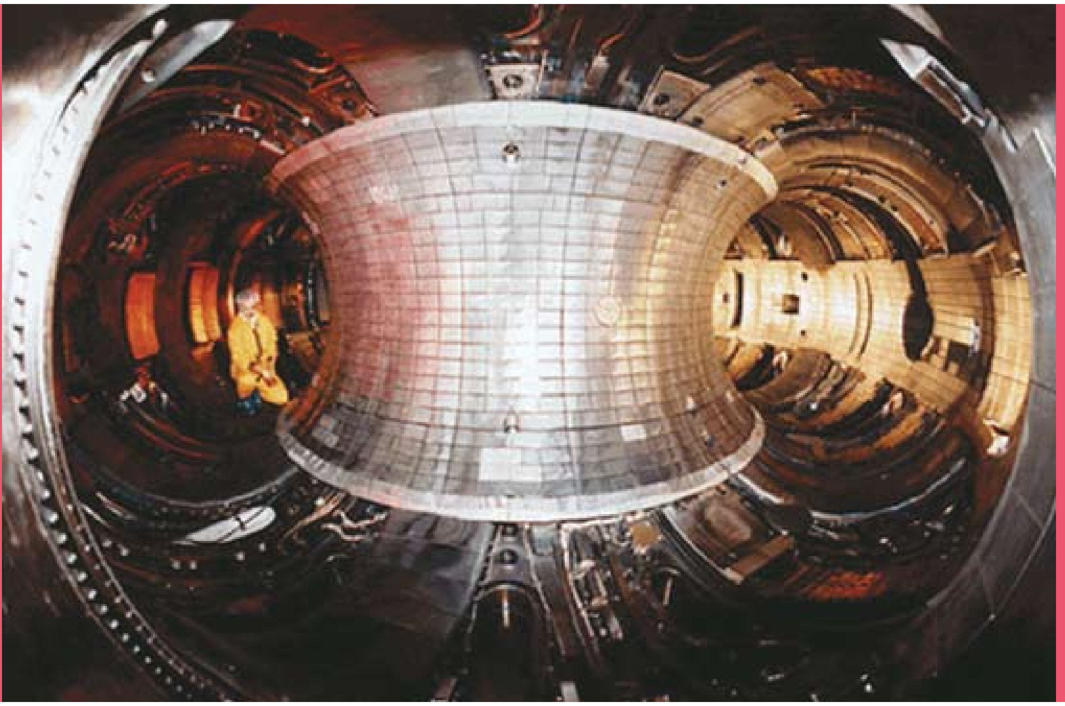


PPPL

Inside the Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory, while it was in construction. The TFTR set world records for plasma temperature and fusion power produced in the late 1980s and early 1990s. But budget cuts closed it down before all its planned experiments were completed.

The True History of The U.S. Fusion Program —And Who Tried To Kill It

An inside analysis of how the U.S. fusion program was euthanized, dispels the myth that "fusion can't work."

by Marsha Freeman

There is no disputing that the world is facing an energy crisis of vast proportions. But this could have been avoided. For more than five decades, scientists, engineers, energy planners, policy-makers, and, at times, even the public at large, have known what the ultimate alternative is to our finite energy resources—nuclear fusion. This energy, which powers the Sun and all of the stars, and can use a virtually unlimited supply of isotopes of hydrogen, available from seawater, has been visible on the horizon for years, but seemingly never close at hand. Why?

Legend has it that there are more problems in attaining controlled nuclear fusion than scientists anticipated, and that little progress has been made. "Fusion is still 50 years away, and always has been" has become the common refrain of skeptics. But the reason that we do not have commercially available fusion energy is not what is commonly believed.

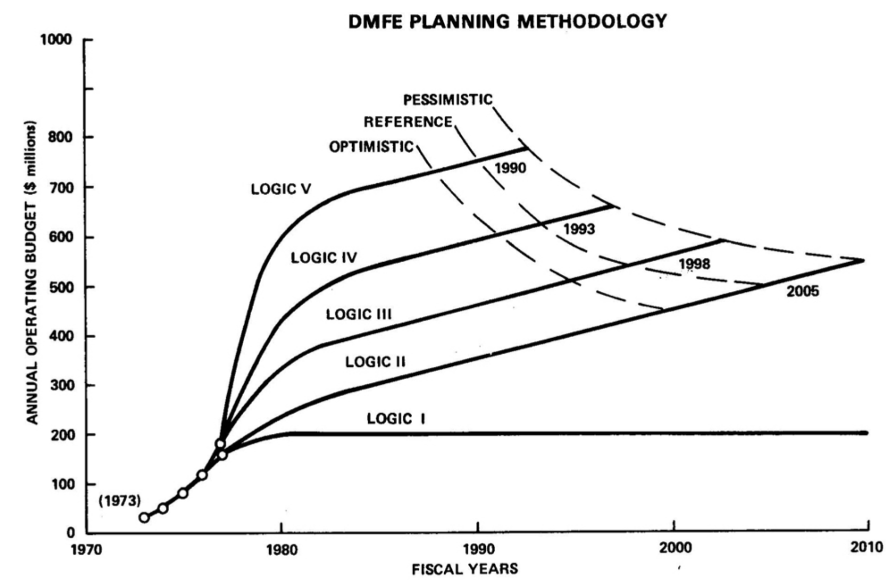


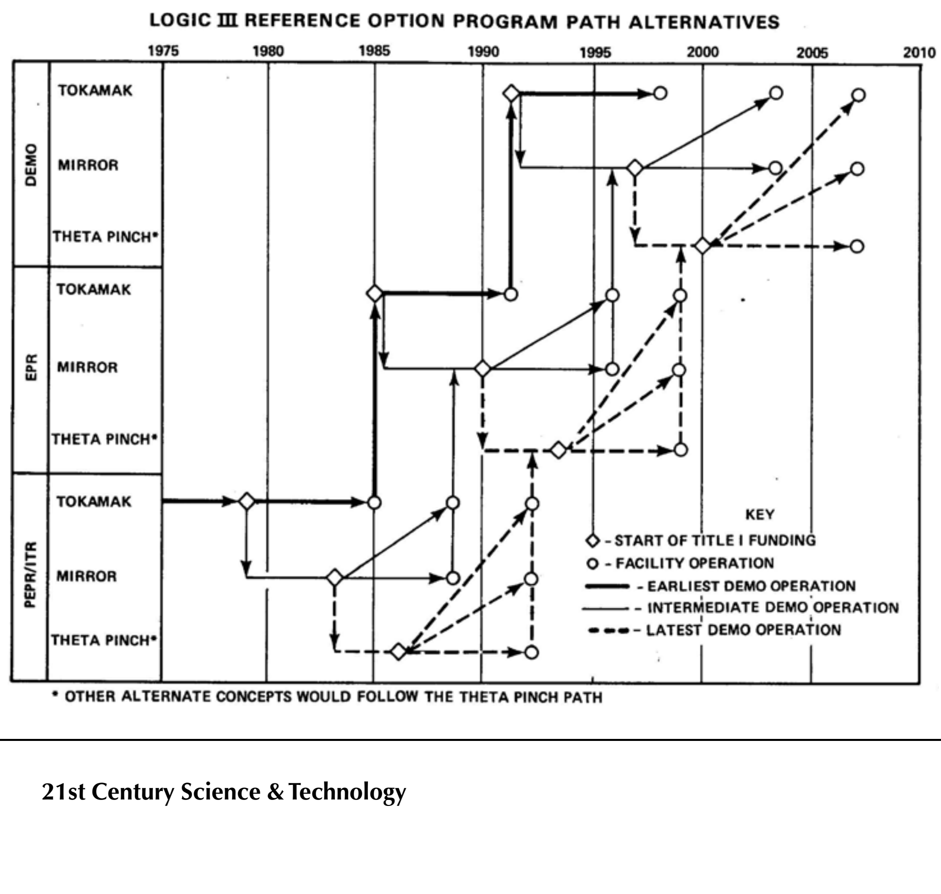
Figure 1(a)
WHAT IT TAKES TO REACH FUSION—ERDA'S LOGIC IN 1976
In 1976, the Energy Research and Development Administration (ERDA) published this chart showing the required fusion operating budgets to reach a working magnetic fusion reactor. Each option was called a "Logic," and each had three variations from optimistic to pessimistic. With $600 million a year, as shown in Logic V, the program would have been able to operate a demonstration reactor by 1990. Logic I, which represents the actual fusion budgets from 1976 to the present, produces "fusion never," as shown.
Source: ERDA, 1976

In 1976, the Energy Research and Development Administration, or ERDA—the predecessor to the Department of Energy—published a chart showing various policy and funding options for the magnetic fusion energy research program. Each option, called a "Logic," described how the level of funding for the research would determine when practical fusion power would become available. The most aggressive profile, Logic V, proposed that a budget of approximately $600 million per year would put the fusion program on a path to operate a demonstration reactor by 1990.

