FUSION

MAGAZINE OF THE FUSION ENERGY FOUNDATION
February 1980
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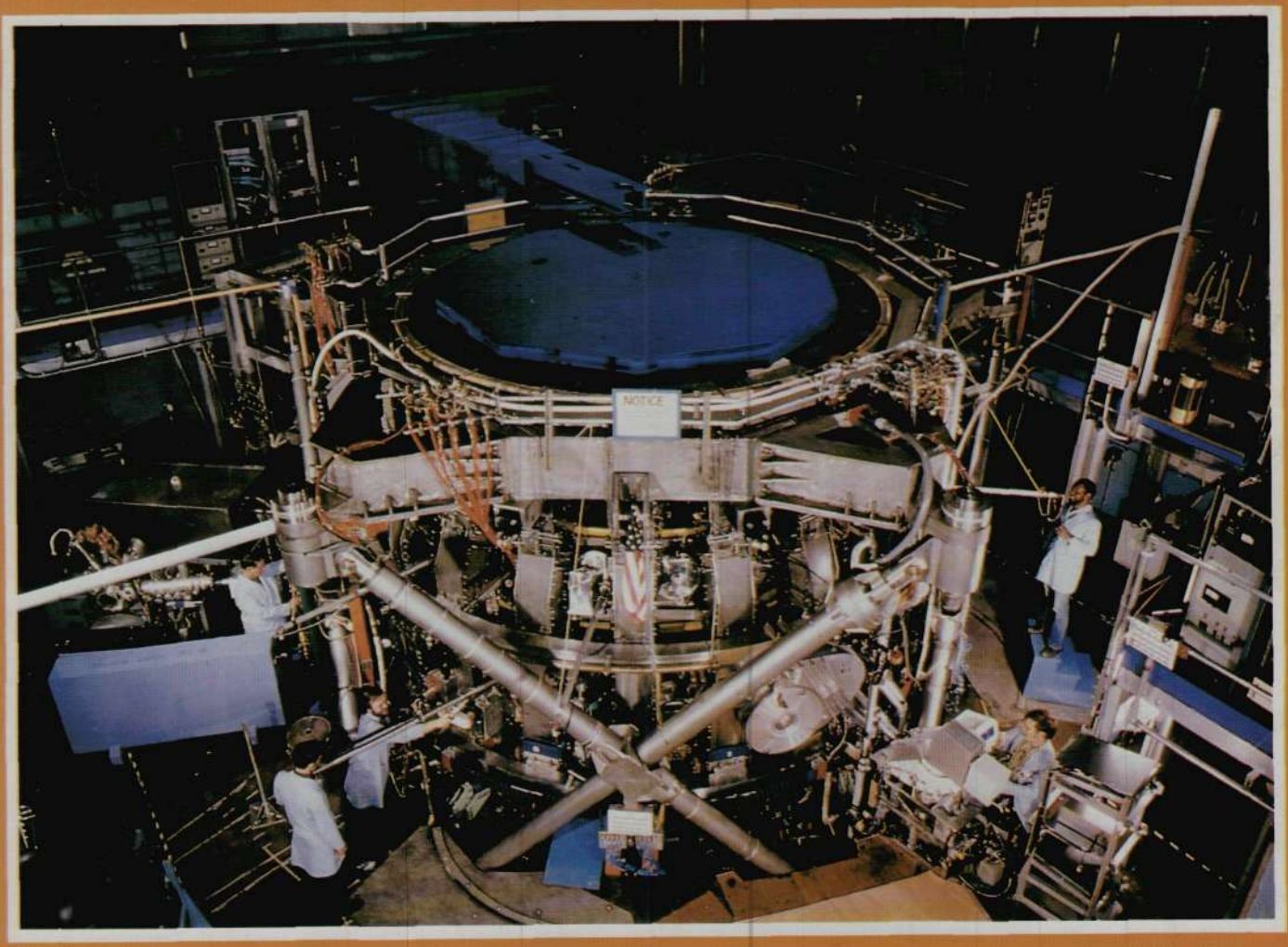
Annual Review

Fusion Technology for the 1980s



Building the Reactors for the 1990s

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FUSION

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Features

News

Departments

Fusion by 1990!

