FUSION

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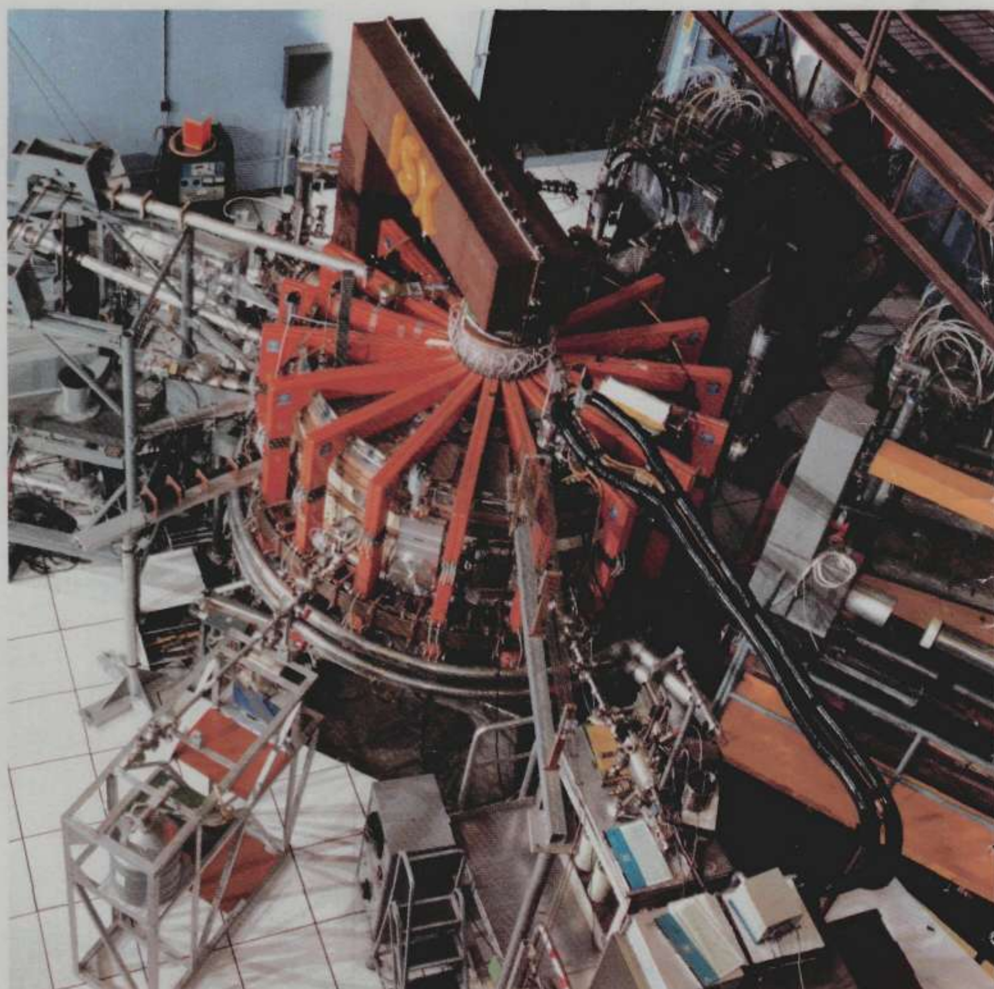
p. 2 Dr. Strangelove Founded The Nuclear Freeze

New Advances Promise Third-Generation Fusion Devices



Oak Ridge National Laboratory

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Features

News

Departments

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Note to Libraries and Subscribers

We apologize for irregularity in our printing schedule this year, but we assure readers that the only pronuclear science magazine in the country intends to continue publishing! Because of financial difficulties, the FEF published only 4 issues of FUSION in 1983, and this issue is being mailed late to subscribers. The FEF will publish 4 issues in 1984, beginning with Vol. 6, No. 1, May-June 1984.

Subscribers who purchased a 10-issue subscription and those who purchased a 6-issue subscription will receive the number of issues they paid for.

Contributions to the FEF are welcome (and tax deductible).

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On the cover: The ZT-40 reversed field pinch magnetic fusion device at Los Alamos National Laboratory has provided a series of spectacular and unexpected results in the past year, opening new engineering and theoretical possibilities for the achievement of nuclear fusion. Photograph courtesy of Los Alamos National Laboratory; cover design by Virginia Baier.

Dr. Strangelove

This guest editorial was written by Paul Gallagher, executive director of the Fusion Energy Foundation.

Those who have considered the real "Dr. Strangelove" to be Henry Kissinger have not looked deeply enough into the history of the antinuclear policy doctrine known as MAD—*mutually assured destruction*—and its corollaries. Kissinger's conscious acts against the strategic security interests of the United States, including his deliberate disinformation to U.S. presidents concerning potential weapons technologies and Soviet policies, have continued for 25 years. But since his 1957 book, *Nuclear Weapons and National Security*, behind Kissinger's nuclear weapons policies has been a far more evil man—Lord Bertrand Russell, and his associates.

The documentation is absolutely clear (only a highlight of it is presented here) that the Dr. Strangelove of Stanley Kubrick's "How I Learned to Stop Worrying and Love the Bomb," was Dr. Leo Szilard, Russell's close collaborator among the pan-European emigré scientist circles.

Founded the Nuclear Freeze

In 1957, Russell and his elite circle of neo-Malthusians founded the Pugwash Conference, the "peace and disarmament" network that has since that time, in fact, formulated all U.S.-NATO nuclear doctrines and all U.S.-Soviet arms agreements. In addition, the Pugwash group has founded or controlled all "nuclear freeze" institutions then or since, including the Union of Concerned Scientists, the Stockholm International Peace Research Institute, and the Council for a Livable World, as well as today's "nuclear freeze" and "green" peace movements.

Pugwash's 'Two Empires'

Since 1957, the Pugwash doctrine has specified world government by "two empires," the Eastern (Russian) and Western (American) divisions. Such a world government would destroy the sovereignty and the *rights to nuclear technology development* of all other nations in the name of "peace" and "metastable tension," to use the words of Leo Szilard.

From 1946 to 1952, Russell, Szilard, and their collaborators wrote articles stating that fear and guilt fantasies about the atomic bomb, among scientists and populations, could be used to force *one empire*, an Anglo-American world government, on the nations of the world. In their view, nuclear science and technology would be driven completely into the jealous and secretive control of a world agency that would have a monopoly of uranium and nuclear arms.

In 1946, Russell and Szilard demanded that the Soviet Union be blackmailed out of its attempts to become an independent nuclear power by threatening it with a nuclear attack!

By 1953-1956, when this "preventive war" scheme had irreversibly failed and it was clear that the Soviets had developed thermonuclear bombs, the great men of peace around Russell stopped threatening Russia and instead started courting the "Eastern Empire."

That decision marks the start of the public celebrity of Henry Kissinger as a sucker for the Soviet Union, a liar to U.S. presidents, and an advocate of decline in U.S. world influence to "25 percent of its postwar level." While Kissinger has styled himself as the agent of Lord Carrington and the British intelligence factional tradition of Bertrand Russell, he has continuously acted on behalf of the Soviet Union in arms policy debate and direct arms negotiations for 20 years.

Kissinger's Treachery

It is the direct responsibility of Henry Kissinger that the Soviet Union today has a nationwide infrastructure for antimissile defense, which is being prepared for operation and upgrading to laser and particle beam defense, while the United States has no such infrastructure and is years behind in the drive to develop directed energy beam weapons. This is the result of what Kissinger admitted to Congress in 1982 were his own unilateral interpretations of the SALT I (ABM) and SALT II Treaties—interpretations never agreed to but simply imposed on "Kissinger's presidents" by deception.

More important, it has been documented (see *Executive Intelligence Review*, June 7, 1983) that Kissinger, as an arms intelligence specialist attending Pugwash conference symposia from 1961 to 1964, knew *then* of the potentials of antimissile beam weapons and of the Soviet military's intention to develop them. Pugwash veteran Dr. Jeremy Stone, head of the Federation of American Scientists, revealed the same facts at a briefing at the Rayburn House Office Building July 26. Stone and Kissinger have both worked from 1962 on to organize opposition to Western efforts to develop laser, particle, microwave, and other antimissile beam weapons, knowing that the Soviets had a continuous high-priority program to develop them since 1962.

The years 1961-1964 were the period of the most intimate and intense cooperation between the Pugwash Conference leaders and the Soviet leadership (at the time, Khrushchev). Szilard, Kissinger, and the Pugwash group retailed Khrushchev's particularly lurid and fantastic MAD scenarios throughout the West—knowing in full detail that the Soviet military general staff had rejected the MAD strategy and was completely committed to war-winning offensive and defensive capabilities.

Since Khrushchev's failed bluff that ended with the Cuban Missile Crisis, the Soviet Union has taken the safer, patient route to reach its military goal: Through the vehicle of the Pugwash Conference, Soviet military men and scientists have directly shaped U.S. and NATO strategic doctrine.

Strangelove Appears

At the Third Pugwash Conference in Lac Beauport, Quebec, in 1958, Leo Szilard presented a speech titled "How to Live with the Bomb and Survive," from which Kubrick took his film's famous subtitle and theme. In that speech, whose own subtitle was "The Pax Russo-Americana in the Long-Range Rocket Stage of the So-called Atomic Stalemate," Szilard popularized the doctrines of mutually assured destruction, limited "theater" nuclear war, and the complete "decoupling" of military security from economic-industrial strength as a supposed characteristic of the "era of long-range rockets" (ICBMs).

These doctrines, later attributed to Kissinger, James Schlesinger, Robert Strange McNamara, and the Rand Corporation, were fully elaborated by Szilard in 1958. As he laid it out, the two imperial superpowers would pursue wars of conquest with nuclear-armed rapid deployment forces, destabilizing and destroying the nations of the Mideast and Africa in particular, and conducting periodic *limited nuclear wars* to maintain the level of "metastable tension." Szilard wrote out Henry Kissinger's entire career in advance.

Here is Szilard's 1958 "Strangelove" update of Lord Russell's 1946 doctrine of "preventive war":

> Let us now assume, for the sake of argument, that in the long-range rocket stage there may occur some major disturbance affecting the Arabian Peninsula which threatens to cut off Western Europe from its Mideastern oil supply. Let us further assume that America is on the verge of sending troops into Iraq and Saudi Arabia, that Turkish troops are poised to move into Syria, and that Russia is concentrating troops on her Turkish border for the purpose of restraining Turkey. Let us suppose further that at this point America may declare that she is prepared to send troops into Turkey and to use small atomic bombs against Russian troops in combat on Turkish territory and perhaps, in hot pursuit, also beyond the prewar Turkish-Russian boundary.
>
> Russia . . . might proceed to name some 20 American cities and make it clear that in case of American troop landings in the Middle East she would single out one of these cities, give it four weeks warning to permit its orderly evacuation, and then demolish that city with a single long-range rocket.
>
> If America, being willing to lose one of her major cities, were to decide in favor of intervention, then both Russia and America would lose the same amount in "property destroyed" and America would be free to occupy Iraq and Saudi Arabia without having to fear any further Russian reprisals.

Russia might do the same in "northern Europe" or wherever else it had "understandable" strategic objectives of conquest, continued Szilard. In fact, each side would publish "price lists" for each area of the world, expressing the number of cities of a certain aggregate population it would threaten to destroy, "after four weeks warning," in the other superpower's territory, to make the other superpower pay a price for invasion and conquest of that area of the world. Again to quote Szilard:

> If Russian troops were to invade an area which is on the American list, this might show that America has underestimated Russia's willingness to pay a high price [in cities destroyed] for gaining control over certain contested areas. In such a case America might then decide to revise the old price list upward.

As for relations among allied, sovereign nations, Szilard's formulas clearly allow no such thing in the age of the ICBM:

> It is clear that, if America were to base her security

"It is a foregone conclusion that American efforts toward creating an orderly and livable world will be frustrated in Southeast Asia and Africa.... In the end the people may have to choose between chaos and communism."

—Leo Szilard, 1962

on long-range rockets alone. . .even if America should continue to maintain an alliance with the nations of Western Europe, she would be bound to regard these allies more and more as expendable.

No Defense Allowed

The Russian scientists attending that 1958 Pugwash conference, led by Alexander Topchiev, must have taken eager and careful notes for transmission to their outposts in Mideast and Western European countries.

In 1962, in the *Bulletin of the Atomic Scientists*, Szilard extended the doctrine to Asia, in anticipation of the Vietnam War's course:

> The objective of the use of force must no longer be victory. The objective must only be to make a conquest difficult and expensive. . . . It is a foregone conclusion that American efforts toward creating an orderly and livable world will be frustrated in Southeast Asia and Africa. . . . In the end the people may have to choose between chaos and communism.

In 1958, the Pugwash Conference as a whole, in its Vienna Declaration, insisted that the terror of MAD was the fundamental and permanent condition of mankind *because of nuclear technology itself*, and admitted that all its own "peace and disarmament" antics are and always have been a hoax. According to the Declaration:

> Although the nations may agree to eliminate weapons of mass destruction from the arsenals of the world, *the knowledge of how to produce such weapons can never be destroyed. It remains for all time a potential threat for mankind.* In any future war, each belligerent state will feel not only free but compelled to undertake immediate production of nuclear weapons. . . . [Despite agreements against their use] the decisive power of nuclear weapons would make the temptation to use them almost irresistible.

A 20-Year Campaign Against Beam Defense

When Szilard's 1958 "Strangelove" speech was reprinted in the September 1960 *Bulletin of the Atomic Scientists*, he pointedly added: "Occasionally, there are hints in speeches of officials, who should know better, that there is work in progress on a defense system aimed at destroying long-range rockets in flight. Such a defense system is not in fact in sight."

Again, Russian scientists took note. The laser had just been invented by both Western and Soviet research teams. Some 18 months later, in the 1962 Soviet book *Military Strategy*, by Marshal V.D. Sokolovskii, appeared the following:

> Possibilities are being studied for use against rockets, of a stream of high-speed neutrons as small detonators for the nuclear charge of a rocket. . . . Various radiation, anti-gravity, and anti-matter systems are also being studied as a means of destroying rockets. Special attention is devoted to lasers; it is considered that in the future, any missile and satellite could be destroyed with powerful lasers.

At this point began the intense and deliberate 20-year campaign of disinformation and suppression of facts concerning the potentials of relativistic energy beam technologies for antimissile defense, conducted by the scientists of the Pugwash Conference and its "peace" and "nuclear freeze" spinoffs. Conducted in full collusion with the Soviet scientists who themselves were working on beam weapon programs, this campaign of treasonous disinformation has marked the entire career of Pugwash participant Henry Kissinger as "advisor to presidents."

It continues with particular intensity today against Ronald Reagan's policy of ending MAD. While Kissinger's Scowcroft Commission and Kissinger's cothinker Secretary of State George Shultz offer to bargain away beam weapons at Geneva, the August 1983 Pugwash Conference at Venice takes as its major theme the necessity of the "peace forces" to stop Reagan's program for the development of antimissile defenses.

The Soviets—140 attended the Venice Pugwash Conference—do not take seriously what is said on these occasions. They have continued to build layer after layer of surface-to-air defenses, perimeter missile defenses, and ABM radars, with whatever technological capabilities are available at every point—pursuing *strategic* defense with large and accelerated scientific programs for laser and particle beam defenses.

The only possible U.S. response to the widening Soviet military superiority, which is now accompanied with blatant threats against President Reagan's beam weapons commitment, is to immediately make that commitment into a crash "Manhattan Project" for beam weapon development and deployment, throwing out Henry Kissinger and the Pugwash baggage so that American presidents, not the Soviets, can make American strategic and scientific policy.

Letters

Kepler's Planetary Geometry

To the Editor:

I read with interest both articles in the November 1982 *Fusion*. On page 15, Figure 2 is an insert on Kepler's planetary geometry. I believe that the data presented under "Kepler's Polyhedrons" are misleading. In deriving the distances of the planets by the method described in Kepler's *Mysterium Cosmographicum* I obtain the following figures:

Planet	Distance by Kepler's Original Method*	Figures in *Fusion*
Mercury	.459	.400
Venus	.795	.738
Earth	1.01	.0
Mars	*1.2581*	.432
Jupiter	3.7744	.881
Saturn	6.5419	.726

*All distances are given in astronomical units (AU); 1.0 A.U. is the mean distance between the Earth and the Sun.

Are the published figures labeled Kepler's Polyhedra actually derived from his method method of musical intervals? If so and I have made no error, I think we must reject the application of the Platonic solid method proposed by Kepler in *Mysterium Cosmographicum* as not actually describing the lawful ordering of the solar system.

Lawrence S. Taylor
Columbia, Maryland

The Editor Replies

Martin Howard Nieto of Los Alamos National Laboratory has published a book on the Titius-Bode law in which he presents roughly the same figures as you do. The figures are wrong. They are based on an incomplete applica-

Continued on page 8

Viewpoint

The Embalse Nuclear Plant and Argentina's Nuclear Independence

by Luis Calviño

EDITOR'S NOTE

Over the past year, every country in Latin America with aspirations of independent technological and industrial development has been under pressure to succumb to the Malthusian dictates of the International Monetary Fund. In such debtor nations as Mexico and Brazil, nuclear energy programs that were among the most advanced on the continent have been brought to a virtual halt.

Argentina stands out as an exception to this pattern. Even in the midst of the worst economic crisis in its history, which has caused some delays and budget cutbacks, the Argentine Atomic Energy Commission (CNEA) successfully completed the country's second nuclear plant, inaugurated at Embalse, Cordoba, in May 1983. A third plant, Atucha II, is also under construction. Argentina is at the same time pursuing a policy of transfer of nuclear technology to other nations of the continent.

Luis Fernando Calviño, the author of this Viewpoint, is director of the Buenos Aires-based *Energeia* magazine and an active proponent of Argentina's nuclear program. Mr. Calviño is a member of Argentina's Justicialista Party, founded by Gen. Juan Peron, and is a founding member of the Club of Life.

* * *

With the inauguration on May 3, 1983, of the Embalse nuclear plant in Córdoba, a fundamental phase of the Argentine nuclear program was completed, and a lengthy process plagued by technical, financial, and political difficulties finally ended.

The completion of a plant of Embalse's scope—a 600-megawatt plant supplied by Atomic Energy of Canada, Ltd.—has rescued the Argentine Nuclear Plan. The plant's coming on line has given a firm impulse to the country's legitimate aspirations for developing its nuclear sector in an independent manner and for peaceful purposes—for which it has earned undisputed leadership in Latin America.

The case of the Argentine Atomic Energy Commission (CNEA) is an exception, in a highly unstable political situation, because of the clarity of its stated goals and the continuity of the efforts undertaken over 30 years ago. The words of CNEA president, Vice-Admiral Carlos Castro Madero, at Embalse's inauguration, are perhaps the best summing up of this phenomenon: "This project is further testimony of what can be achieved when factors of continuity and coherence come together within a rigorous ethical framework in fulfillment of a stated policy. Such continuity and coherence, preserved throughout CNEA's history despite the political avatars suffered by the nation, have allowed us to select the natural uranium and heavy water line of reactors that offers the country the possibility of attaining the greatest autonomy possible in the nuclear sector, by permitting the local development of the entire fuel cycle."

The Fight for Energy Independence

Naturally, this goal has won us enemies here and abroad. Over the past seven years, the nuclear plan has suffered from savage budget cuts, which would have threatened the continuity of the program had it not been for the tenacity of our nuclear authorities. Nuclear energy was seen as an unnecessary luxury, within the model imposed by the financial establishment after the 1976 military coup that overthrew Isabel Peron. Expressing his unrepentent Malthusian view, the monetarist finance minister from 1976 to 1981, José Martínez de Hoz, once said that Argentina should ideally have only 10 million inhabitants [rather than the current 28 million or more—ed.].

This monetarist establishment had incalculable assistance from international pressures, which tried at every point to strangle Argentina's nuclear growth. The country was the victim of threats and pressures wielded in the name of nuclear "nonproliferation."

A third element in the strategy of preventing any transfer of nuclear technology to developing nations has been the activities of environmentalist and antinuclear groups.

"Green terrorism" has its eyes on my country, encouraged by the ideological arguments of the international left, financed by the world power centers. Argentina, which over the past decade has had to confront Marxist subversion and British imperialism, must now prepare to face a nonproliferation offensive in all its guises, which seeks to undermine the popular support given our country's nuclear development.

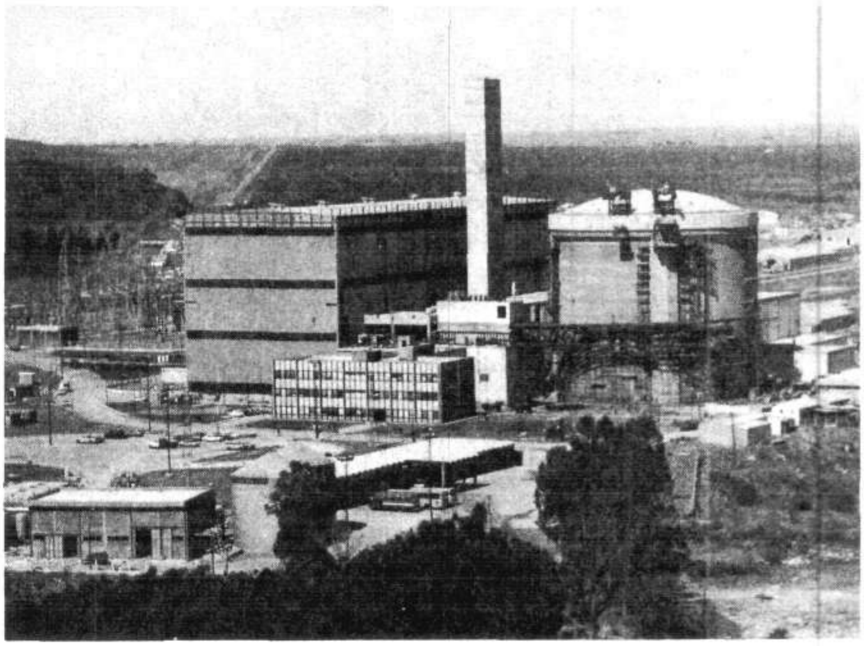
Embalse's Importance

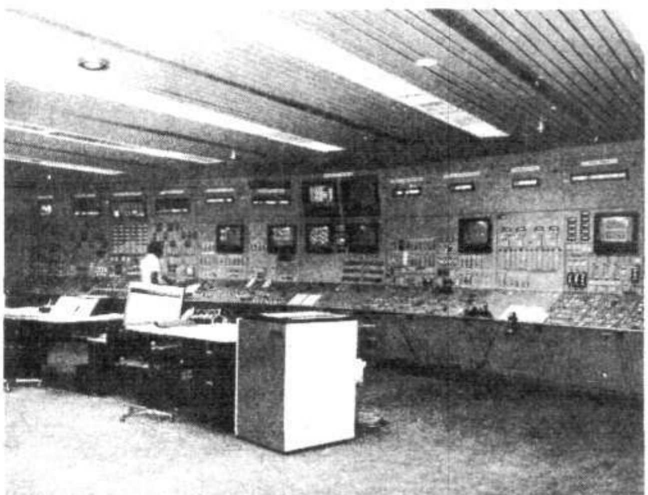
On Dec. 20, 1973, the Argentine Atomic Energy Commission (CNEA) signed an agreement with Atomic Energy of Canada, Ltd. and the Italian firm Italimpianti that was subsequently approved by Decree 706 of March 7, 1974. CNEA's promise to sign a technology-transfer agreement with my country, plus the advantages of the CANDU reactor (Canadian deuterium uranium) it proposed, made the Canadian offer more attractive than that of the German firm KWU.

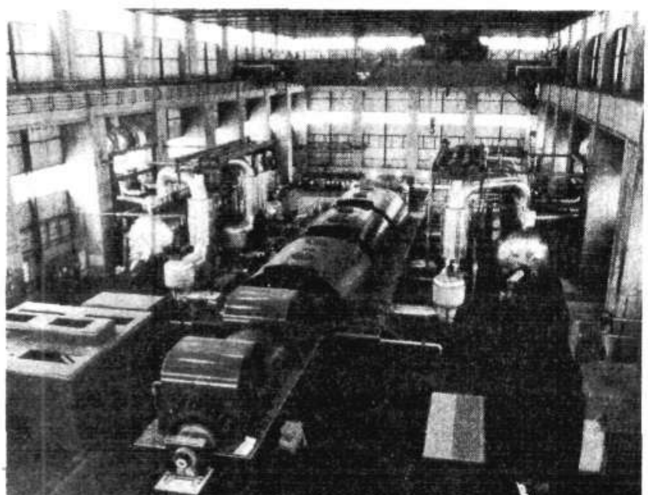
Originally scheduled for completion in January 1980, the plant was delayed by more than three years as a result of financial and political obstacles placed by the architects of Argentina's post-1976 financial policy and by the Canadian government itself. The project was finally completed in December 1982, at which point the transfer of fuel and heavy water to the reactor began, and it entered critical phase in March 1983. On April 25, the Embalse nuclear plant was synchronized with the National Interconnected System, and it was inaugurated officially on May 3.

The construction of Argentina's second nuclear plant is a decisive step in

Continued on page 63







Top left: Argentina's second nuclear plant, the newly completed 600-MW Embalse plant in Cordoba. Bottom: Embalse's control room (left) and turbine room (right).

Continued from page 7
tion of Kepler's procedure in his *Mysterium Cosmographicum* (The Secret of the Universe).

Kepler's model of the universe in the *Mysterium* determines the spacing of the spheres of the planets by inscribed and circumscribed regular or Platonic solids. He assigns to the spheres or orbits of the planets in his model a thickness, determined by the difference between the perihelion and aphelion distances from the Sun in a planet's orbit. Or as Kepler puts it, the solids space "the lowest point" (perihelion) of a superior planet from "the highest point" (aphelion) of the next inferior planet. The figures from Los Alamos and your letter, however, are based on a *zero* thickness for the planetary spheres.

The procedure is as follows. Assign the distance 1.0 AU to the mean distance between the Earth and the Sun. Then determine the thickness of the Earth's sphere from its perihelion and aphelion distances. Kepler used Copernicus's data—resulting in a thickness for the Earth's orbit of 0.204 AU. Then inscribe an icosahedron within this sphere of 0.204 AU thickness and circumscribe a dodecahedron about it.

This yields 0.762 for the aphelion of Venus and 1.311 for the perihelion of Mars. Determine the thickness of these spheres in the same way and circumscribe a tetrahedron about the sphere of Mars to estimate the perihelion of Jupiter and inscribe an octahedron inside Venus's sphere to estimate the aphelion of Mercury.

Continue this procedure using the cube to determine the spacing between the orbits of Jupiter and Venus. Then take the arithmetic mean of the estimated perihelion and aphelion distances for each planet to arrive at the mean distances determined by Kepler's method. (For ellipses of low eccentricity this is a good estimate of the mean distance and the one used by modern astronomy.)

The box on Kepler's model in the November 1982 issue generally followed this procedure. However, I repeated the calculations based on the data from Copernicus presented on page 213 of *Mysterium* and again based on data from modern astronomy. I also calculated the variance from the mean distances from modern measurements. The result is as follows:

Planet	Copernicus Mean Distance	Copernicus % Var.	Modern Data Mean Distance	Modern Data % Var.	Actual Mean Distance
Mercury	0.378	2.4	0.366	5.6	0.387
Venus	0.740	2.0	0.776	7.3	0.723
Earth	1.0	0.0	1.0	0.0	1.0
Mars	1.438	5.4	1.421	6.8	1.524
Jupiter	4.945	5.0	4.941	5.0	5.203
Saturn	9.820	3.0	9.530	0.1	9.539

Copernicus's data on the perihelion and aphelion of Mercury is way off. Kepler adjusted his procedure to correct this (using a circle inscribed into one face of an octahedron rather than the sphere inscribed inside the solid) to arrive at a mean distance for Mercury. The result is that the average variance from modern astronomy's measurements of the six planetary distances is 3 percent using Copernicus's data and 4 percent using data from modern astronomy to determine the thickness of the orbits or planetary spheres.

The Titius-Bode law fits somewhat better with a variance of only 2.6 percent. As Nieto says about Titius-Bode, "these deviations are nothing compared to what today's theorists in high energy and astrophysics are all to often willing to call agreement with theory."

It is characteristic of Kepler of that once he had developed this model, he immediately went to work to supersede it. His *Harmony of the Spheres* and his *New Astronomy* accounted for the entire system, including the necessary existence of the asteroids, discovered much later.

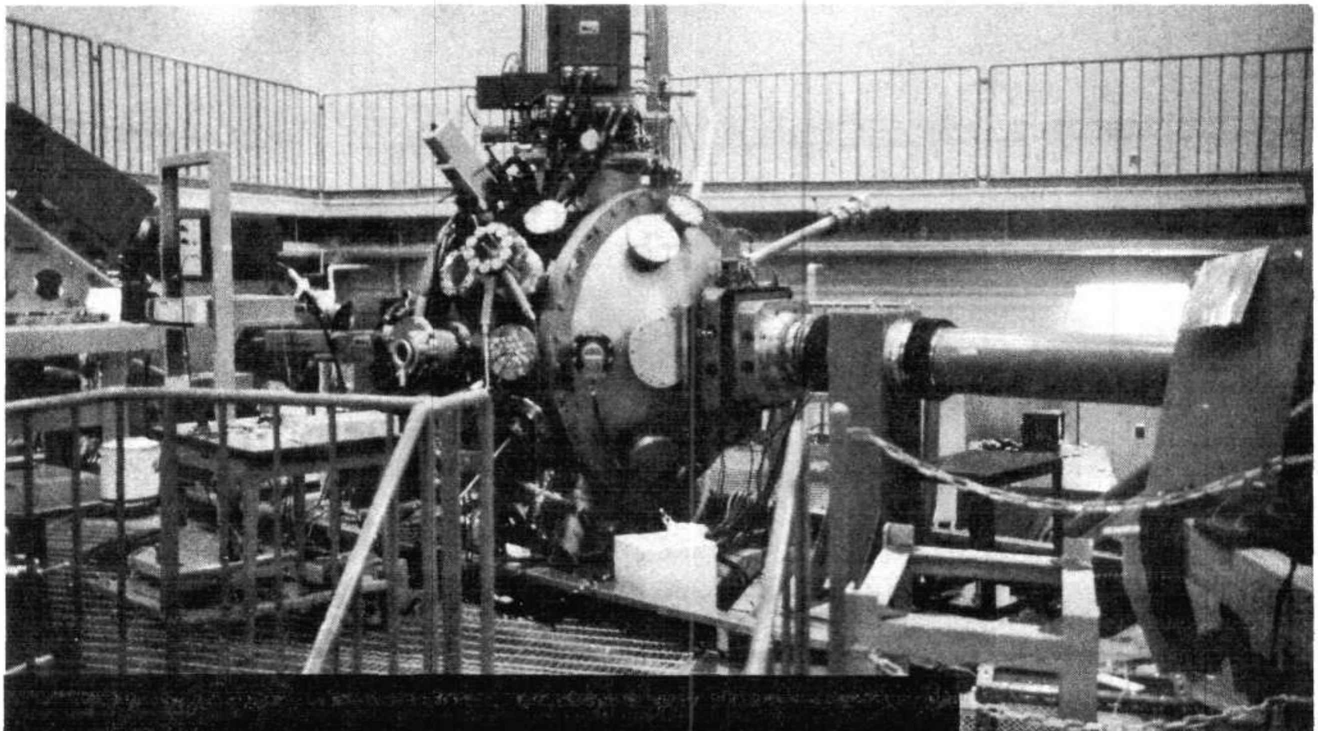
—Robert Gallagher

The Distributive Law

To the Editor:

In the March-April 1982 article on geometry ["A Mathematics Curriculum for Creating Citizens" by Dr. Jonathan

Continued on page 61



Steven Bardwell

The Secret of Laser Fusion: The Japanese Have It!

Target chamber of the Gekko IIM glass laser at the Institute for Laser Engineering.

by Dr. Steven Bardwell

EDITOR'S NOTE

In March-April 1979, *Fusion* published a special issue that described many of the most classifed aspects of the U.S. inertial confinement fusion program. Convinced that secrecy serves only to impede progress in this area of fusion research, and convinced that classification of fusion specifically continues to be motivated by political considerations, *Fusion* published a detailed description of three of the most closely held "secrets" of laser fusion:

First, the most favorable geometry for irradiation of a laser fusion target is *not the spherically symmetrical cartoon* usually shown in the public literature, but rather a cylindrical geometry.

Second, the essential physical coupling between the laser energy and the fusion fuel is not direct absorption of laser light, but rather a two-step process: The laser light is converted to soft (low-energy) X-rays. This radiation then drives a converging (Guderley or Busemann) shock wave that compresses and heats the fuel.

Third, changes in the equation of state of the fuel make efficient compression possible, even though calculations made on the basis of the normal (uncompressed state) fuel give more pessimistic results.

As a result of our 1979 publication, significant changes occurred in the U.S. classification guidelines, and some of the research conducted on radiation-driven, or *hohlraum* targets was declassified. However, the physics of these targets, their construction, and their geometry remained a very closely held secret. Specifically, three questions are now the center of the classification effort:

(1) What is the most favorable configuration of driver energy and target material so that the amount of radiation absorbed is maximized and at the same time the hydrodynamic compression efficiency is maximized?

