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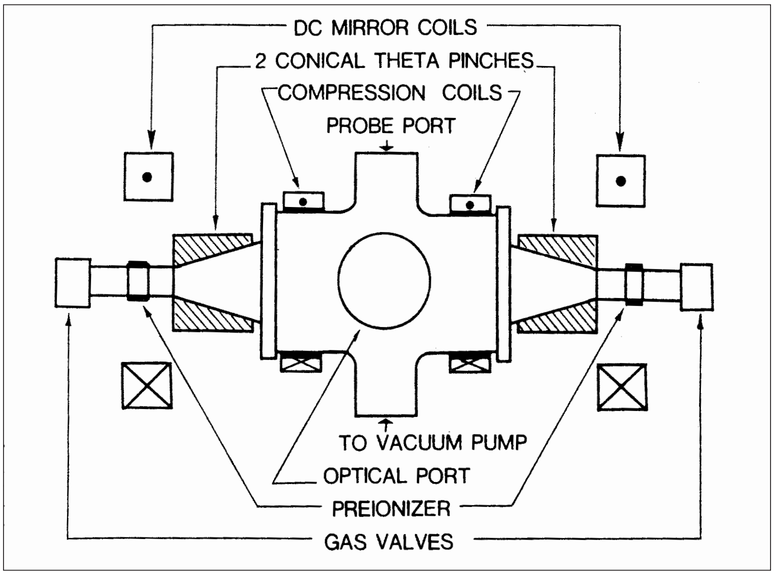
We May Have Stable Fusion Power Plasmas Earlier than a Stable Financial System

by Joel Dejean, Paul Gallagher, and Dr. Ned Rosinsky

May 20—Relatively small scientific development teams have recently forecast that they are on the path to generation of fusion power at commercial levels by the end of this decade. For example, in the words of the CEO of one of these groups, Los Angeles-based TAE Technologies' Michl Binderbauer, fusion power is the answer to this question: "Over the next 25 years we're going to double power demand in the world. So, the question is, how is that going to get generated?" This is a more powerful idea than that of nations planning to spend those 25 years just achieving a first demonstration reactor for fusion power technology.

But even more interesting is the method of thinking of some of these teams about the *plasma*, the so-called fourth state of matter, the superheated and ionized gaseous form of some light elements which will undergo fusion to heavier elements, generating tremendous energies in the process, which can produce electric power and/or propulsion.

FIGURE 1



The original idea 40 years ago: Two ionized plasmas fired into a central chamber to collide and mix with "guide" magnetic fields. Dr. Daniel Wells wrote, "The vortex structures are formed by conical theta pinch guns.... A co-linear core is surrounded by a force-free flow structure that supports the high-pressure, hot dense plasmas."

From Wells et al., "Hydrodynamic confinement of thermonuclear plasmas: TRISOPS IIX," 1980.

The dominant track for fusion research for many years has been to achieve magnetic fields so powerful that they can hold a plasma gas stable even as it's heated to extraordinarily high energies in the range of 100 million degrees Centigrade, five times the temperature of the Sun, and keep it from escaping the magnetic fields and slamming into the walls of the containment vessel.

A different conception, which has been part of fusion research all along, has begun to take a central role: Generating plasmas which maintain their own stable configuration by electrodynamic processes, and actually become *more* stable the hotter they get. A further feature of this conception, in some of the methods now advancing, is to aim for fusion reactions whose energetic products are protons and electrons only, rather than neutrons. Charged protons and electrons, when they escape a plasma where fusion is taking place, can be directed by magnetic fields as "beams" which can do work—for example, propulsion—whereas neutrons are loose cannonballs.

Almost 40 years ago, the late economist and founder of this news service and the Fusion Energy Foundation (FEF), Lyndon LaRouche, participated in a series of seminars under the auspices of FEF where scientists from a generation of early pioneers in fusion research addressed this objective of generating a self-sustaining fusion plasma or *plasma vortex*. One participant, Dr. Daniel Wells, with a small experimental device named Trisops at the University of Miami in Florida, generated self-sustaining—or what Wells described as "force-free"—rings of plasma, rotating around the electric current and magnetic field lines which they generated, and which maintained their stability without powerful compression by external magnetic fields. He called them "plasma smoke rings," likening them to those smoke rings blown, back in those bad old days, by cigarette smokers. (See **Figure 1**.)