In the usual media reviews of the highlights of 1979, it is unlikely that you will find mention of the progress made toward harnessing fusion energy. The energy news reviews are more likely to focus on the uncertainty of Mideast oil supplies or on the new uncertainties of nuclear power after Three Mile Island.

Even if the availability of fossil and nuclear energy supplies were not to remain in question—which is a *political* question, not intrinsically a technological or economic question—the compelling need for the most rapid possible development of fusion energy could not be clearer. Yet, our nation has been offered the choice of energy "conservation" and a several hundred-billion dollar boondoggle investment in the most inefficient and costly types of synthetic fuels.

The inconsistency in allowing the current forms of large-scale, cheap energy (fossil and nuclear) to go by the boards while at the same time sabotaging our future cheap energy source (fusion development) is only an apparent inconsistency. In fact, the situation is perfectly consistent with the scenario for the future that the principal policy makers of the Carter administration are in the process of implementing.

Having brought the United States and the world to the brink of economic collapse and thermonuclear confrontation by their policies of deindustrialization and global political destabilization, they now call for "controlled economic disintegration," depopulation, and war as the only solutions.

Why Fusion?

Given this reality, the question of the fusion timetable might seem a secondary one. But that would miss the point of what really is at stake. There are two closely related reasons that the nation must launch a crash effort for fusion reactor development now.

First, the fundamental issue in the world today is which of two irreconcilable world views predominate: Either we have cooperation by the sovereign republics to develop the Third World and to morally and materially elevate their populations by higher forms of science and culture; or we suffer a "One World" order dedicated to the eradication of science and the principle of progress. (Admittedly, this fundamental division in worldview is obscured by the raging conflicts throughout the world that certainly are based on real hostilities. The point remains, nevertheless, that the timing of the eruptions and the obstacles to their settlements are primarily the result of both specific actions of the "One Worlders" and their present as well as their accumulated historical policies.)

Second, the world needs a source of highly efficient, high-temperature energy in order to provide the energy and raw materials of all types necessary to support a human population of 7 to 10 billion during the first decades of the 21st century.

Fusion and fusion science are the unique focal points for a positive solution to both fundamental issues. Only fusion can provide the quantitative and qualitative type of energy necessary for future human survival. And research on plasma processes is also the most important frontier in science today for comprehending the negentropic processes of the universe.

Fusion: How Soon?

How quickly, then, can we develop fusion power? The Department of Energy, in its usual Orwellian doublespeak, says not until about the year 2025. But this is based on the DOE arbitrarily spacing out research and development milestones to ensure that it takes at least that long.

As this issue's annual review of the status and prospects for fusion makes clear, we *can* have fusion by 1990. That will not happen, however, simply by

speeding up the existing DOE fusion timetable. A number of other things must occur simultaneously. In addition to a Manhattan-Project-type effort to condense the time for the technological development of all the current magnetic confinement machine projects (tokamaks, mirrors, pinches) there must also be a sharp acceleration in the upgrading of all other alternative approaches in both magnetic and inertial confinement (electron beams, laser beams, and ion beams).

This accelerated fusion effort requires rapidly breaking through the billion-dollar-a-year budget level and moving quickly to an Apollo budget level of $4 to $6 billion a year in order to bring the necessary number of high-technology engineering teams from industry into permanent collaboration with the fusion program. Many different types of machines must be constructed and tested to learn the physics of burning plasmas in each case and to determine the economic advantages and limits of each. *There is no doubt, however, that this brute force approach will yield a viable fusion reactor by the end of the 1980s that brings us into the age of fusion.*

If, at the same time that we are pursuing this brute force program, we also broaden and deepen the scientific base of the effort by training thousands of plasma scientists and supporting the maximum possible research on critical plasma phenomena and theory, then we also guarantee the achievement of our most important objective—the constant improvement of the economics of fusion-based energy (through improved efficiency and productivity) and raw materials technologies as the by-product of a self-expanding burn wave of scientific progress.

Our New Year's Resolution

Those unfortunate individuals who, wittingly or not, have chosen to be instruments for the destruction of the nation and of humanity will do everything possible to prevent the rapid development of fusion, just as they have undermined our ability to use fission and export it and other American technology.

