer applications of radioisotopes has been in the study of catalytic cracking operations (Figure 1). Catalyst beads are tagged with some suitable gamma emitter, such as cobalt-60 or zirconium—niobium-90, and inserted into the fluidized bed. It is possible with this technique to determine the distribution of particles within the chamber, the residence time, and the effects of chamber geometry on the results of the cracking operation. Corresponding information can be obtained for the gas stream through insertion of radioxenon. The importance of this work in controlling cracking operations cannot be overestimated since the process involves the production of billions of dollars worth of petroleum products.

Tracer techniques have proved valuable in connection with consumer as well as industrial products. For example, one study using carbon-14-labeled acetic acid investigated the penetration of vinegar into polyvinyl chloride bottles. It was found that 0.5% of the acetic acid in the vinegar diffused into the wall of the container bottle in a month; this would have been nearly impossible to measure by any other method. These results were useful in developing and evaluating the process for fabricating the bottles.

Another analytical technique involving radioisotope tracers is neutron activation analysis. The sample to be analyzed is exposed to a flux of neutrons produced by a nuclear reactor, isotope source, or particle accelerator, and certain elements in the sample are radioactivated. The gamma radiation emitted by the neutron-activated sample is analyzed to determine the energy of the gamma rays and the intensity and rate of decay of the radiation. (Figure 2.) Since each radioisotope has a characteristic half-life and set of gamma-ray energies, the identity and amount of the neutron-activated radioisotopes can be determined by