At the other end of the scale, Logic 1, set at a level of about $150 million per year, was the option colloquially described as "fusion never," because the funding never reached the level where the remaining challenges in fusion could be overcome. The U.S. fusion program has been at that fusion-never equivalent level, or *below,* for the past 30 years.

It is a specious argument to claim that there has not been the money available to aggressively

Figure 1(b)
ERDA'S OPTIONS FOR MAGNETIC FUSION IN 1976
These are the pathways planned for the tokamak, the tandem mirror, and the theta pinch (and other alternative concepts) if the reference option in Logic III (see a) were followed. Logics II and III would have put demonstration reactors online by now.
Source: ERDA, 1976



pursue fusion research, when one considers the multi-trillion-dollar cost to the U.S. economy of importing oil. In the 1970s, comprehensive studies had already been done, outlining the application of high-density fusion power, not only to produce electricity, but also to create synthetic fuels, such as hydrogen; to create fresh water from the sea, through desalination; to economically create new mineral resources with the fusion torch; to propel spacecraft to Mars and beyond; and myriad other applications.

The lack of progress in the U.S. fusion program is entirely a result of a lack of political will, a lack of vision, and the promotion of false and destructive economic and energy policies, which have now left us behind the rest of the world in developing practical fusion energy.

One might think that if the United States doesn't push ahead for fusion development, other nations will, leaving the United States in the lurch. In reality, the situation is far worse. At the present rate of world physical economic collapse, the ability to sustain the Earth's 6.7 billion population is already nearly lost. A crash program to develop the required physical infrastructure in agriculture, mining, water resource development, housing, health care, and, most of all, power production, must start now. Nuclear power now and fusion power within a generation is an absolute requirement. Without it, human civilization goes the other way—into a Dark Age, and the descent has already begun. We must reverse it now.

The United States in the Lead

At one time, it should be recalled, the United States was a world leader in fusion energy research. This was the result of the vision of policymakers, and the optimism and hard work of hundreds of scientists and engineers committed to fusion's development.

The dependence of the United States on imported energy supplies was dramatically demonstrated during the so-called energy crisis in the mid-1970s, following the 1973-1974 Middle East war, and oil embargo. The Nixon/Ford Administrations and energy policy planners responded with a broad-brush energy R&D initiative, which included increased funding for advanced nuclear fission, and for fusion research. In fiscal year 1974, the magnetic fusion energy R&D budget was $43.4 million. By fiscal year 1977, the funding had increased

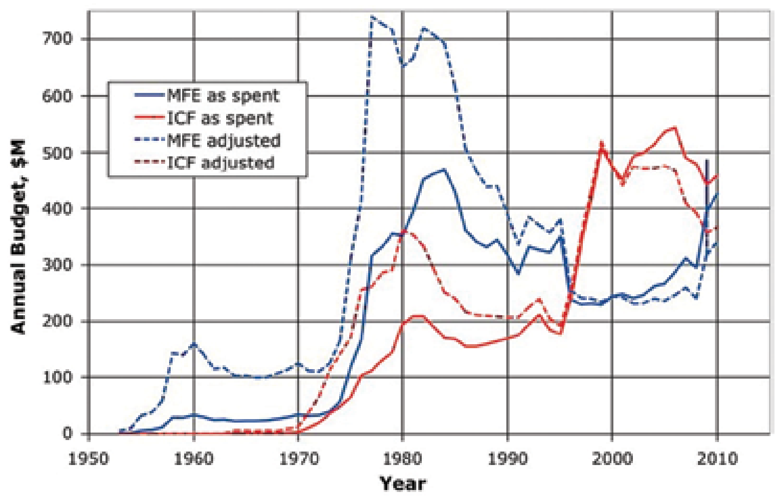


Figure 2
ANNUAL FUSION BUDGETS FOR INERTIAL AND MAGNETIC CONFINEMENT (1950-2010)
The annual budgets for magnetic fusion energy (MFE) and inertial confinement fusion (ICF) in millions of dollars. The magnetic fusion energy budget today, in real, inflation-adjusted dollars, is about one third what it was in the late 1970s. MFE is funded under the Department of Energy Office of Fusion Energy Sciences, and the ICF budet is funded under defense programs.
Source: U.S. Department of Energy, U.S. Energy Information Agency

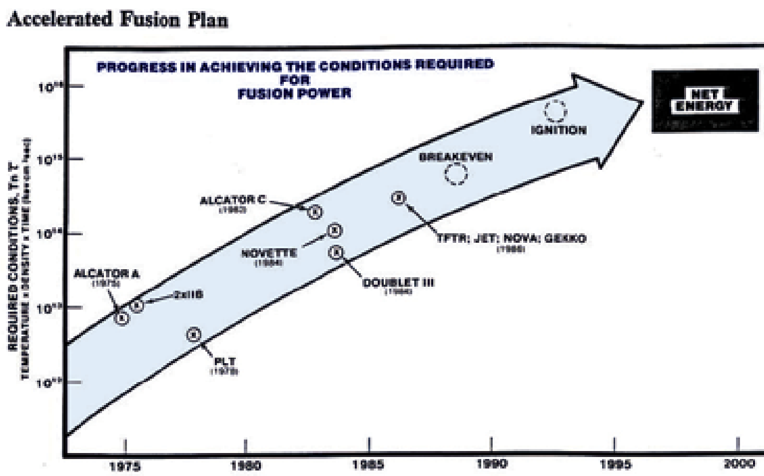
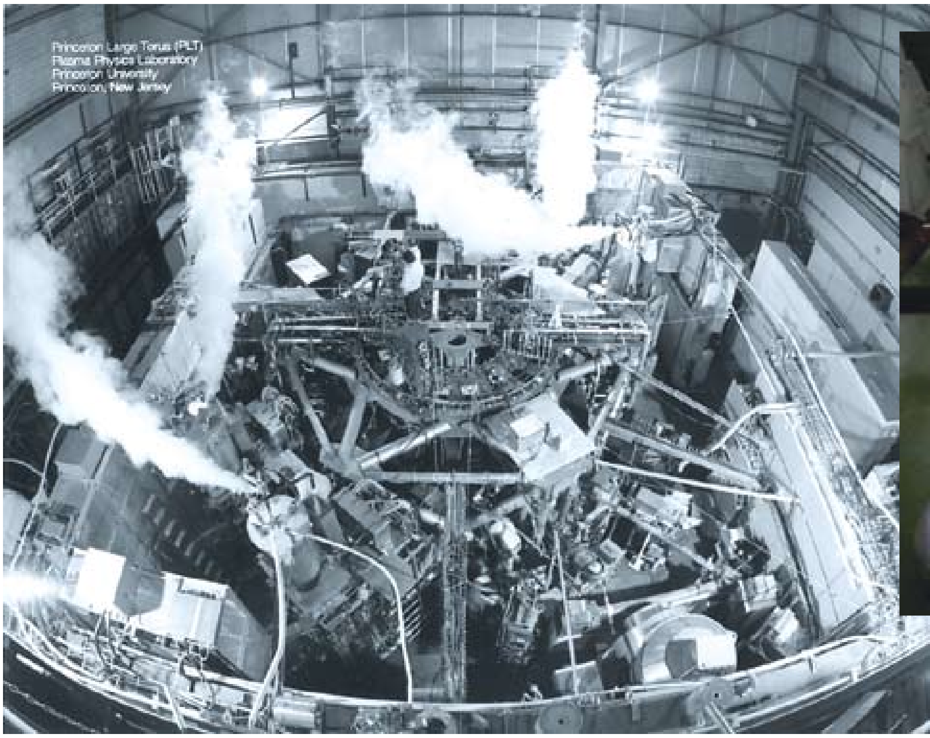
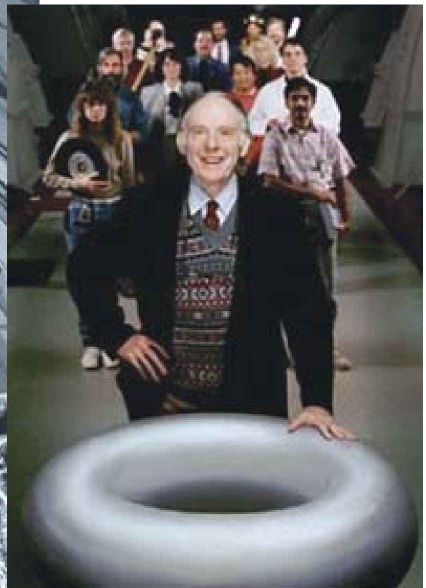


