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Plasma focus can transform medical diagnostics

Charles B. Stevens reports on a fusion device which is ready for near-term applications, although it contravenes all conventional scientific opinion. First of two parts.

While simple in design, modest in requirements, and prolific in output among the world's fusion research devices, the plasma focus has been relegated to the scientific basement and generally avoided like the plague by the big R&D laboratories and leading plasma science authorities. This unscientific anomie probably derives from the propensity of the plasma focus for generating anomalous results whose most regular feature is that they contravene conventional scientific opinion and wisdom. But despite this policy of scientific apartheid, the plasma focus has continued to progress experimentally in small research laboratories throughout the world and has now reached the point where it has demonstrated the capacity for many near-term technological applications, to such a degree that mere prejudice can no longer hold it back.

Among these near-term applications is that of utilizing the plasma focus to generate short-lived, radioisotopes for medical and biological diagnostics. In fact, the demonstrated capabilities of the plasma focus are such that it alone could reduce current costs for many medical diagnostics by as much as an order of magnitude. This would lower the cost sufficiently to permit the general proliferation of these procedures throughout all major health facilities. (Today, the most advanced radioisotope diagnostic capabilities are found only in a handful of large hospitals, and then, at great cost.)

A second, near-term application is to use the plasma focus for generating relativistic beams for destroying ballistic missiles and their thermonuclear warheads over ranges of thousands of miles. This Plasma Focus defense technology is currently being pursued by Soviet scientists in a crash program which, experts have determined, began about five years ago.

The third area of near-term application of the Plasma Focus is that of providing the test-bed for developing materials and engineering technology for thermonuclear fusion reactors.

This article and its sequel will review the general scientific background of the plasma focus and recent experimental developments. The first and third areas mentioned above will be explored in some detail, while the second area will only be touched upon.

With Part II, we will publish an interview with the world's leading pioneer in plasma focus research, Prof. Winston Bostick of the New Jersey Stevens Institute of Technology. Dr. Bostick has set up Plasma Focus research groups throughout the world, while his home-base group at the Stevens Institute has been a continuing leader in exploring its experimental frontiers. While fundamentally an experimentalist, Dr. Bostick has significantly contributed to the recent development of a coherent "unified" field theory based on insights garnered from the plasma hydroelectrodynamics of the plasma focus. Their "theoretical" advances promise to revolutionize every aspect of physical science and optical biophysics.

An energy-compressing transformer

What makes the plasma focus such an experimental powerhouse is the fact that it functions like an ideal energy compression and storage-transforming device with no moving parts—except possibly the plasma which it generates. Depending on its initial set-up mode, the plasma focus can efficiently generate intense high-energy clustered-ion and electron beams, microwaves, x-rays, and neutrons. More recently, it has shown that it can produce copious heavy ion

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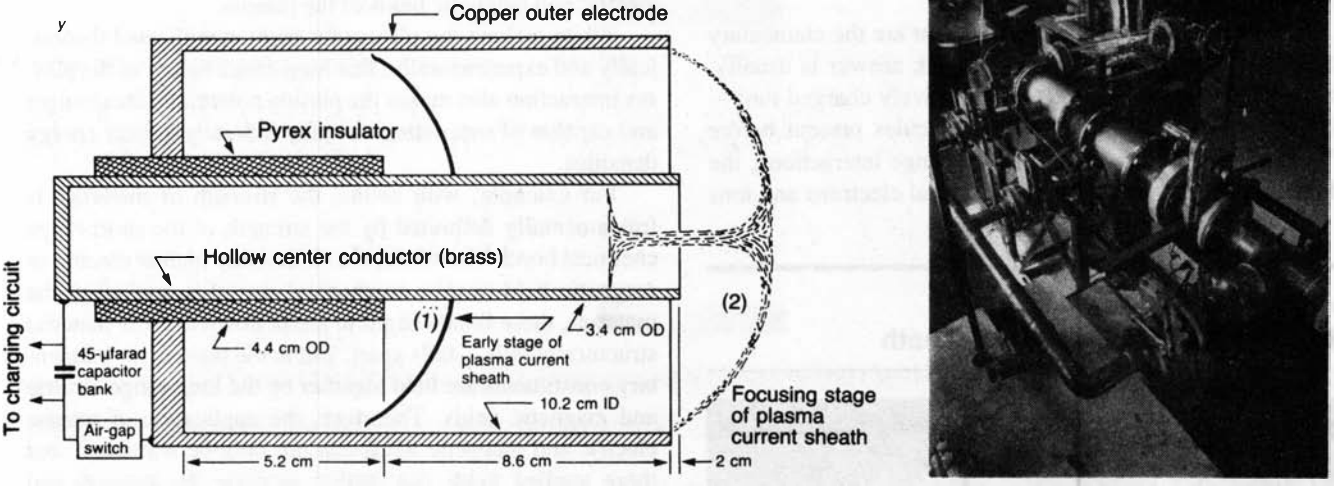
FIGURE 1
Schematic cross section of plasma focus