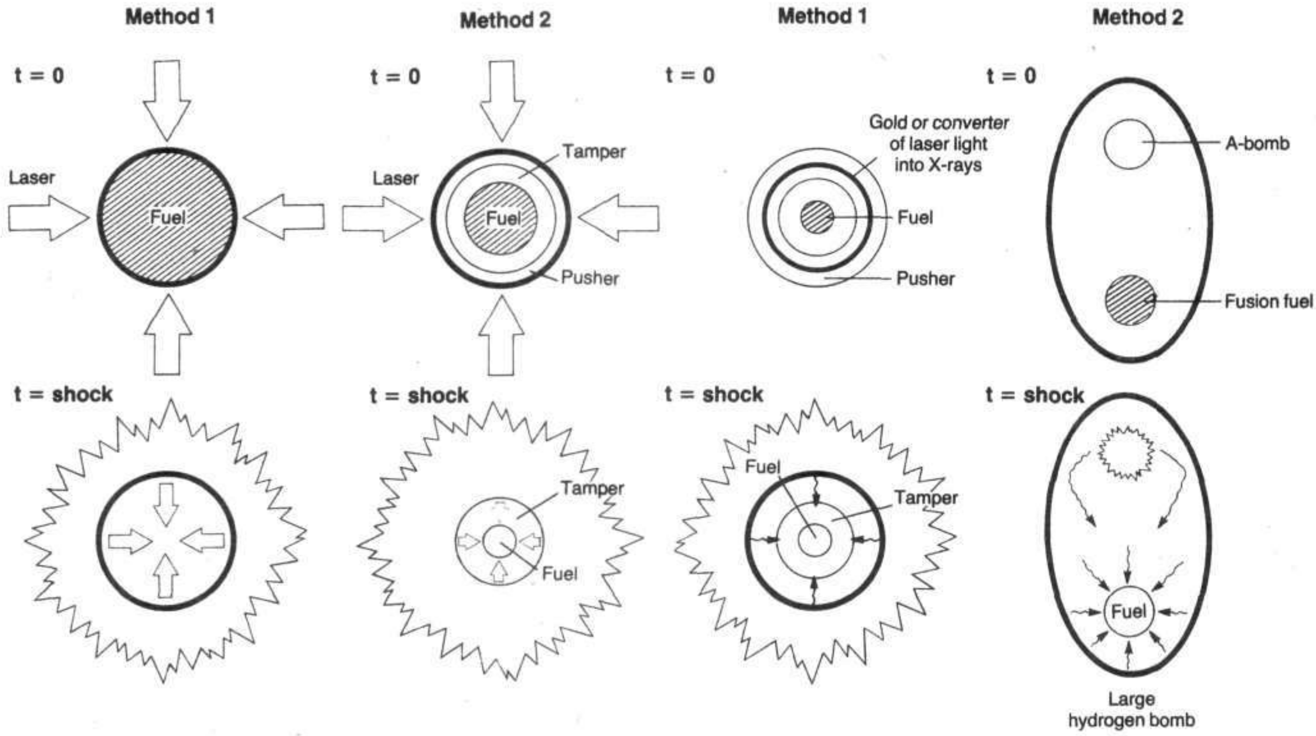
(2) What is the physics of the radiation production and absorption processes in the target (so-called nonlocal thermodynamic equilibrium radiative transport)?

(3) What processes occur as the target is compressed by a strong shock wave; for example, megagauss mag-

Figure 1
STRATEGIES FOR 1,000-FOLD COMPRESSION OF FUSION FUEL

Direct Illumination
The oldest, simplest, and only unclassified approaches use a high-intensity laser beam to vaporize the surface of the fuel assembly. The blow-off (ablation) of this layer drives a compression wave into the fuel.

Radiation-Driven Compression
The radiation-driven compression first converts the intense laser light into X-rays that then drive the compression wave into the target. This is the principle of the large hydrogen bomb.



netic fields generated by the laser, changes in the equation of state of the fuel, and inhibition of traditional energy transport processes?

In the past, the arrogant presumption of the protectors of these secrets was supported more by the U.S. monopoly on large laser research than by any rational justification of the policy.

That monopoly no longer exists: The largest laser in the world is now Japanese; the largest laser fusion research budget is Japanese; and the most aggressive pursuit of laser fusion is occurring in Japan. And, much to the chagrin of the classifiers, the Japanese program is completely open.

In the past six months, the Japanese research has shed tremendous light on the three "secrets" mentioned above. This research is reviewed here. It is ironic—indeed pathetic—that this research cannot be published in the United States. For any American who does not have access to the Japanese or Soviet journals, or the one or two independent European journals, these Japanese results remain classified, because the U.S. government has prevented their publication. *Fusion* is proud to publish this report on the Japanese laser fusion program, in the conviction that the classification of such research continues to impede progress in laser fusion and serves only the interest of the opponents of fusion and advanced energy development.

* * *

On May 10, 1983 (Showa 58 in the Japanese calendar), the largest, most powerful laser in the world was officially opened. This laser, the GEKKO XII glass laser at Osaka University's Institute of Laser Engineering, releases more energy in its billionth of a second pulse than the rest of Japan uses in that time. That energy is focused in time and space on to an almost microscopic sphere filled with fusion fuel, producing temperature and pressures at the center of that fusion fuel that are higher than those at the center of the Sun.

The GEKKO XII laser is the dramatic climax to the Japanese commitment to fusion development begun in 1976 under Prime Minister Takeo Fukuda. Identifying fusion as the lead technology of the 1990s, the Japanese, since the late 1970s, have made a massive investment in both magnetic and inertial confinement fusion (see *Fusion*, August 1981)—an investment that today is the largest in the world. Under the direction of Dr. Chiyoe Yamanaka, the Institute of Laser Engineering at

Nonablative Compression

Osaka University was established as the primary site for laser-driven and beam-driven (inertial confinement) fusion research. The table (p. 14) shows the impressive range of Yamanaka's institute, bounded on one side by the world's largest glass laser, and on the other by the world's most advanced, short pulse gas laser, LEKKO VIII.

The construction of GEKKO XII was the result of a close collaboration between the Japanese optical and electronic industries and the scientific staff of the laser institute. After the completion of the new facility's building, the 12 arms of the laser were constructed and completed in less than one year! (The comparable laser in the United States at Lawrence Livermore National Laboratory has been under construction for two years and continues to be delayed by funding cuts.)

By using the Nippon Electric Company as the manufacturer of the laser, rather than making it by hand at the laboratory, the first steps have been taken to establish Japan as the only country with a laser fusion *industry*. This strategy has already paid off; the U.S. laser laboratories, including Lawrence Livermore, buy laser glass from Japanese factories.

From the very beginning, the Japanese laser fusion program has been forced to reinvent or rediscover the most classified secrets of the U.S. laser fusion program. The centerpiece of their research on inertial confinement targets is a target design called the *Osaka cannonball*—and therein lies our tale.

In 1975, the Japanese designed a very clever solution to the classic problem of laser fusion physics: How can a small amount of fusion fuel be raised to fusion ignition conditions with a short burst of energy small enough to allow net fusion energy release to occur. This process is not too difficult if the amount of fuel is large, as is evident by the ability to build a hydrogen bomb. But, as a simple calculation shows, decreasing the linear dimension of the target means that the density of the fuel for ignition must increase in the same proportion; the product of the radius of the target and its density will be approximately constant for ignitable fuel assemblies. Thus, ignition of a hydrogen bomb with a fuel assembly 10 centimeters in diameter can be accomplished at near normal densities, but a target 1 millimeter in diameter requires 100-fold to 1,000-fold compression!

According to researchers in U.S. laser fusion laboratories, from the early 1970s there have been three strategies for achieving this compression:

(1) *Direct illumination*. The only unclassified approach, and one known to be insufficient, direct illumination uses the ablation of the outer surface of the pellet to drive a rocket-like shock wave into the fuel. (See Figure 1.) These targets are widely researched to provide information on laser-target interaction, behavior of the fuel at high temperatures and velocities, and the phenomena surrounding spherical compression, but they are not seriously considered for laser fusion itself, (at least not at the energies available in current lasers).

(2) *Radiation-driven compression*. From work on the hydrogen bomb, it was discovered that the most efficient carrier of energy for compression is radiation in the low-energy or soft X-ray band. These X-rays are absorbed completely and at the very surface of the target, creating an ideal shock wave compression (again by ablation-reaction). If an adequate amount of X-rays with this spectrum can be generated in the laser-irradiated target, then the conditions inside a hydrogen bomb would be replicated, in which the X-rays are created by the detonation of a *fissionable* trigger. Many target designs using this radiation-cavity or hohlraum idea have been proposed, and, since 1981, have been begrudgingly discussed in the open literature. (See Figure 1b.) However, there are many indications that these radiation targets will also be insufficient to achieve the required 1,000-fold compression at reasonable laser energies.

(3) *Nonablative compression*. These targets received only one mention in the open U.S. literature and have otherwise been the subject of complete classification in the United States.

The Osaka Cannonball

As long as U.S. laboratories had the only very high power lasers, classification of the nonablative target designs was possible. However, the Japanese program has changed all that. The principal area of research in Japan is on a unique target design, published nowhere except in Japan, that uses nonablative compression!

Figure 2 is a schematic diagram of a recent cannonball target used at the Osaka Institute of Laser Engineering. The basic idea behind the cannonball target rests on the difference between a cannon and a rocket. A rocket, just like the ablatively driven compression in conventional laser fusion pellets, derives a very high velocity from the momentum reaction of a large mass emitting a stream of small mass at very high velocity. A rocket derives very high velocities but at relatively low efficiency. A cannon, on the other hand, uses the pressure of a confined gas to push a heavy mass to high velocities. The velocity can never exceed the ve-

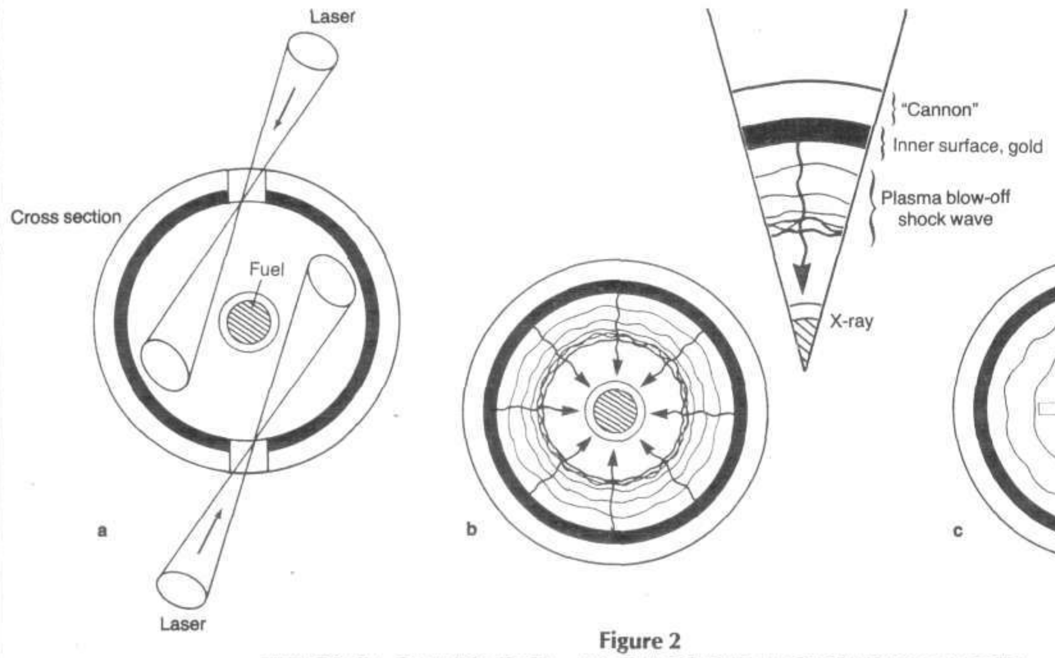


Figure 2
THE OSAKA CANNONBALL—A NONABLATIVE LASER FUSION TARGET

*The target consists of a hollow sphere (the cannon) with two holes in the shell and a fusion fuel target in the center (the cannonball). Laser light (**a**) is focused through the holes, illuminating the inside of the cannon. The deposition of this laser energy creates an intense burst first, of X-rays, and second, of plasma (**b**). This "gas" of radiation and plasma quickly closes the two holes through which the laser light entered, and then begins to compress the target of fusion fuel (**c**). In the beginning, this compression consists of a shock wave generated by the ablation of the surface of the fuel assembly as it absorbs the X-rays; added to this is the compression caused by the slightly later arrival (and reflection) of the plasma blast from the cannon.*

locity of the expanding gas, but the efficiency is very high.

In the Osaka cannonball, the high efficiencies inherent in a cannon are used to minimize the energy required for target compression. As shown in Figure 2, the laser light enters the cannonball target and creates an "expanding gas" of plasma and X-radiation in the target. This expanding gas then drives a series of reflected shock waves that hammer the fuel assembly in the center of the target, compressing and heating it. This sequence of events in its initial configuration succeeded in solving three of the most significant problems of inertial confinement fusion:

First, efficiencies of absorption of laser light and its conversion to hydrodynamic compression in excess of 10 percent have been achieved. This is an order of magnitude higher than any ablative target and represents a signal success in solving the problem of converting laser light into compressional motion.

Second, highly symmetric compression has been achieved with a small number of beams. A classic problem in inertial confinement fusion in the direct illumination scheme is that any nonuniformity in the deposition of laser light is amplified as the pellet is compressed. The resulting wrinkles or ripples will disrupt the compression. The cannonball, like the radiation-driven target, circumvents this problem by using the plasma and radiation produced by the laser, rather than the laser itself, to drive the compression. Thus, the multiple reflections of the internal plasma expansion and the "gas" of X-rays provide a natural mechanism for spreading out and smoothing the energy on the surface of the pellet. This has been spectacularly proven on recent cannonball target experiments.

Third, these achievements have been combined to achieve high compression even with relatively small lasers. Compressions to 20 times solid density have occurred with cannonballs many times, a result comparable to the best achieved anywhere. When these pellets are used on the GEKKO XII, whose first target experiment is set for Dec. 8, 1983, the world's highest compressions are expected.

The sequence of events that occur after irradiation of the cannonball target, shown schematically in Figure 2, is as follows:

(1) *The laser light is absorbed on the inner surface of the cannon.* The composition of this layer will determine the composition of the energetic products of this irradiation; if the inner surface is plastic or another light material, the primary product is a hot plasma that is blown off and converges toward the center of the fuel pellet, exactly in the way a cannon functions. If the inner surface is instead a heavy metal (gold is used in many Osaka experiments), the laser produces a large amount of soft (low-energy) X-rays along with the plasma, in a manner resembling the radiation-driven target.

(2) *The radiation is rapidly reflected*

back and forth in the cavity, becoming isotropic and then being absorbed by the pellet. This absorption results in the ablation of the surface of the fuel assembly and compresses the fuel in a way similar to that used in the other target concepts.

(3) *The plasma blown off by the laser travels more slowly (at about 50 kilometers per second) than the X-rays, which travel at the speed of light, and therefore it reaches the fuel slightly later than the X-rays.* This plasma blast creates a second shock wave that combines with the X-ray ablation shock to compress the fuel.

Figure 3 shows an Osaka laboratory computer simulation of the density history of a slice of a simple cannonball target, with the plasma compression dominant.

The research on the cannonball target has already shed considerable light on the three major areas of classification mentioned above—the most carefully guarded "secrets" in the United States. That answers to these questions hold the key to workable inertial confinement fusion is obvious. That continued secrecy on these questions is self-defeating for the United States is also obvious. The real question is: *cui bono*? Who benefits by impeding fusion research?

The "Secrets of Laser Fusion: Radiation-Plasma Physics

The first and most highly classified area of research opened up by the cannonball target is what is called *non-local thermodynamic equilibrium radiative transport* or non-LTE. This topic deals with the physics of interacting plasma and radiation, the prediction of the resulting radiation distribution (in frequency, space, and time), and the plasma dynamics of such a system. In 1976, this appeared to be concerned primarily with the physics of soft X-ray generation by a laser-irradiated plasma. However, the control and optimization of laser interactions with matter (or, in fact, the energy balance and transport in any high-energy plasma) require a knowledge of the way a plasma absorbs and reemits electromagnetic radiation.

In the past, the only plasmas for which these radiative processes were signficant occurred in the study of stellar atmospheres and the hydrogen bomb. In fact, much astrophysical research on non-LTE radiative transport escapes classification because it has dealt only with the plasma mixture specific to stars and has not generalized these results to other plasmas.

The understanding of the hydrogen bomb (and hence its optimization and miniaturization) on the other hand, depends on the physics of LTE radiation transport under a wide variety of plasma densities, temperatures, and hydrodynamic conditions. After Edward Teller's discovery that X-ray compression could be used to ignite a thermonuclear weapon—a concept still classified—one main purpose of nuclear testing was to accumulate data on non-LTE radiative transport. These data were the basis of a large amount of secret theoretical and computer modeling of radiation in plasmas.

After the negotiation of the test ban treaty in 1972, the only ways of generating plasmas under the variety of conditions of interest in military applications were underground tests and laser-created plasmas. This intersection of laser fusion, the basic physics of electromagnetic radiation in a plasma, and military research meant that laser fusion and the laws of nature were classified!

The Japanese program changes all that. The basic physics of non-LTE radiative transport occupies a significant part of the Japanese research team, and a large computer code for modeling these processes is under way. Already, however, three techniques have been developed by the Japanese for controlling and optimizing these radiation-plasma interactions:

(1) *The use of heavy metals to increase soft X-ray emissions.* This idea, certainly used in some way in bomb design, is used in the cannonball target to tailor the relative strength of the radiative and plasma compression of the fuel. Gold coatings on the inner surface of the cannonball result in dramatic increases in uniformity and efficiency of compression. This "degree of freedom" is one important variable available to make laser fusion possible.

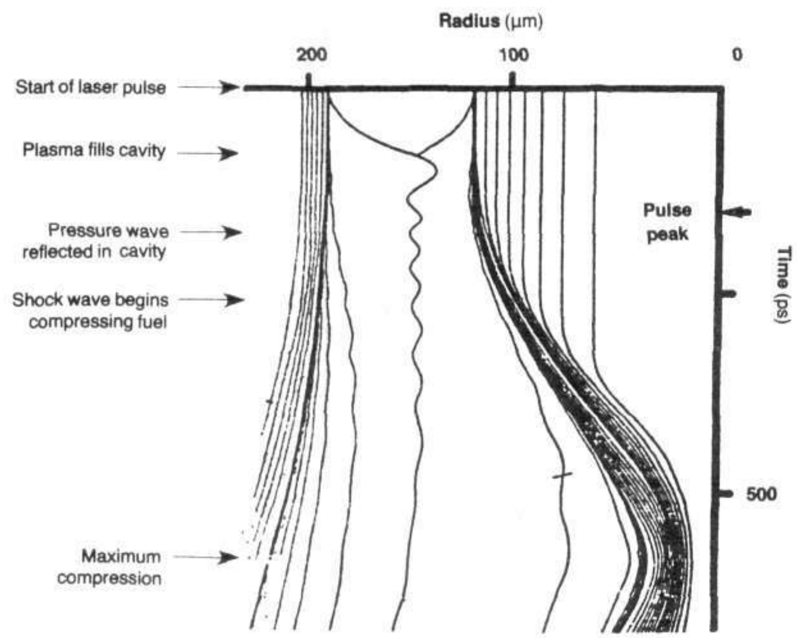


Figure 3
COMPUTER SIMULATION OF CANNONBALL PLASMA COMPRESSION
The contours of constant density as a function of time and position show the time history of the compression of a cannonball target in which the plasma compression is dominant. In this simulation a total compression of about 20-fold was achieved.

(2) *The use of light metals and foams to enhance compression and heating.* The Japanese have replicated a widely rumored and essential "secret" of an efficient hydrogen bomb, beryllium doped foam surrounding the fusion fuel. This beryllium serves to amplify and concentrate the energy in the soft X-ray part of the spectrum, dramatically increasing the compression produced by a given plasma. It is almost certain that the ability to miniaturize a hydrogen bomb is the result of this technique. Japanese researchers have further speculated that suitable foams may be used to generate cavitational compression of the blackbody radiation contained in the bubbles, giving a significant enhancement of the X-ray intensity through local hot spots (like cavitation phenomena in flowing fluids).

(3) *The use of intermediate-weight elements to "filter" the X-ray radiation.* Since the band of X-rays most favorable for efficient compression is known to be centered around 30 nanometers, the Japanese have proposed using the opacity of silicon and tantalum, which absorb on either side of 30 nanometers, to filter the X-rays. Suitable mixtures of these two elements should, given the right pressure and temperature conditions, generate a cannonball plasma that is transparent only to soft X-rays, suppressing the hard X-rays that preheat the fuel and the ultraviolet energy that is too soft to generate efficient compression.

High Energy Lasers at the Institute of Laser Engineering

Name	Type	Wavelength (microns)	No. of Beams	Energy (kilojoules)
Gekko II	Glass	0.355	2	0.3
Gekko IIM	Glass	1.05	2	1.6
Gekko IV	Glass	0.526	4	0.6
Gekko XII	Glass	1.05	12	20
Lekko II	CO_2	10.6	2	1
Lekko VIII	CO_2	10.6	8	10

All these lasers are in operation now. They are part of a project called Kongoh, which is scheduled to reach breakeven by 1987 with a 100 kj driver using whichever of these lasers is determined to be the best experimentally.

Shock Wave Physics

The second component of Teller's original conception of a thermonuclear bomb depends on shock compression of the fusion fuel using a convergent spherical shock wave—a so-called Guderley shock, after its discoverer, Kurt Guderley in 1942. This shock wave is configured so that its convergence at the center of the sphere of fuel generates the very large *temperatures* and *pressures* required for fusion ignition. The exact amplification of temperature and pressure depends on the equation of state of the fuel as it is compressed, as explained below. This same principle is proposed to be used in laser fusion research, but because it overlaps the bomb-makers' classification of Guderley's 1942 doctoral thesis, research on convergent spherical shocks in laser fusion is also classified.

The Japanese program has pursued investigation of shock wave physics since its inception. A series of early papers was the first to publish results on the use of soft X-rays to drive a shock wave, describing in detail a conversion of laser light into shock wave kinetic energy of 50 percent *when that conversion was mediated by soft X-rays.* The behavior of this shock wave as a function of ion mass and target thickness was also investigated. These results have been used to select optimum composition and dimensions for the outer shell of the cannonball target.

New work has concentrated on control of this shock wave. One of the key variables is the reflection of the pressure waves back and forth inside the target. (See the rippled contours in Figure 3 that are caused by this reflection.) By variation of the distance between the outer shell and the fuel assembly, this pressure wave can be controlled. Detailed studies on the optimization of the target geometry are now being undertaken. The interaction of this plasma pressure wave with the radiation-driven shock wave is a second variable that the Japanese are using to control the compression of the fusion fuel. Because these two shock waves arrive at different times (they travel at different speeds), the size of the pellet can be used to modify the impact of the two waves. In addition, the radiation interacts with the plasma depending on the wavelength of that radiation, so that the energy flux on the target is a complex function of the size of the target, the temperature and opacity of the plasma, and the composition of the plasma created by the laser.

Of course, all this basic physics is highly classified in the United States. That such classification protects the secret of the hydrogen bomb is unlikely; what is certain is that it has impeded the search for fusion energy.

Equation of State

The successful implementation of either a hydrogen bomb or a laser fusion target requires one additional component: an understanding of the behavior of the fuel itself as it is compressed under pressures of many hundreds of millions times atmospheric pressure and is heated to temperatures of many hundreds of millions of degrees. This behavior is summarized in the equation of state that expresses the relation between the pressure, temperature, and density of the fuel. This relation, in turn, determines:

(a) the effect of a given compression wave on the fuel; that is, what volume change and temperature increase will result from a given pressure wave.

(b) the efficiency of conversion of the shock wave into hydrodynamic motion; that is, how much of the compressional energy is lost in entropic heating and how much actually results in a volume change.

(c) the tailoring of the pressure wave

to ensure that it converges at the center of the target; that is, the speed and focusing of a Guderley shock wave are conditioned by the equation of state of the medium that supports the shock wave.

Data relating to the equation of state of highly compressed fusion fuel are classified since they are part of the design information for a hydrogen bomb. However, these data are also critical for the design of an efficient fusion target, and so the Japanese program has done extensive research on this equation of state. As was first pointed out by Bernhard Riemann in 1859 and documented 120 years later for laser fusion by researchers at the Fusion Energy Foundation, the most important aspect of the equation of state is the change that it undergoes when the shock wave compresses the fuel. The shock wave is a real singularity, not merely because there is a sharp change in pressure across the shock front, but more because the passage of that front changes the properties of the medium in a qualitative way.

In the case of laser fusion, the appearance of very strong (many megagauss) magnetic fields, spontaneously generated by the shock wave, is the key to understanding the change of state that the fusion fuel undergoes. These magnetic fields create a "fluid-like" equation of state, in which the pressure is decoupled from the temperature and so allows extremely efficient compression of the fuel. Considerations like this have led the Japanese research group to pursue extensive studies of these magnetic fields. They have predicted the appearance of magnetic fields of more than 100 megagauss and are beginning an ambitious program for the measurement of these fields.

The End of Classification?

With the publication of these Japanese results over the next year, the major scientific "secrets" of the U.S. laser fusion program will be publicly available, at least to readers in Japan, Europe, and the Soviet Union. Whether the United States takes advantage of this and finally opens its own program to the benefits of free discussion and inquiry will to a large extent determine whether or not the U.S. program can maintain its lead in the world fusion effort. And if the United States does not maintain the lead in fusion, the Japanese certainly will be number 1.

Dr. Steven Bardwell, a plasma physicist, is editor-in-chief of Fusion. *He spent two weeks in Japan in May 1983, touring the fusion laboratories and attending seminars with Japanese fusion scientists. Bardwell was accompanied by fusion scientist Dr. Friedwardt Winterberg.*

NOTES ON REFERENCES

X-ray Compression

The first papers on this subject came from the Soviet Union and Japan:

S.L. Bogoliubskii, B.P. Gerasumov, V.I. Liksonov, A.P. Mikjhailov, Yu. P. Popov, L.I. Rudakov, A.A. Samarskii, V.P. Smirnov, "Thermonuclear-Neutron Yield from a Plasma Compressed by a Shock," *JETP Letters*, 24: 182 (1976).

H. Takabe, K. Nishihara, T. Tanuiti, *J. Physical Soc. Japan*, "Deflagration Waves in Laser Compression," 45: 2,001 (1978).

K. Nozaki, K. Nishihara, "Deflagration Waves Supported by Thermal Radiation," *J. Physical Soc. Japan*, 48: 993 (1980).

The coverage of this last paper in *Fusion* magazine sparked interest in the subject outside of classified circles, and led to a series of papers that were subsequently refused publication in the U.S. journals:

F. Winterberg, "Blackbody Radiation As an Inertial Confinement Fusion Driver," *Nature*, 286: 364 (1980), and "Magnetic Booster Target Inertial Confinement Fusion Driver," *Atomkernenergie/Kerntechnik*, 38: 81 (1981).

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J. Mizui, N. Yamaguchi, T. Yamanaka, C. Yamanaka, "Energy Transport through High-Z Metal Foil in a Laser-Produced Plasma," *Phys. Rev. Lett.* 39: 619 (1977)

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T. Mochizuki, S. Sakabe, K. Okade, H. Shigura, T. Yabe, C. Yamanaka, "Ablative Accelertion of Pellet Shells Irradiated by External Soft X-ray Sources, *Japanese J. of Applied Physics*, 22: L133 (March 1983).

T. Yabe, S. Kiyokawa, T. Mochizuki, S. Sakabe, C. Yamanaka, "Soft X-ray Driven Ablation and Its Positive Use for a New Efficient Acceleration," *Japanese J. of Applied Physics*, 22: L88 (Feb. 1983).

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T. Yabe, "Soft X-ray Drive Ablation and Its Scaling," Osaka Institute for Laser Engineering, ILE-QPR-82-1, May 1982.

K. Nishihara, "Scaling Laws of Plasma Ablation by Thermal Radiation, *Japanese J. of Applied Physics*, 31: L571 (1982).

T. Yabe, T. Mochizuki, "Impact Radiative Fusion Concept," *Japanese J. of Applied Physics*, 22: 261 (April 1983).

T. Mochizuki, S. Sagabe, C. Yamanaka, "X-ray Geometrical Smoothing Effect in Indirect X-ray-Drive Implosion," *Japanese J. of Applied Physics*, 22: L124 (Feb. 1983).

Nonablative Compression

The Japanese group has the first published description of a nonablative target:

T. Yabe, K. Nishihara, J. Mizui, "Research Report of Institute of Plasma Physics," Nagoya University, No. IPPJ-235 (1975).

Similar independent concepts were published shortly afterward:

F. Winterberg, "Recoil Free Implosion of Large-Aspect Ratio Thermonuclear Microexplosion Targets" *Lettere al Nuovo Cimento*, 16: 216 (1976), and "Ignition of Thermonuclear Microexplosions Inside an Egg-shaped Cavity," *J. Phys. & Appl Phys*, 9: L105, (1976).

B. Allboin, *J. Phys. Soc Japan*, 50: 3,762 (1981).

The current Japanese design has been evolving since the early 1980s:

H. Azechi, N. Miyznaga, S. Sakabe, T. Yamanaka, C. Yamanaka, "Model for Cannonball-Like Acceleration of Laser-Irradiated Targets," *Japanese J. of Applied Physics*, 20: L477 (1981).

The experimental results of their program have been widely reported except in U.S. journals:

K. Yamada, M. Yagi, H. Nishimura, F. Matsuoka, H. Azechi, T. Yamanaka, C. Yamanaka, "Improvement of Absorption and Hydrodynamic Efficiency by Using a Double-Foil Target with a Pinhole," *J. Phys. Soc. of Japan*, 51: 280 (1982).

The results also have been presented in international meetings:

C. Yamanaka, et al., *Proc. 9th International Conference on Plasma Physics and Controlled Nuclear Fusion Research*, Baltimore (1982), IAEA-CN-41/F-1.

Their latest experimental work is contained in a paper to be printed in a future issue of the *Japanese Journal of Applied Physics*:

N. Miyanaga, Y. Kato, Y. Kitagawa, T. Kouketsu, M. Yoshida, M. Nakatsuka, T. Yabe, C. Yamanaka, "Efficient Spherical Compression of Cannonball Targets with 1.052 μm Laser Beams," ILE 8305P, May 7, 1983.

Other Effects in Plasma-Radiation Physics

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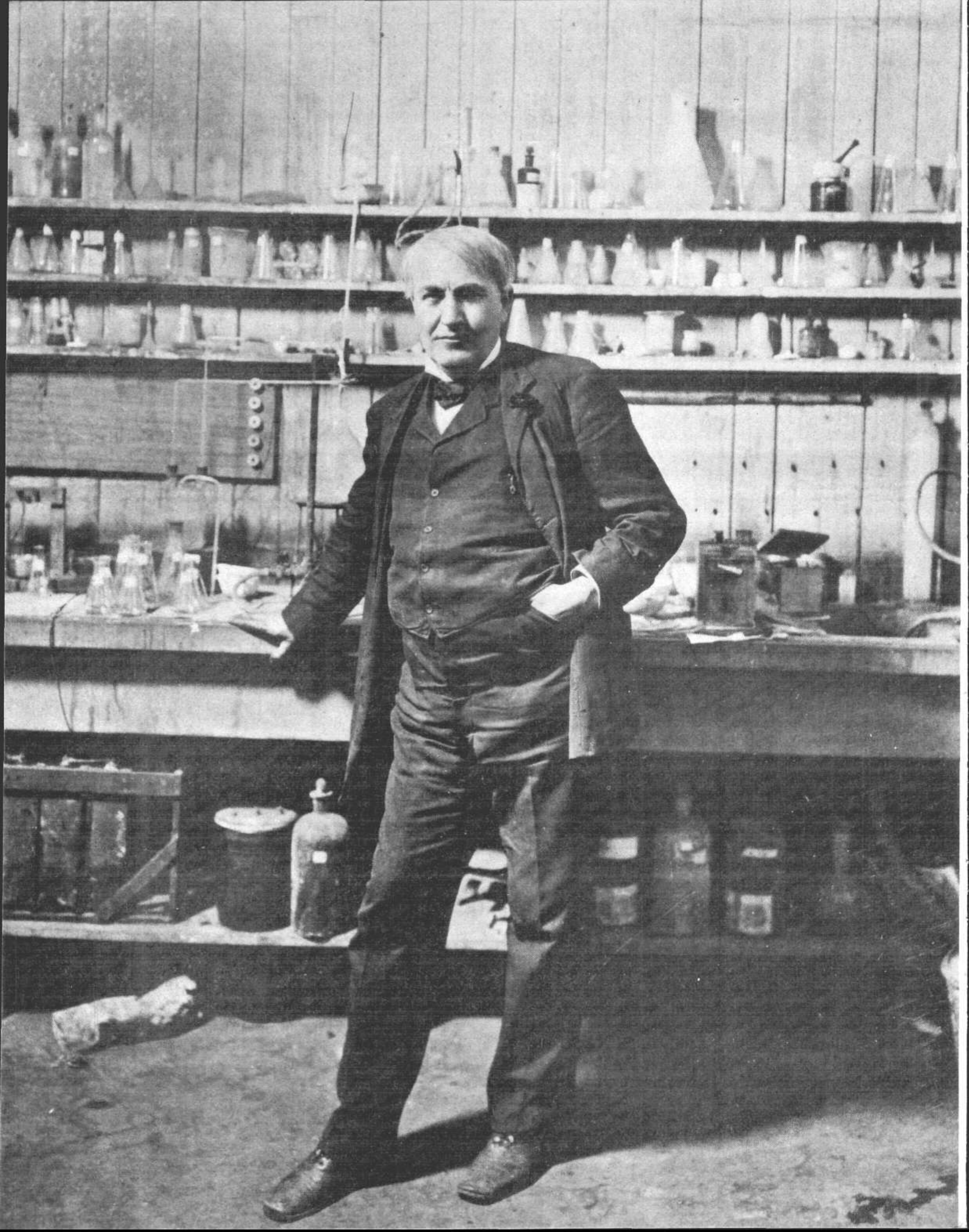


This is the suppressed history of Thomas Alva Edison, who waged a successful 10-year battle to build efficient centralized electric power stations to light the world and power its industries.

Thomas Alva EDISON

The Scientist Who Created The Electric Light and Power Industry

by Michael Tobin

THE GROWING WORLDWIDE industrialization maintained its pace as Abraham Lincoln was laid to rest in Springfield, Illinois. Railroads were proliferating in France, Germany, Russia, and elsewhere but especially in the United States where the momentum of Lincoln's dirigist policy still prevailed. Many a young man of that period hitched a ride into the industrial future to which the railroads were leading. Thus, Thomas Alva Edison and Andrew Carnegie, among others, became telegraphers, outrunning the trains to their destinations with news and ideas along the easy rights of way that had been created by the roads of steel.