Figure 3
PROGRESS IN ACHIEVING THE CONDITIONS REQUIRED FOR FUSION POWER
This 1991 assessment shows how the improvement in plasma parameters of ion temperature (T), density (n), and confinement time (t), often expressed as the product Tn, could be linked with the operation of new experimental facilities. The improvement required for a power plant compared with 1991 values was no greater than the improvement fusion had made in the 15 years preceding 1991.
Source: Stephen O. Dean et al., "An Accelerated Fusion Power Development Program," *Journal of Fusion Energy*, Vol. 10, No. 2, 1991



PPPL

In July 1978, the Princeton Large Torus (PLT) tokamak set a world record for ion temperatures of 60 million degrees C, using neutral-beam heating. For the first time, ion temperatures exceeded the theoretical threshold for ignition in a tokamak device.



Denise Applewhite/PPPL

Melvin B. Gottlieb was the director of the Princeton Plasma Physics Laboratory from 1961-1980. Although there were more than 100 tokamaks operating in 1978, the PLT results were unique, according to Gottlieb.

to $316.3 million.

This investment laid the basis, more than 30 years ago, for dramatic progress in the U.S. fusion program. That investment paid off. In August 1978, scientists at the Princeton Plasma Physics Laboratory reported that the previous month, the plasma in their Princeton Large Torus (PLT) tokamak had reached the record-setting temperature of 60 million degrees. This exceeded the ignition temperature of 44 million degrees which it had been determined was required for a sustained fusion reaction. One of the key barriers for fusion—the application of external power for heating the plasma—had been overcome.

At that time, the broad-based domestic magnetic fusion program wisely supported an array of, not just tokamaks, but a variety of machines with different geometric configurations, in which novel concepts for attaining fusion energy were being investigated. While advances using the tokamak design, created by the Soviet Union in the 1960s, showed great promise, the problems of plasma purity, superconducting magnet technology, new materials required for fusion reactors, methods for extracting energy from the fusion reaction, and other challenges, were being investigated in experimental facilities in national laboratories and universities around the country, and also internationally. But as Princeton laboratory Director, Dr. Melvin Gottlieb, proudly reported in 1978, although there

The Princeton PLT breakthrough in 1978 brought the energy policy war out into the open.

Rep. Charles Rangel: The solution of the world's energy problem is before us.

Stephen Dean: The biggest thing that ever happened in fusion research.

DOE Undersecretary John Deutch: Not a breakthough, just a significant result.

R.D. Ward/DOD

Energy Secretary James Schlesinger: We did not want to hype it up.

were then more than 100 research tokamaks around the world, all doing important research, the Princeton results were unique.

The reaction to the Princeton announcement was electric. In an interview with CBS News, Dr. Stephen Dean, director of the Magnetic Confinement Systems Division of the Department of Energy Fusion Office, stated: "The question of whether fusion is feasible from a scientific point of view has now been answered." The Princeton fusion breakthrough became front-page news in newspapers around the world.

Rep. Charles Rangel (D-N.Y.), counseled: "This breakthrough compels us to redirect our energy and funnel further funds and attention to highly promising and vitally important nuclear fusion research." The press hailed the achievement, recognizing the fundamental importance for the future prosperity of mankind of developing fusion energy.

But not everyone was excited by the breakthrough. In fact, a war that was being waged over energy policy somewhat behind the scenes, burst out in to the open.

For days, pressure was put on the Princeton scientists by the Department of Energy not to make a big deal over the results. A press conference that the Princeton team was to hold to make the announcement was almost cancelled. When it finally did take place, officials of the DOE, under James Rodney Schlesinger, spared no effort to try to downplay the importance of the Princeton achievement. As reported in an article appearing in the August 16 issue of the *Christian Science Monitor,* "Public affairs officers for the U.S. Department of Energy . . . say the DOE was both puzzled and embarrassed at what it considers an unauthorized and overblown announcement of the Princeton work." DOE public affairs director Jim Bishop emphasized that, "While the Princeton work is a major scientific achievement, it probably won't shorten the time scale or the cost of fusion power development"! Energy Secretary Schlesinger was incensed at the optimism that followed the Princeton fusion announcement.

Library of Congress

Cartel manipulation of the oil market created gas lines like these—and their accompanying zero-growth energy and economic policies in the 1970s.

Why?

The Administration of President Jimmy Carter came into office in 1977, just three years after the "Arab" oil embargo, which manipulation, it was shown, was created not by "Arabs," but by the international oil cartel. Gasoline lines, and the quadrupling of energy prices, were the result of these manufactured shortages, and it created the opportunity to implement a conservation, zero-growth energy and economic policy, which had been promoted by the British Malthusian interest through such institutions as Prince Philip's World Wildlife Fund, the Club of Rome, the Ford Foundation, and other think-tanks, since the 1960s.

For the first time in the history of the United States, the idea that "less is more," that "small is beautiful," that there are "limits to growth," that the world was running out of resources, became the policy of the Federal government. The possibility that there could be virtually unlimited fusion energy made an embarrassing mockery of the "conservation," and "turn-down-the-thermostat" belt-tightening policies being promoted by the Carter White House.

The most important, visible, and respected public advocacy organization for the full-scale development of fusion energy, at the time of the Princeton breakthrough, was the New York-based Fusion Energy Foundation. In its coverage of the Princeton results, in October 1978, the Foundation released a proposed budget for fusion development, in the form of a Memorandum to the Congress. The Memorandum proposed an acceleration of the fusion research program in both magnetic and inertial confinement, increased international collaboration, and a funding level comparable to that of the 1960s Apollo space program.

The Foundation proposal included funding for next-generation experimental machines across the range of tokamaks, plus magnetic mirror experiments, and scyllac, theta pinch, stellarators, and other magnetic geometries. Advanced laser, ion beam, electron beam, and other inertial confinement experimental facilities were included. Basic engineering, materials, component, and test facilities were part of the upgraded and accelerated program.

At the time, and with the aid of the Fusion Energy Foundation's massive outreach through its widely read magazine, *Fusion*, an awareness was growing in the Congress that the high-technology path was the real way to energy independence. The Carter White House and financial interests who saw the development of unlimited sources of energy as a threat to their vested interests, mobilized to squelch the enthusiasm.

In July 1978, a group described as the Nuclear Club of Wall

(Text continues on p. 22)

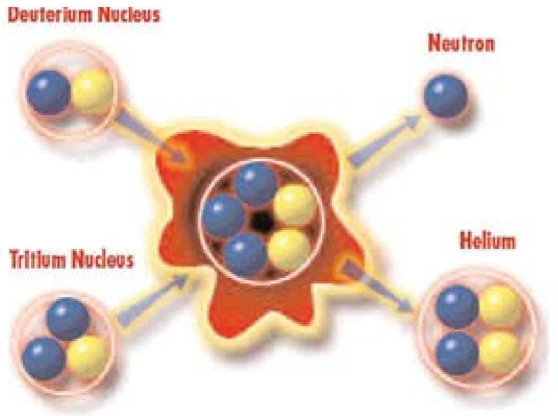


Figure 4
THE FUSION REACTION
A fusion reaction takes place when two small atoms combine to form a larger atom, releasing a large amount of energy in the process. Here, two isotopes of hydrogen, deuterium (1 neutron and 1 proton) and tritium (2 neutrons and 1 proton) combine, producing a helium nucleus (two neutrons and two protons) at 3.5 MeV, and a high-energy neutron (14.1 MeV).
Source: DOE