The plasma focus consists of two cylindrical electrodes, one placed inside the other. In the schematic, a cross section of the outer copper electrode and inner hollow center brass electrode are indicated. These two "coaxial" electrodes are separated by a Pyrex insulator. The entire assembly is placed within a vacuum chamber, which is not shown in the diagram. A current pulse is switched into the plasma focus from a capacitor bank. This leads to the formation of an annular plasma sheath near the Pyrex insulator end, which is marked (1) in the diagram and shown in cross section. This sheath accelerates down the length of the space between the electrodes—left to right in the diagram—and forms a plasma pinch at the right-hand, open end of the machine, which is marked (2) in the diagram. (Inset: the laboratory plasma focus at the Stevens Institute in New Jersey.)

Source: *International Journal of Fusion Energy*, Vol. 3, No. 1, January 1985.

fusion—a result which directly bears on its capacity for short-lived radioisotope production.

In general, the plasma focus's versatility and compactness derive from its ability to compress and transform energy. In terms of its basic operation, the laboratory plasma focus looks like a large radio tube. It consists of two electrodes, both shaped like hollow cylinders, with one placed inside the other, as shown in **Figure 1.**

The motive power for the device consists of a pulse of electrical current which is generated by a bank of capacitors. Capacitor banks provide an initial means of compressing energy. They can be charged up in series using a commercial power line input. Once brought up to full capacity, the bank can be discharged in a relatively short pulse through the use of fast-acting circuit switches which reconfigure the bank from a series connection to a connection in parallel. The resulting, compressed current pulse is simultaneously switched into one of the plasma focus electrodes.

The plasma focus vacuum chamber, in which the two cylindrical electrodes are located, is usually filled with a small quantity of hydrogen gas, though alternative materials such as oxygen, nitrogen, and carbon can be utilized.

Within the few billionths of second that the current pulse takes to arrive at the electrodes, a large electric field is generated between the electrodes. This field causes the fill gas to "break down." That is, free electrons in the gas are accelerated to high velocities, and they cause gas molecules to become ionized through collisions. Within a few billionths of a second, the gas is transformed into an ionized plasma. This takes place at the end of the plasma focus where the two electrodes are mechanically connected together with an intervening layer of insulator.

The plasma state

Plasma is sometimes referred to as a "fourth state of matter"—solid, liquid, and gas being the first three. Like the first three, plasmas are, generally, macroscopically electrically neutral. Plasmas sometimes act like a solid, sometimes like an incompressible fluid, and sometimes like a compressible gas. In fact, it is better to think of solids, liquids, and gases as being three special varieties of plasma.