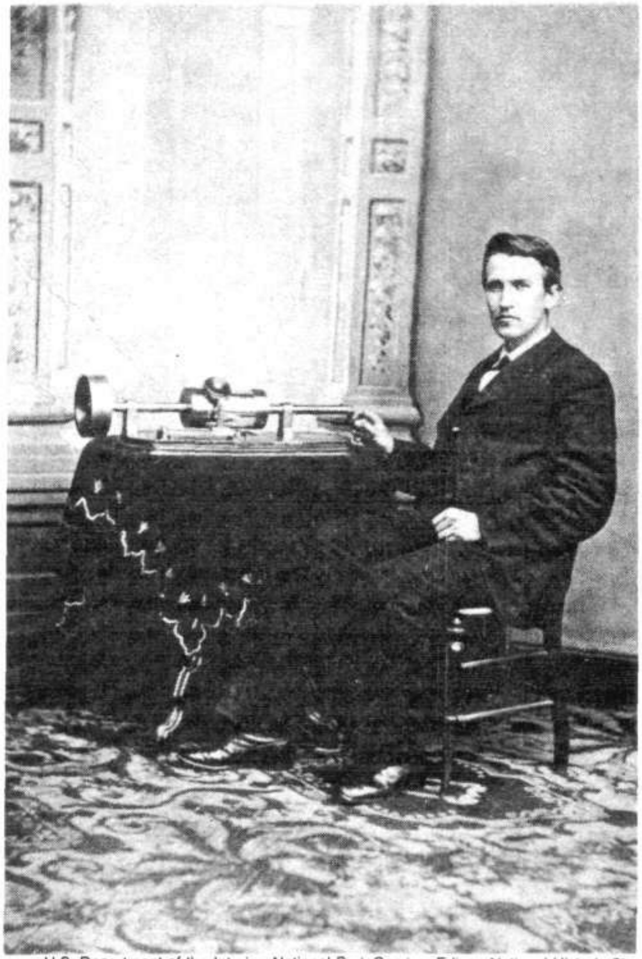
But the owners of obsolete technologies and manufacturing plants, especially in England, viewed the new ideas and their implementation with alarm, since this threatened to undermine their monetary hegemony in the world market place. To protect themselves from such an eventuality, they attempted to modulate the pace of technological growth. Gifted individuals, such as Edison, were encouraged by financiers like J. Pierpont Morgan to develop their ideas and were paid small sums for research in exchange for the patent rights to the resultant inventions. By "sitting" on such patents, this London-centered anti-industrial faction had many times succeeded in stifling further industrial development.

Despite the go-slow financiers who did not want it to happen, and despite the scientists who said it couldn't be done, industry used the American System method—moving as fast as possible to ensure that the most advanced technologies set the pace for economic growth. Relying on his more informed understanding of the actual relation of power transfer, efficiency, and electrical design, Edison proposed and built a generator with low impedance by feeding a relatively high impedance load through a low impedance transmission line. He overcame all the scientific and engineering barriers to an efficient and practical electrical power and light system. Then he designed and manufactured the necessary equipment—lamps, generators, and accessories; organized the capital to finance the new technology; and built the power stations to supply electricity.

The antiindustrialist faction, especially the London-centered Morgan interests, tried to stop Edison from creating an industrial base for the manufacture of his electric power and light system. The Morgan interests were the embodiment of the British System of trustification—buying out new industries to keep them under control and stagnant and purchasing patent rights simply to "sit on them," in order to protect their financial assets. Understanding that an independent electric power industry would be the basis for an uncontrollable takeoff in American economic growth, the Morgan group threw one obstacle after another in Edison's way, even infiltrating his staff.

Edison's successful counterattacks in this war were mounted from his growing industrial base. To all provocations, Edison's response was the same: He improved and cheapened the technology he had created and he accelerated the expansion of his manufacturing capacity. In three years, 1885-1888, Edison installed 200 central stations and 1,500 isolated lighting plants throughout the United States.

Edison's aggressive dirigist policy kept his enemies at bay until the worldwide industrial explosion was safely launched. The defeated Morgan was finally able to remove Edison from leadership in 1889, by a financial swindle in which his best friend and his personal attorney betrayed him (and which, in his mind, implicated his


U.S. Department of the Interior, National Park Service, Edison National Historic Site
The young Edison with his early phonograph, June 1878, photographed by Mathew Brady.

young bride), Edison yielded control over his manufacturing plants to the Morgan interests at a fraction of their true value. He then retreated to the Musconetcong Mountain in the northwest corner of New Jersey, where he exiled himself for a good part of the next decade.

Edison came down from the mountain a much diminished man, although by ordinary standards he lived a useful and fruitful 32 more years. This later Edison is the one known to most people as "America's greatest inventor," the persevering tinkerer, a benign old man much given to mainly foolish pronouncements in the Sunday newspaper supplements.

This is the story of the real Edison, whose successful war on behalf of the American System has been buried for 100 years.

Invention

By the early 1870s, Edison's outstanding telegraphy developments brought the representatives of Jay Gould's Atlantic and Pacific Telegraph Company and of Cornelius Vanderbilt's Western Union to Edison's small, Newark, New Jersey, machine shop. The two railroad right-of-way telegraph companies, then in mortal combat, vied for Edison's services as inventor and contractual manufacturer of sample telegraphs. But both companies resisted larger capital expenditures for the mass production of Edison's telegraphs.

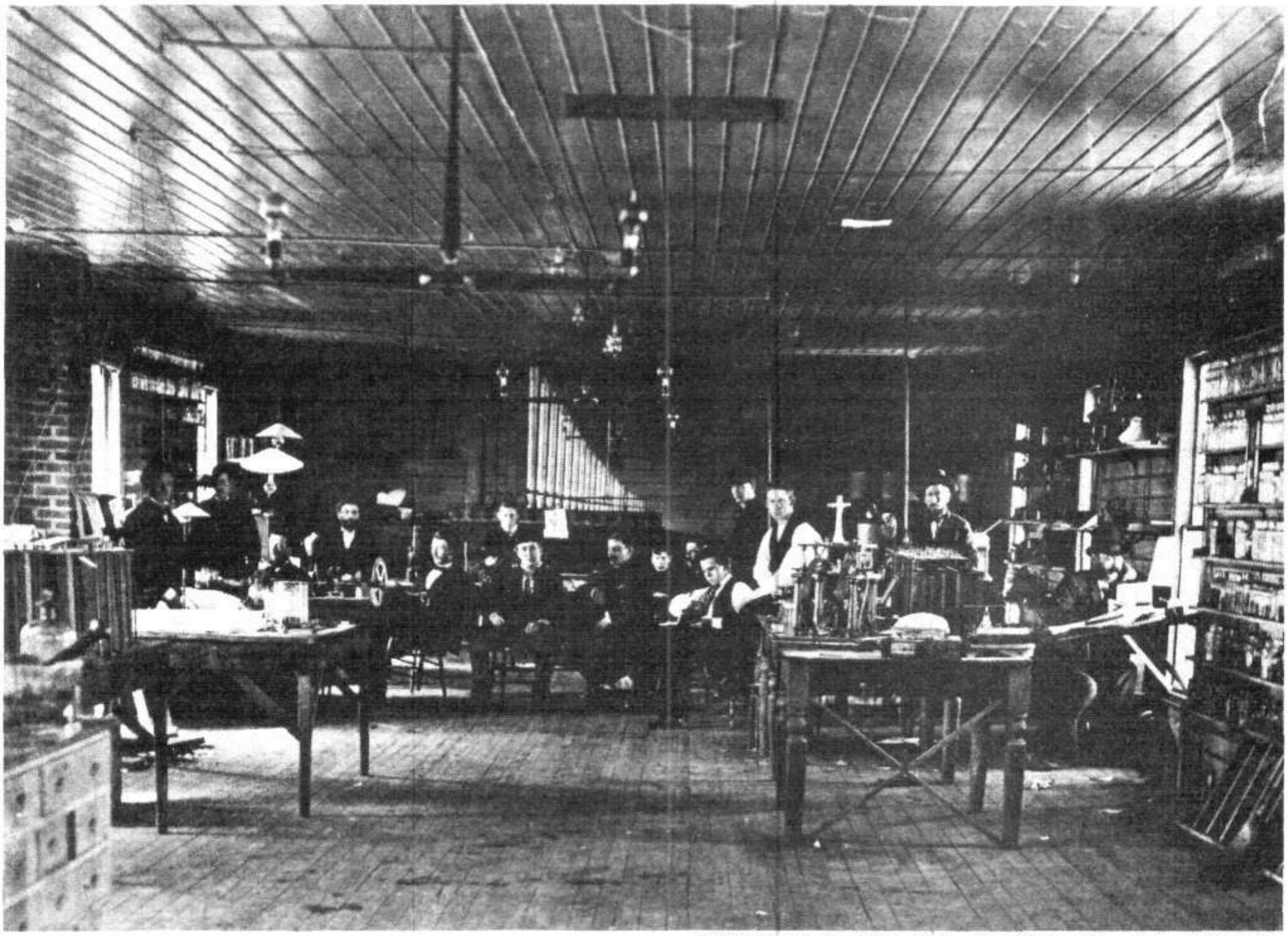
Edison planned to break free from the close embrace of his financiers as soon as he could accumulate sufficient escape capital. Meanwhile, for lack of any other option and despite swindles by Gould and Western Union, Edison maintained a working relationship with both financial camps.

By 1875, at age 28, Edison had to his credit the phonograph, the carbon microphone, the "Etheric Force" experiments (inducing sparking in a remotely located circuit), and the mimeograph machine, as well as the automatic telegraph system. He had developed a cadre of skilled assistants—chief among them Charles Batchelor, John Kruesi, and Sigmund Bergman—and he had accumulated a shop full of precision machine tools and electrical instruments. With independent capital in hand from some of his inventions, Edison notified the press that he was closing his Newark, New Jersey shop and retiring from contractual manufacture. In the future he would devote his full time to "Invention!" To that purpose he announced that he was building a 100 by 30 foot two-story wooden structure in Menlo Park, a small community 15 miles south of Newark.

By June 1876, Edison and his family and his assistants and their families moved into the few farmhouses near the Menlo Park Laboratory and began a series of labors that literally changed the face of the earth and man's existence. Almost all who worked in that laboratory sensed that they were participants in a great enterprise. As John Ott, Edison's machinist and draftsman, commented later in life: "My children grew up without knowing their father. When I got home at night, which was seldom, they were in bed." "Then why did you do it?" he was asked. "Because . . . he made me feel that I was making something with him. I wasn't just a workman."[1]

The pace of research and development activity at Menlo Park quickly made up for lost time in the move from the Newark shop. The first 18 months' work, ending in February 1878, yielded approximately 30 patent applications. Although many of these were improvements on telegraphic devices, they also included Edison's phonograph, his telephone carbon transmitter, and his telephone amplifying transformer. The two Edison telephone inventions plus Alexander Graham Bell's electromagnetic earpiece are the three essential components of the modern telephone.

From the end of February 1878 to the beginning of October, however, Edison submitted only one minor patent application, an unusual hiatus of seven months. Edison's laboratory notebooks of that period strongly suggest that he used the first five of these months to prepare for his planned entry into the field of electrical power. Among the entries are numerous descriptions of prevailing electrical practices including a June 1, 1878 *Telegraph Journal* (London) report on the most advanced electric arc lamp lighting system on display along the Avenue de l'Opera of


U.S. Department of the Interior, National Park Service, Edison National Historic Site

Edison (center, with hat and scarf) and his laboratory staff in the Menlo Park laboratory, shortly after the installation of Edison's second lamp in February 1880.

Paris, a string of brilliant "electric candles" created by the Russian Jablochkoff. These notebooks also reflect Edison's studies of the technology and economics of the gas industry, which in 1878 had a worldwide $1.5 billion investment. By comparison, the net capital worth of the electric industry then was perhaps a small fraction of 1 percent of this. Edison understood that his proposed electrical system would have to be competitive both in price and convenience with the older well-established gas technology.

Electrical Power

In Edison's Laboratory Notebook No. 184, to which he gave the special title "Prospectus Book," are some of his detailed notes. Speaking of himself in the third person, he begins:

> Object, Edison to effect exact imitation of all done by gas, so as to replace lighting by gas by lighting by electricity. To improve the illumination to such an extent as to meet all requirements of natural, artificial, and commercial conditions.

Then, in embryonic form, the future Edison electrical system began to take shape. He discussed dynamo efficiencies, motors, metering, and other components of his proposed system. He also discussed the greater efficiency and economy of a central power system compared to isolated factory lighting systems, because "a general system of distribution is the only means of economical illumination."

Edison set himself the goal of creating an incandescent lamp whose "light [has] the mildness of gas." Based on his studies of raw material costs, including the calculated cost of the necessary copper for distribution, he set a goal for a "100 ohm lamp [of] 16 candles." (The light emitted by a gas jet was approximately 8 candle power.)

By mid-July 1878, Edison had concluded his preliminary studies and sketched in some of the details of his proposed electrical system. He needed time away from his laboratory and library to think through some other details of his system and how best to bring his ideas into the realm of practice. It was for this reason that he readily accepted an invitation to join a group of astronomers and other scientists who were taking a special Union Pacific train to the Rockies to view the July 29 eclipse of the sun. The trip to the Wyoming eclipse viewing site, and the continuation of the trip to the West Coast and the leisurely return, served Edison's purpose well. The issues were fully decided in Edison's mind before the train's return to New York at the end of August 1878.

On Sept. 8, 1878, Edison used the occasion of a visit to the Wallace Manufacturing Shops in Ansonia, Connecticut, where a string of eight 500 candle power arc lamps powered by a Wallace-Farmer dynamo was on display, to issue a friendly challenge to his host: "I believe I can beat you in making the electric light. I do not think you're working in the right direction." Since the challenge was issued in the presence of an accompanying reporter, Edison's statement and subsequent descriptions of his proposed electrical system quickly became world news.

In part, Edison's announcement was meant for Western Union's general counsel, Grosvenor P. Lowrey. Edison was warning him that he did not intend to be boxed into the obsolete technology of arc lighting, as Lowrey had suggested via an intermediary who had attached himself to Edison during the trip to Wyoming. He would choose his own path in electrical lighting, bypassing arc lamp lighting at the time of its greatest success, because he correctly saw that the technology had no future. In the first place, the lamp's glaring arc (500 to 3,000 candle power), formed by the passage of lightning-like currents across the air gap between two carbon rods, was unsuitable for indoor lighting. Second, the large currents through the arc lamps required stringing the lamps like beads in series so as to minimize the cost of copper transmission lines. Finally, this series arrangement decreed a dynamo design with an armature resistance at least equal to the total series string resistance of the lamps, so as to obtain a more constant current and hence a more constant light per lamp. This set the upper limit for the generator efficiency at 50 percent, because at least half of the generated power would be dissipated in the dynamo's internal resistance.

Edison conceived his electrical system as the equivalent (dual) of the gas jet lighting system then in use. The gas pipes entering public or private buildings supplied gas at almost a constant pressure, and the individual jets obtained gas through small pinholes in the pipes. Hence, individual jets would be turned on or off without affecting the gas pressure in the pipe or the light intensity emitted by the other jets.

The electrical equivalent of a gas jet fed through a pinhole is a lamp whose resistance to the flow of current is relatively high. The electrical equivalent of the pipe with the gas at a constant pressure is an electrical generator with a constant voltage across its two output terminals. Each individual high resistance lamp is connected across two wires attached to these terminals, and since each lamp uses only a small quantity of current, it can be turned on or off without noticeably affecting the light intensity of the other lamps. Finally, if the generator's armature resistance could be kept much smaller than the expected load, the constant voltage generator theoretically could attain efficiencies approaching 100 percent.

Edison's three important design hypotheses of 1878 were the conceptual framework for the electrical system that he began putting into place the following year: (1) a constant voltage, minimum armature resistance generator; (2) high resistance incandescent lamps wired in parallel; and (3) a low resistance distribution system. On Sept. 8 and throughout the following month, Edison spoke of a central dynamo of great efficiency from which electricity would be sent through underground cables into individual households and public buildings. The electricity would be metered and protected with fuses. Inside wiring would bring the electricity to sockets with individual on-off switches which, in turn, would receive electric lamps of a pleasant light intensity of 10 candle power. In addition, other outlets could receive electric motors, electric heaters, or other devices as needed.

Edison's 1878 outline of his projected central power and light system seems altogether familiar and reasonable today. But in 1878, his announcement caught the world by surprise. Edison's plan to "divide the light" to intensities equivalent to those of gas jets shook the financial markets. Gas company securities plummeted. The leading British scientists, including Lord Kelvin, John Tyndall, and others, goaded by Parliament to counter the crash in gaslight securities, stated that Edison's proposals were "unworthy of the attention of practical and scientific men." The true meaning of that phrase was that they did not have a clue as to how Edison proposed to "divide the light."

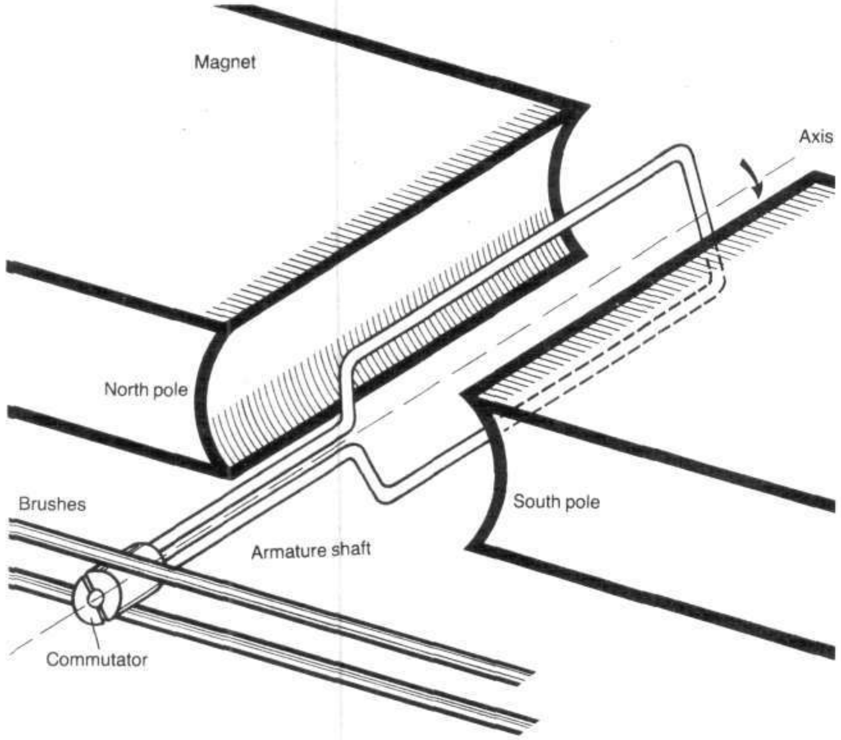
The Maximum Efficiency Question

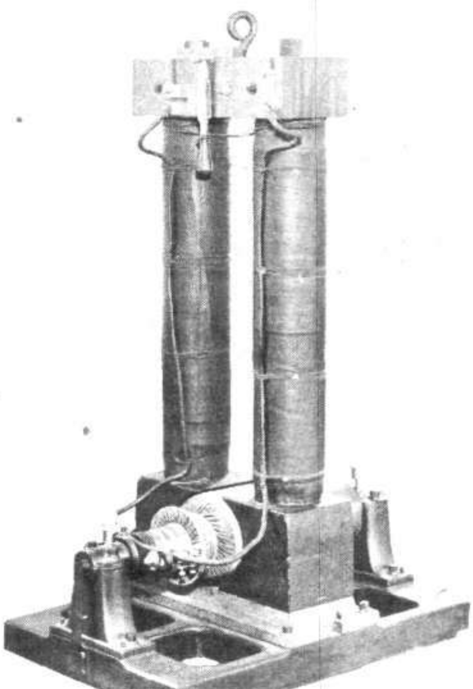
What startled the scientists most was Edison's proposal to build an electrical generator with an efficiency greater than 50 percent. From their extensive experience with batteries in laboratories and in classroom demonstrations, these scientists had proved beyond doubt that the measured energy per unit time or the power supplied by a battery became a maximum when the external load of the battery exactly equaled the internal resistance of the battery. If the load resistance was either smaller or larger, it was proven that the power transfer was lower than this maximum. Since the transferred power equaled that consumed within the battery, these scientists concluded that the maximum efficiency of power transfer of all energy sources must be 50 percent. This so-called law of nature had guided the design of contemporary electrical generators. As noted above, the pre-Edison armature generator coils were wound with small-diameter wire and connected in series so as to yield a resistance equal to the expected load resistance. In practice, this yielded efficiencies in the 40 percent-plus range for the Werner-Siemans generators, the best of the lot.

The 19th-century scientists other than Edison took the "below 50 percent efficiency" readings for the arc lamp generators as additional confirmation of the so-called 50 percent maximum efficiency law. Edison argued that the maximum 50 percent efficiency law was not a law of nature but a law of man, based on present practice, which he proposed to change forthwith. What outraged most scientists on both sides of the Atlantic was Edison's implication that they did not understand the physics of electrical generation.

Figure 1
EDISON'S SINGLE COIL DIRECT CURRENT GENERATOR

This single coil schematic representation of a direct current generator shows the rotating segmented commutators, which reverse the induced current at the proper time, mounted at one end of the armature shaft. Edison's major innovation was to use a small number of windings of large-diameter wire so as to yield the smallest resistance possible and thus the largest possible efficiency.





U.S. Department of the Interior, National Park Service, Edison National Historic Site

"Long waisted Mary Ann," Edison's 1879 dynamo, which yielded a measured efficiency of 90 percent—40 percent more than scientists at the time thought possible. Edison's innovation was a low armature resistance, obtained by winding the armature coil with large-diameter wire.

Unfortunately for their vanity, this was indeed the case. The designers of electrical generators had primarily overlooked the fact that the source of energy for electrical generation was not within the generators themselves, but within their *drivers,* such as steam engines. Because of this important fact, it was no longer necessary, as it was for batteries, to squeeze the maximum power out of these energy sources to attain a paltry 40 percent to 50 percent efficiency.

Scientists were blinded from seeing this new freedom, however, because of the similar constraints imposed by electrical generators for arc lamp lighting. Edison, who rejected arc lamp lighting as an obsolete technology, was the first to discover and seize the new freedom that was inherent within electrical generators, and he pushed the efficiency of electrical power generation to 90 percent for the first unit he built. This low impedance-high efficiency generator was the primary prerequisite for the entire electrical system that followed its completion.

Morgan: Surveillance and Investment

Edison's move to Menlo Park in 1876 was understood as a bold declaration of independence from his former backers at Western Union. But Edison had been wise enough not to sever all his previous ties into the council rooms of his chief financiers. He had retained Col. George Gourand, Jay Gould's man in London, as his own London representative, and he continued his direct working relationship with the leadership of Western Union, especially its general counsel, Grosvenor P. Lowrey. Later he accepted Lowrey's suggestion that he hire as his private secretary Stockton L. Griffin, a junior executive at Western Union.

Edison depended on the reports from these observers of his Menlo Park work to help shake loose necessary capital investments. Hubristically, Edison even supplemented such reportage with frequent press interviews in which he not only described ongoing work but also announced contemplated research directions. In most instances, Edison's openness had the desired financial effect.

Edison's activities were monitored closely in England and New York. In 1876, on the advice of Britain's most eminent scientist, Lord Kelvin, Parliament had appointed a commission chaired by Professor John Tyndall to evaluate Britain's position in the field of generators and arc lamp lighting systems, which Kelvin knew to be the direction in which Edison was headed. The commission's report in 1877 was no surprise; it showed that England trailed Europe and America by a wide margin. The 1877 report should have resulted in actions to encourage investment in scientific research and industrial development, particularly in the field of electrical generation. But England's immediate post-1877 policy was instead to intensify surveillance of Edison, this time via the London banking house of J. S. Morgan & Co. and its New York affiliate, Drexel Morgan & Co.

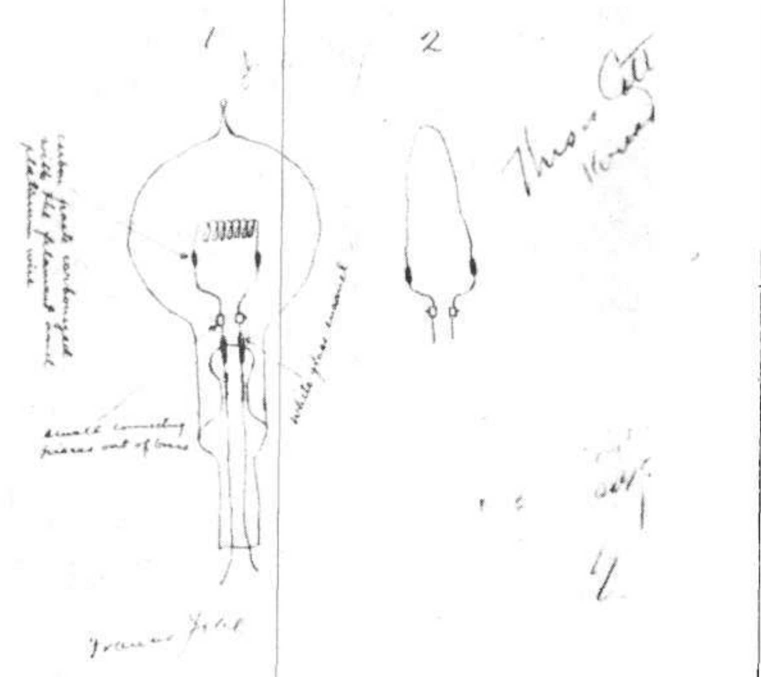
The London Morgan firm handled most of the British funds invested in the United States, and therefore the head of the London office, Junius Spencer Morgan, was already in frequent telegraphic communication with his son, John Pierpont Morgan, the head of the New York office. J. P. Morgan, the silent partner of Western Union, gradually assumed control over Edison.

Of course, Edison's Sept. 8, 1878 announcement caused great concern within the Drexel Morgan boardrooms. Was Edison bluffing? Was it pure bombast, as most of Morgan's advisers suggested? If they financed Edison, this mark of confidence in his yet nonexistent electrical system might induce a further drop in gas investments.

Yet, despite the universal verdict of "impossible" given by their scientific advisers, if Edison succeeded in building his electrical system without their financial support, then the gas stocks would fall even more.[2] When the Menlo Park reports reaching J. S. Morgan in London made this seem likely, the New York office was instructed to strike a deal with Edison as soon as possible. Since Edison was too busy to come to New York, J. P. Morgan forgot his dignity and made the trip to Menlo Park himself to secure the rights to Edison's electrical patents for the Morgans.[3]

Within a month, a Morgan partner, Eggisto Fabbri, became treasurer of the newly formed Edison Electric Light Company (EELC), the holders of Edison's lighting patents, and subsequent board meetings were held in Morgan's office. The U.S. rights to Edison's electrical patents for the following five years were vested in this Morgan-dominated consortium, and its Nov. 15, 1878 incorporation provided Edison with $30,000 immediately, plus $20,000 in installments later. The board of directors included Edison, Lowrey, Fabbri, and others well disposed toward Morgan.

Edison accepted Lowrey's recommendation that he hire two new assistants for his Menlo Park laboratory, Francis



U.S. Department of the Interior, National Park Service, Edison National Historic Site
Drawing by Edison and Francis Jehl that was used to create the first successful incandescent lamp experiment in October 1879.

Jehl, a young apprentice in Lowrey's office, and Francis R. Upton, a mathematical physicist with a master's degree from Princeton University and a year of postgraduate study at the University of Berlin under Dr. Hermann Helmholtz.

The $50,000 was grossly inadequate for the necessary research and development. Edison was trying out platinum lamp filaments and other expensive metals, and he was purchasing high vacuum pumps and arc lamp generators as a temporary power supply until his own generator would be built. His staff would have to be increased considerably, and he would need an additional building. But Edison hoped that Morgan's pockets would open wider on receiving direct progress reports from Edison's two new staff members and others at Menlo Park.

The Edison-Upton Generator

When Jehl and Upton arrived at Menlo Park, work on all parts of Edison's electrical system was in full swing, and they were both quickly pulled into the whirlwind of activity. Upton, especially, sensed the enthusiasm and the competence of the laboratory staff and the respect they accorded Edison. He soon discovered that despite his professional training, Edison's understanding of electrical generation and lighting were more advanced than his own. It didn't take Upton much longer to recognize the preeminence of Edison's conceptions in other areas.

Though he had great difficulty in understanding the full sweep of Edison's electrical system until much later, Upton avoided the pitfalls of petty professionalism, and accepted

Edison's leadership in all areas of research and development, placing the formal "tools of his trade," mathematics, into the common pool of the laboratory's instruments. And Edison, in his own way, showed his appreciation of Upton's contributions. A rare, most exceptional relationship developed between these two men. Upton, the trained physicist, became the willing pupil of Edison, and thereby made unique contributions in collaboration with Edison to science and engineering.

The first result of this collaboration was the Edison-Upton generator, whose most important innovation was a low armature resistance obtained by winding the armature coils with large-diameter wire. The generator was completed in July 1879 and yielded a measured efficiency of 90 percent.

This result and a detailed description by Upton of the new generator that would become a model for all future electrical generators were published as an unsigned article in the *Scientific American* Oct. 18, 1879. But the scientists and engineers on both sides of the Atlantic would not believe a word of it. The incautious among them shouted "fraud" and other hysterics—outbursts reflecting the tenacious hold of the 50 percent maximum efficiency law on the world scientific community. Even Francis Upton lapsed back to embrace this law almost one year after his article had appeared in the *Scientific American.* Much later, Upton acknowledged his confusion:

> I cannot imagine why I did not see the elementary facts in 1878 and 1879 more clearly than I did. I came to Mr. Edison a trained man with a year's experience at Helmholtz's laboratory . . . a working knowledge of calculus and a mathematical turn of the mind. Yet my eyes were blind in comparison with the eyes of today; and . . . I want to say that I had COMPANY![4]

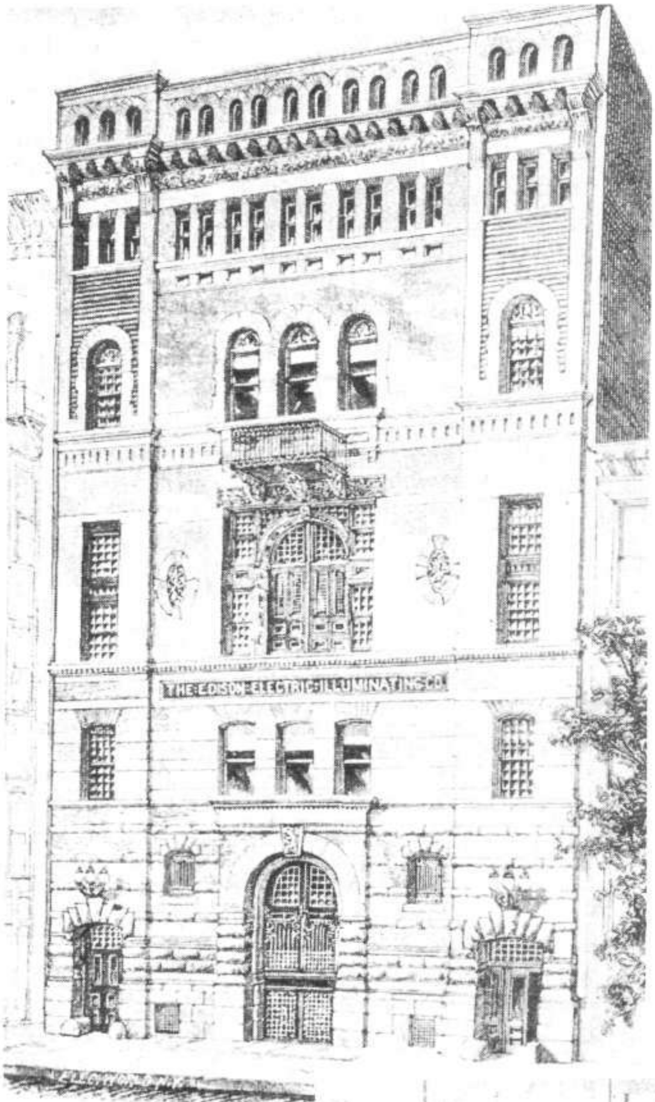
The Incandescent Lamp

At about the time the major work on the generator was nearing completion, Edison directed his efforts toward building the high resistance incandescent lamp. But this time he returned to his earlier choice of carbon as a filament, rejecting the platinum lamp as impractical. The previous lamp experiments using platinum and other esoteric filaments, however, had yielded the vital clues toward building the successful carbon filament lamp. In the meantime, he had pushed the lamp design toward an ever greater vacuum, improving the state of the art by almost two orders of magnitude. Ludwig Boehm, a gifted glassblower, had executed Edison's one-piece glass globe design, and Edison had learned the all-important technique of removing occluded gases from filaments by passing a current through them just before sealing off the interconnecting wires extruding from the sealed glass globe. This not only removed the gases trapped within the filaments, but gave them a hardness that extended their life.

Edison applied these vital techniques and others to the horseshoe-shaped filament made out of carbonized cotton sewing thread on Oct. 21, 1879. The lamp glowed with a brilliance of 16 candle power for 40 hours! Soon many more carbonized cotton filament lamps were carefully produced in the laboratory and the resistances of the filaments were tabulated. They were all approximately 120 ohms when red hot—a perfect match for the already completed low resistance generator.

Within the next year or so Edison would demonstrate that his technology was equally successful with thin filaments made of carbonized cardboard, bamboo, and other fibrous materials, but now it was time to put on a small demonstration for the world, as he had promised in September 1878.