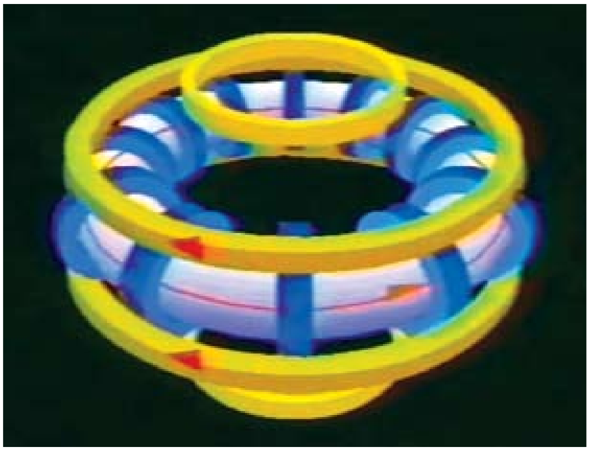


Figure 5
CONTAINING THE FUSION PLASMA IN A TOKAMAK
In magnetic confinement fusion, the combination of toroidal (long way around the tokamak) and poloidal (short way around the tokamak) magnetic fields contain the fusion plasma, preventing it from hitting the walls of the reactor.
Source: PPPL

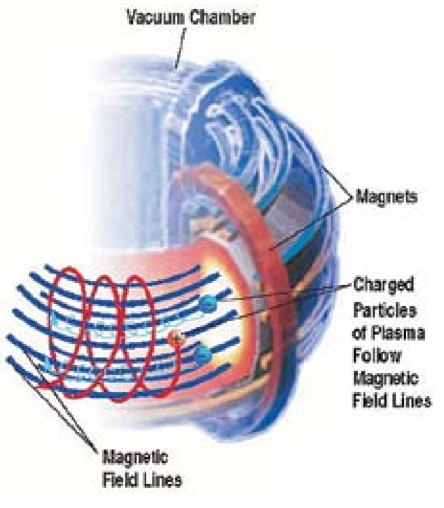
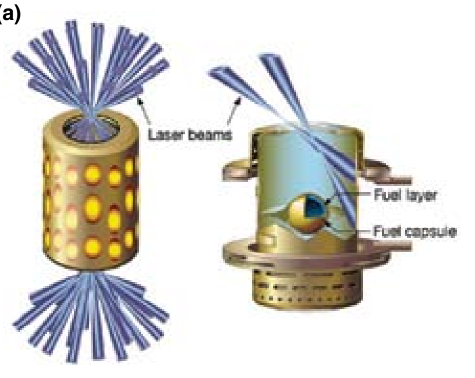


Figure 6
CUTAWAY VIEW OF MAGNETIC CONFINEMENT
This diagram of a tokamak shows the magnets, the magnetic field lines, and the charged particles of plasma that follow the magnetic field lines, spiralling around the tokamak.
Source: "The Surprising Benefits of Creating a Star," U.S. Department of Energy

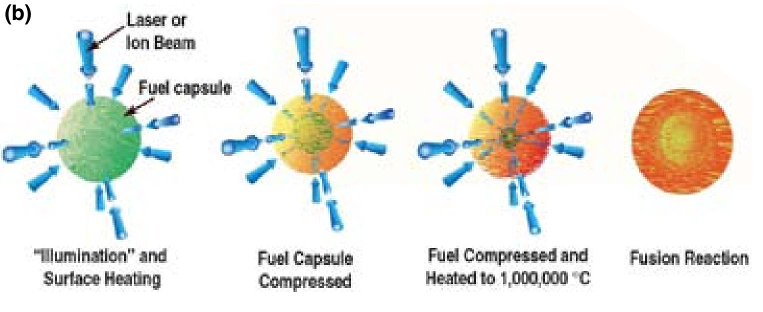
Figure 7
INERTIAL CONFINEMENT FUSION:
THE NATIONAL IGNITION FACILITY

(a)



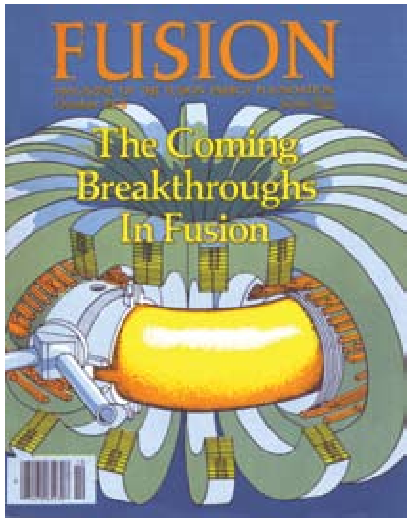
This schematic (a) of the National Ignition Facility shows the array of 192 laser beams focussed on a tiny pellet of deuterium and tritium fusion fuel, encapsulated in beryllium and carbide. The laser beams compress and heat the fuel pellet (b) in a billionth of a second, so that the deuterium and tritium fuse before the pellet flies apart. The term inertial refers to the fact that the atoms must have enough inertia to resist flying apart before they combine.

(b)



Source: Lawrence Livermore National Laboratory

The Fusion Energy Foundation was founded in November 1974 by Lyndon H. LaRouche and leading scientists, including Manhattan Project veteran Robert J. Moon. Here, LaRouche (center) at the reception following the founding meeting.



Fusion *magazine, published by the Fusion Energy Foundation, grew rapidly in circulation and influence in the 1970s, and was available on newsstands nationwide. This is the October 1978 issue that covered the PLT breakthrough.*

Princeton Plasma Physics Laboratory director Melvin Gottlieb (reading program) at a celebration in his honor given by the Fusion Energy Foundation in 1980. Speakers included both Gottlieb's teachers and students. At right is Dr. Robert J. Moon, one of Gottlieb's professors. At the podium is FEF director Morris Levitt.

Carlos de Hoyos

Carlos de Hoyos

e Kiyoshi Yazawa

Fusion Energy Foundation representatives visited and wrote about fusion reactors around the world. Above: Charles Stevens (second from left) on a tour of the TFTR at Princeton, and Tanu and Susan Maitra (at right) in 1984 with Dr. Miyoshi, the director of the Plasma Research Institute at Tsukuba University, which operated a tandem mirror experimental reactor.

Suzanne Klebe

EIRNS

The Fusion Energy Foundation worked closely with Rep. Mike McCormack (D-Wash.) and other members of Congress to organize and educate the public to support fusion and the "McCormack bill." Left: the author with Representative McCormack at fusion hearings on Capitol Hill. Right: McCormack addresses a Fusion Energy Foundation conference in Washington, D.C. in May 1981.

(Continued from p. 19)
Street helped stitch together the Society to Advance Fusion En ergy, or SAFE, funded primarily by the Slaner Foundation. While their stated goal was to promote fusion energy research, their attacks on nuclear energy, as "unSAFE," and on the then-leading tokamak program, revealed that SAFE's intention was not to advance support for fusion energy. In fact, as SAFE explained to inquiries, its sole purpose was to discredit and blunt the influence of the Fusion Energy Foundation! This attempt did not succeed.

Energized by the Princeton results, and the promise of the next critical breakthroughs in fusion, Rep. Mike McCormack, a Democrat elected to Congress in 1970 from the State of Washington after a 20-year scientific career, introduced a bill in January 1980 to accelerate the development of fusion energy. A scientific advisory panel, which McCormack had convened over the previous year, had concurred with his evaluation that the most significant barrier to the commercial development of fusion was the lack of a national commitment, and an inadequate level of funding. The bill soon garnered 140 cosponsors.

One week before introducing his bill, McCormack spoke at a conference in Washington, D.C., on nuclear safety. There, the anti-nuclear Carter Administration "energy" policy was laid bare. Department of Energy Undersecretary John Deutch, a Schlesinger appointee who had downplayed the Princeton results, stated that conventional nuclear power should be an energy source "of last resort." He continued that the DOE "would like to minimize the use of nuclear energy through conservation and the use of coal."

Representative McCormack also addressed the meeting. "We must take the offensive on nuclear energy," the Congressman stated. "Nuclear power as a 'last resort,' was never realistic and now is irresponsible," he continued. He stated that the United States "must have 500 gigawatts of nuclear energy by the year 2000, which is not overambitious," in order to ensure economic growth and a rising standard of living. Nuclear energy and coal would be the "bridge" energy sources to the future.

McCormack used the occasion to announce that he would be introducing legislation "to make it the policy of the U.S. government to bring the first electric-generating fusion power plant on line before the year 2000. We must move into the engineering phase with fusion," he said. "We must not wait for somebody else to do it."

McCormack called the decision to proceed with an Apollo-style fusion program, as promoted in his bill, "the single most important energy event in the history of mankind." He explained that, "once we develop fusion, we will be in a position to produce enough energy for all time, for all mankind. This is not hyperbole, but fact." In an interview with this writer after the bill's introduction, Rep. McCormack also added that fusion, which should be developed internationally, "for all mankind," could "be the most important deterrent to war in all of history."

