connected vortices form closed loops—little plasma tori. And the turbulent plasma flow in the general pinch region generates the conditions to maintain these vortex tori as stable structures.

These tori are apparently the dense plasma nodules from which intense electron and ion beams—and neutron bursts due to thermonuclear fusion reactions—are seen to emerge. They apparently have the highest energy densities.

It is these dense plasma nodules that appear to be responsible for the enhanced rates of thermonuclear fusion reactions in plasma foci, when these devices are scaled to larger sizes, and the efficient rates of heavy ion fusion needed to generate the short-lived radioisotopes required for positron emission tomography (PET).

Application of the plasma focus to PET

The radioisotopes utilized for PET have half-lives measured in minutes—that is, half of any given quantity of the material disintegrates every few minutes. Therefore, these isotopes must be generated through nuclear reactions shortly before they are utilized. The existing method is to deploy a small, high-energy particle accelerator called the cyclotron. The cyclotron high-energy hydrogen ion beam, which reaches energies of millions of volts, is directed onto a solid target. The beam generates nuclear reactions when it strikes the target, and, given the presence of the appropriate elements, the required radioisotopes are generated.

These radioisotopes are then chemically extracted from the solid target and transferred to a gaseous reaction vessel in which the desired chemical molecules are produced. The extraction process requires several hours of time, and so the initial production of the radioisotopes must be relatively large, because half of the material is disintegrating every few minutes.

The plasma focus is both much more compact and efficient than the cyclotron for the production of short-lived radioisotopes. The required cyclotron accelerator size presently costs on the order of $1 million. The required scale for the plasma focus would be about one order of magnitude less than this. This is because the plasma focus generates these radioisotopes much more efficiently and in a gaseous form that is directly ready for chemical processing into the required molecules—no solid target extraction is necessary.

Experiments at the Stevens Institute have shown that significant rates of the desired reactions can be obtained in the plasma focus. Mixtures of deuterium (the heavy isotope of hydrogen that contains one proton and one neutron) and carbon, and mixtures of deuterium and nitrogen have been tested as gas fills in the Plasma Focus. The reactions are, for the first:

deuterium + carbon-12 = neutron + nitrogen-13

The generated nitrogen-13 is a positron-emitting radioisotope of nitrogen with about a 10-minute half-life. The second case:

deuterium + nitrogen-14 = neutron + oxygen-15

Oxygen-15 is a positron-emitting radioisotope of oxygen with about a 2-minute half-life.

Less than 10% of the generated radioisotopes escape from the plasma focus pinch. This means that most of the generated material remains in the plasma focus in gaseous form once

Positron emission tomography (PET) scanner

The information obtained from x-ray imaging techniques only gives a static picture of body structures, usually according to their density differentials. But processes involving time-dependent chemical reactions and tissue compositions can provide far more information about how the body is functioning and can lead to early detection of disease. For example, most diseases involve distinct chemical changes in body metabolism and biochemistry. These chemical transformations occur long before macroscopic changes in body organs and their densities.

PET utilizes radioactively labeled compounds that are injected into the body in trace amounts to follow what is happening along various chosen biochemical pathways. The general use of such radioisotope tracers in the medical and biological sciences has a long history. But applying the techniques of computerized tomography permits us to actively map the distribution of these radionuclides and, therefore, obtain a spayial and temporal image of these biochemical processes in the body.

The radioisotopes used for PET must meet three requirements. First, they must have behaviors similar to chemical elements found in metabolic processes. Second, their radioactive emanations must be able to escape bo y and follow paths that can be predicted. Third, the radioisotopes must be short-lived—that is, they must have a short "half-life." This will mean that the intensity of the radioactive emission will be large enough to detect with very dilute levels of radioisotopes present, and the actual body exposures will be very low—hundreds of times less than with an x-ray CAT scan.

Radioisotopes which emit positrons—antimatter positive electrons—meet these requirements. When the positron is emitted, it travels only a microscopic distance before it is annihilated in an antimatter reaction with a normal electron. This antimatter-matter annihilation reaction generates two gamma-rays, each of which have a

the plasma cools down. In this way the output is ready for chemical processing within seconds, instead of hours, as is the case with the cyclotron.