On the other side, those of us committed to the American System can settle for nothing less than what is really necessary: the maximum rate possible of scientific and technological advance. Thus, it is our New Year's resolution that we will continue to use every political and scientific weapon at our disposal to win this battle for progress.

Calendar

February

11–13
3rd Int'l Conference on Nondestructive Evaluation in Nuclear Industry
American Nuclear Society
Salt Lake City, Utah

17–20
101st Annual Convention & Trade Show
Ohio Grain, Feed, and Fertilizer Assn.

18–22
Int'l Symposium on Management of Gaseous Wastes from Nuclear Facilities
International Atomic Energy Agency
Vienna

26–28
Topical Meeting on Inertial Confinement Fusion
American Nuclear Society
San Diego

28–29
Specialists Meeting on Decay Heat Removal and Natural Convection in Fast Breeder Reactors
American Nuclear Society
Brookhaven National Laboratory, Upton, N.Y.

Letters

To the Editor:

For a number of months, I've been regularly checking the newsstands where I purchased two copies of your excellent publication but I haven't seen it for six months.

None of the libraries in town has any copies of your magazine. Are back issues available? I'd like to read them all, but may not be quite up to purchasing them. I'm not sure how libraries select their magazines, but you can be sure I shall request your magazine, even showing them my sample copies . . . .

The regular newsstand fare in this town is aimed at the lowest common denominator. *People* magazine is among the most intellectually stimulating among the magazines available. I wonder if your magazine is a victim of some factors that brought about the demise of many above-average publications. Freedom of the press seems to have been effectively overcome during the past decade.

Lawrence D. Carter
Kansas City, Missouri

The Editor Replies

We are happy to say that we are alive, well, and growing. Most libraries will subscribe to a magazine like *Fusion* if they know there is a demand for it, and our readers can do us a service by making such demands known.

We have a limited number of back copies available so that libraries can purchase complete sets. We also will soon have available for purchase reprints of the feature articles *Fusion* has published in the past three years, as well as important articles that appeared in *Fusion's* predecessor, the Fusion Energy Foundation *Newsletter*. (See the reprints ad, this issue for some titles and prices.)

As for newsstand sales, *Fusion* is sold on selected newsstands throughout the nation, especially in areas that have a concentration of scientific laboratories and high-technology industry. We are just embarking on a campaign to solicit major advertising for the magazine; once that is underway we intend to increase our distribution through media advertising and expanded newsstand sales.

Continued on page 4

Did you miss . . .

"The ABC's of Plasma Physics"
by Dr. Steven Bardwell

"Poetry Must Begin to Supersede Mathematics in Physics"
by Lyndon H. LaRouche, Jr.

"Economics Becomes a Science"
by Dr. Uwe Parpart
and Dr. Steven Bardwell

"Riemann Declassified: His Method and Program for the Natural Sciences"
by Dr. Uwe Parpart

"The Secret of Laser Fusion"
by the Editors
of **Fusion** Magazine

"Fusion Energy—How Soon?"
by Dr. Stephen O. Dean

"The Coming Breakthroughs in Fusion Research" (1978)
by Charles B. Stevens
and Dr. Steven Bardwell

FEF Reprints

Reprints of these landmark **Fusion** articles are now available at $1.25 postpaid. Order from *Reprints*, **Fusion** *Magazine, Suite 2404, 888 Seventh Avenue, New York, N.Y. 10019.* Make checks payable to the Fusion Energy Foundation.

Continued from page 3

KUDOS

To the Editor:

I was pleased to see with what accuracy you exposed the plans of the antinuclear groups. I'm happy to note they did not quite have the success they expected, but I am praying they will not destroy our economy.

Olive Foster
Albany, Oregon

To the Editor:

Our 17-year-old son has enjoyed your magazine tremendously and learned much from it. He wrote an excellent research paper on fusion for a high school extended learning class. He plans to enter nuclear and power engineering at the University of Cincinnati next fall . . . .

Mr. and Mrs. James R. McCullum
Muncie, Indiana

SCIENCE MADE MINDLESS

To the Editor:

I would like to comment on the book review section of the October issue of *Fusion* ["Science Made Mindless"].