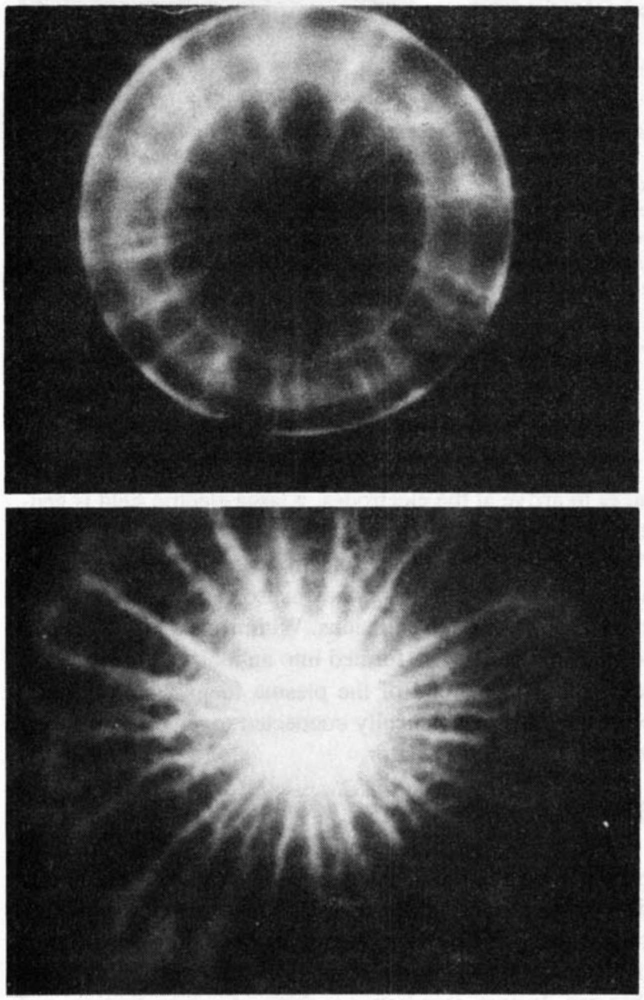
In general, the electrons and nuclei which make up atoms and molecules become separated in a plasma, i.e., ionized. In other words, the atoms and molecules which constitute the relatively electromagnetically insulated elementary constituents of a solid, liquid, or gas are broken up. With plasma, long-range electrodynamic forces predominate over the short-range chemical bonds and molecular interactions which characterize solids, liquids, and gases. And it is this long-range electrodynamic interaction which is the chief manifestation of the plasma state.

The question arises, therefore: What are the elementary constituents of a plasma? The textbook answer is usually: negatively charged electrons and positively charged ions—the fragments of the atoms and molecules present before "breakdown." But, because of long-range interactions, the dynamics and motion of these individual electrons and ions cannot be accounted for locally. In place of these "elementary constituents," we find that plasmas generate non-particle coherent structures: various types of waves, solitons, vortices, and circulation cells. In place of short-range chemical bonds and van der Walls molecular interactions, the plasma's fundamental constituents are held together by the long-range electric and magnetic fields of the plasma.

While making the plasma far more complicated theoretically and experimentally, this long-range nature of the plasma interaction also makes the plasma potentially far stronger and capable of supporting virtually infinitely greater energy densities.

For example, with solids, the strength of materials is fundamentally delimited by the strength of the short-range chemical bond. Therefore, if a sufficiently intense electric or magnetic field (and/or mechanical stress) is applied to the material, these bonds begin to break down and the material structurally fails—falls apart. But in the plasma, its elementary constituents are held together by the long-range electric and magnetic fields. Therefore, the application of intense electric and magnetic fields can not only be withstood, but these applied fields can further increase the strength and rigidity of the plasma structure. Because of this, plasmas are capable of sustaining virtually unlimited energy densities compared to what ordinary solids and liquids can sustain. And, as we will see with the plasma focus, if given sufficient freedom, plasmas will naturally configure themselves into such dynamically stable structures when an intense field is applied to them.

FIGURE 2
The plasma focus current sheath



Winston Bostick

The inner electrode is located at the circle at the center of the sheath. The outer electrode is located at the circumscribing circle. Barely visible in these photographs, as pairs of radial lines, are pairs of plasma vortex filaments which carry the electric current between the plasma focus electrodes.

