tagged with the radioisotopes, these organic compounds become known as radiopharmaceuticals. Each is designed to seek out a unique area or bodily function. They are typically introduced into the human body intravenously and carried along in the bloodstream to that area or organ requiring observation.

Radioisotopes are inherently unstable and give off unique and detectable signals (energetic particles) as they transform themselves into more stable and non-radioactive forms. For the radioisotopes used in PET, all undergo the same type of transformation. They emit positively charged particles, called positrons. Important to PET, a positron tends to annihilate itself in the presence of a nearby electron. This final destructive event broadcasts two oppositely-traveling gamma rays, which can be observed by PET outside the body.

In this way, the location, concentration, and rate of disappearance of tagged, metabolizing sugars, for example, can be quantitatively observed. Positrons combine with electrons from nearby molecules in surrounding tissue, releasing gamma rays. These are precisely recorded and counted by a large ring of detectors in the PET instrument. The signals are processed by a computer to reveal a high resolution picture of the phenomena.

The short life of the radioisotopes used to tag the sugars and other carriers means that the associated radioactivity is brief and relatively harmless to the patient. Typically for these radioisotopes, half their number disappear within minutes. This also means, however, that they must be created, chemically combined with other elements into small molecules, attached to carriers, purified, and made ready for injection into the patient, all within the brief period of time before their usefulness disappears.

For all these steps to take place quickly, two scientific advances were necessary. The first was a practical means for locally producing the short-lived positron-emitting radioisotopes. The second was a detailed set of procedures, or chemist's protocol, for creating the small molecules to be attached to the larger organic structures of the carriers. Both successes stemmed from Basic Energy Sciences research.

Concerning the first advance, positron-emitting radioisotopes are atoms that are short-lived and unstable because they have too many positively charged nuclear particles, called protons, relative to the number of neutral particles, called neutrons. Although the process for creating them is indirect, it usually involves bombarding ordinary atoms with protons in order to create this imbalance. This is accomplished by accelerating protons in special laboratory machines known as a cyclotrons.

Before the invention of the compact cyclotron, these machines were typically large and expensive. They were operated by scientists and housed in special research facilities. These requirements were not easily accommodated by the physical, technical, and budgetary constraints of most hospitals.

Using the larger machines, Basic Energy Sciences researchers derived the data on radioisotope production rates under a variety of conditions. These data made practical highly accurate predictions of production rates, which led to optimum methods for maximizing production yields. These data and methods, in turn, laid the foundation for the subsequent development of the smaller, less costly, compact cyclotrons more suitable for use by hospitals.

Concerning the second advance, the process of creating radioisotopes in this way gave rise to a number of unique conditions under which the chemical reactions in the next step of the overall process would have to take place. Specifically, the energy and momentum of the incoming proton was imparted to the new atom, causing it to "recoil," either from the initial collision or from the spontaneous ejection of one or more other nuclear particles. The high energy of the recoiling atom, referred to as a "hot atom," can lead to unusual chemical interactions with other atoms, especially those with which the hot atom collides in the process of slowing down.

Basic Energy Sciences researchers focused on understanding and characterizing the chemistry of these "hot atoms" and their interactions. Gradually, an extensive base of knowledge was established. This was important to predicting how the newly formed radioisotopes would react chemically immediately after being created.

Ultimately, this knowledge led to the development of precisely controlled procedures for producing small, labeled "building block" molecules, known as intermediates, such as carbon dioxide