I do not understand Mr. Schoonover's distaste and criticism of the scientific and sociological disciplines and research areas, which he discussed. His attack was purely an emotional one, disregarding the role pure theoretical thinking has played in the course of modern scientific research. To state such things as he did under the title of "an ugly career" is to attack and undermine any attempt to expand and broaden the frontiers to which human thought can be extended. To state that Gerald K. O'Neill's ideas are fundamentally useless or that they are lacking in interest to both the layman and the scientist is inconsistent with Mr. Schoonover's claim for his desire for scientific progress. His attack on the multidisciplinary sciences such as cybernetics and its associated research of "artificial" intelligence is unsound and asinine.

I indeed admire Mr. Schoonover for his writing abilities and his candid exposé; however, he should be more open-minded and far less critical of both the scientists and the sciences of which he speaks . . . . You publish a truly excellent magazine . . . .

Dr. Joseph A. Monaco
Brooklyn, N. Y.

The Editor Replies

There are clear epistemological grounds on which to separate actual frontier conceptions from garbage. Ultimately, scientific progress will be destroyed if science "proves" the human mind does not exist. This is the implicit program both of the cybernetics-artificial intelligence project and of the MK-Ultra operation to hook youth on psychotropic drugs.

Similarly, by proposing pie-in-the-sky plans for solar powered satellite colonies and similar zero-growth utopias, O'Neill and his ilk deflect thinking from the necessity for developing *higher* (instead of lower) energy-density utilization.

Dr. John Schoonover

SINGING FOR NUCLEAR POWER

To the Editor:

I have had the privilege to be associated with the nuclear industry for 10 years. During this time, it has been my pleasure to come into contact with many dedicated and highly competent professionals . . . . However, I have become increasingly aware and alarm-

Continued on page 66

Statement of Ownership, Management, and Circulation
(Required by 39 U.S.C. 3685)

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Extent and nature of circulation, October 1979

	Average no. copies each issue during preceding 12 months	Actual no. of copies of single issue published nearest to filing date
Total copies printed	55,000	71,000
Sales through dealers, street vendors, counter sales	34,125	42,225
Mail subscriptions	13,500	20,825
Total paid circulation	47,625	63,150
Free distribution	622	1,150
Total distribution	48,247	64,250
Copies not distributed	1,200	1,600
Returns from news agents	5,553	5,150
Total	55,000	71,000

The Lightning Rod

My dear friends,

My afternoon nap was interrupted the other day by a telephone call from an individual identifying himself as "Solar N. Coleman, duly authorized candidate for President of the United States of the Consensus Opinion Party." Although bubbling over with good fellowship, there was no mistaking the note of pique in Mr. Coleman's voice as he noted that his views had not been identified among those of the other presidential candidates presented in the Energy Scorecard in *Fusion*'s January issue.

As best I could, I apologized to Mr. Coleman, assuring him that the editors would doubtless have treated him more benevolently had his reputation been advertised up to its merits. "A good p.r. man is hard to find," he volunteered ruefully.

To make amends, I offered to throw open to him the narrow space allotted me by the editors, and we conducted the following interview on the spot:

Dr. F: What is your policy on present and future energy technologies?

SNC: No doubt about it, the energy thing is here now and will be with us for many years to come. As an American, I think we need all we can get, in just the right proportions, without wasting a drop of it, to meet the awesome challenges and responsibilities we face. This will require sacrifice from all of us, but I have full confidence that if we renew our renewables, improve our improvables, maintain a proper balance between man and nature, and cut down our use of foreign oil, this nation, under God, will find itself with all the energy worthy of a great and humble people.

Dr. F: Quite a statement. But what energy technologies should we emphasize over the coming half-century or so?

SNC: I prefer not to engage in mere speculation on the relative importance or unimportance of what we can't yet see or hear, touch or taste, smell or sell. We need a little bit of everything, and a lot of things we'll only know about when we make a buck out of them.

Dr. F: Can you be a little more specific about some energy source?