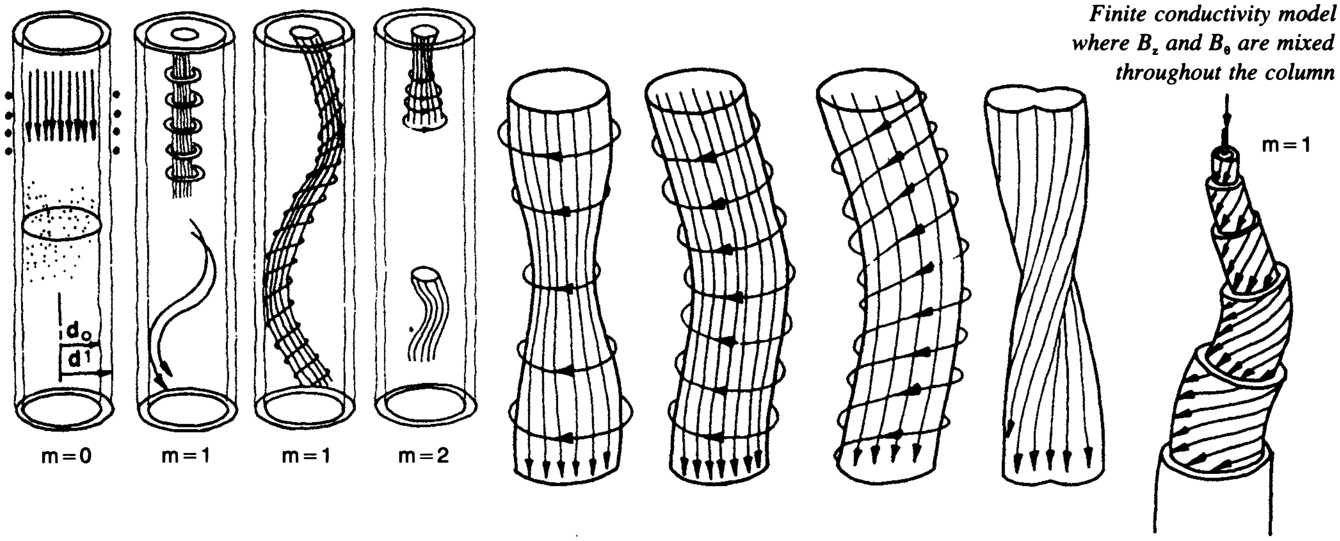
Computerized axial tomography: the CAT scanner

CAT scanners (computerized axial tomography scanners) have revolutionized medical diagnostic techniques. And it is useful to discuss how the CAT scanner works before describing the more advanced positron emission tomography (PET) technique.

Computerized tomography consists of generating an image of a slice—*tomos*, which means slice in Greek—of a three-dimensional object by combining a large number of scans through the object at different angles. For example, ordinary CAT scanners utilize a beam of x-rays to generate a number of scans which are combined to make a three-dimensional slice. Many of these slices can be put together to give a full three-dimensional reconstruction of an object like the brain.

FIGURE 3

Idealized diagram of electric current passing through a column of plasma



The initial conditions are shown in the upper left drawing marked m = 0. The electric current is represented by the arrows. The plasma gas is represented by dots. The azimuthal magnetic field generated by the passage of the electric current is represented by a circle, though such circles extend along the full length of the column. The pinch effect is shown in the next drawing to the right. The azimuthal magnetic field has compressed the plasma column. As indicated in the remaining diagrams, this initial configuration is unstable and the plasma column will undergo magnetohydrodynamic motions to reconfigure itself into a Beltrami configuration shown in the last, lower left drawing.

Source: *International Journal of Fusion Energy,* Vol. 3, No. 1, January 1985.

In contrast, ordinary x-ray exposures have many limitations. They do not provide a three-dimensional image, nor do they distinguish between two body structures that have the same density. The CAT scanner overcomes these limitations through combining directed x-ray beams with computer analysis.