LaRouche proposed that the rings reflected the principles of planetary orbits in a solar system, discovered by Johannes Kepler in the 17th Century. Wells tested LaRouche's hypothesis, to his surprise proved it correct, and presented a paper for the FEF seminar in early 1986, to which LaRouche responded with a memo 35 years ago last month (printed in this issue). He suggested that a better term than "force-free" for these self-sustaining rings of plasma was "least action." This is a principle of universal physical laws—as, for example, when light rays being bent or refracted through liquids of varying densities, always take their least-time (fastest) path through the liquids rather than the shortest path.

Moreover, LaRouche commented that Dr. Wells' experimental work had the effect of "correlating what appear to be anomalous phenomena occurring on the scale of the very large (i.e., astrophysics) with seemingly anomalous events in the very small" (the microphysics of ionized atoms in a plasma). Wells had himself made this analogy of a superhot plasma to a solar system in formation with fusion (a star) igniting in the central area. It demonstrated, LaRouche wrote, that "the most fundamental laws of astrophysics and microphysics are defined in terms of what Newtonian physics must view as 'force-free' configurations." Wells' results appeared in the July-August 1988 issue of *21st Century Science & Technology* as "How the Solar System Was Formed."

'Laws of Physics Are on Our Side'

The notable advances toward fusion power at TAE Technologies, cited above, come from the work on generating a self-sustaining plasma by Dr. Norman Rostoker, one of the most broadly-accomplished of that first generation of fusion scientists, who died in 2015. Rostoker developed what is called the "field-reversed configuration," a long cylinder at the mid-point of which multiple high-energy particle-accelerator beams of plasma collide—different from the donut-shaped or spherical tokamak designs which are the public's image of fusion power research. TAE calls the latest version of its experimental fusion design "Norman," after Rostoker, and not surprisingly, it generates a stable, rotating toroid of superhot plasma, "similar to a smoke ring." After the beams collide, the resulting plasma ball is sent into rotation by particle beams shot along its sides, similar to the way the rapid air flow under plane wings stabilizes the air turbulence around the wings themselves.

Dr. Rostoker was familiar with the work of Dr. Winston Bostick of the Stevens Institute of Technology, another of the original fusion generation (and a founder of the Fusion Energy Foundation), who discovered this stable plasmoid on a much smaller, table-top scale and named it a "plasma vortex."

TAE Technologies' public release of April 8, 2021 says that "Norman" has hundreds of times generated a plasma which is indefinitely stable even at temperatures over 50 million degrees Centigrade. The stability means a large portion of the high-energy ions have time to meet each other in the right kind of collisions in order to fuse and release energy. In another departure, the fuel, which is superheated and ionized, is a mixture of hydrogen and boron, and the products of the fusion reactions (besides energy) do not include neutrons, only charged protons and electrons. Some of the early fusion researchers referred to this very advantageous result as "polarized fusion."

TAE CEO Binderbauer is quoted in the release:

> Norman and I wrote a paper in the 1990s theorizing that a certain plasma dominated by highly energetic particles should become increasingly better confined and stable as temperatures increase. We have now been able to demonstrate this plasma behavior with overwhelming evidence. It is a powerful validation of our work over the last three decades, and a very critical milestone for TAE that proves the laws of physics are on our side.

TAE's self-stabilizing plasma means it is compactly confined *long enough* for fusion to produce more energy than a fusion device is using. But its bold choice of fuel comes with a very high bar for *hot enough* to produce net energy. The plasma ions must be heated, or energized, to the equivalent of several *billion* degrees Centigrade. The company hopes the next-generation "Norman," called "Copernicus" and under construction now, can do that and lead to a prototype commercial fusion reactor in this decade.