The bill authorized the construction of a fusion Engineering Test Facility by 1987. The first experimental power reactor would be developed by the year 2000, to produce net power, and lay the basis for commercial development. The bill estimated that this program would require a $20 billion expenditure over the two decades from 1980 to the turn of the century; considerably less, in 1980 dollars, than what the United States spent to land a man on the Moon. The funding included the expansion and upgrading of the nation's science education programs.

The Fusion Energy Foundation mobilized its tens of thousands of supporters to tell their Representatives in Washington to support the McCormack bill. Statements of support were elicited from labor leaders, clergy, civil rights activists, state legislators, and other elected officials, industrial leaders, and the fusion research community.

On August 27, the House of Representatives passed the fusion bill by a vote of 365 to 7. Soon after, the Senate passed a companion bill by voice vote. President Carter signed the bill into law on

The passage of the McCormack bill set off a wave of optimism in the U.S. press.

October 7. The path to commercial fusion energy was clear.

But a month later, President Carter became a lame duck, as Ronald Reagan won the 1980 Presidential election. Regardless of the next Administration's policy toward fusion, the scientists warned, every new Administration wants to do its own review, which only delays progress. Worse still, because President Carter conceded the election before the voting polls were even closed on the West Coast, Democrats in key states, such as Washington, did not even bother to go to the polls to vote. Rep. Mike McCormack, and key collaborator, Governor Dixy Lee Ray, lost their bids for reelection.

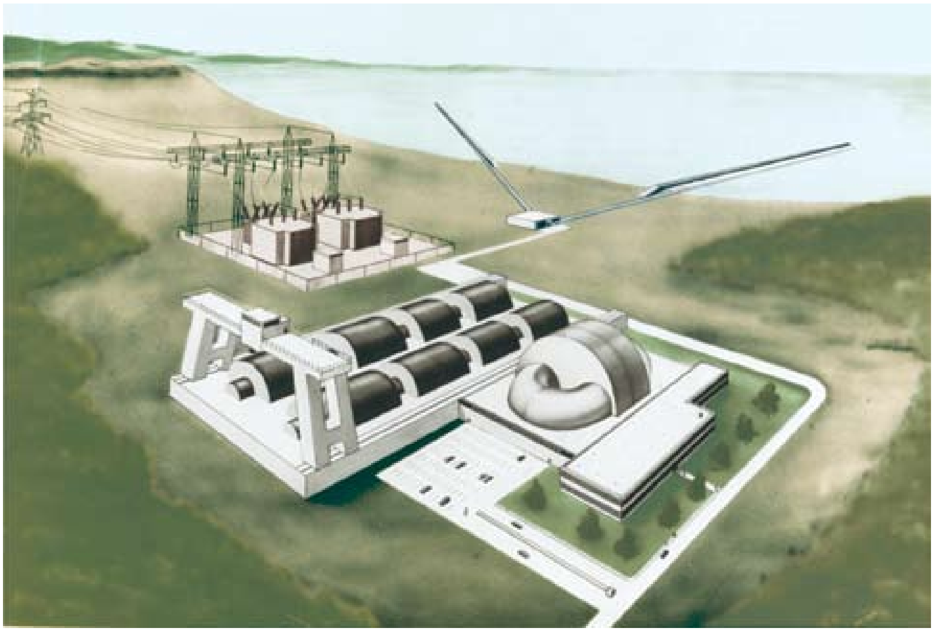
Recognizing that fulfilling the commitments of the fusion law would take a multi-generational commitment from the Congress, the Subcommittee on Energy Research and Production of the House Committee on Science and Technology, chaired by Rep. McCormack, issued a report in December 1980 providing an overview of the fusion energy program, for the incoming Reagan Administration. In the Preface, the report states that the signing of the bill into law "marked the end of the beginning" of "what may be the most historically important road mankind has ever taken." But, the report warns, "the hardest battles are yet to come. There must be continual annual authorizations and subsequent appropriations of funds." The report concluded: "It will take tremendous vigilance and determination on the part of the Nation to carry through the 20-year development plan which is necessary to make fusion a reality."

Even while the McCormack fusion bill was still being debated, conservative congressional representatives were responding to the Federal budget deficit, created through the Carter Administration's failed economic policies, by attempting to reduce Federal spending on energy R&D. Only an intervention on the floor of the House by Science and Technology Committee chairman Rep. Don Fuqua (Democrat from Florida), restored a proposed cut in Fiscal Year 81 funding that would have delayed construction of Princeton's next-step Tokamak Fusion Test Reactor (TFTR) for at least a year.

The handwriting was on the wall. It did not take long for the plan that had become law, to demonstrate commercially viable fusion energy by the turn of the century, to be derailed. In the incoming Reagan Administration, opposition to fusion would not come from radical "left" zero-growthers, but from an otherwise well-meaning President, who had been captured by the conservative free-market "right."

A Policy of Mediocrity

The Reagan White House's fusion budget request for fiscal year 1982, forwarded to Capitol Hill in early 1981, had, with breakneck speed, tossed aside the Congressional mandate for the McCormack law fusion engineering development program.

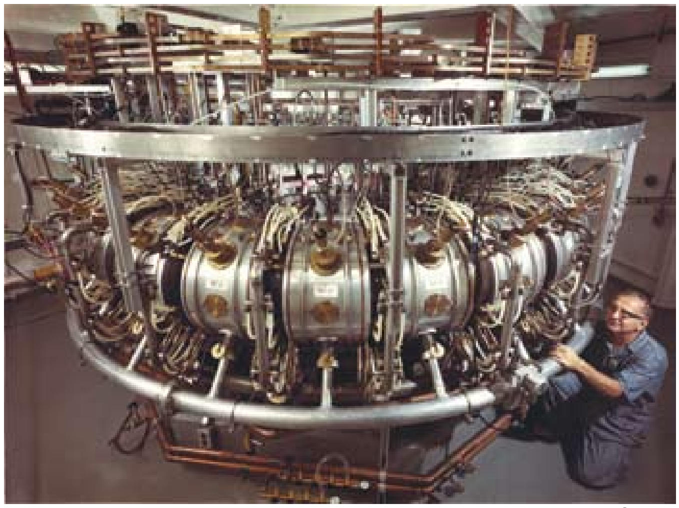


AEC

As early as 1972, research in magnetic fusion had shown so much promise that Westinghouse Nuclear Energy Systems created a concept of a fusion power plant for the U.S. government. The reactor shown here is an Atomic Energy Commission depiction of a commercial reactor that the AEC predicted would be in operation "about the year 2000."

Union Carbide

The dedication of the Elmo Bumpty Torus fusion site in Oak Ridge, Tenn. Rep. Marilyn Lloyd Bouquard, chairman of the House Energy Research and Production subcommittee, is third from left; Ed Kintner, head of the DOE Office of Fusion Energy is second from right. Kintner resigned his post in November 1981, in protest of the fusion budget cuts.



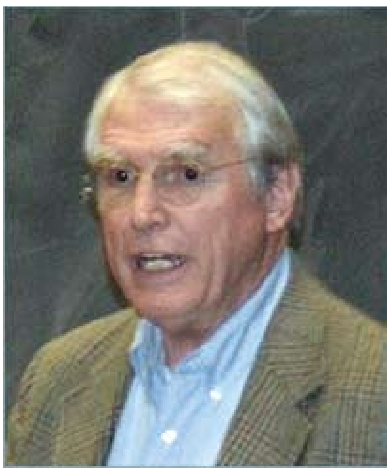
Union Carbide

The Elmo Bumpy Torus in 1978. The EBT concept used mirrors in a toroidal configuration with steady-state, high-power, electron cyclotron resonance heating to produce a steady-state plasma. Budget cuts shut it down in 1984.

At a briefing on Feb. 26, Energy Secretary James Edwards answered a reporter's question by stating that "we're going to fund fusion," adding, "but we're not going to throw money at it irresponsibly." At the same briefing, Treasury Secretary Don Regan said the Reagan Administration's economic objective was to "give the economy back to the people." Tax cuts and deregulation were on the agenda, not Federal investments in R&D.