For example, in a CAT scan of the brain, a patient's head is inserted into the "hole" of a special doughnut-shaped scanner. An x-ray beam generating tube rotates along a circular path within the doughnut, always pointing at the patient's head. These x-ray beams pass through the head. The brain tissue absorbs x-rays in proportion to the density of the various brain components that the beam passes through. (White brain matter differs from gray matter, and normal brain tissue has different densities from diseased brain tissue.)

The intensity of the x-ray beam that is not absorbed is recorded by sensitive crystal detectors, or what are termed scintillators, that convert incident x-rays into electronic signals. A computer is then used to carry out elaborate calculations based on the known input intensity and measured output intensity of the x-rays that pass through the brain and the angles at which the x-ray beams pass through the brain. These calculations permit a three-dimensional reconstruction of a slice of the brain.

In general, the way this works can be seen by examining an elongated rectangle, which will represent a side view of the brain slice. An x-ray beam passing through the rectangle along a path parallel to a diagonal goes through more brain material than one going along a path parallel to the rectangle's side. If the density is uniform, more x-rays will be absorbed along the diagonal path. Now, if we place irregularly shaped blobs in the rectangle to represent regions of higher density, we see that when the diagonal path and the side-parallel path both pass through such a blob, they do not usually have the same path lengths. The longer the path through denser materials, the more x-rays will be absorbed and the weaker the beam. By combining many such "cuts" at different angles, it is possible to reconstruct the outlines of the regions of higher and lower density. This principle is simply extended to three dimensions by rotating the rectangle—i.e., rotating the x-ray beam generator in the doughnut.

Positron emission tomography (PET) works on the basis of the same principles. But in this case not only is the brain structure pictured, but the brain activity, too.

Beating the Alfven limit

Returning to the description of plasma focus operation, we left off where the current pulse from the capacitors generates an intense electric field between the two cylindrical electrodes and the gas fill breaks down and forms a plasma at the insulator end of the focus. This breakdown plasma has a high electrical conductivity and therefore permits the flow of electric current between the electrodes—the current is driven by the electric field. In fact, an annular sheet of conducting plasma rapidly forms between the electrodes (**Figure 2**).

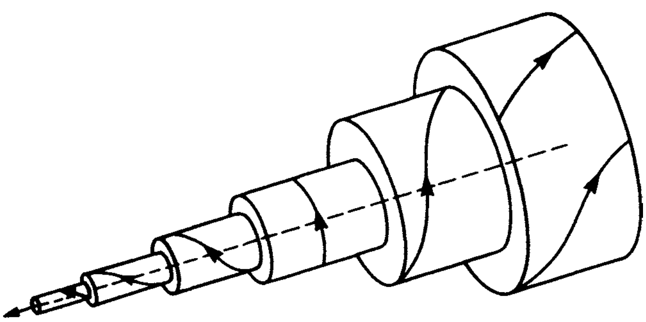
For comprehending how the plasma focus compresses, stores, and transforms the energy input, it is essential to examine the fine, microscopic plasma structures that are formed by this annular plasma sheath. But to give an immediate overview, what happens is as follows. The current flowing through the plasma current sheath interacts with the ambient magnetic field and generates a force which accelerates the plasma sheath laterally away from the insulator end of the focus toward its open end. (The ambient magnetic field is generated by lateral current flows in the cylindrical electrodes.)

While the plasma sheath undergoes acceleration toward the open end, it gathers up more mass deriving from the background gas fill. It also absorbs a significant fraction of the electrical current passing through it and stores this energy input in the form of intense magnetic fields within the plasma sheath.

Once the sheath reaches the open end of the two cylindrical electrodes, a stationary plasma pinch is generated. As this compressed plasma is formed, the stored magnetic energy is transformed back into intense electric fields and kinetic energy of the plasma electrons and ions. Small nodules of dense plasma form within the pinch plasma. These dense plasma nodules sustain energy densities trillions of times greater than that of the capacitor bank. Intense, relativistic electron and ion beams are generated together with bursts of x-rays. The ambient densities and temperatures are sufficient to support copious thermonuclear reactions with resulting neutron outputs.