SNC: Coal is very good, you know those little hard balls you can hold in your hand give you a very substantial feeling. You can dig it and burn it; it comes liquefied, gasified, and petrified; and the Rockefellers already own a lot of it here in the United States, so the oil companies won't be put to the trouble and expense of getting OPEC to raise the price for them; we Americans can do that here all by ourselves.

Dr. F: My friends at the Fusion Energy Foundation tell me the coal-based synthetic fuels are very polluting though. What are you going to do about pollution?

SNC: With solar-powered scrubbers, rubbers, washers, and dryers, we can clean the air up spic and span. In fact I'm big on all forms of solar energy, which as you know is very pure because it comes from the sun. Nobody is against the sun, not even Jane Fonda. I've been dispensing bottled sunshine for years with no ill effects.

Dr. F.: But when the sun doesn't come out. . . .

SNC: Let the clouds roll by, and we'll have more energy, or my name's not Solar N. Coleman!

Dr. F: Well, I can't dispute that. By the way, what does the "N" stand for?

SNC: Ben, Shhh! Haven't you heard about Three Mile Island? I'm trying to keep the "N" in a low profile. In fact I was thinking of dropping it altogether. . . .

Dr. F: You don't mean it stands for. . . .

SNC: Well, I mean we can't afford to do without it altogether right now, and maybe we should even make some more of it someday, but the American people need protection, want protection, and we've got to offer them protection.

Dr. F: But it's been years and there's never been a single fatality from a commercial plant. The science and engineering have been proven.

SNC: Science is not enough. Look Ben, you're not scared, and I'm not scared, but some people say they are scared, and we've got to have ironclad round-the-clock, 24-hour protection—an invisible shield—against anything that might be objectionable or offensive. Like after you eat onions, you want to be sure, I mean really sure, and when we get that kind of confidence, then I might consider spelling out my position on "N."

Dr. F: Just one more question on this—how would you deal with radioactive waste?

SNC: Waste not, want not, I always say.

Dr. F: What role do you think the government would play in the development and production of energy resources?

SNC: First of all, let me say that I believe deeply in our free enterprise system. But I also believe the private sector has a responsibility to the public. On the other hand, public institutions must always respond to market forces. So overall, on this question, I would come down on the side of carefully regulated deregulation.

Dr. F: One final question—how about fusion energy?

SNC: I think that the consensus on fusion is that it will be very good when it gets here, if it ever does, and I'm in the mainstream on this one.

Yr. obt. svt.

Join the Postcard Fusion Campaign

Have you written your congressman and Congressman McCormack to support an accelerated fusion program? Postcard messages are available from the Fusion Energy Foundation, Suite 2404, 888 Seventh Avenue, New York, N.Y. 10019.

Philip Ulanowsky
Marsha Freeman

News Briefs

FEF VIDEOTAPE SHOWN AT DOE HEADQUARTERS

Twenty-five scientists from the Department of Energy's Office of Fusion Energy viewed a 33-minute videotape on the history of the Fusion Energy Foundation Jan. 7 at DOE headquarters in Germantown, Maryland. The tape, which premiered at the fifth anniversary celebration of the FEF in November 1979, was presented to the Office of Fusion staffers by *Fusion* energy news editor Marsha Freeman and FEF European director Hans Bandmann.

After the showing, Fusion Office director Edwin Kintner commented that one of the most important points made in the FEF video presentation was the relationship between science and morality. The ensuing discussion continued on the same theme, in particular, the question of how the kind of energy policy a nation pursues affects the international strategic balance between war and peace.

CARTER AXES ADVANCED NUCLEAR PROGRAMS

The Carter administration plans to submit a Department of Energy budget proposal for fiscal year 1981 that will destroy the advanced nuclear energy capability of the nation, according to sources in the DOE and *Nucleonics Week*.

Among the slated cuts are $200 million from the DOE's budget request of $520 million for the breeder program and the elimination of all funding for the gas-cooled breeder and for an advanced breeder design study. These cuts are in addition to a proposed termination of the Clinch River Breeder Reactor project, which the administration has been trying to kill for the past three years. If these cuts stand as proposed, the nation's breeder program will never see the light of day.