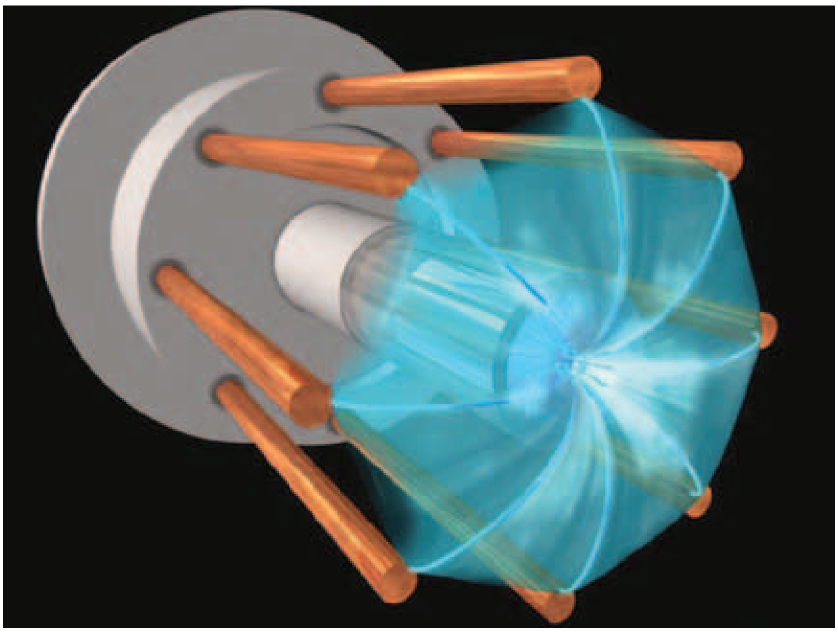
Astrophysics and Microphysics

Former President Trump's Artemis Program for a return of astronauts to the Moon and Mars, now being continued by President Biden, will require a significant increase in spacecraft propulsion to shorten the transit time, particularly in travel to Mars. Using current technology, that trip would take nine months. The development of a rocket engine powered by fusion energy can shorten the time to 3-4 months or less. This results in less astronaut exposure to cosmic radiation during transit, and shortens the time needed for rescue in case of an emergency on Mars.

A spinoff of this technology in the form of fusion energy reactors on Earth would revolutionize energy production, as the raw material for the fusion is 1% of the hydrogen in sea water, so there is minimal extraction cost compared to other fuels, there is no waste produced, and the low cost of energy would be an enormous stimulus to virtually the entire worldwide economy. It would eliminate the political use of scarce resources such as oil. It would provide huge amounts of cheap energy that could be used for desalination of sea water to green deserts in Africa and other continents. This would be the most significant spinoff from the space program since its inception in the 1960s, larger than the development of the microchip for squeezing a computer into the small confines of a rocket, or the use of computers in industrial automation.

This line of research would also push forward our understanding of some fundamental processes that drive the ongoing development of the universe: the self-development and self-stabilization of structures in plasmas that arise spontaneously under certain circumstances. This spontaneous self-development appears to be central to the development of stars and galaxies, and it is a clear demonstration that the universe is not running down into an entropy death, but is moving in the opposite direction towards higher levels of organization and development potential. We are most familiar with this anti-entropy form of development of our own species, and the history of our development shows the same tendency toward ad-

The ‘Dense Plasma Focus’

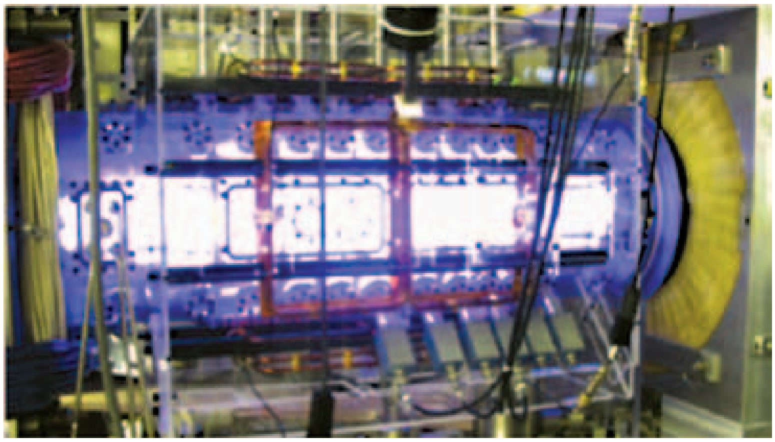


lppfusion.com

LPPFusion in Middlesex, New Jersey, headed by Dr. Eric Lerner who is quite familiar with the work of the early fusion pioneer experimenters, is also pursuing fusion power generation in self-stabilizing plasmas or plasmoids. The dense plasma focus, as LPPF calls its fusion machine design, has long been dismissed as a fusion power candidate. But with truly miniscule resources, and an unusual, 30-year series of collaborations with several university teams around the world, LPPF can boast of some real advances made by developing what is often called a “plasma gun.” This again harks back to early discoveries by Dr. Winston Bostick and even earlier ideas of Nikolay Filipov of Russia’s Kurchatov Institute. In this representation, the plasma is driven by magnetic field up the anode (the central tube) and expands “umbrella-like” between the anode and the cathode (the eight surrounding rods), then collapses very rapidly onto the tip of the anode as “a tiny ball of lightning” reaching extraordinary superheating. Lerner’s team achieved plasma temperature in excess of 1 billion degrees Centigrade, the range required for “aneutronic” fusion with hydrogen-boron fuel; it has achieved this temperature repeatably for very brief intervals over the past decade. LPPF plans to start testing the plasma focus device using that “proton-boron” fuel this year, something TAE Technologies is aiming at a few years later. LPPF hopes to achieve net energy—more energy output from fusion reactions in the device than the energy input to create the plasma—as early as 2022.

vancement, for example in science and the arts.