In other words, the plasma focus "focuses" the energy of the input current pulse in both time and space. It also transforms the energy up to much greater voltages in the process. What allows this to take place is the emergence of highly organized plasma structures which can withstand energy densities trillions of times greater than ordinary materials.

FIGURE 4
Beltramic vortex configuration



This diagram shows a cutout view of a plasma column. The cutouts permit us to examine the flow configurations on interior cylindrical surfaces of the plasma column. While each of these cylindrical surfaces are actually covered with flow lines, only one is shown for each. All of the others on a particular cylindrical surface are similar to the one shown. The cylindrical surface with zero radius is shown as having a straight, axial flow path to the left. The next larger cylindrical surface shows a spiral flow path of low pitch. And on each successive surface these spiral flow paths increase in pitch until a surface is reached in which the flow is purely circular (azimuthal). Cylindrical surfaces of greater radius have spiral flow paths of decreasing pitch, which are oppositely directed to those within the surface containing pure azimuthal flow. The fluid velocity, current density, electric field, magnetic field and vorticity all follow these same flow lines. Because of this particular Beltramic geometry of parallel flow, the configuration is said to be "force-free." Two basic types of vortices are possible. Ones in which the fluid flow, electric field, and magnetic field are all going in the same direction. Or, ones in which the fluid flow is oppositely directed to that of the electric and magnetic field directions.

Source: *International Journal of Fusion Energy*, Vol. 3, No. 1, January 1985.

The plasma pinch

To comprehend how this energy densification comes about, it is necessary to examine the fine grain geometry and dynamics of the plasma structures generated in the plasma focus. This is best pursued from the standpoint of examining how the plasma overcomes several apparent barriers that conventional plasma electrodynamic theory projects. For example, the conduction of electricity by free charges, as in a plasma, appears to be limited to the Alfven current limit. As we pass an electrical current through a plasma column, the axially direct current generates an azimuthal magnetic field (see **Figure 3**).

This magnetic field exerts an inward pressure causing the plasma column to contract—that is, pinch. This decrease in plasma column radius means that the current density increases, and the azimuthal magnetic field strength compressing the surface of the plasma column is proportional to the current density. Thus, the plasma column continues to be pinched to smaller and smaller radii—the plasma pinch. But eventually the magnetic field reaches a sufficiently great that it will no longer permit the linear current to propagate. The current is literally turned inside out by the strong magnetic field and flows backward. This circumstance has been calculated in detail and a specific, limiting current has been determined, which is called the Alfven limiting current.

But the plasma focus has experimentally demonstrated that it regularly beats and overcomes this Alfven current limit. How? Investigations led by Professor Bostick and others have shown that the current in the plasma cylinder does not follow a linear path parallel to the axis. Instead, it follows a spiral path. A nested series of spiral paths are set up such that the generated magnetic fields cancel out in terms of their effects on the motion of the current flow. In fact, all the force fields of the plasma—the electric field, the magnetic field, the fluid flow, and the fluid vorticity—locally follow these same paths. That is, they are collinear. Under this circumstance, the interaction of these "force" fields is zero and the configuration is termed "force free." (See **Figure 4.**)