The same sources reported that the sagging high temperature reactor program might receive a token budget allotment, but on a "go-slow" timetable. Even more surprising was the report that the administration intends to reduce the upgrade of the Shiva-Nova laser, part of Lawrence Livermore Laboratory's laser fusion program, by $60 million. Shiva is the world's largest laser.

Congressional and industry sources are mapping out a vigorous counterattack on the budget.

U.S.-SOVIET COOPERATION ON THE LINE

Informed sources in the magnetohydrodynamics community report that the delivery of a key U.S. MHD component to the Soviet Union, scheduled for January, will most likely not take place. The component is a channel manufactured by Westinghouse.

The Soviet U-25 test MHD generator in Moscow, the recipient of the channel, is providing important data on various components for both the U.S. and Soviet MHD programs, and the Department of Energy had committed the delivery of the channel for joint testing.

U.S. sources report that the U-25 testing of the channel would be very valuable for the U.S. program since there is no facility here large enough to test the component. In fact, the loss of such important test data will delay the U.S. program, according to scientists in the MHD program.

ASPEN INSTITUTE CHIEF: 'WORM HAS TURNED ON SCIENCE'

The 1970s should be happily left behind as a decade characterized by "the mindless march of technology" and "the old ethic [of] rapid material growth—powered by technological innovation." This was a New Year's message from the *Christian Science Monitor*, penned in a special guest feature Dec. 31 by Harlan Cleveland. Cleveland, former U.S. ambassador to NATO and former assistant secretary of state, is now the director of the Aspen Institute's Program in International Affairs in Princeton, N.J.

"The worm has turned on science and technology," Cleveland wrote. "Every

time the pollsters take our national pulse, they discover a deeper alienation from the idea that more and more is better and better."

In Cleveland's view, the current Iran crisis and the threat to European and U.S. oil supplies are not the results of the criminal manipulations of the Carter adminstration, but manifestations of the outrage of Third World nations at western attempts to force technological development upon them.

Cleveland's outlook for the 1980s? The dawn of a new era in which only "planetary politics" and a "pooling of sovereignty" among nations will keep North and South, and East and West, off a collision course and allow for the equitable solution to proliferating questions of resource scarcity.

The Aspen Institute has funded and created environmentalist groups such as "Friends of the Earth" and is well known for its sponsorship of "energy alternative" seminars for corporate and civic leaders.

BRANDT COMMISSION RECOMMENDS SHARING—THE POVERTY

The Brandt Commission on International Development, the panel on North-South relations founded two years ago by World Bank President Robert McNamara, released a giant year-end report in December that catalogues the terms for economic confrontation between the advanced and the developing sectors of the world economy.

The report was issued following the commission's winter meeting at medieval Leeds Castle in England, chaired by commission chief Willy Brandt, chairman of the Social Democratic Party of West Germany.

The Brandt Commission's proposals include a revival of Henry Kissinger's International Resources Bank commodity indexation scheme, which would ensure the debt payments of bankrupt Third World nations by jacking up the cost of their raw materials to the industrial West; the end of the U.S. dollar as a reserve currency and its replacement with a basket of currencies; and a proposal for a World Development Bank that would put the development policies of sovereign nations under the control of a supranational agency.

On the energy front, the commission report proposed investment in "alternative" energy sources such as solar and the sharing of international oil reserves.

NSIPS

Willy Brandt

SCIENTIST URGES PROTECTION OF INDIANS FROM CIVILIZATION

What is the best approach to the development of the 16-million-acre mineral-rich Amazon River Basin? Constance Holden, writing in the December issue of *Science* magazine suggests that the region should be turned over to the primitive Yanomano indian tribe, and a special preserve created to protect tribal culture from modern civilization.

