to use mathematical models in addressing the complexity and dynamics of ecosystems. By the end of the 1960s, ecosystem modeling based on radiotracer techniques was recognized as useful in addressing the Nation's environmental pollution problems.

Benefits The analysis of food chains with radiotracers confirms the importance of food in passing radionuclides to humans. Consequently, calculations and estimations of the radiological dose to humans must take into account the behavior of radioisotopes in food chains. These data are critical because the standards for the release of radioisotopes to the environment have become more stringent. In contrast to the early days of nuclear energy when estimates of release were based on limited laboratory data, detailed quantitative information can now be provided on the rates of accumulation and residence times of radionuclides in a variety of organisms. This ability has proven extremely important in the preparation of environmental assessments of proposed nuclear facilities and has enabled radiation protection specialists to derive dose estimates.

Dynamics of Biological Systems Carbon-14, which omits beta particles with a half-life of 5770 years, with slight toxicity, and hydrogen-3 (tritium), another beta emitter with a half-life of 12 years, are the two most widely used radioactive tracers in biomedical research. Ninety-five percent of the biomedical research reported in leading journals involves the use of these tracers. Research in biochemistry, physiology, and pharmacology relies on the continued use of these tracers.

Carbon-14 is the most popular isotope because of its favorable combination of properties. It emits beta particles strong enough to measure—but weak enough to make shielding unnecessary—and to give good definition in radiographs. Its long half-life makes it unnecessary to correct measurements for decay; and it is available in adequate quantities, with suitable levels of radioactivity, and at low cost. Its toxicity is relatively slight and is not a problem in most applications. Tritium has been used mainly as an auxiliary tracer for carbon rather than as a hydrogen tracer; its shorter half-life offers some advantages. Isotopes of other elements, such as hydrogen, nitrogen, oxygen, sulphur, and phosphorus, are of secondary interest but are valuable for certain uses.

History On June 14, 1946, in the journal *Science*, an announcement was made by Manhattan Project Headquarters, Washington, D.C., that:

> *Production of tracer and therapeutic radioisotopes has been heralded as one of the great peacetime contributions of the uranium chain reacting pile. The use of the pile will unquestionably be rich in scientific, medical and technological applications.*

On August 2, 1946, the first shipment of reactor-produced radioisotopes left ORNL. The compound containing carbon-14 was sent to the Bernard Free Skin and Cancer Hospital in St. Louis. This signaled the beginning of widely available isotopes at reasonable costs for persons trained in their use. By 1962 ORNL had made over half a million shipments of radioisotopes. On July 31, 1964, there were 1085 physicians in the United States licensed to use radioisotopes in private practice and some 1201 medical institutions licensed to handle radioisotopes.

Benefits The use of carbon-14 in biochemical analysis is widespread.

1. Carbon-14 glucose has replaced the classic glucose tolerance test in measuring the absorption of glucose. Molecules "labeled" with carbon-14 are structurally identical to the nonlabeled molecules and behave exactly the same.
2. Carbon-14-labeled compounds have simplified the study of metabolic diseases in man because only the amount of carbon dioxide labeled with carbon-14 ($^{14}CO_2$) in expiratory air needs to be measured. This method is easily applied using carbon-14-labeled tripalmitate or trioleate to diagnose the malabsorption of fat. Problems associated with radiochemical purity are avoided when carbon-14 compounds are used.

One of the most important advances in medical diagnosis was made with the introduction of tissue biopsies, providing information that formerly could be obtained only at a postmortem examination. Usual chemical methods cannot be used because of the small amount of tissue involved. Use of carbon-14 provides a sensitive, specific, and technically easy measurement of biological reactions in these isolated tissues, by measuring $^{14}CO_2$ liberated when tissues are incubated on surfaces containing carbon-14.

Carbon-14 is used mainly for in vitro, or test tube, studies of cells incubated on various carbon-14-labeled surfaces. One development at the Johns Hopkins University Hospital has been for rapid detection of bacterial contamination in various biological specimens. For example, blood or tissue suspected of harboring bacteria is placed in a reaction vessel in contact with an appropriate carbon-14-labeled material. The appearance of $^{14}CO_2$ in the gas above the reaction vessel will indicate the presence of bacteria more quickly than routine bacteriological techniques.

Other advantages of carbon-14 and tritium are the long shelf-life of radioactive-labeled compounds; availability in relatively pure forms; the ease of attaching radioactive atoms to proteins; and broad applications in the production of complex molecules with living organisms, drug metabolism, cytology, and enzyme assays.

Plant Metabolism A complete mapping of the metabolic pathways of carbon in the photosynthesis process from the initial fixation of carbon dioxide from the atmosphere to the production of glucose by green plants was developed by Dr. Melvin Calvin and