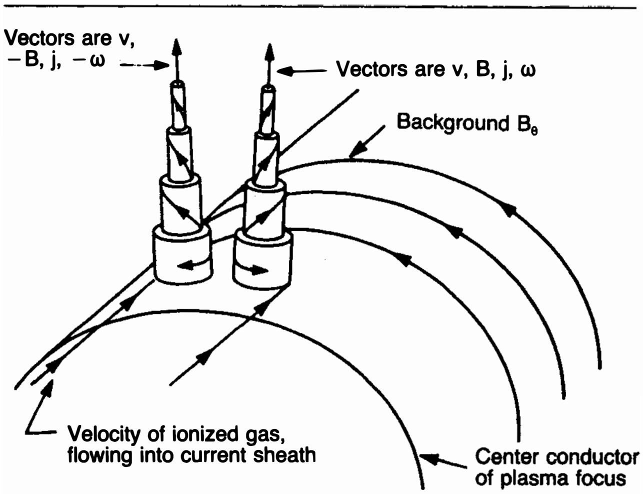
The possibility of this type of flow pattern was first elaborated by the 19th century Italian mathematician E. Beltrami. Beltrami was a close collaborator of the great German mathematician Bernhard Riemann. Winston Bostick and Dan Wells, of the University of Miami at Coral Gables, Florida, applied Beltrami's work to the data they were obtaining in plasma experiments such as the plasma focus. Beltrami had developed these particular hydrodynamic models for analysis of fundamental questions in electrodynamics and as a continuation and elaboration of work which Riemann first presented in his famous paper: "On the Hypotheses Which Underlie Geometry"—a paper which founded the field of Riemannian geometry, modern topology, and is generally considered today to provide the framework for 20th-century relativity theory. (Recently, Professor Wells has succeeded in applying his further developments on Beltrami's theory to provide the first coherent theoretical model for formation of the solar system from a plasma.)

Experimental data show that the annular current sheath consists of a number of Beltrami vortex pairs (each pair consisting of a right-handed vortex and the other a left-handed one) running between the inner and outer electrodes. (See **Figure 5.**)

These Beltrami vortex pairs not only permit the plasma focus to beat the Alfven current limit, but also transform a significant fraction of the input electrical energy into intense magnetic fields. When the final pinch is formed at the end of the focus, many of these Beltrami vortices explosively disintegrate—the Beltrami vortices are highly dynamic, metastable structures which require precise flow conditions to be maintained. When the current sheath is suddenly brought to a halt at the end of the focus, these required flow conditions no longer obtain. The energy stored in the magnetic fields of these vortices is suddenly released and heats the plasma to high temperatures. A few of the vortices are apparently able to reconnect to themselves before disintegrating. These re-

FIGURE 5

A plasma vortex pair in a plasma focus current sheath

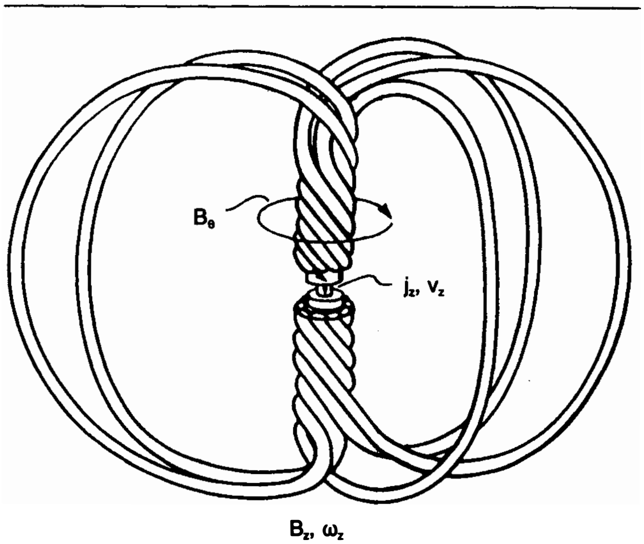


This diagram shows one pair of plasma Beltrami flow vortex filaments within the current sheath of a plasma focus. Actually, the annular current sheath is made up of about a score of such vortex pairs. In each pair, one vortex has a right-handed helical flow (shown by the arrows on the cylindrical cutouts of the plasma columns making up the vortex) and the other has a left-handed helical flow. These vortex pairs literally roll along each other's surface down the plasma focus electrodes.

Source: *International Journal of Fusion Energy*, Vol. 3, No. 1, January 1985.

FIGURE 6

Hypothesized plasma nodule configuration



This diagram shows the configuration which Professor Bostick believes best fits his data for dense plasma nodules seen in the final pinch plasma of the Plasma Focus. This closed configuration is formed when a linear vortex within the current sheath breaks away from the electrodes and reconnects to itself to form a complex toroidal structure.

Source: *International Journal of Fusion Energy*, Vol. 3, No. 1, January 1985.

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.