On March 6, the Fusion Energy Foundation issued a press release, warning that the Reagan Administration's proposed budget cuts in funding for NASA's space programs and for fusion research, would implement the very Carter-era deindustrialization policies that President Reagan had been elected to reverse. Ten days later, the Foundation sent a letter to all of the co-sponsors of Representative McCormack's fusion bill, alerting them to the devastating blow the White House was proposing to the fusion development schedule, pointing out that it violated the law of the land.

On July 31, six months after President Reagan came in to office, Rep. Marilyn Lloyd Bouquard, Democrat from Tennessee, who had replaced Mike McCormack as chair of the Subcommittee on Energy Research and Production, wrote a scathing letter to Energy Secretary Edwards. The Department had proposed that rather than requesting funds to establish the industrially managed Center for Fusion Engineering, mandated in the fusion law, it would instead request for a Fusion Energy Engineering Feasibility Preparations Project, as a way of delaying the day when engineering challenges in fusion would be tackled. Rep. Bouquard described her response as "puzzled and dismayed," and wished to express her "dissatisfaction to you in the most emphatic terms."



Center for Science and Technology Policy, University of Colorado

George Keyworth, the fiscal austerity proponent who served as President Reagan's science advisor, saw no need for fusion development.

The betrayal of the promise of fusion led Edwin Kintner to resign from his post at the Department of Energy in November 1981, after having served since April 1976 as the Director of the Office of Fusion Energy. Kintner came to the Department following 22 years of service with the U.S. Navy, 14 of which were in the Naval Reactors Program, under Admiral Hyman Rickover. His resignation, he made public, was in protest over cuts in the fusion budget which indicated a change in policy, and a delay, or cancellation, of the program Congress had put into law.

Kintner reported, in an article in the May/June 1982 issue of MIT's *Technology Review,* that while the initial request from the Department's fusion office, for 1982-3 was for $596 million, the proposed $557 million, Kintner felt, would still, though barely, meet the Fusion Act commitments. But when David Stockman's Office of Management and Budget presented the 1983 budget to Congress, with a total of $444 million for fusion, or 25 percent less than the 1977 budget, in real terms, the fusion law was dead. The White House policy was that demonstration projects should not be funded by the government, but be left to private industry.

The following month, President Reagan's Science Advisor, George Keyworth, told the House Committee on Science and Technology that the United States "cannot expect to be preeminent in all scientific fields, nor is it necessarily desirable." Never before in its history did U.S. science have mediocrity as a goal.

"Science policy, made without considering economic policy, is irrelevant," Keyworth stated, advising that fiscal austerity dictated "limits" and that R&D must "compete" with other programs for Federal dollars. Members of the Committee wisely pointed out that this was exactly backwards: it is investments in science and technology that are the engine of economic growth; they are not a "drain" on the economy. In the same hearing, Keyworth defended his proposal that NASA discontinue its planetary exploration program, because "we couldn't afford it."

But despite the pull-back in funding in the 1980s, the investments in fusion research that had been made in the previous decade continued to bear fruit.

Princeton's Tokamak Fusion Test Reactor, or TFTR, which had been initiated in 1975, created its first plasma the day before Christmas, in 1982. In May the following year, President Reagan sent congratulations to the Princeton fusion team, looking toward the promise of unlimited fusion energy, which were presented at the official May 5 dedication of the tokamak. The TFTR would indeed prove itself a robust and highly productive research facility.

But in the Fall of 1983, at a fusion hearing, Dr. Dean warned Congress that "the U.S. is no longer the unquestioned world leader in fusion development. The fusion programs in the U.S., the U.S.S.R., Europe, and Japan have comparable accomplishments, facilities, and momentum." The present dramatic rate of progress, he stressed, "is based on the capital investment commitments made in the 1970s." But now, the United States was not making a commitment to move forward.

In July of 1986, the TFTR reached a record plasma temperature of 200 million degrees. Despite cutbacks in funding, and years of delays, in 1993, experiments were carried out which produced a peak fusion power of 10.7 megawatts, a world record, and 90 million times more than what could be generated in 1974, when the TFTR project was proposed. While not literally achieving energy "breakeven," where there is as much energy from fusion produced as is used to heat the plasma, the scientists reported that they "are very close." That year, the TFTR had switched from pure deuterium fuel to deuterium-tritium, similar to what would be used in a power reactor. Two years later, a record 510-million-degree plasma temperature was recorded.

It would have seemed only prudent, on the heels of these stunning results, that there would have been no hesitation to authorize the next-step experimental facility in the tokamak program, as the follow-on to the TFTR. Princeton proposed a Compact Ignition Tokamak (CIT), to create sustained fusion power. But in October 1989, President George H.W. Bush's DOE representative, Robert Hunter, told a Congressional hearing that the Administration proposed to cut another $50 million from the fusion budget, because the Compact Ignition Tokamak was too high risk, and probably would not succeed! Dr. Stephen Dean retorted that the reason you conduct experiments is to learn. "We've got to take some risks if we intend to develop a machine that makes electricity. If Columbus had waited for radar to be discovered before he set out, we wouldn't be there today."

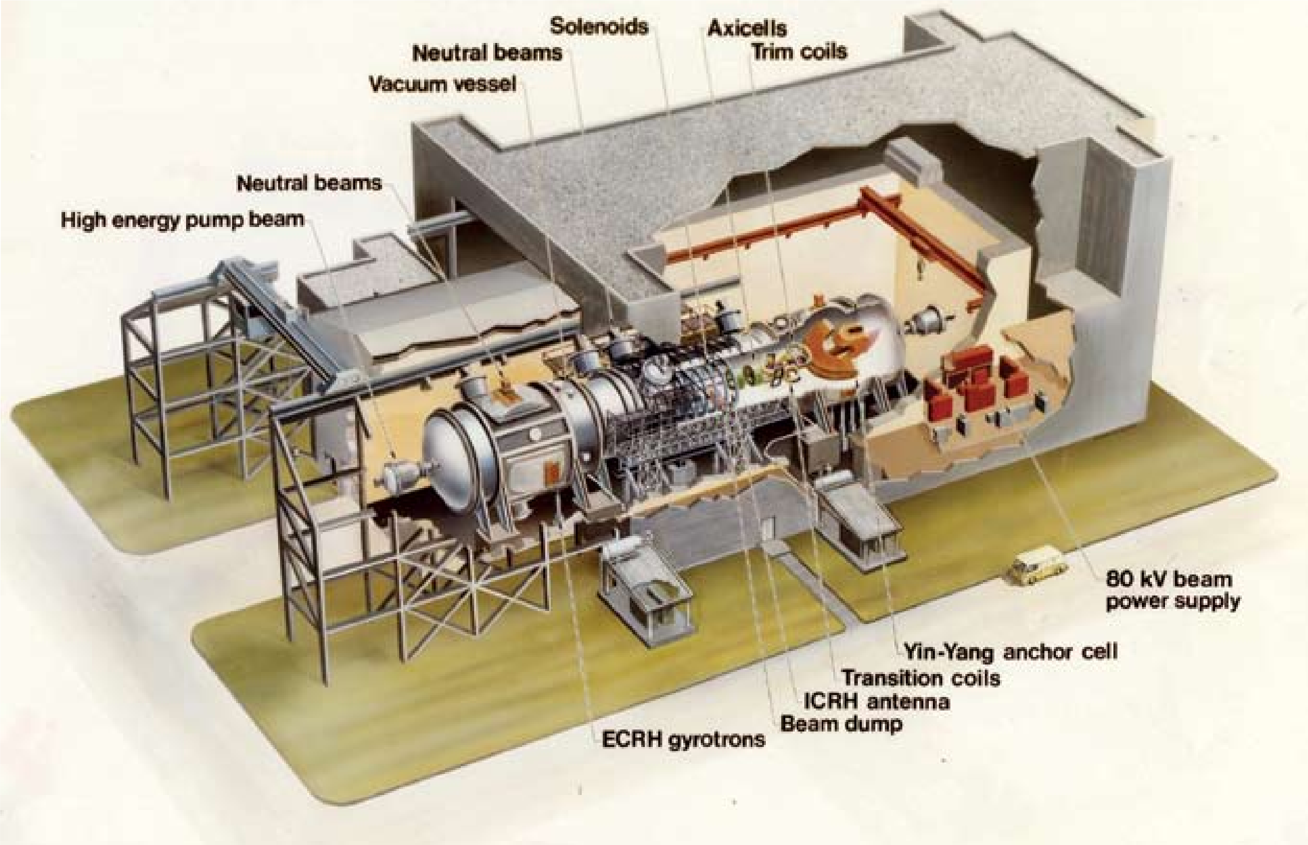
Meanwhile, the Princeton Plasma Physics Laboratory laid off 120 industrial contract personnel, who had expected to begin work on the CIT, as it became increasingly doubtful it would ever be built.