To speed the development of centralized power stations, Edison went into the manufacturing business, producing his own generators and motors, as well as all the fixtures and appliances for electrical power generation. Shown here is the armature winding department at the Edison Machine Works in Schenectady, N.Y., as it appeared in Electrical World *magazine, Aug. 25, 1888.*



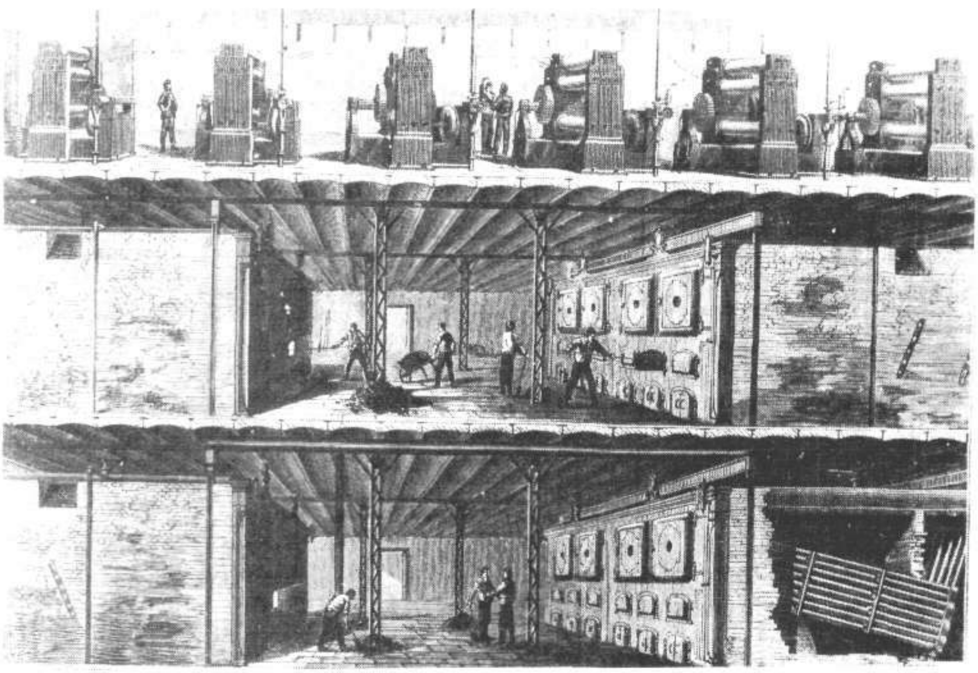
The news of Edison's success, however, leaked out too soon, so that by Dec. 21, 1879, the world knew of his planned New Year's Eve gala display of his lamps, wired on posts outside and from chandeliers and wall fixtures within the Menlo Park laboratory. Thousands of people from all walks of life invaded Menlo Park for the 10 nights preceding and including New Year's Eve. All those who came would agree with the otherwise cynical magazine *Puck*, that Edison had fashioned and brought "a New Light to the World."

The Manufacturing Question

Edison judged this to be an opportune time to request EELC funding for the large-scale manufacture of lamps, electrical fixtures, and generators. He was politely but firmly told by the board of directors, however, that they would not invest in manufacturing and were quite content to remain a patent-holding corporation. As Edison testified later:

> We were confronted with a stupendous obstacle. Nowhere in the world could we obtain any of the items or devices necessary for the exploitation of the system. The directors of the Edison Electric Light Company would not go into manufacturing. Thus . . . I was forced to go into the manufacturing business myself.[5]

The majority of the capital for the manufacturing plants that Edison organized came from the sale of some of his stock in the EELC, and most of the remainder came from his collaborators at Menlo Park. In April 1880, Edison formed the Edison Lamp Company in partnership with Upton and Batchelor. In early 1881, he went into partnership with Sigmund Bergmann, a colleague from his New-



By 1888, Edison had installed 200 central lighting stations and 1,500 isolated power plants. Edison's Central Station in New York City (above), as depicted in Electrical World *magazine and (below) in a cutaway illustration showing the dynamos (top level) and boilers.*

ark manufacturing days, for the manufacture of electrical fixtures, sockets, fuses, and other appliances. Finally, in March 1881, he organized the Edison Machine Works with Batchelor for the manufacture of electrical generators and motors.

Each of Edison's manufacturing entities required contractual agreements with the EELC, since the parent company held all the patent rights and obtained royalties on all products sold. Of course, Morgan made sure that these agreements were on terms favorable to the parent company. As an example, the EELC insisted that the lamps manufactured by the Edison Electric Lamp Company be

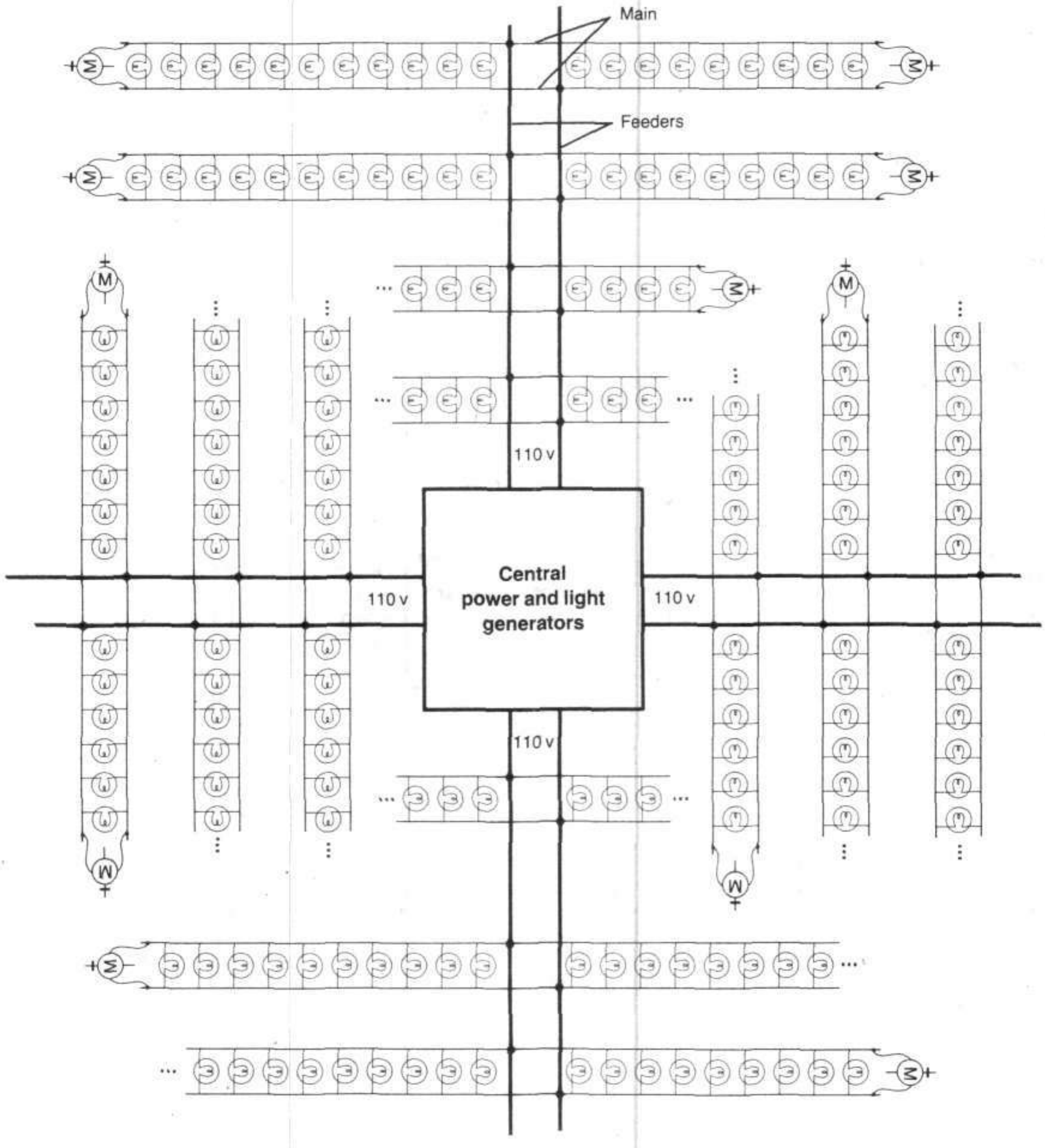


Figure 2
EDISON'S FEEDER AND MAIN ELECTRICAL DISTRIBUTION SYSTEM
Edison's innovative distribution system reduced the amount of copper necessary by a factor of 8 and delivered almost equal voltages to all peripheral locations. Instead of the conventional "tree trunk" design, Edison fed all locations with equal diameter cables called feeders, each connected to a main cable.

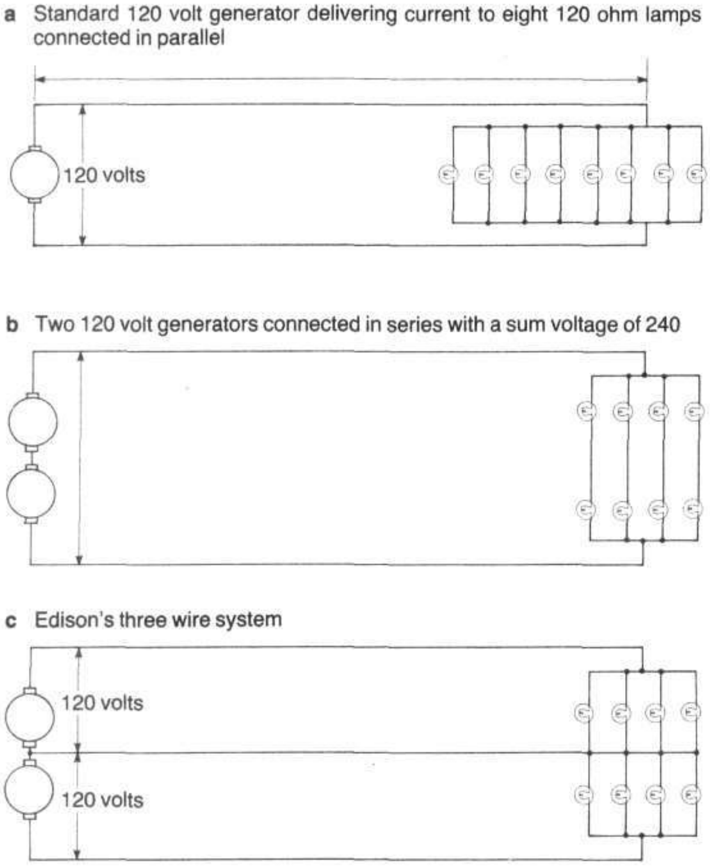


Figure 3
EDISON'S THREE WIRE SYSTEM
Edison further reduced the amount of necessary copper to feed a given number of lamps by his three wire system, shown in **c.** *Notice that the middle wire (neutral) can actually be smaller than the upper and lower feeder wires since it need carry currents only when the number of lamps in the upper and lower branches are different. In addition, Edison's three wire system enables individual lamps to be turned on and off without appreciably affecting any of the other lamps' light in intensity. The additional copper savings of the three wire system are minimally 25 percent, and in practice actually 30 to 40 percent.*

sold to the parent company at a fixed price of 80¢ each, even though the unit cost of production was then $1.21. In this way, the EELC royalty charge could be made larger while Edison was squeezed. A more serious threat to Edison's future was the EELC's refusal to grant his company exclusive manufacturing rights.

These beginning acts of the EELC were discounted by Edison as the typical "greediness" and animosity to manufacturing he had experienced before from Jay Gould and from other "Wall Street types." But this time he was better prepared. He planned to overcome the loss on lamps by optimizing the design to permit replacement of manual labor by mechanization; and within a short time the unit lamp cost was reduced to 50¢. As to the second threat, if it ever came to that, he would join the pirateers of his own patents and continue his manufacturing, using these and other patents he would devise before the EELC could stop him in court.

Edison hoped that this latter eventuality would never come to pass. He reasoned that the efficiency of his plants would be so great that other manufacturers would never have an opportunity to start. As to royalties, Edison foresaw such great profits from the central power stations that he would build throughout the country—and eventually the world—after the preliminary tests of a pilot system were completed, that there would be enough profits to satisfy even Morgan.

The Morgans, father and son, saw things differently. They wanted to keep Edison's manufacturing plants small and strapped for capital. They saw the central electric power stations as a dangerous threat to their gas industry investments, as well as dangerous encouragement for large industrial growth. They preferred electric lighting to be limited to the isolated plants that Edison had already begun to assemble in communities that were remote from gas mains, as well as in some factories and offices.

The successful Jan. 28, 1881 pilot tests indicated that electrical lighting was competitive with gas and that a central large-scale power and lighting system was the next order of business. Although the report had been kept secret, it was very much under discussion in the Morgan boardrooms in New York as well as in London. It was foreseen that the electrical utility would eventually replace gas lighting. The question that had to be decided was how it was to be financed and how soon.

From all indications available to the Morgans, Edison, if need be, would finance such a central light and power system himself by selling every one of his holdings in the parent EELC, and Upton and others would find the remainder of funds necessary. The Morgans' experience with the Edison Lamp Company had shown them that Edison would more than likely create a successful and profitable new enterprise, so that the profits from this utility and from those companies already organized by

Edison would eventually dwarf those of the patent holding company.

It was at this point that the Morgans sent Edison a new private secretary, Samuel Insull, recommended by Edison's London representative Colonel Gourand. The personable young Insull, formerly the private secretary to Gourand, arrived at Edison's New York office March 1, 1881, and was almost always at his side for the next decade. In addition to being Edison's private secretary, he had his power of attorney and was his financial consultant and general factotum to the various Edison organizations. It was through Insull that the Morgans expected to gain future control over Edison's manufacturing facilities.

The Pearl Street Station

Shortly after Insull's arrival, Edison was pleasantly surprised to receive the news that the directors of the parent EELC were committed to creating a utility company to generate and distribute power in New York City. With Morgan committed, Edison reasoned, there would be no problem with either money or city approval for laying cables in lower Manhattan, where Edison had already made a preliminary mapping for what he hoped would be the world's first central electrical power and lighting system, the Pearl Street Station.

Edison readily agreed to the terms that his attorney, the Morgan ally Lowrey, placed before him. The new company, the Edison Electric Illuminating Company, was funded in April 1881 by increasing the stock certificates of the parent company, and Edison was permitted to obtain additional certificates in the parent company by relinquishing 52 percent of the outstanding stock of the Edison Electric Railway Company, which he had recently organized. Edison was quite pleased with the exchange, since he had done little work with his electric railway. What he overlooked, however, was that the new stock reorganization diluted his percentage holdings in the parent company by approximately 21 percent, in favor of the Morgan interests.

Edison then expedited work on the larger dynamos, the Jumbos, that would be installed at the Pearl Street Station, and he made a formal application to the city for laying the distribution cables in the Wall Street area. The New York City aldermen were incredibly obstructionist. They demanded $1,000 per mile of cabling and 3 percent of all gross receipts by the lighting company. (The gas company paid only the normal city property taxes.) Edison's appeal to Lowrey and Morgan met with assurances that these "political matters" take time. As to funding for the new illuminating company, they indicated that money would not be available for months.

Meanwhile, Gourand telegraphed Edison that in London sources could immediately fund a central power and light utility in England. By happy chance, Sir William Preece, chief scientist of the British Post and Telegraph Service, had found an ideal location for the central station at Holborn Viaduct, which was within central London and yet could not be interfered with by pesky aldermen since it was on Crown land. Preece said that he would immediately approve connection of the Holborn Post Office to the central utility and purchase a few hundred Edison lamps. Reluctantly, Edison shipped to London the two Jumbo generators intended for the Pearl Street Station, along with lamps and other accessories, in the care of one of his most competent lieutenants, William J. Hammer.

At Preece's suggestion, Dr. John Hopkinson and J. Ambrose Fleming were hired as scientific consultants. "On-the-job trainees" would have been a better description. These two did a thorough study of Edison's system, including the fine segmentation of the armature to reduce eddy currents, the operation of two generators sharing an external load, and Edison's magnetic saturation of the field pole pieces. Soon afterwards, Hopkinson claimed the discovery of Edison's "three-wire system" and actually filed a British patent for what he called his invention! He also wrote scholarly works on armature segmentation to avoid eddy currents and claimed as his discovery the magnetic saturation of iron.

Although the British studied Edison's system diligently and fought for each scrap of patent priority that was not firmly nailed down, Parliament squelched any further growth in Britain's electrification. As Edison put it:

> This historic plant [Holborn Viaduct] was hurriedly thrown together on Crown land, and would doubtless have been the nucleus of a great system but for the passage of the English Electric Lighting Act of 1882, which at once throttled the industry by its absurd restrictive provisions, and which, though greatly modified, has left England ever since in a condition of serious inferiority as to development in electric light and power.[6]

A Policy of Delay

The political and financial climate for the planned Pearl Street Central Station improved considerably soon after Edison had committed the two Jumbo generators to the Holborn Viaduct plant in London. The New York City aldermen reduced their digging charges to $58.20 per mile, dropping all question of an income tax for the proposed utility, and Morgan discovered the necessary financial resources. Work on the Pearl Street Light and Power Station began in earnest. Despite Edison's commitment of maximum manpower and manufacturing resources, however, the Pearl Street Station did not become operational until September 1882, eight months after the Holborn Viaduct installation and a month or so after the first continental central electrical station in Milan, Italy.

The directors of the EELC were not distressed at this delayed development. As a matter of fact, their report of the Fourth Annual Meeting of the EELC acknowledged the past two months' successful operation of the Pearl Street Station serving 226 buildings and wired for 5,013 lamps, but showed much more concern with Edison's complaint "that the installation will be found to be too small . . . to enable us to furnish all those who wish to become our customers."[7] In response, the directors stated that "the policy of the board is to defer beginning work on the second building until the plant in the first building shall have been run and taxed up to its maximum."[8] They also expressed their peevishness at being pushed into the central lighting business:

> *There was a strong objection on the part of some of your board against changing the policy of our company from what it has always been, namely, that* of merely paying the expenses of experiment and taking out and holding patents and not of investing capital in the actual business of lighting.[9]

At the same time, the Morgan faction effusively praised Edison and made an offer to buy 40 percent of the stock of his manufacturing plants. This proposal, delivered to Edison by Morgan's partner, suggested that the EELC be given "a suitable interest in and large influence over the manufacturing business."[10] Edison's answer was "no." He understood from experience that by "large influence" the Morgan forces meant that they would slow to a snail's pace Edison's plans for the expansion of his manufacturing plants.

In the next two years, the major battle took shape between Edison and the Morgan faction on the EELC board. The board dragged its feet on expansion, while Edison pushed hard to move ahead. To goad Edison, the board complained that Edison's manufacturing plants were making large profits at the expense of the EELC, and they hinted that they were free to purchase lamps and other electrical parts from any manufacturers they chose. But wiser counsel within the Morgan boardroom suggested that the threatening tactics were counterproductive, simply goading Edison to more aggressive behavior. It was clear that Morgan needed Edison more than Edison needed him.

Looking ahead to fall 1884, when the EELC's five year contract for Edison's new electrical patents would terminate, Morgan saw that if he pushed Edison too hard, Edison would find independent capital support and would develop more advanced electrical patents than those held by the EELC. Edison would be able, therefore, to build central power plants throughout the world, free and clear of Morgan. Although anger was building within the Morgan boardroom, wiser counsel again prevailed. The EELC board staged a proxy fight and arranged it so that the independent proxy holders supported Edison. Morgan sent Insull to Edison with the good news that he had won a majority and that, therefore, Morgan supported Edison.

By this maneuver Morgan gained time and yielded nothing substantial. Lowrey was removed as the EELC counsel general for his role in leading the anti-Edison faction, replaced by S. B. Eaton, who was demoted from the EELC presidency. Two new Edison men, Upton and Batchelor, were added to the board; counting Edison, there were now four Edison men on a board of 13.

The Battle Continues

Morgan also agreed to desist from the more open sabotage of Edison's manufacturing plants and of the illuminating and isolated lighting companies—such as outrageous licensing fees, withholding payments for Edison's expenditures, and nonpayment of rent, thereby shifting the burden onto Edison and his individual companies. But Morgan would *not* extend credit to the manufacturing companies or to the lighting companies.

As long as Edison was effectively the only major manufacturer of this system, this posed no insurmountable difficulties. There were enough municipalities and towns that were prepared to raise the necessary capital for the installation and manufacturing costs of either central stations or isolated plants, and before 1885, the pirateering of Edison's patents was comparatively small, consisting mainly in the manufacture of Edison lamps behind the fiction that a prior patent of either the British Swan lamp or the American Sawyer lamp was being used.[11] For instance, the biographer of Elihu Thomson states that the Thomson-Houston lamps "were to all intents and purposes identical with Edison's except that they were protected by the patents of Sawyer."[12]

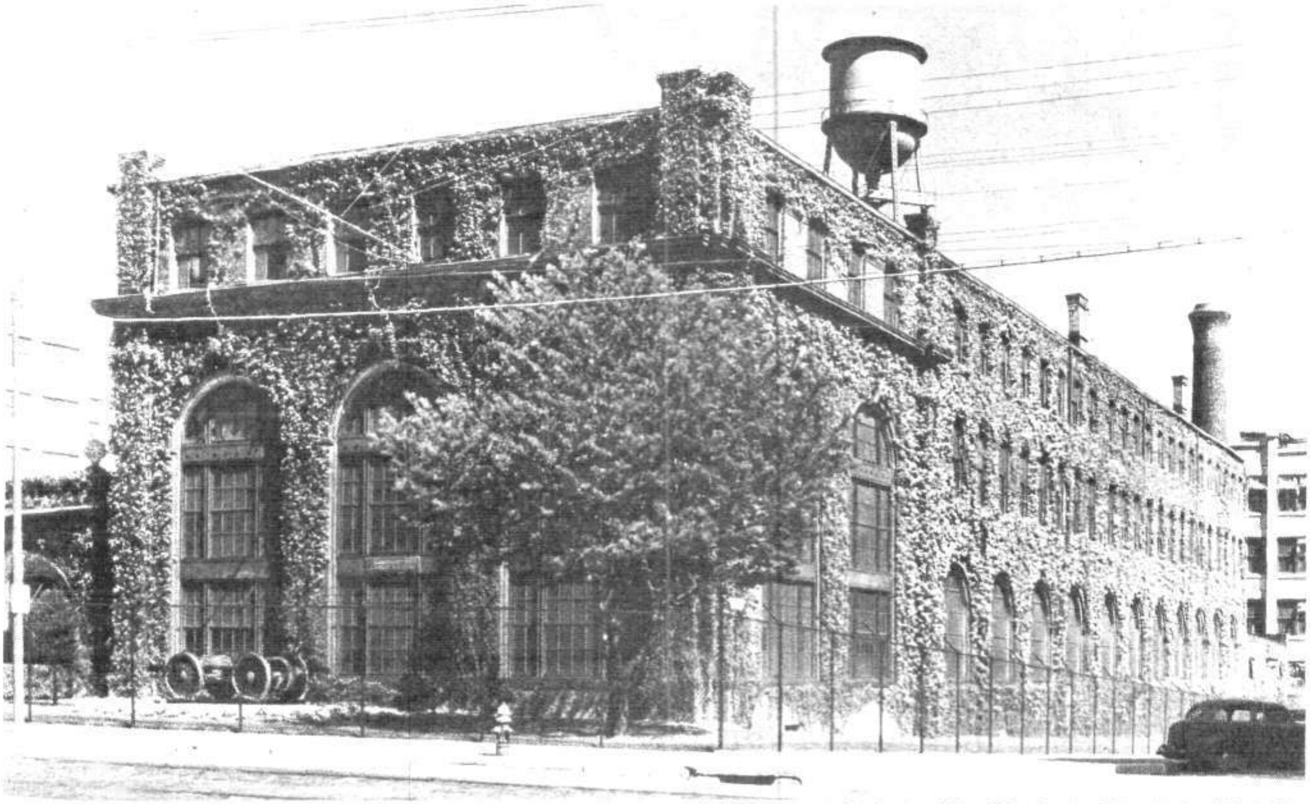
In 1885, however, after receiving an influx of money from Morgan-allied Boston banks, Charles A. Coffin, a shoe manufacturer, purchased the Thomson-Houston company and entered into open aggressive competition with complete electrical systems.[13] In many cases, Coffin overcame the advantage of Edison's name by offering copies of the Edison system in exchange for utility bonds that his customers, the municipalities and villages, would issue. Since Morgan refused to extend similar credit, Edison had to meet this competition by also accepting bonds in payment for his manufactures and installations.

In 1886, George Westinghouse, a successful inventor and manufacturer of railroad air brakes, obtained control of Sawyer's patent by purchasing the bankrupt U.S. Electric Light Company, and he entered the incandescent lighting field with this bald advertisement:

> We regard it as fortunate that we have deferred entering the electrical field until the present moment. Having thus profited by the public experience of others, we enter ourselves for competition, hampered by a minimum of expense for experimental outlay. . . . In short, our organization is free, in large measure, of the load with which [other] electrical enterprises seem to be encumbered. The fruit of this . . . we propose to share with the customer.[14]

Edison met these challenges by shaving prices and by improving manufacturing and operating efficiency. But Morgan's heavy hand still sabotaged Edison's efforts, with the EELC's 20 percent royalty tax on Edison's lighting companies. Edison met this handicap by increasing the scale of his operation, thereby further cheapening the price of manufacture and installation. This, in turn, forced a quickening of the pace of his rivals, so that in the brief period between 1885 and 1888, electrical light and power development took off at an exponential rate. At the end of 1888, Edison had installed 200 central lighting stations and 1,500 isolated plants, and Westinghouse and Coffin were not far behind.

Edison financed his expanded production and other activities primarily by selling more of his stock in the EELC and by taxing his manufacturing plants, which by 1888



U.S. Department of the Interior, National Park Service, Edison National Historic Site

Edison's 1887 laboratory, which he visualized as the center of "a great Industrial Works in Orange Valley," New Jersey. This main building, which housed the 10,000 volume library and machine shops, is now part of the Edison National Historic Site in West Orange.

were loaded down with almost $4 million in bonds that he had accepted in lieu of cash from purchasers of Edison electric lighting systems. In other words, Edison was financing the whole show. Obviously, this could not go on much longer.

A little later, Henry Villard, an associate of Morgan with German banking connections (and the likely source for Westinghouse's "pirateering" money), approached Edison with Morgan's suggestion that he compromise with Thomson-Houston so as to end the "fierce competition and low prices." Edison answered Villard with heat:

> The Thomson-Houston and the Edison Company can no more control the price than the tides. The Company with the best and cheapest machinery will do the business, patents or no patents. Fact is, Mr. Villard, that all electric machinery is entirely too high now. These high prices hurt the business. With the leaden collar of the Edison Electric Light Co. around me, I have never been able to show what can be done. The ground of cheapening has scarcely been scratched. Let us break the leaden collar and you will see a brainy competition that will show them what real competition is. . . . [Prices] must go down 50 to 75 percent lower than now . . . and we will make a great profit. . . ."[15]

Part of Edison's frustration came from Morgan's waffling on the question of patent priority. The EELC had officially decided to prosecute pirateers, but did nothing, thus encouraging Coffin, Westinghouse, and others to enter the industry as pirateers of Edison's patents.

Another source of tremendous frustration was the continuous campaign in the press on the dangers of electrical current.[16] This campaign was launched in 1888 with a letter to the editor of the *New York Post* by an electrician, Harold P. Brown, demanding that New York City outlaw the use of alternating current (AC) as hazardous to human life. The heated debate that followed pitted AC against direct current (DC) and included experiments subjecting animals to high voltages of both currents to test which current was more lethal. The culmination of this continuing front-page horror story was the multilation of a convicted murderer in an electric chair powered by a high voltage AC current. It was later learned that Brown and his campaign, which smeared the name of Edison as well as the new technology of electricity, were financed by Morgan and Coffin.

Edison's Achilles' Heel

By the time the grisly AC-DC debate came to its climax, however, Edison had retreated. To understand how Morgan was at last able to remove Edison from the scene, it is necessary to go back to the year 1884.

The period leading up to the October 1884 board meeting of the EELC and the negotiations with Morgan was one of great stress for Edison. In addition to his preparations to secure a large block of capital for expanded manufacturing as well as for the eventuality that Morgan would break his contract with Edison as the sole manufacturer of lighting products, Edison's wife, Mary, became seriously ill. Edison had to run from his many activities in New York to his Menlo Park summer home where the family had gone to be near Mary's sister.

On Aug. 9, 1884, Mary Edison died at the age of 29 from an unexplained illness. The distraught Edison made arrangements for his three children, sending his two sons to live with Mary's sister, who had married a foreman at the nearby Edison lamp factory, and sending his 12-year-old daughter, Marion, to a boarding school near his office in New York. Marion was a great comfort to him during these trying months. He would find excuses for taking her out of school to bring her along with him to his factories and even to meetings of the EELC board. At night he would take her as a dining companion and to the theater and opera.

During that turbulent fall, an old colleague, Ezra T. Gilliland, helped Edison fill some of the void in his life. Edison had met the fellow-telegrapher 20 years before in Ohio, and occasionally since then in chance encounters. When the annual EELC meeting in fall 1884 had finally formalized Edison's "victory" and he could draw a free breath for the first time in almost a year, he gladly accepted Gilliland's suggestion that he join him and his wife in their forthcoming March 1885 hunting vacation in Florida. Also on Gilliland's suggestion, they detoured first to New Orleans, where there was a World Industrial and Cotton Centennial Exposition.

U.S. Department of the Interior, National Park Service, Edison National Historic Site

Mina Miller Edison, his second wife, who in Edison's mind, was implicated in his betrayal by his dearest friend, Ezra Gilliland.

It was there that Edison met Lewis Miller, a retired manufacturer of farm machinery, and his 19-year-old daughter, Mina. The lonely Edison was immediately smitten. This chance encounter was, of course, nothing of the sort. Mrs. Gilliland had known the Millers in Ohio for many years before her marriage to Ezra,, and she and Ezra had "carefully planned" the meeting between Mina and Edison.

Edison asked Mina's father for her hand in marriage at the end of 1885, and they were married in February 1886. Edison then entered on one of his happiest periods. The Edisons spent their honeymoon in one of two houses he had built in Fort Meyers, Florida the year before (the other house was for his dear friends the Gillilands). He returned to New Jersey invigorated, and reestablished his entire family in West Orange, New Jersey. Then he threw himself into the midst of the activities of his manufacturing companies and other enterprises, including Ezra Gilliland's phonograph development, for which Edison had hired him. At that point, Edison so valued his close friendship with Gilliland that he referred to himself and Ezra as "Damon and Pythias."

Within a few months, Edison added to his friend's prospects by giving him the exclusive North American agency rights for phonograph sales at a 15 percent commission.

Edison's main thoughts then turned toward a vast new undertaking, the building of a research and industrial development laboratory in West Orange. This was to be a laboratory of grand design, dwarfing the Menlo Park Laboratory that had been abandoned a few years back. The new laboratory would have more than 60,000 square feet of floor space, with special conjoined buildings devoted to metallurgy, chemistry, and physics; a 10,000 volume library; a photography section; machine shops and fabrication equipment of every description; and stocks of every known material. Edison gave the laboratory his highest priority, and on its completion in summer 1887, he had spent more than $150,000 obtained from his shrinking EELC stock. He visualized it as the center "of a great Industrial Works in Orange Valley," noting that "the beauty of Orange Valley would be enhanced . . . by dot[ting] it with factories."

The payroll and other expenses for the new laboratory were a great financial burden on Edison, and he took personal charge of the phonograph redesign work as a potential source of quick capital for the West Orange Laboratory. Gilliland and his associate, Tomlinson, who had by then become Edison's attorney, as well as counsel to the EELC, were in negotiations with Jesse W. Lippincott for the sale of all U.S. rights to the phonograph, for which Edison hoped to obtain close to $1 million. Unknown to Edison, however, Gilliland and Tomlinson had made a deal to sell these rights for $500,000, while they took $250,000 under the table. Lippincott, who had obtained a bargain, was sworn to secrecy.

Edison was disappointed at the low figure, but since his dear friend and his personal attorney thought it was the best obtainable, he signed the agreement with Lippincott, just before Gilliland and Tomlinson left for England on an extended vacation.

On Sept. 10, 1888, a financially strapped Lippincott came to Edison and spilled the whole story. Initially, he said simply that he was strapped for cash and could not immediately fulfill his contract. But when pressed by Edison, the whole story burst out like a flood. Lippincott's agreement with Gilliland and Tomlinson was to pay them out the $250,000 in $50,000 installments. But their insistence on more and more installments over the past few weeks left him short of cash. Lippincott affirmed his obligation to Edison, but it would take time. As Edison listened to the bumbling Lippincott, his own world fell apart. He was betrayed by his dearest friend, a betrayal which, in his own mind, also implicated his young bride.

Morgan was waiting. Edison sold his manufacturing plants at a fraction of their true value and received nothing for the $4 million in bonds on installed central and isolated power systems.[17] Then he retreated to the refuge of the Musconetcong Mountain, where he spent a good part of the next decade attempting to extract iron ore by rock crushing and magnetic separation. He worked through all weather conditions and many times did not come down from the mountain for weeks at a time, even though his home and his laboratory in West Orange were less than four hours away. Edison told a reporter who had come up the mountain to inverview him: "I never felt better in my life than during the five years I worked here. Hard work, nothing to divert my thoughts. . . ."

But Morgan's victory in this final battle with Edison gave him no great joy, for he had lost the war. Despite Edison's removal from effective leadership, his strategic policy had by then catalyzed a worldwide industry, including General Electric and Westinghouse, that moved with an increasing momentum of its own. Edison's forced march of the electrical industry had also developed a generation of leading scientists and engineers, many of whom had begun their work under him, and had introduced whole new technologies, including alternating current transmission, radio communication, and electronics.

U.S. Department of the Interior, National Park Service, Edison National Historic Site

Edison in 1895 during his 10-year retreat to Musconetcong Mountain, where he worked on ore extraction and milling.

Epilogue

As the 50th anniversary of Edison's electric system approached in 1929, honors for him were initiated by many of the world's nations, including the Soviet Union and Japan, until finally the U.S. Congress was shamed into belatedly awarding him the Congressional Medal of Honor.