The Princeton Direct Fusion Drive (DFD) is a design for a fusion-propulsion or plasma-propulsion rocket for extensive space travel. Michael Paluszek, CEO of Princeton Satellite Systems, presented the concept, "Nuclear Fusion-Propelled Missions to Mars," to a Schiller Institute international conference panel on Sept. 5, 2020. Attempts to build fusion reactors for energy production have not been successful due to inherent instabilities in the ionized plasma formed by heating the fuel. Over the succeeding decades, research in plasma physics and experimental design eventually focused on plasmas that contained themselves by their own motions and by self-produced magnetic fields. Several of these structures, such as vortex filaments, and closed filaments in the form of rings, have been shown to maintain their self-containing characteristics when external magnetic fields are used to condense them into smaller volumes.



Princeton Satellite Systems

An artist's representation of the Princeton Direct Fusion Drive plasma propulsion engine design.

The main problem encountered is instability that arises as the densities and temperatures increase. The Princeton DFD rocket engine machine requires a temperature of 1.2 billion degrees Centigrade. Thus far the machine has shown stability up to 500 million degrees Centigrade.

Space Travel for Earth Power

The Princeton Direct Fusion Drive is considerably simpler in design and plasma geometry than many of its predecessors. A rocket engine requires reliability and stability, even in the face of sudden accelerations—greater reliability and stability than would be required for a land-based reactor. And the final Princeton rocket design includes six engines, for redundancy over long trips.

Like the TAE Technologies' "Norman," the DFD is a field-reversed configuration; in fact, its design is similar. The plasma is confined in a long cylinder that is narrow at the ends, and bulges out in the middle. (See **Figure 2**.) The final dimensions will be 30 feet long and 6 feet wide. The first step is to pump the fuel into the chamber. The fuel is a gaseous mixture of deuterium and helium-3, a gas found mainly in the soil all over the Moon. An electromagnetic coil, by inducing an electric current in the plasma, creates another magnetic field in the opposite rotational direction around the plasma in the bulge of the cylinder—hence, "field-reversed."

Once this geometry is set up, it is stable to perturbations, and more efficient than most other designs because it requires a relatively low magnetic field by fusion reactor standards.

At sufficient temperature, fusion occurs, producing energy. This energy produces thrust by gas escaping from the end of the chamber. The model used predicts that thrust will consume 35% of the produced energy. Some of the high energy particles are recycled back around the cylinder to directly produce electricity for the spacecraft, which will consume 30% of the energy.

A related idea of ejecting "plasmoids"—not just superhot ionized sub-atomic particles—out of the exhaust of a rocket, is being pursued at Princeton Plasma Physics Laboratory (PPPL) by Dr. Fatima Ebrahimi. These magnetic bubbles of plasma form when magnetic field lines break and then reconnect around a plasma in the Princeton Spherical Torus Experiment, a more spherical shape of the familiar donut tokamak design. Ebrahimi was quoted in a Jan. 27 PPPL release, that "This idea was inspired by past fusion work and this is the first time that plasmoids and [magnetic] reconnection have been proposed for space propulsion." It is based only on computer simulations thus far.