The mainline tokamak program was not the only approach to suffer, as the nation pulled back on research in magnetic fusion. From 1973 to 1984, Oak Ridge National Laboratory's Elmo Bumpy Torus produced promising results, as an alternate magnetic fusion concept to tokamaks. By 1981, the preliminary design for a 1,200-megawatt power plant had been created, and the next-step machine was selected for a scale-up to proof-of-principle. It was never built.

Incredibly, on the very day that Lawrence Livermore Laboratory's Tandem Mirror Fusion Test Reactor was to begin operation, in 1986, it was cancelled. The completed device was nev-

PPPL

Princeton's Tokamak Fusion Test Reactor (TFTR) was conceived as a link between its generation of tokamaks and the first experimental power reactor. It reached record plasma temperatures of 200 million degrees in July 1986 with deuterium fuel, and two years later reached 510 million degrees using deuterium-tritium fuel. But budget cuts precluded further breakthroughs, and the TFTR was decomissioned early, in 1995.



LLNL

Another casualty of the budget cutters was the Mirror Fusion Test Facility (MFTF) at Lawrence Livermore, shown here in an artist's drawing. The MFTF was forced to shut down just after it was fully completed because of budget cuts. It was sold for scrap. (For more on this story, see the Summer 2009 issue of 21st Century.*)*

er turned on, and was dismantled.

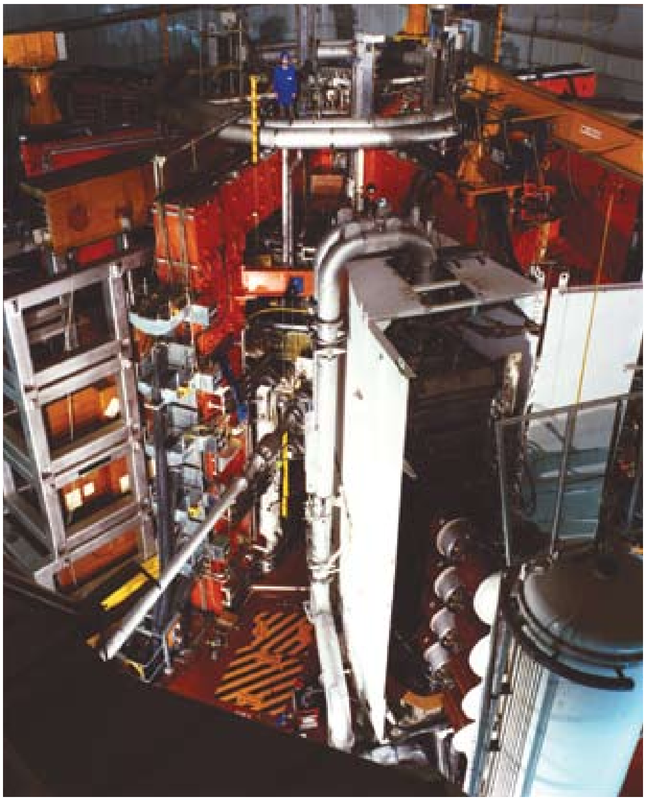
The fusion program did not fare any better during the years of the Clinton Administration, especially after the 1994 takeover of the Congress by the "conservative revolution" of Newt Gingrich. In December 1993, Secretary of Energy Hazel O'Leary sent her congratulations to the Princeton Plasma Physics Laboratory on the production of more than 3 million watts of fusion power, which set a world record. "This is a great day for science," she stated. "This world record is a great step in the development of fusion energy. It highlights the enormous progress being made in the field. This is the most significant achievement in fusion energy in the past two decades." The Princeton scientists proposed that the Tokamak Physics Experiment (TPX) be designed to replace the TFTR when its experiments were completed. This long-pulse machine, they explained, would use many of the existing TFTR facilities, and would develop the basis for a continuously operating tokamak fusion reactor.

Although O'Leary and other Administration officials continued to support the fusion effort, resistance from the Congress delayed fusion's next steps, both in participation in ITER, and in the domestic experimental program. The President himself, in a letter dated July 13, 1994, addressed to New Jersey Governor Christine Todd Whitman, supported "a strong balanced program for the development of fusion energy," endorsing both U.S. participation in ITER, and the construction of the TPX at Princeton.

Congressional wrangling over the fusion program budget led to the incredible decision for an early decommissioning of the TFTR in 1995, after it had achieved a record-setting 510-million-degree plasma temperature, even though more advanced experiments were still planned by the scientists.

All large-scale science and research projects were under attack through the 1990s. In 1988, the Congress had approved construction of the Superconducting Super Collider in Texas, to be the world's largest and most powerful particle accelerator. In addition to its research applications in fundamental physics, the advancement of superconducting magnet technology would have pushed forward the state of the art in medicine, energy storage, and fusion. In 1993, after 14.6 miles of tunnel had been built, the project was cancelled by the Congress.

In the first term of the Reagan Administration, the magnetic fusion research budget was in the $450 million range. By the time President Reagan left office, it stood at $331 million. When George H.W. Bush left office, in 1994, the magnetic fusion budget was stalled at a paltry $322 million. It faired worse during the eight years Bill Clinton was in the White House. The opposition from Congress was not helped by the fact that Vice President Al Gore had been given the responsibility for developing energy policy. Gore put billions of dollars into wasteful so-called "green" and "clean" technologies.



Joint European Torus

Europe moved its fusion program ahead with the Joint European Torus, the first tokamak to use tritium fuel. Meanwhile, the United States killed the Compact Ignition Tokamak at Princeton.

During the 1990s, the magnetic fusion energy budget collapsed in to the $200+ -million range. While there have been some ups and downs, using U.S. Energy Information Agency inflation-adjusted figures, in real dollars, the fusion budget of $286 million in 2008 was about *one third* what it was in 1977. Is it really any wonder that the United States has not achieved new breakthroughs in fusion?

The Rest of the World Moves Forward

While the Princeton TFTR was producing groundbreaking results in fusion research in the late 1980s and early 1990s, other nations were not standing still. In 1991, the Joint European Torus (JET) became the first tokamak to use tritium; the same year that the U.S. government officially nixed the Compact Ignition Tokamak at Princeton, Japan's JT-60 tokamak was on its way to setting its own records.

Today, world records in fusion are not held by the United States, but primarily by Europe and Japan, which provided steady support over the past two decades to upgrade experiments and build new facilities. Other advances have been made in newer fusion programs, such as those in China and South Korea. These countries have the only two tokamak experiments in operation now using advanced superconducting magnets, which will be needed for tomorrow's commercial fusion power plants.

For years, nations have recognized that a joint, international effort to solve the engineering problems in fusion and move toward a commercial demonstration would be the best approach. If you are creating an energy source that will be available to all mankind, why not have the collective brains and talent of all mankind working on it?

In April 1978, respected Russian scientist, vice president of the Soviet Academy of Sciences E.P. Velikhov, privately proposed to officials in Washington the creation of an international tokamak experiment. The proposal was made formally the following month, at the meeting of the U.S.-Soviet Joint Fusion Power Coordinating Committee in Moscow. Velikhov proposed that the project be under the auspices of the International Atomic Energy Agency (IAEA). At the same time, other nations had a similar response to the world energy crisis, and Japanese Prime Minister Takeo Fukuda proposed a $1 billion joint fusion development program during a May 1978 visit with President Carter. These proposals were pushed aside.

Two years later, on March 10, 1980, Academician Velikhov gave a lecture at the Swedish Adacemy of Engineering Sciences in Stockholm. Velikhov, who over the years has been a science advisor to Russian government leaders, outlined the nuclear power plans of the Soviet Union, and, again called for an international fusion project, which he called INTOR.

Finally, in November 1985, fusion was put on the international diplomatic agenda, when the Soviet-American statement issued after the summit between President Reagan and Soviet leader Mikhail Gorbachev stated that they "emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes, and, in this connection, advocated the widest possible development of international cooperation in obtaining this source of energy, which is essentially inexhaustible, for the benefit of all mankind." Europe and Japan were invited to join the new project, the Inter-

ITER

Academician Evgeny Velikhov (with pen), President of the Kurchatov Institute and Vice-Chair of the ITER Council, signing a procurement arrangement for Russia's contribution to the ITER of its upper ports and divertor dome, June 2009. Velikhov had proposed an international tokamak experiment to the U.S. government back in April 1978. But the Carter Administration ignored this proposal, as well as a similar one by Japanese Prime Minister Takeo Fukuda.