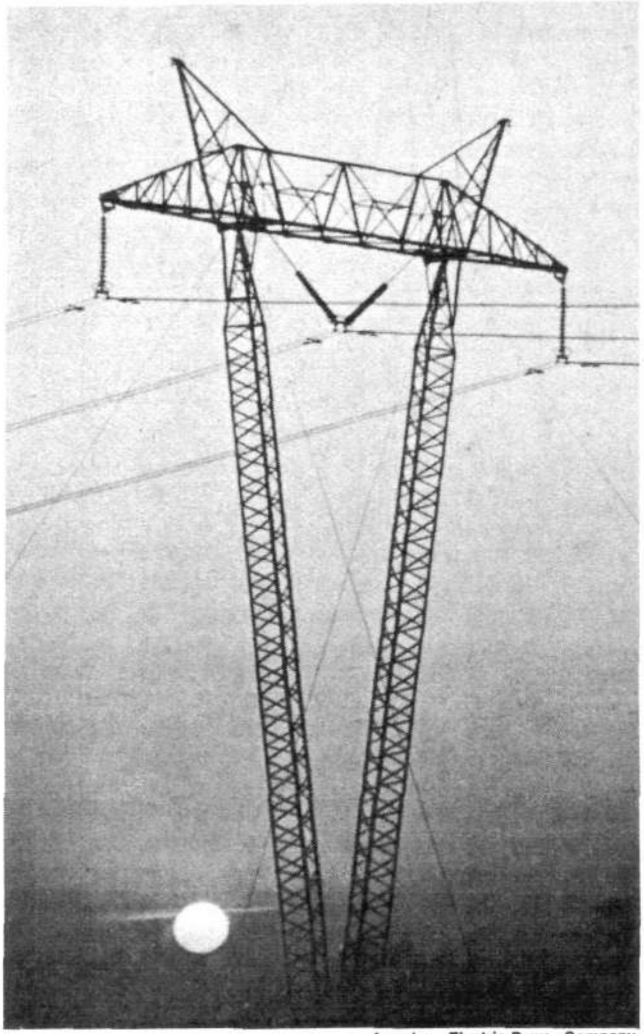
When it became known that some anniversary festivities were planned, the General Electric Company pushed itself into center stage with its program for the "Light's Golden Jubilee," against the wishes of Edison and Henry Ford. Ford was just completing the reconstruction of Edison's Menlo Park Laboratory at Greenfield Village in Dearborn, Michigan, as a gift of affection and respect for his friend. A compromise was struck in which General Electric's "Light's Golden Jubilee" program would be presented at Greenfield Village, rather than at General Electric's headquarters in Schenectady, New York.

Many world political and scientific leaders, including President Hoover and Madame Curie, attended the jubilee to give homage to the lamp's creator. On the evening of Oct. 21, 1929, Edison went through the process of "re-creating the lamp" in an emotional historic event that was broadcast and heard around the world:

> The lamp is now ready, as it was a half century ago! Will it light? Will it burn? Edison touches the wire.
>
> Ladies and gentlemen, it lights! Light's Golden Jubilee has come to a triumphant climax!

General Electric's public relations spectacular was so successful that hardly anyone noticed that Edison's generator and distribution system was not mentioned.

This blackout on discussing Edison's scientific breakthroughs that led to large industrial developments goes back to the 1880s, when the Morgan-dominated American Institute of Electrical Engineers (AIEE) was formed in 1884. Some of the early AIEE presidents included Norvin Green, a former president of Western Union; Elihu Thomson, one of the Coffin pirateers; Edward Weston, who characterized Edison's generator claim as something of a



American Electric Power Company

Edison's indispensable role in creating and organizing central light and power systems has continued to be blacked out of the scientific literature, and was even blacked out of the celebration of the light bulb's centennial in 1979. Edison's recent biographers have taken delight in demeaning him as a scientist and inventor.

"perpetual motion machine"; and Franklin L. Pope, who published attacks on Edison's entire system at every opportunity. Although Edison, one of the 25 founders of the AIEE, served as a vice president during its first year, he was dismissed from office while Pope was president in 1885 for "nonattendance of meetings."

The influence of this anti-Edison grouping was so pervasive that by 1910 no textbook in electric power engineering referenced any one of Edison's 85 generator patents. Today, the blackout is rationalized by many would-be honest scientists and historians with statements such as: "Edison did not really invent the generator or distribution system. It existed long before he entered the field." This argument is tenable, however, only if one ignores Edison's new conceptions of a minimum impedance generator feeding a relatively high impedance load through an efficient distribution system.

Edison died on Oct. 18, 1931. Again, he was honored with testimonials from many nations, including one from the Czechoslovakian National Committee of the International Electrotechnical Commission that proposed Edison's name be assigned to an electrotechnical unit. Whether the U.S. National Commission responded to the Czechoslovak initiative is not known, nor are the responses of other U.S. scientific and technical bodies known.

The Centennial of Light

The 100th anniversary of Edison's electric power system was again hidden, this time under the banner of "The Centennial of Light." A centennial news release in February 1979, for example, lists "Edison's most significant inventions," but none of Edison's 86 electrical generator inventions or his 40-odd electrical distribution system inventions made the list. Even worse, the 1979 centennial superseded the maudlin hypocrisy of the jubilee with outright attacks on Edison and science in general.

For example, the research arm of the electrical power industry, the Electrical Power Research Institute (EPRI), the inheritors of Edison's largesse, allowed the question "Science and Technology—Gone Far Enough?" to dominate its centennial symposium in San Francisco, and most of the invited participants answered this question with a resounding "yes."

The Institute of Electrical and Electronic Engineers (IEEE), the successor organization to the AIEE, celebrated the centennial in similar spirit. The February issue of the IEEE magazine, *Spectrum,* featured an article on Edison by Christopher S. Derganc, whose major conclusion was that "Edison as a systems engineer . . . located, assimilated, and synthesized mainly other people's state-of-the-art scientific inventions and then manipulated experts Lowrey and Upton to bring his system into being."

The Power Engineering Society of the IEEE also sponsored a symposium titled "Thomas Alva Edison: Magician, Electrician, or Engineer?"[18] This event had as its featured speaker Robert Conot, author of a scurrilous and dishonest biography of Edison, *A Streak of Luck.*[19]

Similarly, the annual meeting of the American Association for the Advancement of Science in January 1979 included an Edison symposium panel featuring Conot and Derganc. The AAAS magazine, *Science,* celebrated the centennial by publishing a featured article whose subtitle was "It Is the One Hundredth Birthday of the Light Bulb, and Some Britains Say That Edison Did Not Invent It." Just as egregious, *Science* editor, Philip H. Abelson, noted that *Science*'s "Principal financial backer was the controversial Thomas A. Edison . . . a successful inventor whose flamboyance was offensive to some scientists."

The pervasive demeaning of America's greatest industrial scientist has even penetrated the Edison National Historic Site in West Orange, New Jersey. Among the Edison memorabilia, there are eight films offered. The first film in the brochure is advertised as follows:

> *The Wizard Who Spat on the Floor*
> Presented by the British Broadcasting Co. . . .
> The film reviews Edison's life, successes and failures,

and portrays him as an individual who chewed tobacco, spat on the floor, and made use of the knowledge of others to make his inventions practical.

There has been just one centennial tribute to come to my attention that gave Edison some measure of his due. This is the warm tribute in the February 1979 journal of the International Brotherhood of Electrical Workers (IBEW). Charles H. Pillard, IBEW president and a member of the International Committee of the Centennial of Light, wrote:

> The IBEW can directly attribute its existence to Thomas Edison's inventions. The Centennial Year offers all of us an opportunity to proclaim the benefits of technology and to emphasize the fact that the world's problems will continue to require technological solutions.

What are we to make of the frenzied, almost hysterical, attacks on Edison during the centennial of his electrical system? Is it not the fear of the modern Morgans that despite their 100-year efforts, Edison is still respected and loved by the majority of the American people and people throughout the world? Is it not the fear that the engineers, the scientists, the industrialists, the machinists, and the other skilled working population will choose Edison as a model, and, to use Edison's words, "break the leaden collar" of today's anti-industrialists and so bring a truly human existence to mankind?

Michael Tobin is an electrical engineer with 30 years' experience, specializing in electronics instrumentation and communications technology. This article is adapted from a longer biographical paper on Edison.

Notes

1. Mary Nerney, *Edison: Modern Olympian* p. 64.
2. As Edison knew at that time, their fears regarding the future of the gas industry were groundless, but he kept this to himself since he did not want to slow down the agitated motion within the financial community. Edison's Laboratory Notebook No. 184 contains his insight that the gas industry, upon being driven from indoor lighting by the more efficient electric lamp, would find a more suitable and profitable field in gas range cooking and indoor heating.
3. Morgan's action was undoubtedly influenced by an Oct. 25 cable from Baron S. M. Rothschild of Vienna to his New York representative, August Belmont, that "It would greatly interest me to learn whether really there is something serious and practical in the new idea of Mr. Edison. . . ."
4. Francis R. Upton, Memorandum, 1909, pp. 2-3, (Edison Historic Site, West Orange, N.J.).
5. Testimony of Thomas A. Edison, U.S. Circuit Court of the Southern District of New York, Vol. IV, p. 2,570 ("The Edison Filament Case").
6. Frank L. Dyer, Thomas C. Martin, and William H. Meadowcroft, *Edison: His Life and Inventions,* (New York: Harper & Brothers, 1910), p. 336.
7. *The Bulletin of the Edison Electric Lighting Company,* Fourth Annual Report, Oct. 24, 1882, p. 240 (Edison Historic Site, West Orange, N.J.).
8. Ibid.
9. Ibid., p. 235
10. *Edison Electric Lighting Company Report of the Committee of Three* (to negotiate with Edison), June 18, 1884 (Edison Historic Site, West Orange, N.J.).
11. William E. Sawyer had built a carbon incandescent lamp before Edison, but the characteristics of Sawyer's lamp—a low impedance filament within a nitrogen environment—accounted for its impracticality.
12. D. D. Woodbury, *Beloved Scientist Elihu Thomson*, p. 157.
13. Elihu Thomson and Edwin J. Houston were Philadelphia scientists who had been critical of Edison's work beginning with his "Etheric Force" thesis that the sparking he had observed (in 1875) was something "more than induction." In 1880, they called his generator lamp system claims fraudulent.
14. "A Warning," a pamphlet prepared by the Edison Electric Lighting Company documenting the piracy, 1887 (Edison Historic Site, West Orange, N.J.).
15. Matthew Josephson, *Edison, A Biography,* (New York: McGraw Hill Book Company, Inc., 1959), p. 360.
16. Even today it is alleged that Edison rejected AC current because it was beyond his comprehension. An examination of Edison's work in telegraphy and telephony, his work with electrical generators, and his correspondence on AC more than adequately refutes this fabrication.

    Long before the AC transformer had been thought of, Edison had considered the desirability of high voltage transmission as a means of delivering low cost electricity to remote locations. Edison did not introduce AC in 1886 because it would have placed the existing central stations, in particular, in great jeopardy. The standards for conductor insulation were adequate for 110 volts DC, but inadequate for 110 volts AC. The peak to peak voltage of a 110 volt AC system is actually 311 volts, which, for the already installed street cabling and house wiring, posed serious fire hazards. Also, in 1886, an AC motor had not yet been developed. Edison's electrical system had been conceived from the very first as an integrated lighting and power system. To use AC in 1886, Edison would have had to forget the power part of his system, the DC motors, which were already installed in elevators, factories, and electrical railroad engines.

    Edison lost control of his manufacturing plants before he could implement his all-DC transmission design. However, modern practice has confirmed Edison's judgment that high tension DC transmission was a viable, efficient solution to the problem of moving larger quantities of electrical power.
17. When Edison made a gift of these bonds to Morgan, his financial adviser Samuel Insull did nothing. Why? My working hypothesis in this brief history of Edison was that those who became his associates by way of Morgan should be tentatively considered as spies. Of course, there was the additional caution that their activity against Edison's interests must be demonstrably shown. Within this discipline, agents such as Griffin, Gourand, Johnson, and others were easily identified. Upton was an exception who broke with Lowrey and Morgan and loyally supported Edison in all his activities. Insull posed a great difficulty; there was nothing that he did as secretary or as financial adviser to Edison that identified him as an agent working against Edison. It was only when I began examining how the pirateers financed their activities that Insull's treachery became clear. His crime was that he did nothing, absolutely nothing to sell the $4 million worth of bonds that Edison held in 1888 on already installed electrical systems.

    There are some readers who may not know that Samuel Insull went on to develop a large electrical complex in Chicago and created the billion-dollar holding company that crashed in 1929. In 1888, it would have been a simple matter for this financial wizard to float debentures on these "good-as-gold" utility bonds with the additional aura of "installed by Edison." This is what the pirateers did without the Edison name. Because Insull did nothing, Morgan was able to buy out Edison at a fraction of value and throw him out of the industry.
18. When I learned of this proposed symposium and its participants, I wrote to the chairman of the Power Engineering Society history committee, the organizer for this meeting, stating that the choice of speakers was unbalanced and I suggested that he fit me in as a panelist. I was assured that the panel was "well-balanced," and that the program was already too long.

    When I rose from the audience to comment at the end of the presentations, the chairman officially closed the meeting. Nevertheless, I spoke briefly but with heat, while the panelists and audience remained seated.

    There seem to be other serious lapses of judgment within the Power Engineering Society. When the Centennial Commemoration of the Pearl Street Station in 1982 awarded a medal for outstanding work in power engineering, the medal given was called the Tesla medal, not the Edison medal!

    It should be noted that the IEEE magazine *Spectrum* published my extensive critique of Derganc's work.
19. My review of Conot's book appeared in the May 1979 issue of *Fusion*. This nasty book merited two reviews in the *New York Times,* both laudatory. Reviewer John Leonard wrote on Feb. 17, 1979 that Edison was "a louse" and Conot "is in no way trying to cut Edison down." John Brooks wrote on Feb. 25, 1979 that "Thomas Alva Edison's beliefs and habits were those of a crackpot and a bum. . . . He was the quintessential predatory man. . . . Mr. Conot is right to credit him with a Faustian soul."

The X-Ray Laser

President Reagan, in an historic March 23 speech, proposed to use a layered defense system to render intercontinental ballistic missiles "impotent and obsolete." Most strikingly, his proposal referred to a completely new technology—the X-ray laser—to solve the hardest problem of defense against intercontinental ballistic missiles (ICBMs).

In motivating his speech, Reagan summarized the most striking feature of the past decade's military balance: the development by the Soviet Union of a preemptive strike capability and the unilateral renunciation of defensive capabilities by the United States with a strategic military predicament in which its nuclear arsenal is irrelevant to international political power: too small to destroy Soviet silos, too vulnerable to be a deterrent; and too unreliable to be launched on warning.

As many of the President's advisors point out, a new generation of *offensive* weapons does not redress this vulnerability; it only intensifies the push toward a first-use, "use them or lose them" dilemma.

The only way out of this dilemma is a *defensive* capability that neutralizes these offensive weapons.

As it has been elaborated since the President's address to the nation, the Reagan proposal in its final deployment would consist of:

(1) a boost phase intercept capability using space-based lasers of short wavelength and very high power, such as the X-ray laser;

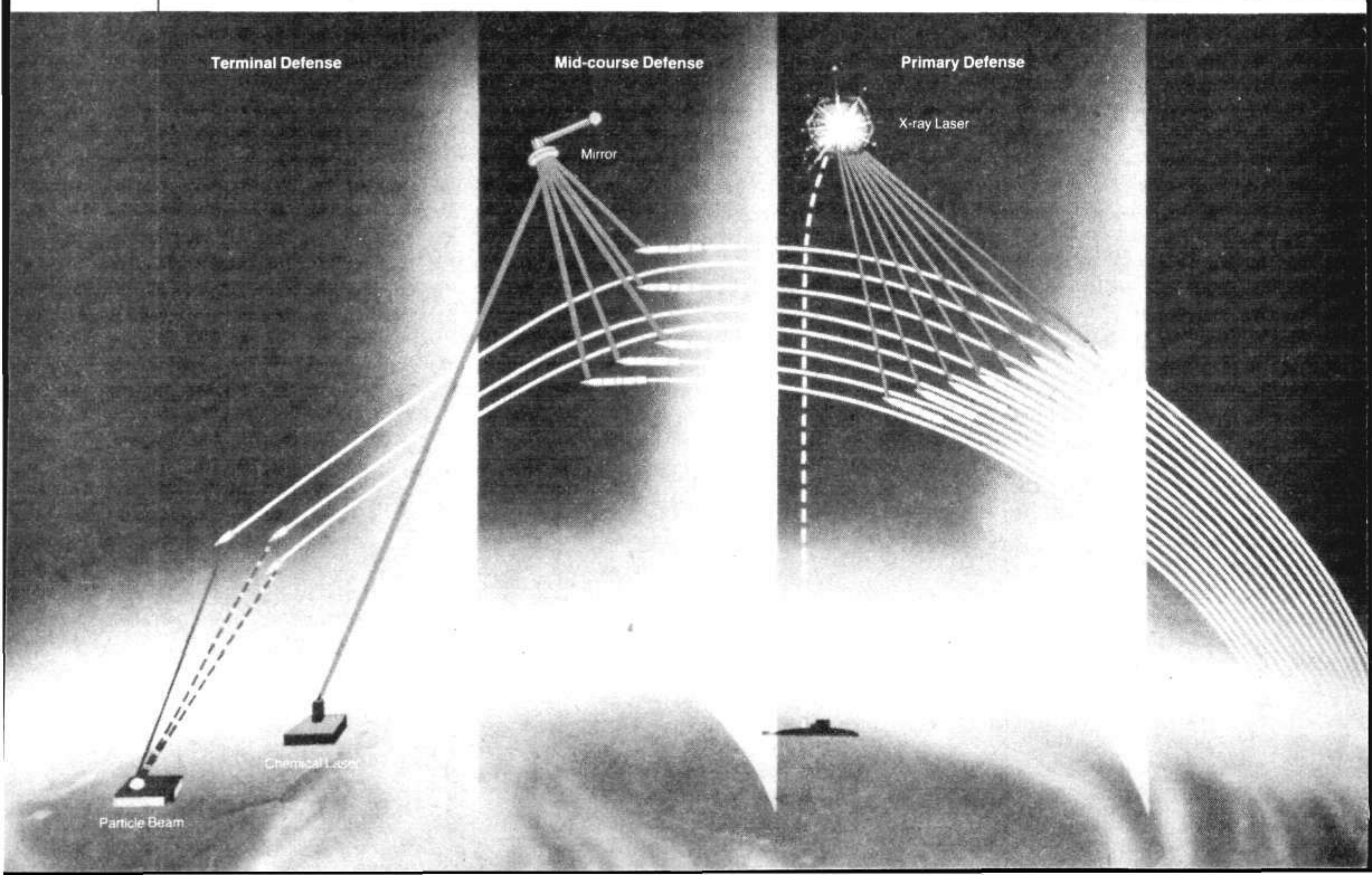
(2) a boost-phase or bus-phase intercept capability using space-based or hybrid (either space-based mirrors and land-based lasers, or space-based free-electron lasers) systems;

(3) a terminal system using particle or projectile beams.

Figure 1 shows this three-phase layered defense system and the table (page 36) summarizes the properties of these three layers.

The criteria that any such defense system must achieve are simultaneously ones of damage-limitation, offense-denial, and a psychological goal requiring the generation of sufficient uncertainty in the military calculation of one's adversary to prevent its deliberate offensive use of ICBMs. Together these criteria require a cumulative capability of destroying more than 99 percent of the adversary's *warheads* in an attack. This percentage would ensure protection of the vast majority of targets, as well as the creation of the objective result that a first-strike would be equivalent to self-disarmament.

It is unlikely that any single technology could be counted on to assure that defense. However, a set of complementary, qualitiatively different systems can achieve that rate of



by 1986!

by Dr. Steven Bardwell

destruction of nuclear weapons with maximum assurance, if each layer has a unique technology, deployment mode, and engagement strategy.

Boost-Phase Intercept

It is clear from the table that the objectively new ingredient in the problem of ballistic missile defense is the technology that makes boost-phase intercept possible—the ability to destroy a large fraction of the incoming missiles while they are still in the "boost" or powered flight stage of their trajectory. This phase, taking up about 5 minutes of the 30-minute flying time for an ICBM, is the missile's most vulnerable stage: It is slow moving, under great mechanical stress, and contains all its nuclear warheads.

An adequate defense against nuclear weapons is possible only when this boost phase intercept problem is solved. Thus, until the development of the beam weapon concept, there was no viable proposal for boost phase intercept of ICBMs: The beam weapon is designed to destroy ballistic missiles using a ray of energy generated on a space-based platform many thousands of miles from the missile's launch site and traveling at the speed of light, to incinerate the missile as it is launched. As little as three years ago, even the phrase "directed energy beam weapon" was classified by the U. S. government; today these technologies are widely recognized to be the centerpiece of ballistic missile defense.

As long as the defense can only intercept reentry vehicles, only a very limited point defense is possible (of the sort contemplated in the original U.S. plans for the Safeguard antiballistic missile program, for example), and the arithmetic of one or two defending warheads for each offensive warhead is very disadvantageous to the defense. However, with the ability to destroy many (10 to 50) ICBMs with a single warhead (a nuclear-pumped X-ray laser satellite, for example), the arithmetic changes from 2 to 1 against the defense to 300 to 1 in favor of the defense. Ironically, with the development of beam weapons, the MIRV (multiple independently targetable reentry vehicle) tactic of putting many warheads on a single booster, which so effectively saturates terminal defense systems, now works against the offense, since the destruction of a single ICBM disables many warheads. The X-ray laser concept and its scientific proof-of-principle demonstration over the past two years is the central new feature of a ballistic missile defense system.

This X-ray laser technology combines small size and weight (a result of the inherent efficiency of nuclear pumping), with relatively low cost and a wide range of deployment modes. Current thinking is that the X-ray laser layer of the system would consist of one component (with perhaps 300 satellites) permanently based in low-Earth orbit. These satellites would be vulnerable to antisatellite destruction (although this danger is minimized by the small size and large number of the satellites).

This component would be complemented by a "pop-up" capability of another several hundred satellites, which would be based on submarines, on land near the Soviet Union, or in the continental United States, and would be launched into low-Earth orbit on warning.

Figure 1
TOTAL DEFENSE IN THREE STAGES

Experts agree that no single antimissile system can be 100 percent effective against ballistic missile bombardment. But, by combining three different systems, each with 90 or 95 percent effectiveness, a total system can be built that provides almost complete protection against ballistic missiles. The first layer must destroy 90 percent of the missiles as they are launched. This space-based system might be launched as soon as the missiles are detected (as shown in the figure) or might be permanently based in space. An X-ray laser station is shown here. The second stage has only to deal with the 10 percent of the remaining missiles, a more modest role of which a space-based mirror and ground-based optical laser would probably be capable. The third, terminal, stage of the system would be a ground-based particle or laser beam designed to intercept the warheads themselves, after they had been released from the ICBM. Because only 1 percent of the original targets would be left after the protection of the first two layers, the last stage can be more expensive and complex, as a particle beam would be.

Christopher Sloan

How Soon?

In an interview in the *Washington Times* on June 14, Presidential science advisor George Keyworth commented on the ballistic missile defense system proposed by President Reagan: "These programs are a lot closer than people think. . . . All the components already exist—we simply have to assemble them."

This striking assessment is confirmed by a new analysis of X-ray laser technologies recently completed by the Fusion Energy Foundation. Based on extensive discussions with leaders in the American physics community and experimentalists in several foreign countries, FEF researchers have concluded that the "state of the art" in X-ray lasers is very far advanced, not only justifying Keyworth's statement, but making development and initial deployment of X-ray lasers possible within the next three years.

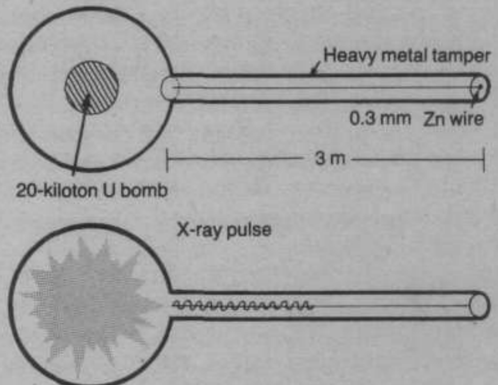
There are three independent indications pointing to the near-term feasibility of an X-ray laser antiballistic missile (ABM) system.

First, scientists at Lawrence Livermore National Laboratory in charge of the X-ray laser system have repeatedly hinted that the scientific and engineering progress has been so rapid that they expected to "present the next President" with a working system for ABM defense. In several conversations they have emphasized that chemical laser-mirror systems are *irrelevant* because the X-ray laser will be deployable *sooner* than a chemical laser system. Apparently, this confidence has been conveyed to Congress as well, because for the past two years, Congress has redirected the U.S. beam technologies research program increasingly toward "short wavelength" lasers—a code phrase for X-ray laser systems.

Second, three independent reports have circulated of very successful tests of different components of the X-ray laser. The first of these appeared in a February 1981 article in *Aviation Week & Space Technology* and was corroborated by a Soviet analysis of this material published in English.[1] This report is not a "leak" in the usual sense. It is known to have been based on detailed written experimental data from the U.S. Dauphin test, which demonstrated the scientific proof of principle of the X-ray laser. Reportedly, this test was so much more successful at producing a monochromatic, collimated beam of X-rays that the diagnostic equipment installed for the experiment was vaporized by the pulse of X-rays. There have been two subsequent reports of tests, one of the sensing and pointing system for an X-ray laser, and the second for other components of the system. One of the great virtues of the X-ray laser is that its small size makes possible separate testing of the sensing and power technologies.

A Layered Beam Weapon Defense System

Layer	Basing	Technology of Choice	Range (km)	Target Stage	Number of Targets
First	Near Earth	X-ray laser	3 to 5,000	Boost phase	5000
Second	Near Earth or hybrid	Chemical or free-electron laser	1,000	Boost or bus phase	300 to 500
Third	Terminal (point)	Particle or projectile beams	100	Reentry vehicles	500



Zn plasma, 10^6 degrees, 10^9 Å/cm² photo current along axis of rod

Figure 2
CONVENTIONAL X-RAY LASER DESIGN

In the public literature, an X-ray laser is envisioned to use an exploding atomic or uranium bomb to generate broad spectrum of high energy X-rays. This bomb, exploded in a spherical cavity, irradiates the ends of the lasing rods surrounding that cavity. When the X-rays from the bomb ionize the solid-state lasing medium, they produce a pulse of collimated, monochromatic X-rays that travels down the rod.

There are two obvious and well-known difficulties with this design. First, it is inherently inefficient because only a small part of the X-rays from the bomb actually intercepts the end of the rod. Second, the rods provide only geometrical focusing for the beam and so produce an X-ray pulse of large diversion.

Third, the significance of these tests has been misestimated by the scientific community not privy to classified data because of the obvious engineering problems of the published designs of a nuclear-pumped X-ray laser. These problems, noted by critics of the X-ray laser, are as follows:

Energy output efficiency. The reported pulse energy of the first experiment was 1 megajoule. For a workable near-term system, an increase in energy of two or three orders of magnitude would be necessary. The problem concerns the inherent inefficiency of the designs described in speculative reports on the device. These designs all showed that only a very small amount of the pumping energy released by the bomb energy could be used, which provided a geometrical limitation on the efficiency of the device that is the result of the small area that the lasing medium subtended at the active surface of the device. (See Figure 2.)

Beam divergence. Since the only known focusing mechanism for collimating the beam was the geometric one of having a very small diameter rod (really a wire) of several meters in length, increasing the area irradiation of the rod meant increasing the beam spread. There is a fatal tradeoff between these two requirements: A brightly focused beam would be of low power and a high power one would be spread over a large area.

Pointing. The pointing difficulty of the X-ray laser of pulse energy in the range of the first test is roughly the same as with a chemical laser system, a challenging task that itself would require about several years. However, if the power could be increased by 100 to 1,000 times, the pointing accuracies would be relaxed sufficiently that the pointing would become within *present* technological capabilities. That is, there is a similar tradeoff between pointing difficulty and energy. Low energy systems conceivable now require very severe pointing accuracies, but the high energies necessary to relax this accuracy seem unattainable with the design in Figure 2.

A Hypothetical Design

Based on discussions with a large number of physicists involved in weapons and inertial confinement fusion research work, the FEF has proposed a design for the X-ray laser that shows that each of the problems listed above can be solved with technologies well known in the weapons field. In fact, these technologies already form the basis for the current generation of "advanced" nuclear weapons.

Figure 3 shows a geometric configuration for the X-ray laser that uses present bomb technology to completely solve the inefficiency inherent in Figure 2. By using X-ray focusing mirrors as shown, the whole pump energy is focused on the lasing medium. These ellipsoidal cavities are a standard component of small, efficient nuclear weapons. This design also removes the tradeoff between accuracy and efficiency, using two physical principles to focus the beam, with reasonable rod dimensions. The result is a beam 20 microradians in divergence, giving dramatically lower requirements for pointing accuracies.

The configuration of lasing medium shown uses a hyperbolic horn at the inside surface of the rod, which focuses the X-rays reaching the rod into a one-dimensional flux of radiation. This radiation in turn produces a zinc plasma and an intense photocurrent. The combination of the photocurrent, its magnetic field, and the inertial effects of the heavy metal tamp, produce focusing beyond that provided by the geometric focusing of the lasing medium itself. Thus, a rod with larger diameter (hence more stable and able to contain more energy) can be used. The technologies involved in the construction of these focusing horns, the tailoring (or filtering) of X-radiation, and the use of intense photocurrents are all standard components of recent generations of nuclear weapons.

This design shows that once the scientific principle of the lasing has been demonstrated (which it was two and a half years ago), it is only a question of known bomb technologies combined with communications and control capabilities that remains to be answered.

Two conclusions follow from these facts:

First, the United States is very close to the deployment of an X-ray laser. This is the significance of Keyworth's June 15 interview. The first deployment would seem to be possible within the next two to three years.

Second, the technologies required for this deployment are those in which the United States is well known to be ahead of the Soviet Union. This is true, for example, concerning the construction of small efficient nuclear weapons. In an ironic turn, the large heavy hydrogen weapons of the Soviet Union are inappropriate for generalization to X-ray laser pumping. The small efficient bombs that are the focus of U.S. R&D use precisely the focusing, filtering, and materials technologies required for X-ray lasers.

This is also true for the command and control demands on the X-ray laser, which require computer and communication capabilities in which the United States has excelled. The industrial base for the software and hardware required for these lasers is in advance here of that in the Soviet Union.

The dilemma facing the Soviet Union is not, of course, that it is impossible for them to develop an X-ray laser in space; with diversion of enough manpower, money, and capital goods, they might succeed on approximately the same time-scale as the United States. However, it is the case that U. S. development of the X-ray laser definitively reverses the present vulnerability and puts the initiative on the American side. The X-ray laser is American technological genius applied to America's greatest strategic asset: its ability to make dramatic, qualitative technological leaps. This is the basis for real national security.

Steven Bardwell, a plasma physicist, is editor-in-chief of Fusion.

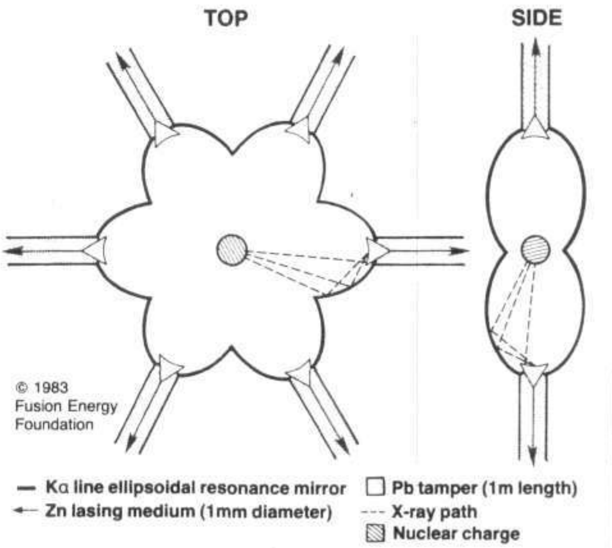


Figure 3
HYPOTHETICAL X-RAY LASER DESIGN

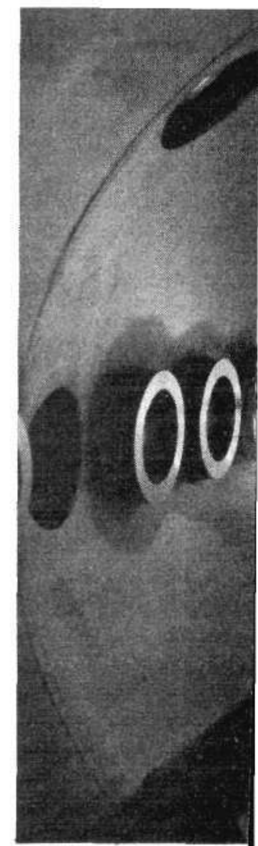
By combining several techniques well known in the construction of advanced nuclear weapons, it is possible to solve the problems of the inefficiency and large divergence of conventional X-ray laser designs. First, the X-rays from the bomb blast can be focused using a set of ellipsoidal cavities. These cavities, using multilayered K-alpha dielectric mirrors, focus all the X-rays from the spherically symmetric explosion on to the ends of the rod. These rods use a conical assembly of lasing material to further focus the plasma produced by the X-rays along the axis of the rod.

The lasing medium itself is embedded in a heavy metal tamper. This tamper provides mechanical stability as well as an inertial focusing of the lasing medium. In addition, a very intense photoelectric current generated by the X-rays in the lasing material confines and focuses the X-ray producing plasma. These techniques increase the efficiency of the conventional design by 2 to 3 orders of magnitude and decrease the divergence of the beam by perhaps a factor of 10.

Notes

1. Clarence A. Robinson, Jr., "Advance Made on High-Energy Laser," *Aviation Week & Space Technology*, Feb. 23, 1981, p. 25. The Soviet report appeared in July 1981: F.V. Bunkin, et al., "Specifications for Pumping X-ray Lasers with Ionizing Radiation," *Soviet Journal of Quantum Electronics*, 11:7, p. 971.
2. The author gratefully acknowledges many valuable discussions with F. Winterberg, as well as his book, *The Physical Principles of Thermonuclear Devices* (New York: Fusion Energy Foundation, 1981).

New Los Alamos Breakthroughs Point to Compact, High Density Magnetic Fusion



by Charles B. Stevens

Los Alamos National Laboratory scientists have achieved a series of experimental breakthroughs with their compact toroid and reversed field types of magnetic fusion systems, including the zeta pinch. Taken together with similar types of magnetic fusion research going on in plasma laboratories throughout the world and, in particular, in Japan, these results constitute the most significant advance yet achieved in fusion technology and science.

The experiments indicate that magnetic fusion devices such as the spheromak can become self-sustaining at high densities, thus making possible an ideal fusion reactor that burns advanced fusion fuels efficiently at an extremely low capital cost.The impact of the Los Alamos breakthroughs are threefold:

First, the Los Alamos developments have immediate theoretical and practical implications for all the various approaches to harnessing magnetic fusion energy, for the development of directed energy (laser, particle, plasma, and hypervelocity projectile) beams, and for the technology of pulsed power, which is essential to both fusion and directed energy systems.