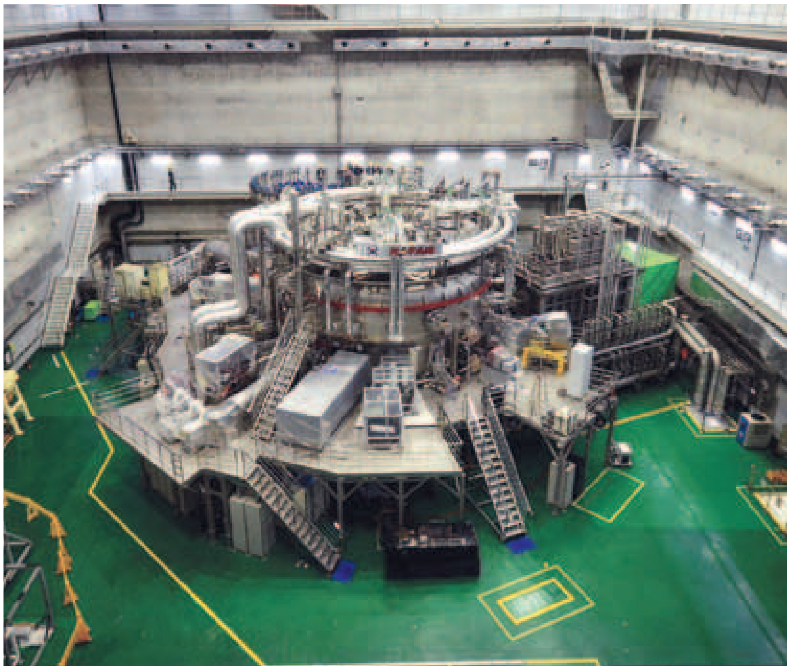
If the Princeton Field Reversed Configuration is successful, the same configuration can be used for fusion machines on Earth. It is fitting that a physical geometry which is based on spontaneously arising self-development would be the basis for a qualitative jump in the entirety of the worldwide economy, and also be the basis for finally ridding the world of poverty. This is a beautiful example of how the self-development of the physical realm is tied to the self-development of the biological realm, which in turn is tied to the self-development of the human creative realm.

More Power-Dense Magnets, Smaller Reactors

There have also been *technological*, rather than scientific, advances in producing more powerful tokamak magnets to simply apply more force to confine the superheated plasma, but within more compact experimental machines than the huge International Thermonuclear Experimental Reactor (ITER) being built by a consortium of many countries in the town of Cadarache, France.

Commonwealth Fusion Systems (CFS), a company formed in 2018 by MIT researchers, is using superconducting wires forming coiled magnets that contain the over 100 million degrees Centigrade plasma of deuterium and tritium. Instead of using liquid helium to cool the magnets, CFS is using newer "higher temperature" superconducting magnets (–253 degrees Centigrade) cooled by liquid nitrogen, as opposed to the –269 degrees required in the ITER superconducting magnets. This allows for higher magnetic field strength and a smaller plasma. Some 200 people are working on CFS' experimental device, to be completed by 2025. CEO Robert Mumgaard says it should be 50 times smaller than the ITER, and produce about one-fifth as much power.

FIGURE 3



ITER

Korea's Superconducting Tokamak Advanced Research (KSTAR) fusion device, part of the ITER project.

A British company, Tokamak Energy Ltd., is working on a similar device with "high-temperature" superconducting magnets of incredible power, shaped like the letter "D" and arranged in a circle around the straight backs of the "Ds" to create a spheromak shape. These magnets, however, are extremely expensive to produce, using hundreds of wound layers of special tape coated with a compound of a rare earth element with barium and copper oxide.

East Asian nations' fusion experiments of this type have made the biggest "headline" advances in fusion power reactions in the past two years.

In December 2020, China announced the power-up and first plasma of its HL-2M Tokamak fusion reactor. It is China's largest tokamak device, an upgrade of its Experimental Advanced Superconducting Tokamak (EAST) fusion reactor, and designed to achieve a confined plasma of over 150 million degrees Centigrade for a sustained period of many seconds.

And already on Nov. 24, 2020, the Korean Superconducting Tokamak Advanced Research (KSTAR), achieved a plasma temperature of over 100 million degrees Centigrade for more than 20 seconds. Its reactors are part of the ITER project, and have a goal of achieving a plasma temperature over 100 million degrees Centigrade for more than 300 seconds by 2025. (See **Figure 3**.)

The U.S. government is spending about $250 million on magnetic fusion development in Fiscal Year 2021—primarily as the U.S. contribution to the ITER experiment—and about twice that much on experiments in very rapid compression of small plasma targets with super-powerful lasers to cause fusion. This is still very little, 10,000 times smaller than the defense/intelligence budget in the same year, for example, and still less annual investment than was understood 40 years ago to be needed to reach commercial fusion. That was when the Magnetic Fusion Engineering Act, an initiative of the Fusion Energy Foundation and Rep. Mike McCormack of Washington State, was passed.

Thus, many of the most exciting fusion programs indicated here rely on private funding from wealthy individuals, foundations and corporations instead of governments, often having to couch their efforts in terms of the need to reduce CO_2 emissions. If we were to listen to the wise words of Lyndon LaRouche and fully fund all promising fusion programs, we could achieve fusion breakeven in the next five years and be on our way to a fusion economy on Earth and beyond.