NASA

Artist's illustration of a rocket returning from Mars to Earth. Without the development of fusion propulsion, we will not be able to travel back and forth to Mars in days—instead of years.

national Thermonuclear Experimental Reactor or ITER, and Canada also joined.

Design work for a reactor was carried out over the 1990s, with scientists from more than a dozen countries contributing to the effort. It is a very ambitious undertaking. The tokamak is being designed to generate 500 megawatts of fusion power for hundreds of seconds, as an important step towards the generation of steady-state power which will be required for a commercial power plant. As the design work proceeded, China and South Korea joined the ITER effort in 2003, and India joined two years later.

As is the case in nearly all international science and engineering projects, design of the reactor took more time than initially envisioned, and in the Summer of 1998, extensions for the work were required. Europe, Russia, and Japan signed the three-year extension agreement. Energy Secretary Bill Richardson tried to do an end-run around the opposition to the project in the Congress, and announced on September 22, 1998, that he had signed a unilateral agreement extending the United States support for ITER.

But the Congress, under the guidance of a Republican leadership intent upon cutting Federal spending, regardless of the consequences, eliminated the paltry $12 million for fiscal year 1999 that was to go toward U.S. work on ITER. "The project has failed," pontificated House Science Committee Chairman, Republican James Sensenbrenner, from Wisconsin. He continued: "It defies common sense that the United States should agree to continue to participate in a dead-end project that continues to waste the American taxpayer's dollars." The other international partners were stunned.

Engineering design work for ITER proceeded, without the participation of the United States. After the design completion, the partners began the process of choosing a site for the reactor. Then, in 2003, President George W. Bush announced that the United States would be rejoining the ongoing negotiations to choose a site for ITER. Perhaps the fact that China and South Korea had become ITER partners had caused the U.S. Administration to rethink fusion policy.

In June 2005, the nuclear research center site in Cadarache, France, was chosen for the construction of ITER Today, the site has been cleared, and preparatory work for the next phase of construction is well under way.

Now that ITER is proceeding, it has become urgent, once again, to return to a robust domestic U.S. fusion energy program, both in order for this country to fulfill its obligatory contributions to ITER, and so the U.S. is prepared to make use of the advancements that are made there.

Engineering Challenges

One of the major challenges of engineering a power-producing fusion reactor is the development of new materials that can withstand the severe fusion environment. At the annual meeting of Fusion Power Associates, Dec. 2-3, 2009, in Washington, D.C., leaders of the fusion programs at this nation's national laboratories, universities, and in industry stressed the need for a

ITER

Construction work at the ITER site in Cadarache, France.

shift from fusion as a purely scientific endeavor in the Department of Energy, toward solving the practical problems.

At the FPA conference, Ed Synakowski, who heads the Department's Office of Fusion Energy Sciences, stated that it was time that fusion broke out of its scientific and political isolation. He said that the nation needs a sensible program in materials research, and experiments to solve outstanding scientific questions.

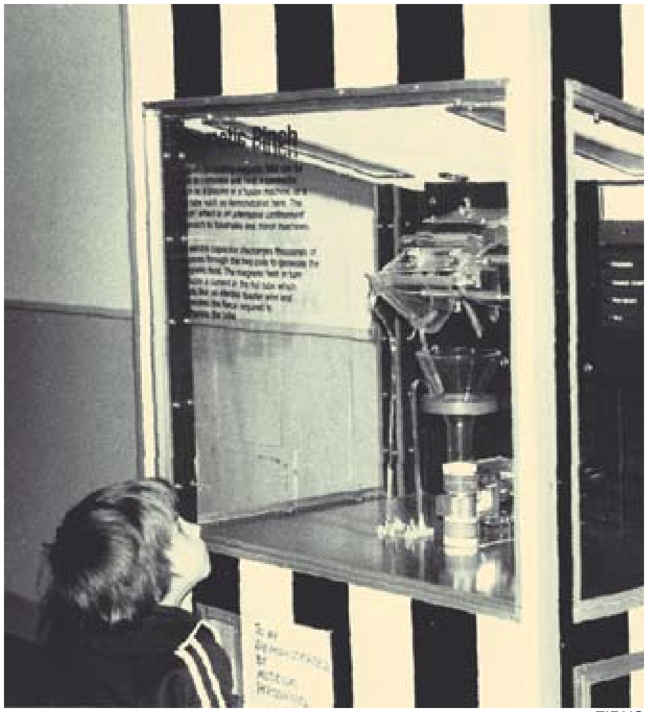
The presentations by U.S. fusion leaders at the conference stood in contrast to that of Dr. G.S. Lee, head of the South Korean National Fusion Research Institute. The Institute is currently carrying out experiments in its KSTAR advanced superconducting tokamak reactor [see article, page 51] and scientists from around the world have sent researchers to participate in KSTAR experiments. Dr. Lee explained that they will be well trained and experienced from their work on KSTAR, once ITER is ready for operation, about a decade from now.

The most exciting remarks by Dr. Lee concerned not Korea's technical progress, but its commitment to create a practical new energy technology. He explained that when the government approved the fusion program in the mid-1990s, it wanted to ensure that the research would not simply be an experiment, but would lead to a reactor. Understanding that this will be a long-term effort, which will have to survive numerous changes in ruling parties and five different presidents, Korea's Fusion Energy Development and Promotion Act was passed in 2007, which created a Federal Commission to oversee the fusion program. It ensures the continuity of the program, and is renewed every five years.

To meet the goal of developing a practical energy source, as stated in the law, Dr. Lee said, his Institute is already evaluating various sites where there are operating conventional nuclear plants, as potential sites for a demonstration fusion reactor. Design of the 700-megawatt Korean demonstration plant will be carried out while experiments are ongoing on ITER, with construction to start in 2027. In the following decade, Korea plans to be building fusion power plants.

There is little question that the U.S. fusion program must be rethought, lest the nation be left to do little but grouse, as other nations continue to leap ahead. One step to try to address this question was taken by Rep. Zoe Lofgren, (Democrat of California), who introduced the Fusion Engineering Science and Fusion Energy Planning Act of 2009 on July 10, 2009. The Act would require that within one year of passage, the Department of Energy present to the Congress a comprehensive plan to identify the range of research and development needed to achieve practical fusion energy. The bill stresses the engineering areas of materials science, in particular. One can question whether or not yet another study, delaying action for another year, is at all necessary. But the impetus of the bill does place the fusion question squarely in front of Congress, once again.

The most forward-looking great projects in science and engineering in the U.S. are barely marking time. The program for the manned exploration of the Moon and Mars, promulgated by the previous Bush Administration, has been so underfunded that layoffs have begun in the space program. If the Congress, which authorized the program, does not wish to see this country become a has-been in space, it must do more than complain. The resources required to maintain world leadership have to be forthcoming.



EIRNS

A young boy looks at a Franklin Institute display demonstrating the magnetic pinch concept for confining a plasma, an alternative to tokamaks and mirror machines. To make fusion a reality—instead of a museum display—will take a political commitment of the kind that put a man on the Moon in 1969.

Fusion Is Absolutely Necessary!

None of the arguments that have been marshaled against the fusion program hold any weight. That fusion is not here yet, and is still years away, is only the result of failed energy and economic policies, and the unwillingness to provide the resources to solve the outstanding problems. In the final analysis, it does not matter how much it costs to develop commercial fusion energy, because it is absolutely necessary to do so. It does not matter how much the first commercial demonstration fusion reactor will cost, or whether it will be competitive with coal, solar collectors, or windmills. Fusion energy will be available to all nations. For the first time in history, a country's finite natural resources will not be the limiting factor in its economic development. And with fusion to power space vehicles, man will be able to reach Mars and destinations beyond in days, thus fulfilling what has to be humanity's mission in this century.

Fusion will make available both a quantity and a quality of energy that is unattainable from any other known source. It is the technology on the horizon that not only can produce electricity, but also can economically create synthetic fuels, potable water, new materials through plasma processing, and employ applications that are still to be discovered The key ingredient for success is the will to do it.

In the 1970s, on the door to his fusion office, Ed Kintner displayed this biblical quote: "Where there is no vision, the people perish." There could be no time when this is more true, than today.