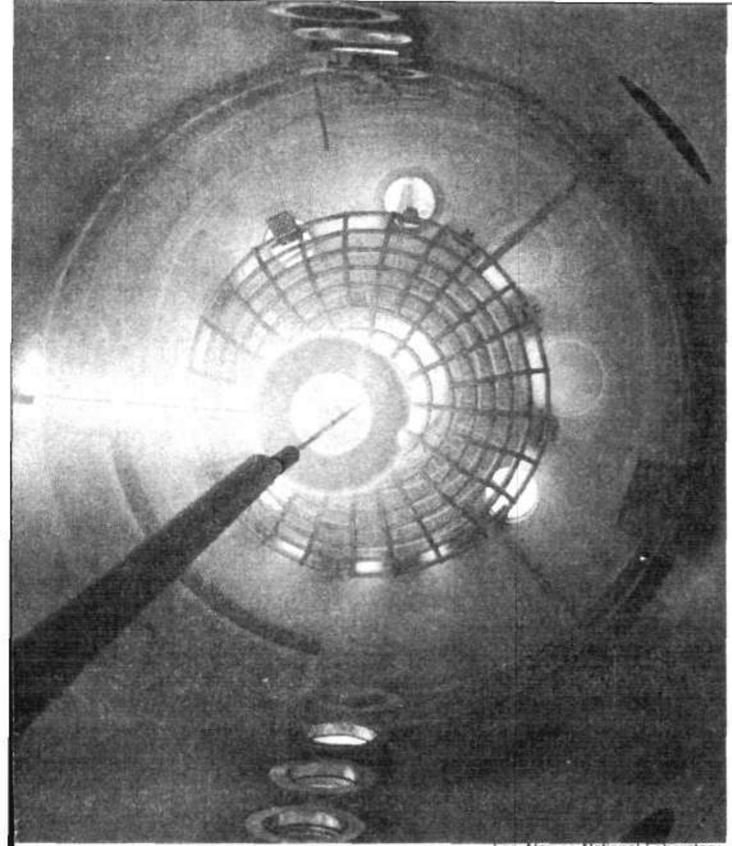
Second, the Los Alamos experiments demonstrate how an almost ideal magnetic fusion energy system can be achieved. This ideal system would be based on self-organized magnetic plasmas that are capable of continuously and efficiently generating fusion energy outputs with a minimum external supporting technology. In other words, this system would be a fusion reactor with a minimum capital cost. Such a fusion system would generate electricity and other forms of industrially needed energy at costs far below those of existing technologies and below those projected for the existing mainline fusion approaches now being researched.

Third, and most significant, these fusion experiments are transversing the frontiers of science as defined by Riemannian relativistic physics. For example, the Los Alamos results have immediate theoretical implications for electrodynamics and the definition and evolution of self-organized structures such as solitons and shock waves. This advance opens up an extremely fruitful path for the experimental reformulation of quantum electrodynamics as recently specified by Lyndon H. LaRouche.[1] The recent theoretical applications of self-ordered soliton-type plasma structures to biology demonstrate that the potential impact of these Los Alamos results is not limited to physical science.[2]

Fusion and Plasma Science

From an economic standpoint fusion cannot be defined as just another potential energy resource, and plasma physics is not just the science upon which the technology for harnessing fusion is based. The fusion process provides the basis for defining and developing entirely new families of resources. For example, fusion transforms simple water and earth and existing forms of industrial waste into valuable resources. And plasma physics, particularly as demonstrated in the fusion torch concept, defines an entirely new industrial technology that has a potential of infinitely higher efficiencies and densities of throughput compared to existing types and has no moving parts.[3]

This economic potential of fusion, defining the parameters for a new industrial revolution, is foreshadowed by the role of nuclear fusion and plasma processes in the evolution of the universe. Fusion is the source for the most active forms of energy observed in dynamics of the universe. It is nuclear fusion energy that makes the stars shine, and it was



Los Alamos National Laboratory

Inside view of the vacuum chamber of the Los Alamos National Laboratory CTX fusion experiment in which the spheromak is formed.

the fusion process that generated the spectrum of chemical elements (matter), out of which the solar system was formed.

The easiest elements to fuse are the heavy isotopes of hydrogen, deuterium (D), whose nucleus has one proton and one neutron, and tritium (T), whose nucleus has one proton and two neutrons. It has been experimentally determined that when the average energy of the electrons and heavy hydrogen (with equal quantities of deuterium and tritium) is the same, the conditions for net-energy-producing thermonuclear fusion can be stated as an ignition temperature (temperature is a measure of the average energy, and therefore the velocity, of an ensemble) and a specific density of reacting nuclei that must be maintained over a specific period of time. For D-T fusion, the minimum ignition temperature is 44 million degrees Celsius or 4,000 electron volts (1 electron volt is equivalent to about 11,000 degrees Celsius or 1.6×10^{-19} joules). And the density in nuclei per cubic centimeter times the time during which this temperature and density are maintained must be equal to 30 trillion seconds-nuclei per cubic centimeter. This energy confinement time/density product is termed the *Lawson condition* for net fusion energy generation.

There are two general approaches to thermonuclear fusion: inertial confinement and magnetic confinement fusion.

In inertial confinement, extremely high power densities are applied to an ensemble of deuterium-tritium fuel, and the fuel burns up before it blows up. That is, only the inertia of the fuel is utilized to confine it to a specific density while it is heated to fusion ignition temperatures.

Magnetic fields are generated by electric currents—a directed relative motion of electrons and ions. For magnetic confinement fusion, these fields can be generated by either external electric circuits such as sets of copper coil magnets or by electrical currents induced within the confined plasma itself. In general terms, the applied magnetic field, whether from an internal or external source, acts as a countervailing force to the gas pressure of expansion exerted by a hot plasma.

From electrodynamics it has been shown that magnetic field lines must form closed circuits. Two important features of plasma magnetic confinement follow from this observation: (1) internally generated magnetic fields will be utilized more efficiently than externally generated ones, and (2) the ideal geometry for magnetic confinement is that of a torus formed out of closed magnetic field lines.

The mainline magnetic fusion approach, the tokamak, is indeed a torus, which derives a significant portion of its confining magnetic field from a toroidally directed plasma electric current. In the tokamak, most of the confining magnetic field is generated by external copper field coils. As noted above, however, the ideal situation would be to obtain the entire confining magnetic field from internal plasma currents. And, indeed, this is the primary characteristic of the Los Alamos compact tori: the CTX spheromak and the FRX-C reversed field theta pinch. Both these devices form closed tori of magnetically confined plasma in which the confining magnetic fields are generated by closed loops of plasma electric current.

The geometry of these magnetic confinement devices is shown in Figure 1. In 1 a, a column of plasma is trapped in an axial magnetic field, where the field lines follow the axis of the cylinder. When this axial magnetic field is generated by a plasma current, this configuration is called a theta pinch. The plasma electrical current flows in an azimuthal direction, circling around the plasma column as shown. The name theta refers to the angular coordinate of this circular path.

In 1 b, the geometry of the magnetic field and plasma electric current have been reversed. The field lines are circular—that is, in the theta direction—while the plasma electric current flows along the axial direction, which is generally given the coordinate designation of zeta. This configuration is termed a zeta pinch.

The reason for the name pinch is that these magnetic confinement configurations are dynamic. The inward pressure exerted by the magnetic field is greater than the plasma gas pressure of expansion. As a result, the column is "pinched" to a smaller radius. Since this by definition increases the plasma current density in both the theta and zeta pinches, the magnetic field intensity increases and therefore the inward magnetic pressure increases.

Both pinches can be made into closed tori (1c) simply by taking the ends of the columns and connecting them. In this case, the axial or zeta direction becomes the toroidal direction—the long way around the torus, while the azimuthal or theta direction becomes the poloidal direction—

the short way around the torus. The Los Alamos FRX-C is a closed toroidal theta pinch, while the CTX spheromak is more like a toroidal belt pinch, where the magnetic field and electric current follow the same spiral paths. The Los Alamos reversed field ZT-40 zeta pinch is a much more complex system, which is described below.

The rate at which fusion reactions take place increases with the fuel density, and therefore the power density of the fusion energy output also increases with the fuel density. However, since the plasma gas pressure increases with increasing density, the confining magnetic fields must be made more intense.

This brings us to the most crucial observations concerning magnetic plasma structures. Matter that is held together by ordinary chemical bonds, such as copper wire, is limited to the energy flux densities—magnetic and electric fields—that it can withstand given the strength of these chemical bonds, which are less than a few electron volts per atom. Self-organized magnetic plasmas—that is, plasmas in which the primary confining magnetic fields are generated by internal plasma electric currents—have no energy flux density limitations. Therefore, self-organized magnetic plasmas offer a unique path to both the most efficient and highest energy flux density fusion plasma configurations.

Theoretical Origins of Self-Organized Magnetic Plasmas

In January 1980, in an article titled "The Zeta Moves into First Place," *Fusion* made a projection for the experimental

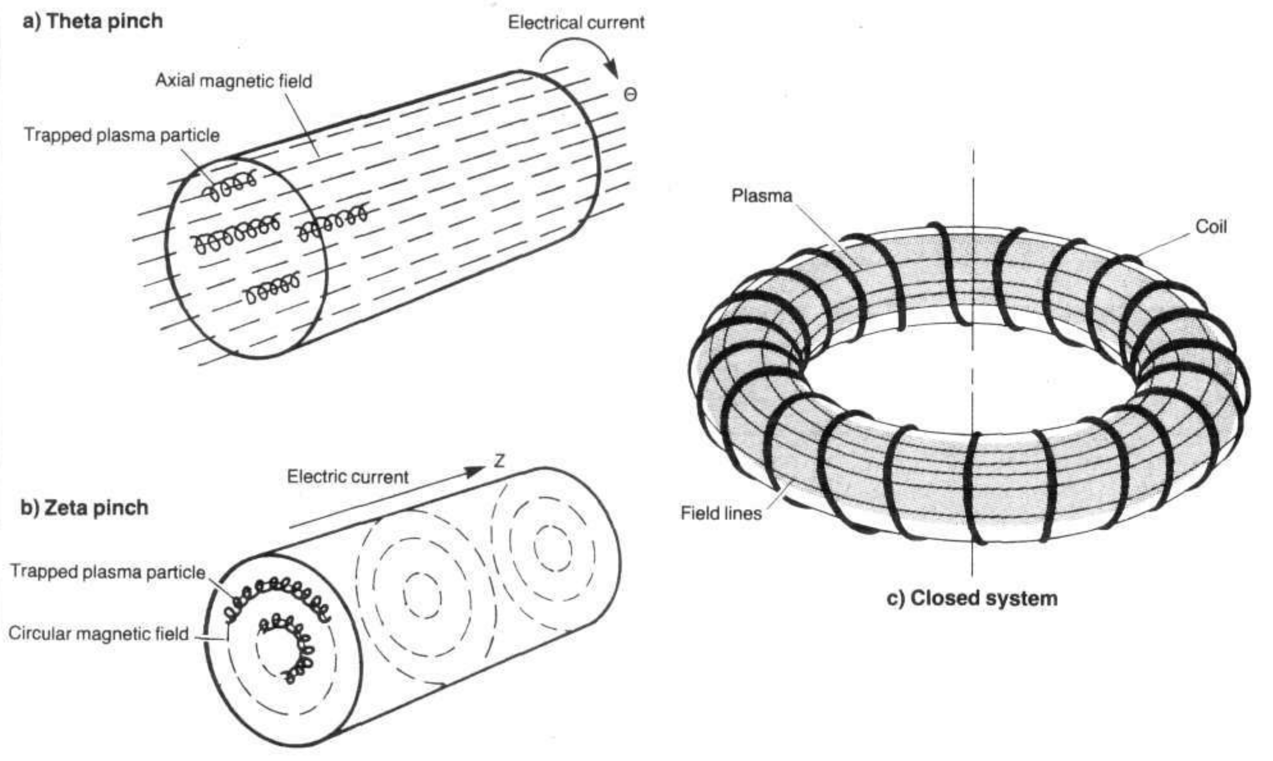


Figure 1
MAGNETIC CONFINEMENT CONFIGURATIONS

The configuration for a theta pinch is shown in a. *An axial magnetic field traps plasma ions and electrons into spiral orbits along the field lines. A plasma current is induced to flow in a circular fashion, the short way around the cylinder, known as the theta direction. This generates a magnetic field parallel to the axis of the plasma cylinder. If the induced plasma current is made to increase rapidly, then the intensity of the magnetic field will increase. This compresses and heats the plasma, which, in turn, leads to an intensification of the magnetic field. This process of a plasma current generating self-compression is called the plasma pinch.*

The configuration for a zeta or z-pinch is shown in b. *A circular magnetic field—the poloidal field—traps plasma particles in "closed" spiral paths along "closed" magnetic field lines. The induced plasma current flows in a direction parallel to the central axis of the plasma—the long way down the cylinder, termed the zeta direction.*

A combination of the theta and zeta pinch configurations will generate spiral-shaped magnetic field lines and electrical current paths.

The magnetic field configuration shown in c *has been closed by bringing the ends of the cylinder together to form a toroidal shape—a donut. The field lines now are closed. Also shown is an external coil that generates the magnetic field within the plasma.*

development of self-organized magnetic fusion systems.[4] The recent Los Alamos successes confirm the projections made in that article as well as the essential aspects of the earlier work of Drs. Harold Grad of the New York University Courant Institute for Mathematical Studies, Dan Wells of the University of Miami at Coral Gables, and Winston Bostick of the Stevens Institute of Technology and the Kirtland Air Force Weapons Laboratory.

To briefly summarize this history: During the 1930s, Dr. Adolf Busemann applied the concept of Riemannian shock waves to aerodynamics and derived the essential features of isentropic flow, which made the development of rocket and jet aircraft possible.[5] He also applied this concept to fusion and derived the fundamental features of inertial confinement. Later, while working for NASA in the 1950s, Busemann developed the essential features of self-organized magnetic plasmas.[6]

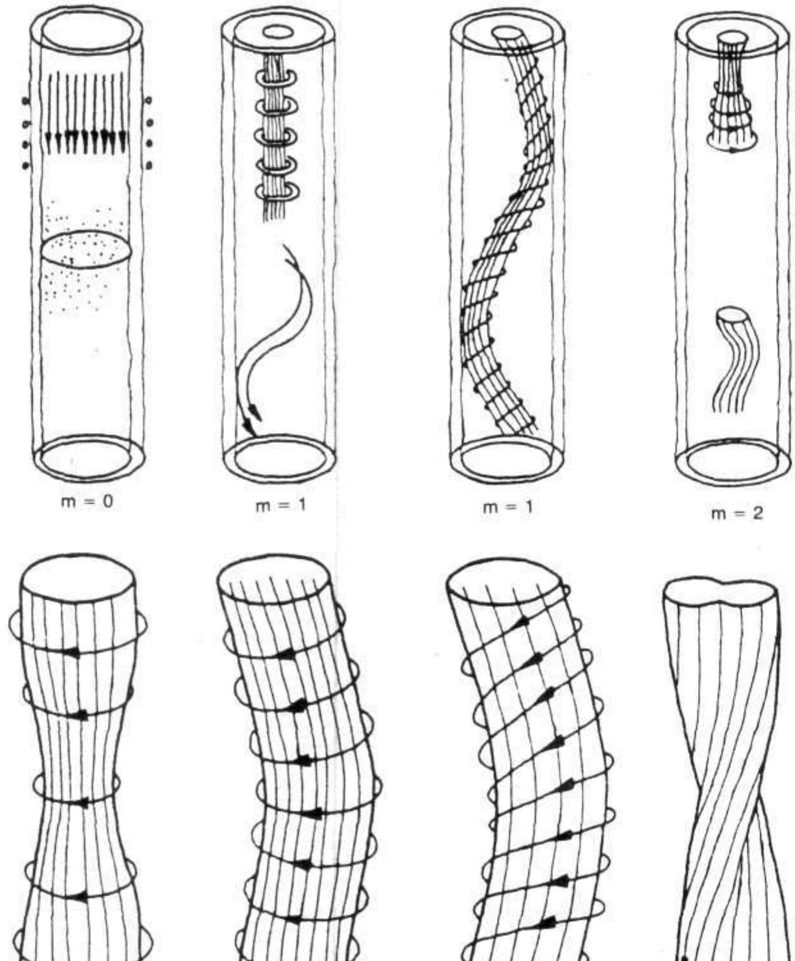
The essential point is that the evolution of magnetic plasmas is dominated by continuum hydrodynamical processes and their singularities—vortices. The plasma domain is represented by a higher-ordered hydrodynamical continuum, which is called *magnetohydrodynamics or MHD. In this* domain, magnetic fields represent a sort of higher-order fluid superimposed and strongly interacting with the plasma fluid (see Figure 2). These MHD vortices exist in two distinct families, and Dr. Fred Tappert of the University of Miami at Coral Gables has shown that given a magnetic plasma, such MHD vortices will naturally appear. Furthermore, Dr. Harold Grad has shown that given the proper global boundary conditions, these MHD structures will evolve to more complex topologies—defined by growing numbers of field geometry singularities—without dissipation.[7]

In the 1960s, Dan Wells applied the experimental obser-

Figure 2
MAGNETOHYDRODYNAMIC (MHD) PLASMA INSTABILITIES

A plasma column in a magnetic field can become hydrodynamically unstable as a result of the interactions between the plasma, which is moving like a fluid, and the confining magnetic field. These motions, or MHD instabilities, as they are termed, evolve according to specific harmonic geometries. The set of diagrams here shows how these harmonic motions can be characterized.

In the terms used to identify the various instabilities, m *is an integer in a mathematical function of the form sin* (mΘ) *that determines the geometry of the MHD motion. For example,* m = 0 *means that the plasma column will move only in a radial direction (that is, with differing thicknesses). In* m = 1, *the plasma column motion takes the form of a spiral or simple coil—a kink—and if this continues to grow, the plasma will hit the wall of the vacuum chamber. In* m = 2, *the column spirals and is squeezed at the same time.*



vations of Winston Bostick and extended the theoretical insights of Busemann to the dynamics of these self-organized structures.[6] Wells showed that these MHD structures represented metastable minimum energy states.

An important point here is that if the global boundary conditions of the system—the placement of the vacuum chamber wall in which the magnetic plasma is being formed, the geometry of the externally induced plasma electric currents, and so on—are not properly chosen, the evolution of these MHD structures will appear as instabilities leading to the destruction of the magnetic plasma. For example, as shown in Figure 2, MHD motions can cause the plasma to come in contact with the vacuum chamber wall. As a result, the plasma would rapidly lose its thermal energy to this wall and recombine to form an ordinary, un-ionized gas that has no free electrons.

However, if the boundary conditions provide sufficient freedom for the plasma to progress to a new, higher-ordered minimum energy state, then this apparent MHD instability will dissipate once such a higher state is achieved. In 1974, J.B. Taylor of the Culham Fusion Laboratory in England utilized Dan Wells's concepts (without acknowledging him, in fact) to demonstrate that this is precisely what happened in the case of the British toroidal pinch experiment called the Zeta.[9]

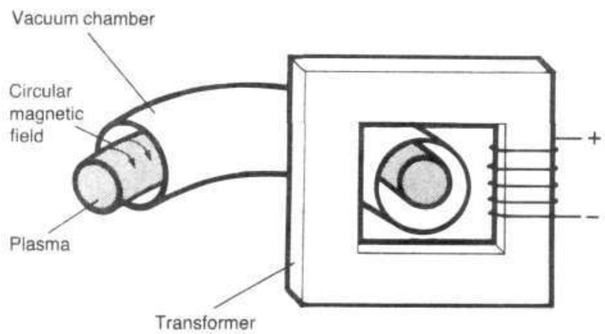


Figure 3
CUTAWAY VIEW OF A SIMPLE TOROIDAL Z-PINCH
In experimental runs, hydrogen gas is pumped into the vacuum chamber to fill up the donut at a low density. Then an electric current is passed through the transformer. This generates an electrical current field that ionizes the hydrogen gas in the vacuum chamber. As the current rises in the transformer, a plasma electrical current is induced to travel around the donut. This generates the circular (poloidal) magnetic field that pinches and initially heats the plasma. As the current continues to rise, it too heats the plasma.

In the later, more sophisticated versions of the toroidal z-pinch, toroidal field coils were placed around the vacuum chamber. These generated an axial (toroidal) magnetic field that helped to stabilize the simple z-pinch against MHD instabilities. Also, "vertical" field coils were added that prevented the plasma donut from simply expanding and hitting the vacuum wall. The vertical field coils generate a magnetic field on the outside of the plasma donut in a direction perpendicular to the plasma column. When the plasma expands outward, it interacts with this vertical field and is forced inward as a result.

The Zeta experiment was basically a toroidal zeta pinch, as shown in Figure 3, with some toroidal axial magnetic field added in order to stabilize the z-pinch against the $m = 0$ MHD mode in Figure 2. Originally, it appeared that the system became completely unstable. Closer examination of the experimental data after the Zeta was shut down, however, showed that the system entered a phase of dynamic MHD motions but then settled down into a quiescent stable phase. To the surprise of the fusion researchers involved, this quiescent phase had an entirely new magnetic geometry that had been created during the dynamic phase.

What apparently happened in the Zeta is that an $m = 1$ MHD mode developed and moved around the plasma column. In the process, it disrupted the toroidal magnetic field lying outside the plasma column and then reconnected the magnetic field such that the field was now directed in an opposite direction. That is, the toroidal magnetic field outside the plasma column was reversed with respect to the direction of the toroidal magnetic field originally imposed on the plasma and the toroidal field remaining within the plasma column. This phenomenon was termed self-reversal, and the Los Alamos ZT-40 is based on this reversed field configuration.

The essential point to conclude from this example of the Zeta device is that if self-organized magnetic plasmas are given sufficient freedom in terms of their boundary conditions, they will "naturally" proceed in a dynamic fashion to higher-ordered configurations. It is the exploration of these boundary conditions, correlated with the dynamic evolution of these higher-ordered structures, that defines the most crucial characteristics and limits of magnetic confinement in general.

The unprecedented success of the Los Alamos ZT-40, and in particular the emergence of the dynamo effect, which is also now being observed in the CTX-spheromak, categorically demonstrates that this is the case.

A final general point is that both the plasma and its boundary conditions are dynamic and experimentally exhibit distinct harmonic—resonant—structures in terms of their interconnection.

The CTX Sphero…

The spheromak configuration is an almost ideal projection of the fundamental concepts that Wells first initiated. In the spheromak, all the confining magnetic field is generated by plasma currents, creating an axisymmetric toroidal pinch configuration.

The Los Alamos CTX spheromak is shown in Figure 4, and Figure 5 shows how the CTX spheromak is dynamically generated with a coaxial plasma source called a Marshall gun (only the plasma gun is shown for simplicity). The plasma gun consists of two cylindrical electrodes that are contained in a vacuum chamber. A low density hydrogen gas fill is introduced into the chamber and a large voltage drop

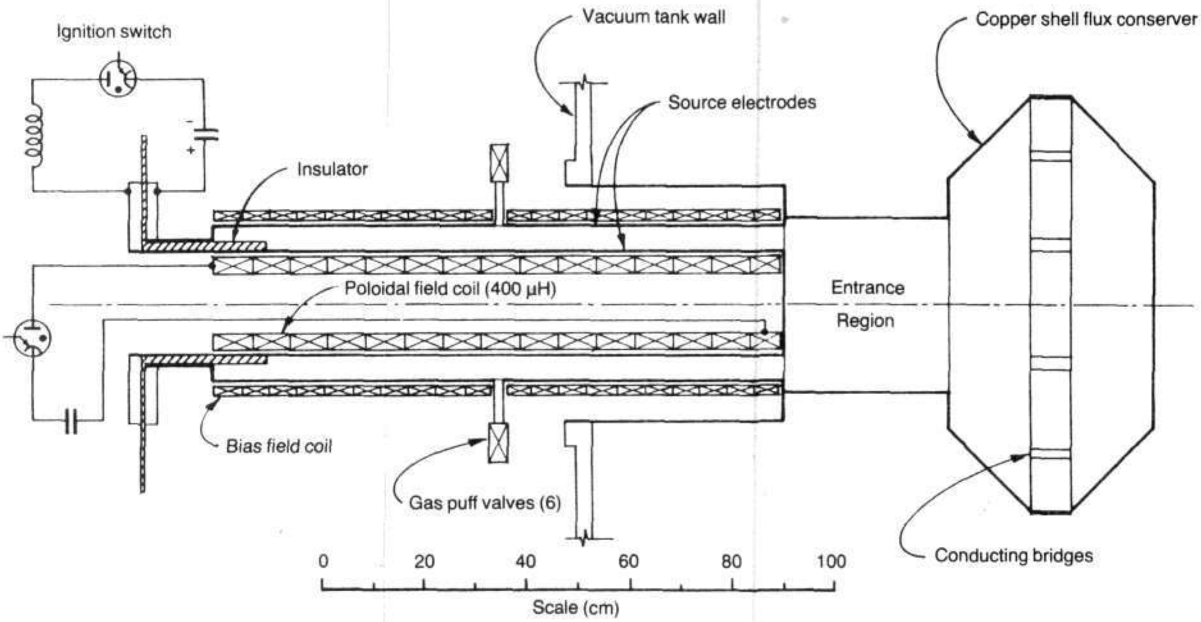


Figure 4
CROSS-SECTIONAL SCHEMATIC VIEW OF THE CTX SPHEROMAK

The diagram shows the Los Alamos CTX spheromak experiment and its electrical circuit. The gas puff valves provide an intake of hydrogen gas. Then the two cyindrical source electrodes, which form the coaxial Marshall gun, are switched on. This then generates a plasma sheath on the left side of the Marshall gun near the insulators. The plasma sheath moves to the right down the gun. When it emerges from the left end of the coaxial gun, the plasma sheath is transformed into a spheromak and interacts with the poloidal magnetic field generated by the poloidal field coil. The completely formed spheromak continues to move to the right until it is trapped within the copper shell flux conserver.

is applied to the two electrodes. The resulting electric field between the electrodes causes the hydrogen gas to break down (ionize) near the left side of the electrode cylinders. Once a plasma sheath is formed between the electrodes, electrical current begins to flow through it from one electrode to the other. The flow of current along the surface of the electrodes—in the axial direction—generates a toroidal magnetic field.

The current flowing through the plasma sheath interacts with this toroidal field to generate a force that propels the plasma sheath toward the right side of the cylinder. When the sheath reaches the end of the coaxial gun, it encounters radial magnetic flux generated within the inner cylinder of the gun. Because of the momentum of the plasma sheath, the interaction between the plasma sheath and this radial flux generates a snipping effect that causes the radial lines to reconnect around the plasma sheath as it emerges from the gun. As a result, the flat sheath is rolled up into a torus with both toroidal and poloidal magnetic field components. This process is shown schematically in Figure 5.

The plasma continues on its trajectory toward the right until it enters a flux-conserving cage made out of copper. The copper cage serves as an external boundary force, which is needed to maintain stability even though force-free self-organized plasma structures are primarily confined by their own magnetic fields. This external force is marginal, however, compared to the forces exerted by the internal magnetic fields.

If the plasma begins to move—for example begins to tilt—electrical currents are induced in the copper cage by the moving magnetic fields in the plasma. This current generates a magnetic field that acts on the CTX torus in a direction opposite to its motion. This effect is used both to halt the plasma motion to the right and to stabilize the configuration.

Spheromak experiments are being carried out in fusion labs throughout the United States and Japan. Although other spheromaks have been dynamically generated with alternative startup systems, the CTX is the first spheromak to burn through the impurity radiation barrier.

During the startup phase of magnetic fusion experiments, plasma energy flows are dominated by atomic radiation generated by heavy element impurities. All magnetic plasma systems begin operation with significant quantities of nonhydrogen elements in them. The source of these impurities derives from the metal electrodes, the vacuum chamber walls, and the vacuum system itself. Because of the higher energy electron orbit structure associated with these heavy elements, in a plasma these nonhydrogen impurities will radiate energy out of the plasma at a very rapid

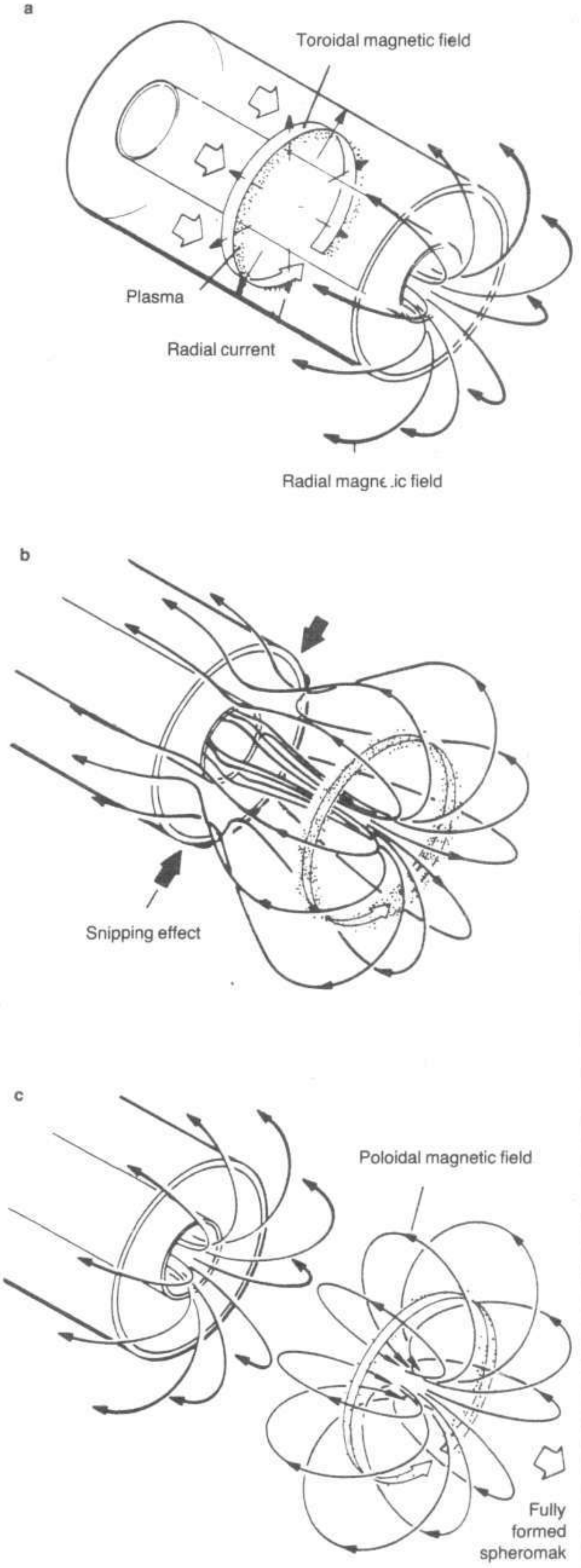


Figure 5
MAGNETIC FIELD GEOMETRIES IN THE STARTUP OF THE CTX SPHEROMAK

These three diagrams show how the CTX spheromak is formed. In the first stage, a, *the coaxial Marshall gun (represented by the two cylinders) generates a plasma sheath that carries a large, radially directed electrical current between the two cylindrical electrodes of the Marshall gun. At the same time, the current flowing along the cylindrical electrodes generates a toroidally directed magnetic field.*

*The interaction between this toroidal magnetic field and the radial plasma current results in a force on the plasma directed toward the right, down the cylinder. The plasma, therefore, accelerates down and out of the coaxial gun (*b*). Because of the momentum of the plasma sheath, the interaction between the plasma sheath and the radial flux creates a snipping effect that causes the radial lines to reconnect around the sheath as it emerges from the gun.*

*At this point, the flat plasma sheath is rolled up and becomes a plasma ring or torus. This ring then interacts with the radial magnetic field generated by the poloidal field coils within the inner cylindrical electrode (shown in Figure 4). This interaction leads to the formation of a self-contained spheromak configuration (*c*) whose magnetic field consists of both poloidal and toroidal components. The completely formed spheromak continues to move to the right until it is trapped inside the flux conserver (shown in Figure 4).*

rate. If the magnetic plasma can be maintained for a sufficient period of time, these impurities will generally diffuse out of the plasma in a process termed "burning through the impurity radiation barrier."

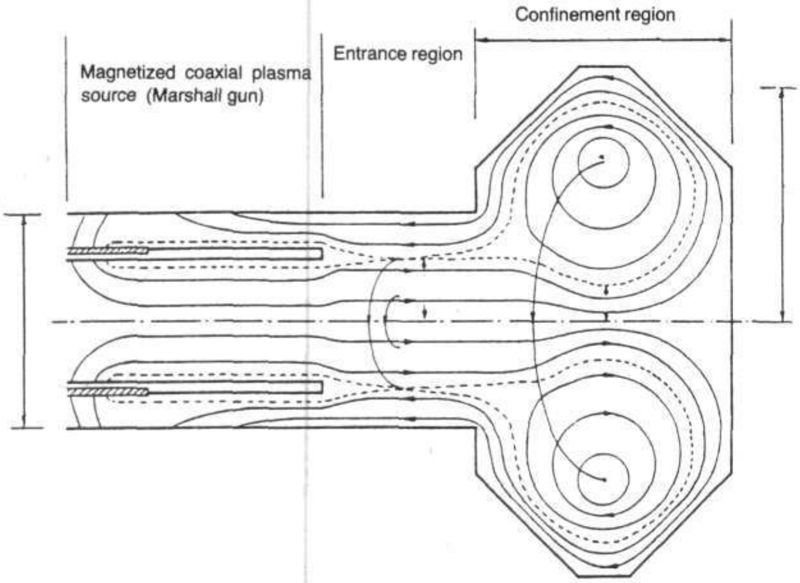
The CTX achieved success in overcoming this impurity stage by implementing cleanup routines that removed most of the impurity sources before the CTX operation and then by using a *porous* copper flux conserving cage instead of the solid one that had been used previously. The porous nature of the copper wire cage apparently enhances the migration of impurities out of the CTX plasma region, and the geometry of the wire permits the development of plasma sheaths around the copper, which, in turn, prevent the migration of impurities from the copper wire itself.