Apparently, it is the closed plasma nodules in the final plasma pinch that are responsible for both efficient generation of the required nuclear reactions and the trapping of the product radioisotopes in the plasma pinch region. These nodules contain very intense electric fields which make them act like micro-accelerators to produce high-energy particle beams which then produce the required nuclear reactions. Furthermore, these nodules are held together with very intense magnetic fields—in some cases reaching intensities 100 million times that of the Earth's magnetic field. These strong magnetic fields entrap the radioisotope products and keep them within the plasma pinch so that they will be present in the Plasma Focus gas fill once the machine cools down following a shot.

To be continued.

precise energy of 511 kiloelectron volts and each of which is oppositely directed. Because of their short wavelength, gamma-rays can pass undisturbed through large quantities of matter—much more so than other, shorter-wavelength electromagnetic waves, such as x-rays.

In general, the best radioisotopes for PET are carbon-11, nitrogen-13, oxygen-15 and fluorine-18.

From the outside, the PET system looks much the same as the x-ray CAT scanner. Gamma-ray scintillators are arranged in rings; typically, there are about 100 detectors per ring, with up to five rings in the gantry. The coincidence detection between two detectors across from each other on the doughnut ring defines a line through the object being imaged, along which positron annihilation must have occurred.

Collecting millions of such coincidence counts along thousands of possible projection rays permits the reconstruction of the positron distribution—and therefore, the radioisotope distribution—through the use of back-projection techniques. The resolution of the image can be improved by placing the detectors closer together. Alternatively, determining where along the coincidence line positron annihilation took place can also improve resolution. Fast scintillator counters and "time-of-flight" measurements for the gamma-ray are being utilized along these lines.

Very small amounts of radioisotope tracer are required for PET. Carbon-11-labeled carbon monoxide is used to trace blood flow to detect motion abnormalities of the heart walls through measuring heart contractions. Fewer than 200 billion carbon monoxide molecules are required for this imaging—less than one-third of a picomole.

PET differs from other radiologic imaging techniques in that it gives a dynamic picture. And while this can be generally applied to all organs, the application of PET to dynamic brain imaging has made the greatest contributions to medical diagnostics. For example, a fluorinated analogue of glucose, 2-fluor-2-deoxyglucose (FDG), tagged with fluorine-18 positron emitter, can be injected into the bloodstream and pass through the blood-brain barrier. But since this compound cannot be metabolized by brain cells in the same manner as regular glucose, it therefore tends to accumulate within the brain cells in direct proportion to brain activity at a given time. If the visual cortex is active, the FDG accumulates in the visual areas.

After detecting and recording the PET scan, the computer computation converts this data into a colored biochemical motion picture of brain activity. And, while active PET scans are increasingly providing physicians with the means for early detection of brain tumors and with crucial measurements on disorders such as Alzheimer's disease and senile dementia, it is the application of PET to the normal brain that holds the greatest promise. For example, it is possible to observe patterns of glucose use while the subject is listening to a symphony or engaged in a variety of activities.

These measurements of "normal" brains with PET hold particular promise when combined with the rapidly developing technology of brain electrical activity mapping. Combining these two widely differing diagnostics has been likened by researchers to transforming a black and white snapshot into a color motion picture. The use of different radioisotope tracers for PET is like changing the filters on a camera—new and different pictures are obtained of the same process. At the present time, such diagnostic combinations are difficult to carry out in practice. One of the major technical roadblocks has been the computing time required for analyzing PET data. But with the recent development of cheap, real-time, large-scale computing capabilities by the Strategic Defense Initiative, this roadblock is ready to disappear.

PET is by no means limited to providing insights to biological and medical processes. In fact, many aspects of the living process have been shown to be anomalous when compared to similar, non-living chemical and physical processes. Some leading researchers believe that a combination of PET with other diagnostics on electrical and chemical brain activities, when applied to workings of nerve action in a human brain which is consciously engaged in creative activity, could provide crucial insights into fundamental questions of electrodynamics, the curvature of space-time, and the real basis for living processes.