The key observation demonstrating that the impurity radiation barrier has been superseded is that the CTX plasma begins to heat up because of the electric currents flowing in it. This form of plasma heating is called ohmic heating. Peak electron temperatures of several hundred electron volts have been measured.

When Los Alamos initiated its compact tori and zeta pinch reversed field programs in the mid-1970s, it was believed that extremely high power pulsed electric systems would be crucial. This proved not to be the case with the ZT-40, and it is again being shown to not be true in the case of the

Figure 6
SCHEMATIC OF STEADY-STATE SPHEROMAK

The diagram shows a cross-section of the CTX spheromak and its magnetic field components. The lines in the plane of the schematic represent poloidal magnetic field lines. The circular lines coming out of the diagram represent the toroidal magnetic field lines. The closed spheromak structure contains both toroidal and poloidal magnetic fields. If the coaxial gun is kept on it will directly regenerate the toroidal field within the closed CTX. However, the spheromak structure itself acts on incident toroidal field to transform a part of it into poloidal field within the CTX.



CTX. The original CTX experiments utilized a fast generation mode with input powers of 10 to 15 gigawatts. Now much better results are being obtained with much longer plasma sustainment times at power inputs of 100 to 800 megawatts.

In the fast mode, spheromaks were formed within 3 to 6 microseconds. In a slower startup mode, with 200 to 800 megawatt electrical current power levels, formation of the CTX took about 60 microseconds. Both the slow and fast modes decay in the same manner over 950 microseconds.

The Dynamo Effect

Los Alamos researchers have seen indications of a third experimental mode for the CTX. If the coaxial gun is left on at a low power level, it appears that the formed CTX spheromak is absorbing the magnetic flux and plasma coming out of the gun, and some of this incident toroidal flux is transformed into poloidal flux within the CTX spheromak (Figure 6). This opens up the prospect of a steady-state spheromak. The key point here is that while toroidal flux within the spheromak can be directly regenerated by the gun, only the apparent action of the plasma dynamo can provide a source for the essential poloidal flux.

Although the question of how and why the ZT-40 and CTX plasma dynamo action develops is for the most part still unanswered, it appears that this self-organized phenomenon is closely related to the Wells concept mentioned above of metastable minimum energy states. One crucial aspect of the Wells theory is that magnetic plasmas will tend to form into force-free vortex configurations. Taylor showed that this tendency is probably the cause for the dynamic progression of the toroidal z-pinch to a reversed field configuration. The trajectory toward this more stable state can be shown in a *F*-theta diagram (Figure 7), where *F* and theta are ratio measures of the geometry of the magnetic field structure: *F* is the ratio of the toroidal magnetic field mea-

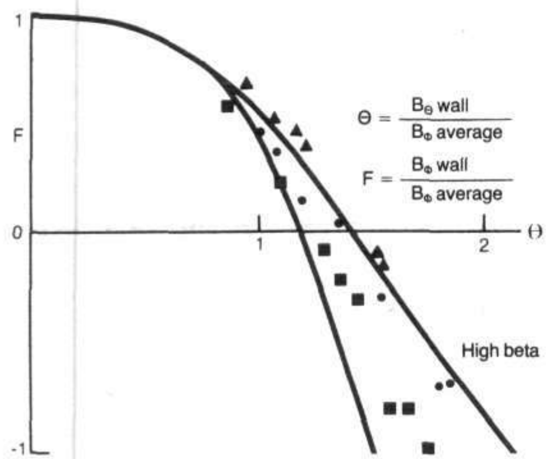


Figure 7
GEOMETRIC RELATIONS OF MAGNETIC FIELD STRENGTHS IN MAGNETIC CONFINEMENT

The graph shows the geometric relations of the magnetic field strengths for magnetic confinement. F, the y axis, is the ratio of the toroidal magnetic field found near the wall of the vacuum chamber, B^{*}_{Φ}, to the average toroidal magnetic field found throughout the plasma. Theta here is the ratio of the poloidal field B_{Θ} found at the wall to the average toroidal field throughout the plasma.

Tokamaks are located in the upper left region of the graph, while the reversed field pinches are the points plotted within the shaded area.

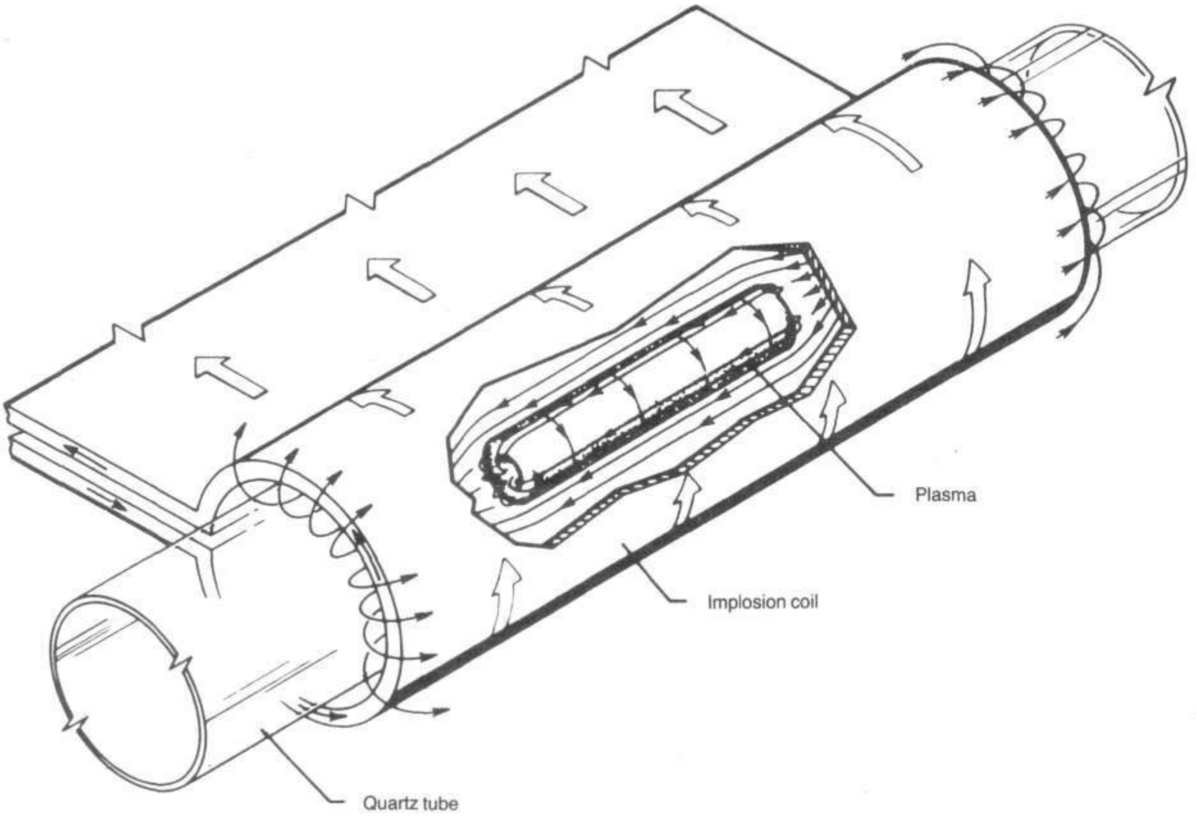


Figure 8
SCHEMATIC OF THE FRX-C REVERSED FIELD THETA PINCH
In this general configuration of the fully formed FRX-C reversed field theta pinch, the arrows show the direction of the magnetic fields generated by the electrical current in the implosion coil and the FRX plasma ring. The general plasma background is separated from the coil by a quartz tube vacuum chamber.

sured at the vacuum chamber wall to the average toroidal magnetic field throughout the plasma column. Theta is the ratio of the poloidal magnetic field at the wall to the average toroidal magnetic field throughout the plasma column.

The fundamental criterion of minimum energy states demands that all self-organized magnetic plasma structures conserve their force-free vortical (or helical) geometry. Also it requires that the dynamic evolution of these minimum energy states follows a specified trajectory in the phase space defined by the *F*-theta diagram since these parameters are a direct measure of the force-free nature of the geometric structure of the combined magnetic fields. The most straightforward explanation for this is that the plasma is generating this dynamo in order to maintain its minimum energy geometry.[10]

In fact, ongoing experiments indicate that the CTX could be sustained by a steady-state gun at power levels sufficiently low to use existing electrical technology. Dr. Thomas Jarboe projected such steady-state spheromak operation based on both the ZT-40 experimental results and the theoretical prediction that the spheromak minimum energy configuration will act to conserve magnetic helicity—that is, act as a dynamo to maintain the magnetic field geometry.[11]

The densities achieved in the CTX are several hundred trillion nuclei per cubic centimeter, comparable to those found in tokamaks but at much higher plasma betas. Once these initial results have been corroborated and the plasma dynamo sustainment mechanism definitively demonstrated, plasma heating experiments must be carried out to demonstrate that the CTX can be stably brought to the 100 million degree temperatures required for fusion.

If funds are available, heating experiments are planned within the next year or two at Los Alamos. The first heating method being planned is that of Alfven wave heating, where microwave generators are utilized to initiate Alfven waves external to the CTX. These Alfven waves form between the plasma and the magnetic field, and once within the CTX spheromak they would rapidly be damped and their energy would be transformed into thermal motion of the plasma electrons and ions.

The FRX-C Reversed Field Theta Pinch

While at first glance the FRX-C appears to be of an entirely different species from the CTX and ZT-40, its development has depended on the same general MHD theoretical developments that are exhibited in the CTX and ZT-40. At the same time, the FRX-C is sufficiently different from the CTX and ZT-40 to offer unique insights into that general theory.

The FRX-C is a reversed field toroidal theta pinch formed in a open-ended linear theta pinch system (Figure 9). This is accomplished by programing the currents in the theta pinch coil, as shown in Figure 10. As a result, the theta pinch plasma bunches up into the center of the cylinder defined by the coil. In this process, magnetic field lines are broken and reconnected to form an elongated, closed torus of poloidal magnetic field and plasma. This field is sustained by the toroidal plasma current induced by the external theta pinch coil.

The FRX-C is unstable to the m = 1 MHD mode. However, aware of the nature of this instability, researchers added additional magnetic field coils to the experiment to counteract the instability. As a result, stable operation has been achieved. Experiments indicate that energy confinement times between 70 to 190 microseconds are being reached at densities of several thousand trillion nuclei per cubic centimeter and temperatures of several hundred electron volts.

These results are extremely significant since the density-confinement time products attained on the FRX-C are comparable to those achieved on the early tokamaks, except that the FRX-C is operating at high plasma betas. The experiments also indicate that the energy confinement time scales as theory predicts. That is, the energy confinement time is a linear function of the radius squared of the overall torus, divided by the ion gyroradius. The ion gyroradius is proportional to the ratio of the square root of the ion temperature to the strength of the magnetic field. Furthermore, there are indications that better energy confinement time scaling can be attained by moving the plasma torus closer to the external field coil. From a practical standpoint, this would be best achieved by moving the FRX-C plasma torus into a new chamber in which a special coil system—not as complex as the startup coil—could be utilized to achieve this closer fit.

Construction of such a experiment is currently under way at Los Alamos.

Near Term Implications

The most dramatic immediate practical implications of these Los Alamos advances are in the areas defined by pulsed power technology and directed energy beam generation. According to the projections by Drs. J.H. Hammer and C.W. Hartman of Lawrence Livermore National Laboratory, the CTX has already entered the regime of interest for plasmoid acceleration.[12]

To be more specific, self-organized magnetic plasmas are inherently quite mobile. Once formed, they need only a minimal boundary force to keep them stable. This can be supplied by the pressure of the Earth's atmosphere or a simple flux conserving cage, as in the CTX case. (Without an external boundary force the force-free structure will rapidly disinegrate.)

Compact tori are also intrinsically easy to accelerate to high velocities because the ratio of the plasma ring's mag-

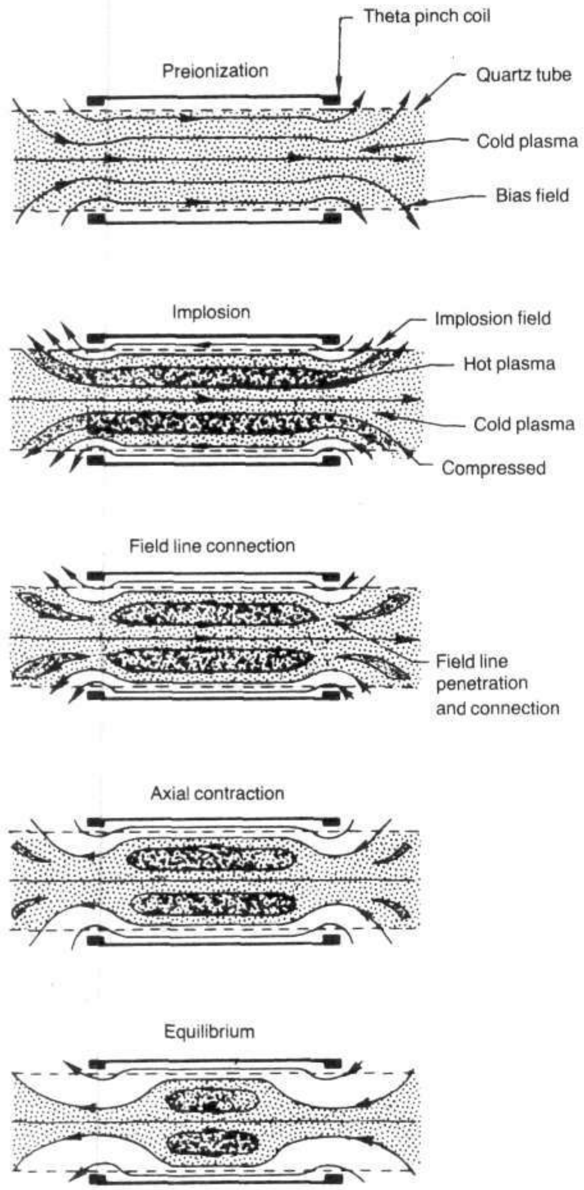


Figure 9
STARTUP OF THE FRX-C
REVERSED FIELD THETA PINCH

In the first of the five stages shown here, a cold plasma is formed by the current in the theta pinch coil. This magnetic plasma constitutes an open ended, simple theta pinch: The plasma is free to simply diffuse out the two ends of the theta pinch cylinder. (See Figure 8.) By rapidly increasing the current in the theta pinch coil the plasma column is imploded. And by programming this implosion current, the compression of the plasma is made asymmetrical. The result is that axial magnetic field lines are broken and reconnect to form a closed ring of magnetic plasma—the FRX-C.

netic field energy to its plasma mass is quite large, and potential acceleration of an magnetic dipole, such as a compact toroid, is a direct function of this ratio. It is the interaction between the magnetic field and an external electromagnetic force that can be utilized to accelerate the compact toroid.

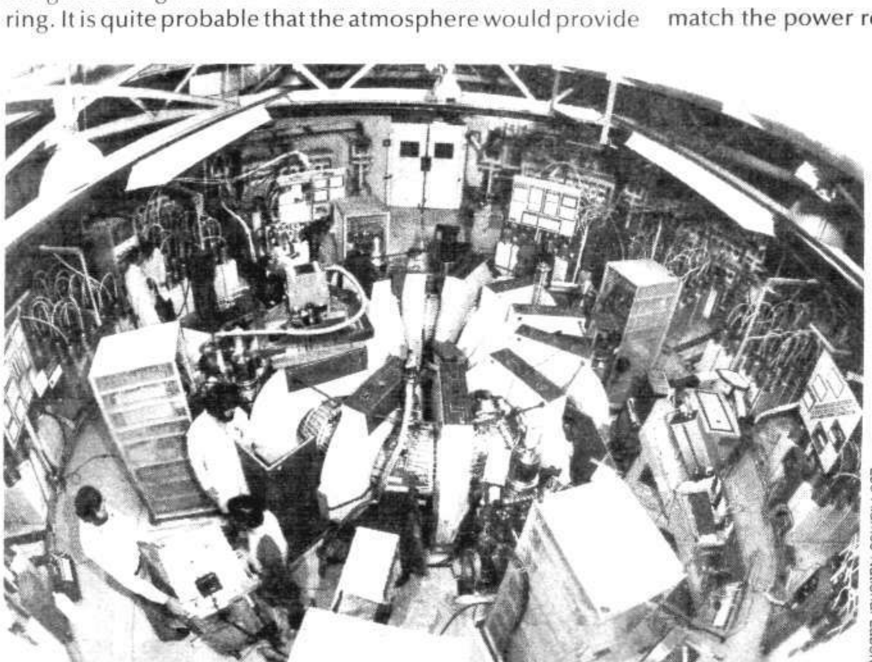
In a 1980 Livermore Laboratory report, Dr. Hartman shows that substantial ring velocities and kinetic energies (the energy represented by the ring's motion) can be achieved in a magnetic rail gun, similar to that which generates the spheromak and of a quite reasonable length—several meters. This is particularly true in the case where the ring plasma is made up of heavy nuclei.

In a more recent series of papers given at the Fifth Symposium on the Physics and Technology of Compact Toroids, Dr. Hartman and his collaborators propose a two phase acceleration of plasma rings.[13] First, the ring is accelerated toward the apex of a conical magnetic rail gun. As a result, the ring undergoes a self-similar compression (focusing) during acceleration. And because the allowable acceleration force on the plasma ring is inversely proportional to the square of its linear size, the accelerating distance for conical electrodes is considerably shortened over that required for cylindrical coaxial electrodes. Furthermore, Hartman et al. note that in either case, "since the accelerating flux can expand as the ring moves, most of the accelerating field energy can be converted into kinetic energy of the ring leading to high efficiency."

During the second phase, the compressed plasma ring is accelerated again in a conical-shaped rail gun, but this time the plasma ring is allowed to expand. As a result, some of the energy contained in the magnetic field is converted into kinetic energy—that is, motion of the ring. In their calculation, the plasma ring attains velocities of 9,300 kilometers per second with about 50 percent of the input energy to the rail guns being transformed into the kinetic motion of the ring. It is quite probable that the atmosphere would provide the essential boundary force to keep the ring together during the time it traveled several hundred kilometers. Hartman et al. note: "If the ring at the maximum kinetic energy (4.4 MJ) were allowed to strike a target, the deposition power would be roughly 1.2×10^{16} watts (deposition time of about .3 nanoseconds) with a power density of 5.3×10^{15} watts/sq. cm." This would kill almost any target.

Hartman et al. note a range of other applications of accelerated plasma rings going from those where the input energy is comparable to the magnetic energy of the ring, to those where the input energy is larger than the magnetic energy, and, finally, to where the input energy is substantially larger. For example, at low energies accelerated plasma rings can be used for plasma current drive and plasma fueling.

At medium energies, accelerated rings can be focused radially by conducting cones that cause an increase in the field intensity and adiabatic heating. If the rings are designed to reach fusion temperatures, they can provide a high flux pulsed neutron source for simulating fusion reactor conditions and simulating nuclear weapons effects. Along these same lines, utilizing heavier elements in the plasma ring will cause the compressed rings to become copious generators of X-rays. By varying the elemental composition and plasma parameters of the ring, the spectrums of the X-ray radiation can be made to range over a myriad specified values. This is particularly useful in regard to pumping X-ray lasers and simulating nuclear weapons X-ray radiation effects. Another medium energy application is the development of high field moving ring reactors. At high energies, Hartman et al. point out, accelerated rings would have applications for fast switching/power amplification, as well as an inertial confinement fusion driver. As Hartman et al. describe, rings moving at about 1,000 kilometers per second with dimensions of less than 1 centimeter and kinetic energies of about 10 megajoules would match the power requirements for inertial fusion. In addi-



Los Alamos National Laboratory

Looking down on the Los Alamos ZT-40 reversed field toroidal z-pinch device. Technicians are shown making adjustments to the scientific diagnostics used on the ZT-40 experiments.

tion to the efficiency, the compactness of the accelerator (lengths of about 10 meters), they point out, is an advantage that makes this a reasonable candidate for fusion powered rocket propulsion.

Still another application is the synthesis of transuranic elements and the use of accelerated rings as a high flux ion source. Finally, two additional applications are noted, the attainment of super high magnetic fields and inertial fusion by sudden ring deceleration.

A second line of fusion application not mentioned by Hartman is that of utilizing the spheromak as the input for metal liner compression systems. A compressed spheromak is almost the ideal magnetic plasma input for such liner systems. The liner is quite similar in effect to the conical compression scheme outlined by Hartman, except that the metal electrodes consist of a cylindrical metal liner that is either explosively or electromagnetically collapsed. This causes a "stationary" compression of the spheromak plasma.

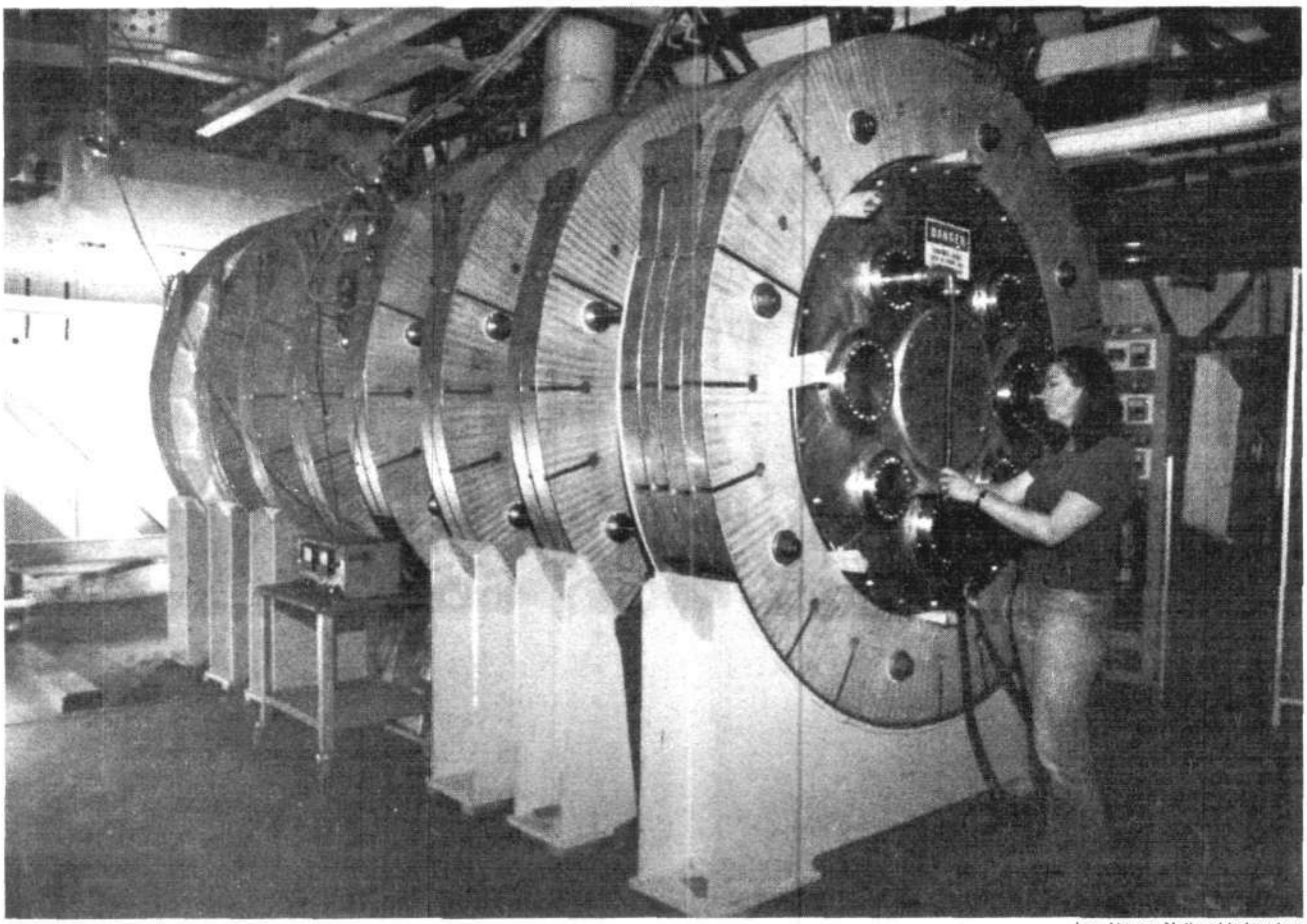
Magnetic Fusion Reactors

Because of the flat budget levels of the U.S. fusion research program maintained throughout the Carter administration and continued by the Reagan administration, research on alternatives to the mainline tokamak and tandem mirror magnetic confinement systems has been starved for funds. Hopefully, this situation will be changed in the near future, particularly given the directed energy implications of the developments described below.

From a theoretical and technological standpoint, there appear to be no significant barriers to the rapid development of the spheromak as a fusion energy system. All existing magnetic fusion experimental and theoretical knowledge strongly indicates that the spheromak should become more stable as it is heated to higher temperatures.

The CTX spheromak opens up the prospects for the development of an almost ideal magnetic fusion energy system that consists of several stages. In the first stage, the spheromak would be generated. The plasma ring would then be moved to another location and heated to fusion ignition temperatures. It would then be moved to a third location containing a simple, low power coaxial coil gun and flux conserving chamber needed for maintaining and fueling the spheromak. Fusion energy would provide the spheromak with an internal heat source sufficient to sustain fusion temperatures.

More so than any other type of magnetic confinement system, compact tori do not appear to be limited to the



Los Alamos National Laboratory

Vacuum chamber tank in which the Los Alamos CTX spheromak is formed. The tank is surrounded by external magnetic field coils. Originally it was thought that external magnetic fields would have to be used to stabilize the self-organized CTX magnetic bottle. However, experiments have demonstrated that external magnetic fields are not needed.

ultimate, stable operating temperatures that they can attain. This makes possible the burning of advanced fusion fuels—elements heavier than hydrogen. With these advanced fuels, significantly fewer neutrons are generated as fusion reaction products, thus lessening one of the chief engineering problems in fusion reactor systems: neutron-induced materials damage, a primary source for power density limitations in fusion reactors.

Developments along these lines are particularly bright if spin polarized fusion is successfully demonstrated and shown to be practical in the spheromak.[14] A neutron-free fusion plasma is particularly amenable to various MHD and direct particle methods of converting plasma energy into electricity. On the speculative side, directed fusion product effects, which derive from spin polarized fusion, could be combined with self-organized plasma effects to give the spheromak system a wide variety of energy output capabilities ranging from X-ray laser beam to microwave, through to electric and charged particle beam generation.

The economic prospects of compact tori fusion electric reactor systems can be judged by the above ideal possibilities, which are by no means necessarily remote at this time. The capital cost of such a system would basically consist of the cost for the flux conserving chamber, the low power gun, a control system, the vacuum chamber and pump, and an MHD coil or a direct particle conversion system. In the more versatile advanced case noted above, the plasma would directly generate the desired energy output. Furthermore, the gun could be replaced by a second spheromak. If located in space, of course, there would be no need for a vacuum chamber and pump. (The initiating system is an extremely small portion of the cost for an individual spheromak since it would be capable of generating thousands of such fusion plasmas per second.)

At this point in the description of such a system, it can be seen that the projected capital costs are being reduced to basically the control system and fuel. But since only extremely weak boundary forces are needed to control an individual spheromak, this means that the capital costs have been reduced to operating costs. In the case of fusion reactors in general, the operating costs, which include fueling, have already been shown in reactor designs based on more conventional type power plant designs to be only a small fraction of those found for all other types of power plants.

The result is the increasing prospect of perfecting fusion energy systems that have infinitesimal capital costs compared to existing types of systems. If viewed from the standpoint of energy payback time—that is, the time it takes the fusion reactor to generate the equivalent energy utilized in its construction—the energy payback time decreases from the several years of operation needed in the case of nuclear fission and more conventional fusion reactor designs to a few milliseconds in the case of the spheromak.

Viewed from the standpoint of versatile energy generation systems, these spheromaks could provide a universal modular unit for all industrial processes—both materials processing and forming. And as Hartman notes, the spheromak could be utilized as the most efficient form of rocket propulsion.

Theoretical Implications

The Los Alamos developments represent a tremendous advance for magnetic plasma confinement theory in general. Many of the immediate consequences of self-organized plasma theory experimentally realized at Los Alamos can be immediately applied to all other magnetic confinement schemes to generate significant improvements in their performance. This in particular applies to achieving higher beta operation in tokamaks.

At a higher level, these results have immediate implications for astrophysics, geophysics, and ionosphere physics. Fundamental questions concerning star structure, the nature of the magnetic dynamo of the Sun and the Earth, solar system formation, magnetic field line reconnection, and the dynamics of the ionosphere geomagnetic *x* point are just a few of the most obvious examples.

But it is at the level of Riemannian relativistic physics that these developments have their most significant impact. The self-organized plasma experiments reviewed in this article intrinsically demonstrate precisely the same character of evolution that Riemann discovered in the case of acoustic shock waves. The projected natural path of evolution of these systems—if provided with the proper boundary conditions—is that of negentropic action. Once this is recognized these self-organized plasmas provide a unique experimental ground for further expanding empirical knowledge of Riemannian relativistic physics. And it is this that will accelerate the rate of development of self-organized fusion systems as well as humanity's real scientific knowledge.

Charles B. Stevens is director of fusion engineering for the Fusion Energy Foundation and well known for his popular articles on fusion technology and science.

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The Young Scientist

NASA

Artist's drawing of the Space Telescope in space.

Looking Deep into Space With NASA's Space Telescope

by Marsha Freeman

Imagine being able to observe a distant planet as clearly as if you were orbiting it in a spacecraft, or to see back in time—to the period billions of years ago when the universe was just forming.

When the Space Shuttle launches NASA's large Space Telescope into orbit around the Earth in 1986, astronomers will routinely be able to see such things, and they won't have to wait for a clear night on Earth to see deep into the heavens. The Space Telescope will also enable astronomers to see objects that have never been seen before. We may find, for example, that other stars besides the Sun have planets circling them.

We will see the birth, growth, and death of stars, and we may see all the way to the edge of the universe. We will see 14 billion light years away—a distance of trillions of billions of miles. And we will see objects as they existed 14 billion years ago, when scientists think our universe was just forming. We will see the most distant and oldest things that man has ever seen.

Viewing Space from Space

When in 1610 the scientist Galileo turned the first telescope toward the heavens, he saw craters on the Moon, four moons around Jupiter, and that giant planet's red spot. He also identified projections coming out of the sides of Saturn, which were later observed to be rings.

Since then, larger and more sensitive telescopes have been built. However, not until the beginning of the space age in 1957 was man finally able to get beyond the distorting effects of the Earth's atmosphere to look into space. The layers of the atmosphere allow visible light, radio waves, and infrared radiation to penetrate, whereas ultraviolet and higher frequency radiation are filtered out. But even the radiation that gets through is blurry. Looking out through the atmosphere is like looking up under water from the bottom of a lake or pond.

Getting even the first simple and small telescopes above the atmosphere allowed astronomers to see everything more clearly, and the radiation from the high-frequency end of the spectrum became visible for the first time.

The other serious obstacle with Earth-based astronomy is the weather: The heavens can only be observed on clear nights. Clouds, haze, and heat currents limit ground-based observation to about 2,000 hours a year. The Space Telescope will more than double the number of hours that can be productively used for astronomy.

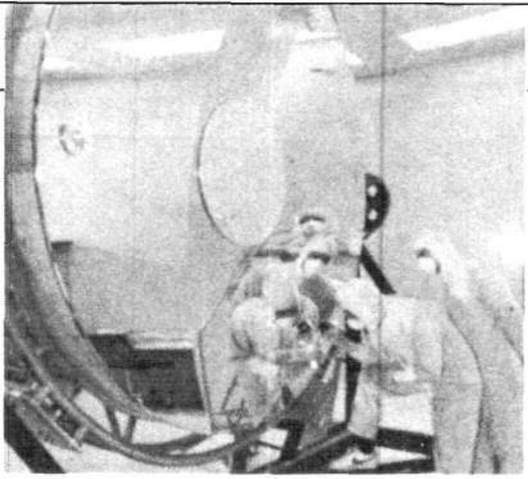
The Amazing Space Telescope

The Space Telescope will be taken up into space inside the payload bay of the Space Shuttle. It will be lifted out by the 50-foot long Remote Manipulator System and deployed on an orbit about 373 miles above the Earth.

Using a primary mirror that is 8 feet in diameter—less than half the size of the telescope on Mount Palomar—the Space Telescope will be able to see things 50 times dimmer and 7 times farther away than any telescope on Earth. Weighing 25,000 pounds and more than 43 feet long, the Space Telescope will have two sets of solar panels to generate electricity from sunlight during the day, and batteries to store electricity for the telescope when it is facing away from the Sun during its night.

The unaided eye can see about 600,000 light years away at night (a light year is the distance light travels in one year, or 5,878 billion miles). With a ground-based telescope, an astronomer can see objects about 2 billion light years away. The Space Telescope will stretch that to 14 billion light years. What might we see with that amount of magnification?

We will be able to look at neighboring planets in the Solar System with great clarity—including the clouds on Venus; polar ice caps and deep valleys on Mars; the atmosphere and moons of Jupiter; and the rings, moons, and clouds of Saturn. We will receive pictures of the outer plants that will be comparable to those the Voyager spacecraft sent back when it flew by them. But now we will be able to see these bodies regularly, right from Earth orbit.



The primary mirror of the Space Telescope is eight feet in diameter. It is made of titanium silicate glass with a reflective coating of aluminum-magnesium fluoride. Here it is shown in preparation by technicians at the Perkin Elmer Corporation.

The Space Telescope will give us more detailed images of the farthest out planets—Uranus, Neptune, and Pluto. At the present time, with our ground-based telescopes, Pluto looks like just a dot of light.

The Space Telescope will be able to tell us if there are other nearby stars that also have planetary systems. It will not see these planets directly, but it will observe perturbations or irregular motions in the movements of these stars. Within 10 light years of Earth, there are 10 Sunlike stars, which the Space Telescope will be pointed at to investigate for planets.

We will also be able to observe galaxies beyond the Milky Way galaxy—hundreds of galaxies that we can now only dimly see. With the Space Telescope, we hope to see stars in these galaxies in various stages of formation: the condensation of gas into stars, the ignition of stars to produce thermonuclear reactions, and the death of stars.

The Space Telescope will also see new galaxies, each with billions of stars. By comparing the rate at which faraway galaxies are moving toward us, scientists should be able to determine how the universe was expanding as long ago as 15 billion years.

How It Will See

The Space Telescope is made up of three systems. The *Support Systems Module* provides the electrical power, communications, and pointing and control for the satellite carrying the telescope. The pointing accuracy will be greater than anything ever orbited before—within 0.007 arc seconds. This is like being able to point the telescope at a dime in Boston from Washington, D.C. The telescope will lock onto an object and be able to point at it for 10 hours, a time span that will be necessary when it is looking at a very faint object.

The heart of the telescope is the *Optical Telescope Assembly* consisting of the primary and smaller secondary mirrors, the opening or aperture through which the light strikes the mirrors, and the focusing lens that creates a focused image. The light will enter the aperture, strike the primary mirror, and then be reflected back to the secondary mirror.

This smaller mirror will narrow the beam of light and intensify it. The beam will then go through a small

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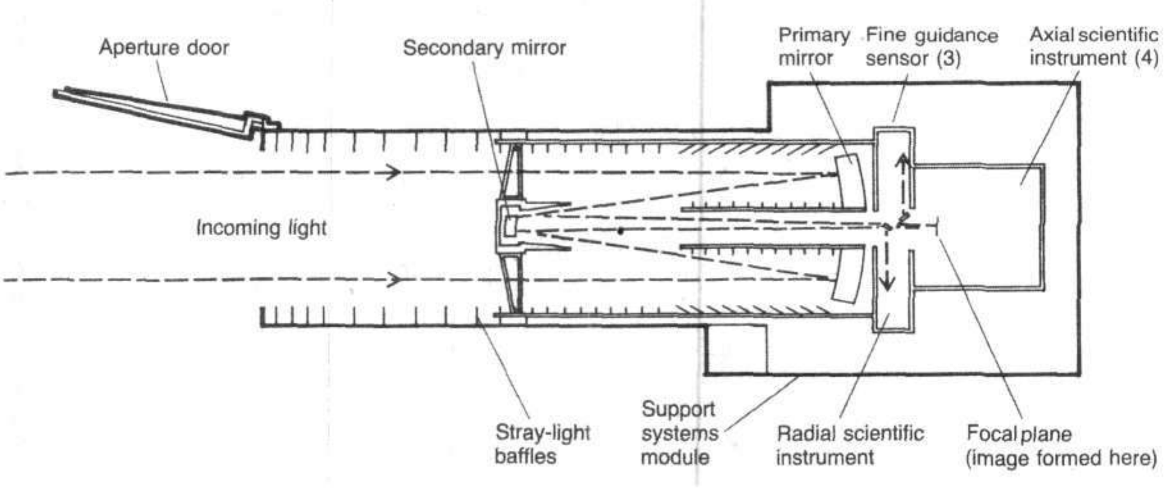


OPTICAL TELESCOPE ASSEMBLY

The Space Telescope contains two sets of mirrors to collect and focus the light that strikes it from distant celestial objects. First the light hits the primary mirror; then it is reflected to the secondary mirror, which narrows and intensifies the beam of light. The light is then sent through a small hole in the primary mirror, where the focused image appears on the focal plane. There the image is available to the scientific instruments that process the information and send it back to Earth.

Marie Curie, 1867-1934

Pierre Curie, 1859-1906

Marie and Pierre Curie And the Discovery of Radioactivity

by Jon Gilbertson

The discovery of radioactivity in 1896 is one of the most important scientific discoveries of the past 100 years. It led to the discovery of two new elements, polonium and radium, and opened up a whole new field of medicine, now called radiation therapy. At the time it was called radium therapy, but in France it was known as *Curietherapy* after its French discoverers, Marie and Pierre Curie.

The story of these two scientists and how their discoveries were made actually begins with another French scientist, Henri Becqueral, who was investigating X-rays. X-rays had been discovered a few years earlier by the German physicist Wilhelm Roentgen (pronounced "rent-gen"). In experimenting with an electron tube, the forerunner of the present-day television tube, Roentgen had artificially produced an unusual type of emission. These rays were similar to light but much more powerful. When he placed his hand in front of the glowing rays, they allowed him to see a shadowy picture of the bones in his hand and fingers.

The French scientist Becqueral continued to investigate X-rays by looking at the "strange" element uranium.

Uranium was known to exist in 1896, but it was thought to be "a heavy, practically worthless metal." However, uranium salts were known to make some materials fluorescent when mixed with them—when stimulated, the materials would emit light. To study this phenomenon, Becqueral would set a sample of the uranium salt mixture in the sun a while to generate the fluorescent glow. He would then set the glowing sample on a photographic plate, which was wrapped in thick, black paper. After developing the plates, Becqueral found what he expected—that the plates had been exposed underneath the uranium and the image of the uranium appeared on the plates. He thought that the sun was somehow activating the fluorescence, which was then giving off something else that exposed the plates—perhaps X-rays!

Then one day Becqueral did the same experiment, but without first putting the uranium salt sample in the sun. Much to his amazement, the same thing happened to the plates. Whatever was going on came from within the uranium itself. It was not dependent on the sun or the fluorescence. Although he didn't know it, Becqueral had discovered radioactivity.

Picking Up the Uranium Puzzle

It wasn't until the famous scientific team of Marie and Pierre Curie picked up the trail of uranium that radioactivity really began to be understood. The Curies were familiar with Becqueral's work and knew there was much more to be learned about the radiation from uranium.

To do this, they began with pitchblende, a brownish black ore that was known to contain some uranium and other elements as well. Starting with nearly a ton of ore, Marie Curie, who was a trained physical chemist, began to separate the various elements from the ore. After first eliminating the rock and then the minerals and lighter metals present in the ore, she focused on the uranium. Each time she concentrated the remaining material, she would measure its radioactivity, and it kept getting higher and higher.

The uranium was then separated and removed, but the radioactivity of what remained of the sample still kept getting higher. Did this mean that the uranium was not the only thing that was radioactive? Marie Curie kept separating and analyzing, and she discovered a new element, naming it *polonium* after her native country, Poland. She then discovered that the radioactivity of the sample increased even further after the polonium was removed. There must be yet another radioactive element, one that was even more radioactive—nearly two million times more so than the original ore. Marie called this element *radium,* meaning "the radiating one."

In describing the excitement of their discovery many years later, Marie Curie wrote:

> One of our joys was to go into our workroom at night; we then perceived on all sides the feebly luminous silhouettes of the bottles or capsules containing our products. It was a really lovely sight and one always new to us. The glowing tubes looked like faint, fairy lights.

A Nobel Prize and Tragedy

Over the next few years, the Curies worked on separating and purifying the new elements they had discovered in order to make a more exact determination of their atomic weights. Then in 1903, the Curies and Becqueral were jointly awarded the Nobel Prize for physics for the discovery of radioactivity and the new elements, polonium and radium.

There was still a great deal more work to do, but the Curies' research was tragically delayed in 1906, when Pierre was killed in an accident with a horse and carriage. Marie Curie was forced to raise her family alone, as well as continue the scientific work she and Pierre had been doing—a responsibility she accepted.

An early photograph of Marie and Pierre Curie in their laboratory.

Throughout the next years—and in fact, even before Pierre died—Marie Curie recognized and pursued the medical benefits of their new discoveries. When World War I broke out in 1914, she put her expertise to work in the service of France. The X-ray tube, invented in 1890 by Roentgen, was beginning to be used in the larger civilian hospitals around Europe. The army, however, had used it very little and was not prepared to use it during the war. Knowing how important the X-ray tube would be in locating bullets, shrapnel, and broken bones in wounded soldiers, Marie Curie began to build the X-ray equipment.

As the X-ray tubes were finished, she would take them to the field hospitals at the battle front and train the medical personnel there to use them. Knowing that she couldn't build enough tubes to supply the entire front, she designed and built portable X-ray units, which were carried in trucks. She even drove the trucks herself, until personnel were trained to operate the equipment.

You can read more about Marie Curie's accomplishments in her biography of Pierre and in a biography written by her daughter Eve.* Marie describes very beautifully that what guided the work of the Curies was the sense that their scientific discoveries were producing enormous benefits for all mankind:

> It may be easily understood how deeply I appreciated the privilege of realizing that our discovery had become a benefit to mankind, not only through its great scientific importance, but also by its power of efficient action against human suffering and terrible disease. This was indeed a splendid reward for our years of hard toil.

* *Madame Curie: A Biography*, by Eve Curie (New York: Doubleday, 1937) and *Pierre Curie*, by Marie Curie and Peter Smith (New York: MacMillan, 1923 or Dover, 1963).

Stuart K. Lewis/NSIPS

A technician at the Alfacell biotechnology laboratory explains the laboratory production of biological products to FEF staff members John Grauerholz and Marcia Merry Pepper.

Putting Biological Breakthroughs To Work for World Development

Biotechnology, the industrial application of biological processes, has the potential for vastly transforming and upgrading the world's economy. By using the highly efficient principles of biological chemical reactions in large-scale test-tube situations, large quantities of vitually any animal or human substance—such as human insulin—can be easily and cheaply made. Also, large amounts of vaccines and antibodies could be made cheaply, as well as possibly such anticancer agents as human interferon.

Another area of biotechnology uses whole bacteria to perform useful functions, such as chemically changing minerals for easy mining, or for producing specific hydrocarbons for industrial use. In all these applications, the high specificity and efficiency of biological enzymes are used to catalyze reactions and increase output by thousands of times or more. This is equivalent, quantitatively, to the revolution in energy production by fusion, or the revolution in manufacturing by laser-based machine tools.

Biotechnology, a term in use for about 15 years, has come under attack recently from zero-growth environmentalists like Jeremy Rifkin [see Books, p. 58] who see such advances in man's control over nature as "tampering" with human life and genetics. It is no coincidence that it is exactly the ongoing breakthroughs in biotechnology that will enable us to "leapfrog" over the current biological and agricultural devastation worsening under the world depression and to create global economic growth on a higher level than ever before possible.

Consider the example of malaria.

In the early 1960s, malaria was declining worldwide, as a result of concerted efforts at mosquito eradication and the development of water supply and sanitation infrastructure. However, after the the United States banned the production of DDT in 1972 and the World Bank, the World Health Organization, and other such agencies curtailed water development projects in the name of austerity, malaria has increased to major proportions. In Africa today, 160 million people out of 480 million are stricken with the debilitating disease. And leading entomologist Dr. J. Gordon Edwards has predicted that malaria may soon appear in California, carried by mosquitoes that will acquire it from Pakistani farmworkers, in whose home country malaria is on the rise.

Biotechnology could transform this disastrous situation. Researchers at New York University are developing an antimalaria vaccine, which they predict is just three years or less away from completion. Production methods based on biotechnology can then mass-produce the vaccine, providing the possibility of stopping the spread of the disease and perhaps eliminating it.

Food Production

Biotechnology can play a major role in world food production itself, if it is focused on increasing real food production rather than developing so-called hardy, low-yield plants and animals adaptable to subsistence farming on unimproved land, as is the current emphasis by the World Bank, et al.

The current situation is alarming. In the last 10 years of economic depression, rates of food output in many nations have declined, including major countries that were once food exporters like Mexico and Nigeria. In Africa in the last five years, food production has declined by a full 10 percent. Under the current drought conditions now afflicting almost every region, 500,000 people are expected to die from starvation this year.

If the political decision were made to reverse the austerity policies creating these conditions—as called for by many world leaders at the June conference in Belgrade of the United Nations Conference on Trade and Development (UNCTAD)—the applications of biotechnology in farming and animal husbandry would enable fast strides in restoring and exceeding agricultural output around the globe.

Much of the scientific work in biotechnology takes place in private companies and scientific laboratories, and close to 150 new companies have formed in the past two years. Perhaps the most well known is Genentech in California, which last fall began marketing human insulin produced from bacteria. The distinguishing feature of these companies is not size or fame, but a certain flexibility, which enables them to concentrate on areas that are not easily accommodated in large academic or industrial concerns.

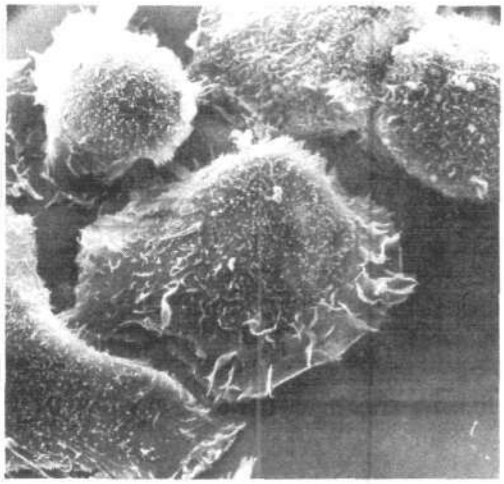
Profile of a Biotech Firm

A new company in New Jersey, Alfacell, is a good example of such flexibility. The company grew out of a 13-year effort of scientists to develop a substance that retards cancerous tumors. In order to fund their research, they pooled their talents and founded Alfacell in September 1981. In January 1983 the company went public, and will offer 450 biological products, from diagnostics to custom-designed research chemicals. The company stock is now traded on NASDAQ.

Because of its small size, its high level of the scientific staff, and its advanced equipment, Alfacell has the flexibility to provide most products on 24-hour notice. Alfacell's special advantage is its proximity to supplies of fresh animal blood, enabling it to provide research institutions and hospitals with sera for special needs.

Alfacell's research activity is centered on a nonspecific tumor toxic agent (NSTT). This material is derived from animal cells and has produced destruction of a number of benign and malignant tumors in animals. Present work in this area is directed to the purification and identification of the active portion of the substance.

Dr. Emil Szebenyi, president of Alfacell, began research on the antitumor agent in 1971 with Ms. Kuslima Shogen, then a graduate student at Fairleigh Dickinson University and now vice president of Alfacell. Szebenyi was then chairman of the biology department of Fairleigh Dickinson University, a position he reached by a circuitous path from his native Hungary, where he had gained an international reputation in the fields of animal genetics and embryology. In addition to Szebenyi and Shogen, a group of consultants in pharmacology and medicine works with the company.



Scanning electron micrograph of rat tumor cells being fused with normal mouse cells to form hybridomas (hybrid cells), which are used to produce monoclonal antibodies. The fused cell lives and reproduces indefinitely, like the original tumor cell; however, it also produces the specific antibodies characteristic of the original normal mouse cell. Therefore, this technique can provide large quantities of specific antibodies cheaply in the laboratory.

Exemplary of the advantages of a smaller biotechnological operation is the association of scientists, like Szebenyi and his network of collaborators, in a setting that minimizes administrative and other distractions associated with large academic and commercial organizations. In this situation a greater amount of time is available for creative scientific work. The existence of such companies, however, is dependent on the continued existence of a large industrial and research infrastructure for them to service, as well as on the commitment to develop the Third World, to which the products of biotechnology can make a unique contribution.

—*John Grauerholz, M.D.*

Return to the Caves: Jeremy Rifkin's *Algeny*

Algeny
by Jeremy Rifkin
New York: The Viking Press
1983, $14.75

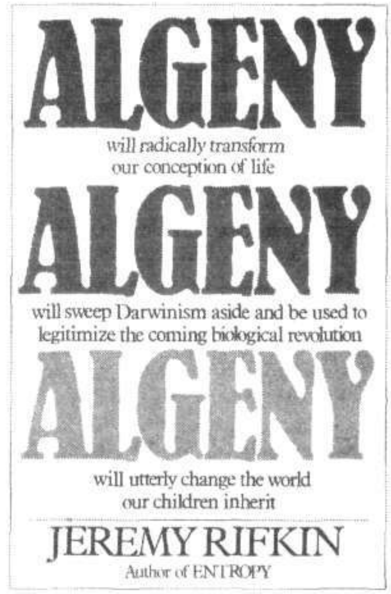
"Cosmologies are our way of convincing ourselves that there is no void, no unimaginable, unthinkable abyss beyond our reach to which we will never be privy and which can never be brought under our domestication. Our cosmologies relieve our great sense of apprehension about what truly lies out there. They assure us that the world does indeed make sense and that it can be understood in the same terms that we understand it."

This quote appears in the last chapter of Jeremy Rifkin's latest attack on science and progress, *Algeny*. The title is a recently coined word that he derives from "alchemy" by replacing the reference to chemistry with the word "gene," and is in line with the central theme of Rifkin's book: Recent advances in biotechnology, Rifkin says, such as genetic recombinant techniques, are leading us into the same mystical madness as the medieval alchemists who were preoccupied with transforming elements into gold.

A Radical Malthusian

Rifkin's latest attack on technology should come as no surprise to those familiar with his career as a "radical." After training at the Wharton School of Economics, Rifkin began working with the Institute for Policy Studies, the supporter of many prototerrorist environmentalist groups. He is now consulting with the Club of Rome on rewriting the Book of Genesis to conform to the Malthusian view of man. In addition to the book *Entropy*, Rifkin has authored *The Emerging Order: God in an Age of Scarcity*, both of which boldly put forward an extreme version of zero growth. Most recently, Rifkin drafted a national call to end genetic engineering applications to human beings, which was then endorsed by 64 clergymen.

It is amusing that in *Algeny* Rifkin comes to the conclusion that the correct scientific perspective is to acknowledge that the great majority of physical reality is an "unknowable void," a mystical agnostic position if



there ever was one! From his own mystical perspective, Rifkin argues that we must put an immediate halt to the development of biotechnology because it will destroy a nature which we can never really comprehend or improve upon.

Rifkin's long, winding, and twisted argument begins by announcing that the first phase of human civilization is now ending, what he terms the Age of Pyrotechnology. This is the era starting with man's discovery of fire and characterized by man using up the world's wood, coal, and now oil. Man has been "the wily and ingenious scavenger of history," feeding on and now using up the stored energy of the past like parasites. "The end of the age of fossil fuels presages the end of the Industrial Age that had been molded from it." Rifkin conveniently ignores the currently available fission nuclear energy and the potential for near-term development of fusion, a virtually unlimited source of "fire" for "pyrotechnology"!

Rifkin then moans that now that mankind has raped the earth of its stored energy, he will turn his destructive forces toward the living species, attempting to exploit them to continue his satanic quest for immortality and security. Rifkin's main blunder here is to assume that man's capacity for radically altering life forms is something new. In fact, it was precisely man's ability to transform grasses into efficiently grown edible grains that made farming possible in the first place, which was the backbone of the neolithic revolution and the first major increase in human population density, the ultimate measure of the advancement of civilizations.

Thus the two major pillars of Rifkin's argument—that we are running out of energy for the Industrial Age, and that this will be replaced by something new and foreign, the manipulation of species—both crumble to dust.

Rifkin then spends several hundred boring pages "proving" that Darwin was wrong because first, he was a reductionist (what else is new), and second, because he was only expressing the colonialist mentality of the British Empire as "survival of the strongest" as a way of justifying economic exploitation (again, what else is new).

However, Rifkin again blunders when he identifies reductionist biology as a product of the Industrial Age itself. The line of scientific investigation that gave rise to the industrial revolution is precisely antireductionist, from Plato's Timaeus through Cusa, Kepler, Leibniz, and Riemann, all of whom would have laughed at Darwin's backward simplemindedness. Likewise, Rifkin characterizes the new replacement for Darwinism as the "field, rhythm, process" approach, a bowdlerization of the continuum physics of the Riemann tendency. However, he then goes beyond bowdlerization and identifies the continuum approach with cybernetics, information processing, and computer programs, and takes as the cultural equivalent the playing of video games.

Having equated the Riemann school with cybernetics, Rifkin then proceeds to attack the new tendency of continuing scientific advancement in biotechnology as politically fascist, a continuation of the eugenics movement from earlier this century: "If diabetes, sickle cell anemia, and cancer are to be cured by altering the genetic makeup of an individual, why not proceed to other 'disorders': myopia, color blindness, left-handedness? Indeed, what is to preclude society from deciding that a certain skin color is a disorder? Is guaranteeing our health worth trading away our humanity?" Perhaps Rifkin intends, therefore, that we should pass laws forbidding surgeons from using scalpels, because they just might possibly decide to cut the patient's throat in the middle of an operation.

What kind of mentality produces this pessimistic and warped vision of humanity? Listen to Rifkin: "Our monuments, our edifices, our inventions are things that have passed. Everything we leave can only be a corpse; some remains of what was once a possibility and is now an aftermath, a finality. What is alive is in the next moment; what is dead is the last moment. Immortality can exist only in what is potential, not in what has already been. What lives forever is the potential we left behind, the great possibilities we chose not to squander. For millennia we left a legacy of death, when in fact the only living legacy that we can ever leave is the endowment we never touched. Our presence in the future will not be felt by what we spent but by what we left unspent."

This is the statement of a poor soul who believes that everything he touches turns to excrement. Unfortunately, this kind of thing becomes a self-fulfilling prophesy. Even more unfortunate, Rifkin appears to have convinced a section of the U.S. fundamentalist Christians—specifically around the "Praise the Lord" television show, which has promoted him and his book—that this is a good thing.

—*Ned Rosinsky, M.D.*

Contributions to the FEF are tax deductible!

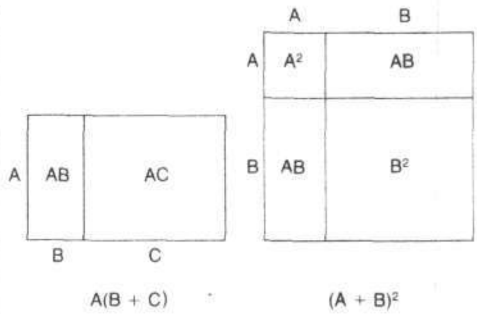


Figure 10
THE DISTRIBUTIVE LAW
Usually mystified as "algebraic" laws, the distributive law and the formula $(A + B)^2 = A^2 + 2AB + B^2$ correspond to the simplest division of a rectangle and square.

Letters

Continued from page 8

Tannenbaum], there is an error in the Figure 10 on the distributive law, where the square labeled BC should be labeled AC. This mistake is due to the fact that the figures are too close together.

Michael DiMarco
Burlington, N.J.

The Editor Replies

You are quite right. A corrected version of the figure appears here.

NASA's Space Telescope

Continued from page 52

hole in the primary mirror to a focal plane, where the focused image will appear. Scientific instruments that are in the focal plane will then capture the light and process it to find out different kinds of information.

The information processed by the five scientific instruments will be converted to electronic signals that will be sent back to the scientists waiting on Earth. A special institute has been established in Maryland at the Johns Hopkins University to give scientists from all over the world access to the new data Space Telescope will provide. One of the scientific instruments was donated by the European Space Agency, and the other four were made in the United States.

The *wide-field planetary camera* will produce images from the outer planets of comparable quality to those sent back by Voyager. Each image is made up of 640,000 separate picture elements, which are transmitted to Earth and are assembled into pictures.

The *faint object spectrograph* will take the beam of light that has been collected and focused by the mirrors and break it down into the different colors of light and also ultraviolet light. From the amount of light in each wavelength or color, this instrument will tell scientists what chemicals make up the object, how hot or cold it is, whether it is dense or rarified, and how much energy is in the material.

The *high resolution spectrograph* will look at the ultraviolet radiation from objects; this radiation otherwise never reaches the Earth. This information will reveal the detailed chemical composition of heavenly bodies and detect objects 1,000 times dimmer than those observed by previous spacecraft.

The *high-speed photometer* will measure the total light emitted from the object by recording the number of photons, or particles of light, that hit the telescope's mirror. This instrument will be able to measure very quick changes in brightness of objects and will look at pulsating objects.

Finally, the *faint object camera*, built by the European Space Agency, will detect very faint stars. It will collect data from a star that the Space Telescope might have to fix on for up to 10 hours in order to collect enough light so we can see it. We will discover many objects that may actually be quite bright, but look very faint to us on Earth because they are so far away.

The Space Telescope will be serviced in space by astronauts from the Space Shuttle, and it will be outfitted with the latest, improved scientific instruments when they are ready.

It will orbit the Earth for at least the next 10 years, and then can be brought back to Earth and refitted with new optical and other systems. It is the first permanent space facility in Earth orbit, and it will be a great step foward in all astronomical sciences. In fact, scientists are expecting the Space Telescope to launch a revolution in astronomy even greater than the changes in man's thinking about the universe brought about by Galileo's first telescope.

Viewpoint

Continued from page 8

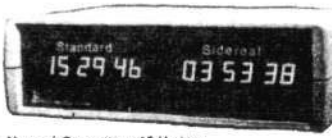
the development of the country's industry and nuclear engineering capability. National participation in Embalse's construction was as follows: 33 percent of the engineering, 100 percent of the civil construction, 95 percent of the assembly, and 33 percent of the electromechanical supplies—figures that surpass by a significant percentage national participation in the construction of Argentina's first nuclear plant, Atucha I.

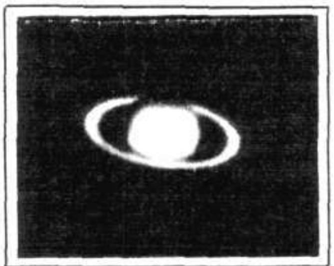
From the standpoint of energy generation alone, Embalse's importance is obvious. The country's nuclear electrical power will be increased to 935 megawatts, and the new plant has the most powerful turbo group in the country. With Embalse's coming on line, the participation of the nuclear sector in the country's installed capacity increases to 7 percent, increasing the overall percentage of energy supplied from this vital sector.

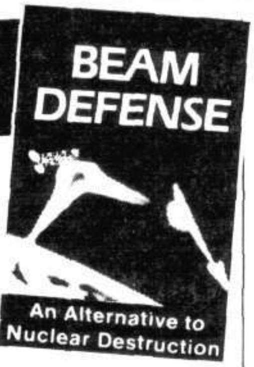
What Lies Ahead?

On the eve of a profound institutional change [Argentina will hold elections for the first time in 10 years in October 1983—ed.], which will undoubtedly culminate in a return of the Peronist movement to power, it is worth analyzing the opportunities that will open up for the nuclear sector. There is no question that the next Peronist government will back the progress achieved in this area, given that it was General Peron who first laid the basis for the development of nuclear energy during his first and second governments (between 1945 and 1955).

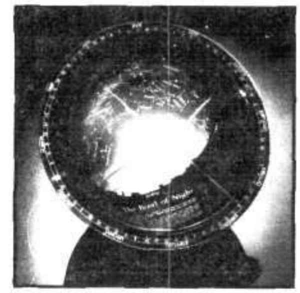
But we can also expect a variety of pressures aimed at freezing Argentina's nuclear development over the next months. In addition to British Intelligence's intrigue around our alleged development of nuclear weapons, we should also anticipate, given the climate of electoral agitation, some future action by nascent antinuclear organizations. It is hoped that Peronism will oppose this pincers movement with a will to make the nuclear sector the cornerstone of a true Argentine recovery, at the same time placing this achievement at the service of a cause in which it has been a pioneer: Latin American integration in the context of a more just international order.

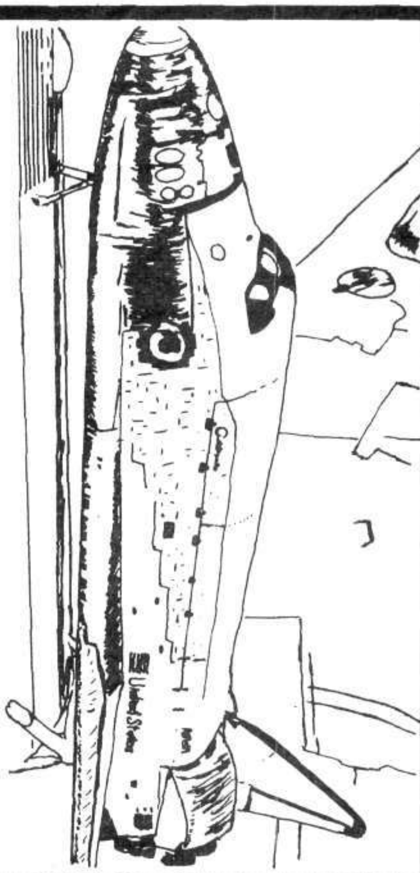


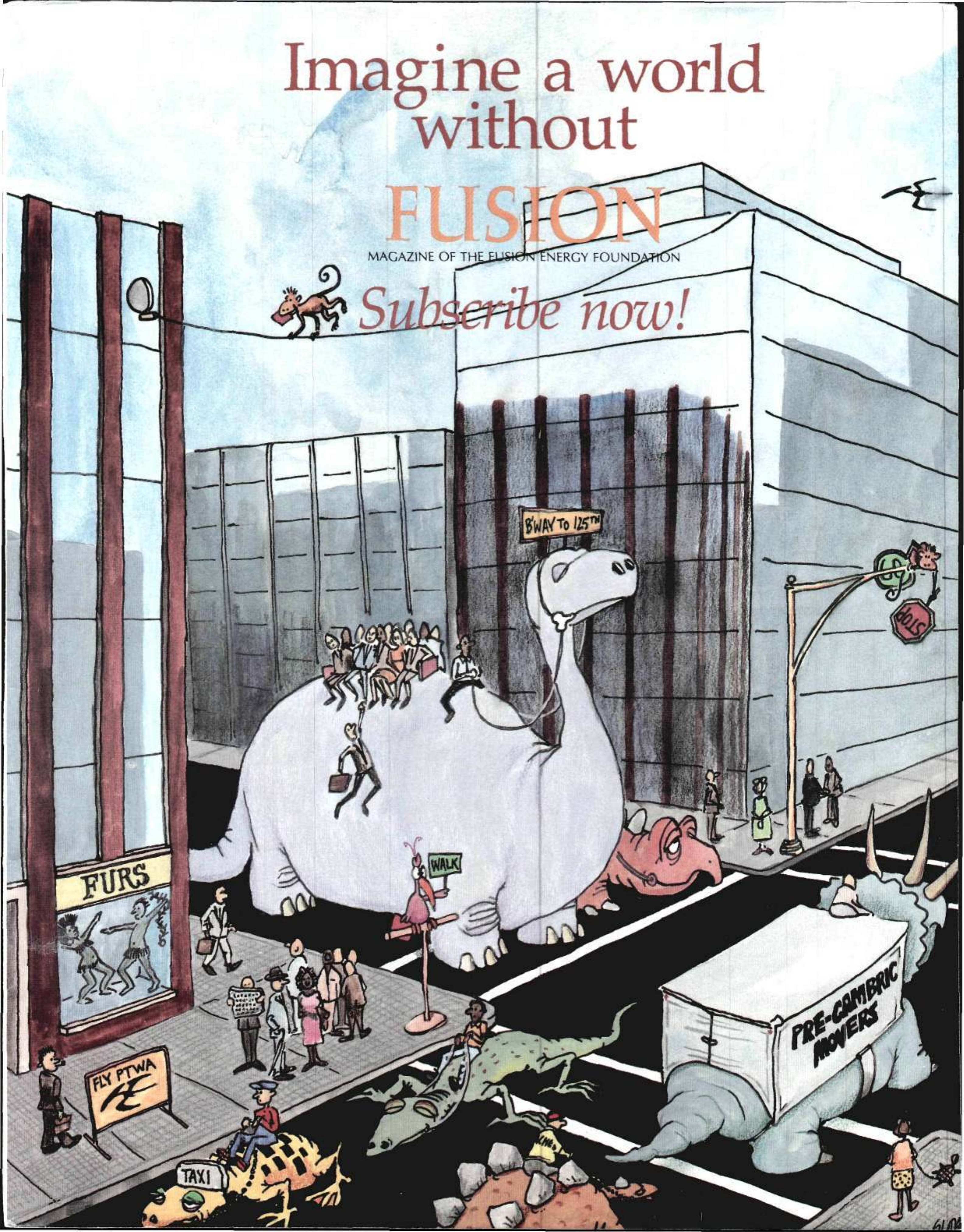




BEAM DEFENSE
An Alternative to Nuclear Destruction



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In This Issue

From the spheromak fusion device at Los Alamos National Laboratory to the Gekko XII laser at Osaka University's Institute of Laser Engineering in Japan, the impressive results of the latest fusion experiments demonstrate that the cheap, clean energy from fusion power is close at hand—if there is the political will to get the job done.

- This issue's cover story by Charles B. Stevens describes in detail the advances made by self-sustaining magnetic fusion devices at Los Alamos. The question is, will the U.S. fusion program be funded at a high enough level to continue the scientific and experimental achievements?
- The Fusion Report is a first-hand account by editor-in-chief Steven Bardwell of how the Japanese laser fusion program is aggressively and successfully pursuing promising lines of research that are classified in the United States. As Bardwell notes, the United States no longer has a monopoly on laser fusion; the Japanese, with the largest research budget and the largest laser, are surging ahead.
- In a related area, the development of the X-ray laser as a defensive weapon, the same situation exists. Our article on the X-ray laser shows that the science and technology are ready now to perfect this directed energy beam weapon. But to achieve a defensive system that can prevent nuclear missiles from exploding will require a national commitment similar to that of the Manhattan Project.
- The development of both fusion and the X-ray laser will usher in a technological revolution greater than that caused by the introduction of electricity at the close of the 19th century. This issue features the little-known story of the man responsible for making that first revolution happen, Thomas Alva Edison. As told by Michael Tobin, Edison waged a 10-year battle against the technology doubters of his day to establish the centralized electric power stations that provided the power for industrial growth worldwide.

(Right) *Dr. Chiyoe Yamanaka, head of the Institute of Laser Engineering at Osaka University, briefs the Japanese press May 10, 1983 at the dedication of the GEKKO XII glass laser, the most powerful laser in the world.*

(Below) *Thomas Edison with his early phonograph, June 1878, photographed by Mathew Brady in Washington, D.C. where Edison demonstrated the new device to the White House.*

U.S. Department of the Interior, National Park Service, Edison National Historic Site

In this design by the Fusion Energy Foundation, X-rays from a bomb blast are focused by a set of ellipsoidal cavities (a). Using multilayered K-alpha dielectric mirrors, these cavities focus all the X-rays from the spherically symmetric explosion on to the ends of the lasing rods. These rods use a conical assembly of lasing material to further focus the plasma produced by the X-rays along the axis of the rod (b). The lasing medium is embedded in a heavy metal tamper, which provides mechanical stability as well as an inertial focusing of the lasing medium (c). In addition, a very intense photoelectric current generated by the X-rays in the lasing material confines and focuses the X-ray producing plasma.

Steven Bardwell