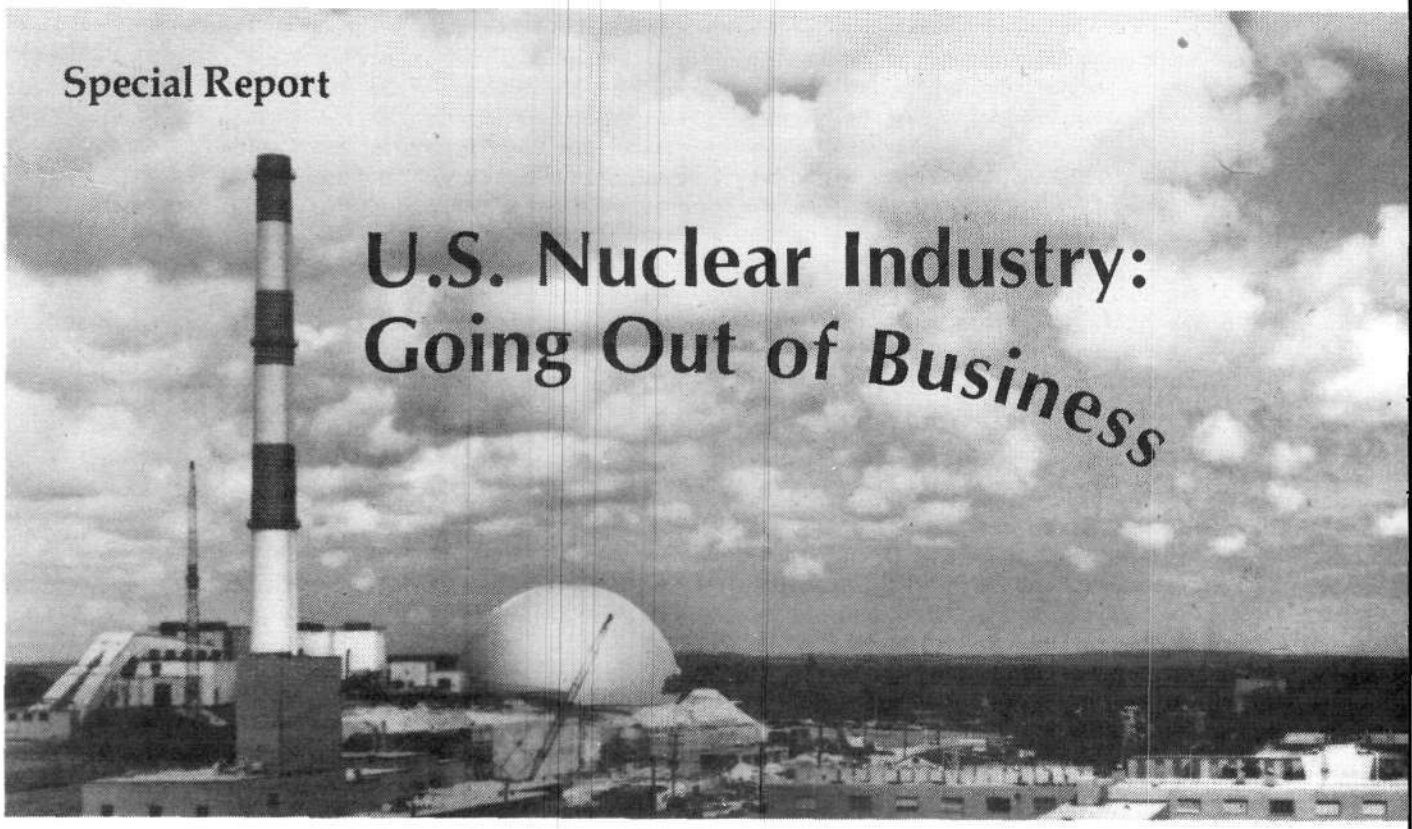
Under the headline "Park is Sought to Save Indian Tribe in Brazil," Holden quotes a development expert who believes that "the Indians of the Amazon are the only ones who know how to develop the region. Their destruction may mean the loss of the ability to develop the Amazon without destroying it."

As Holden details, the Yanomano are a hunting and gathering rainforest tribe that has increased to a population of about 20,000 through the use of occasional slash-and-burn cultivation of yams and other indigenous vegetables. Infanticide, wife-stealing, and chest-pounding duels are traditional elements of Yanomano culture.

LOUSEWORT LAURELS TO BALTIMORE GERONTOLOGIST

The February lousewort laurels are awarded to Charles L. Goodrick of the Gerontology Research Center in Baltimore, Maryland, for his conclusion that "health, vigor, and a long life may be maximally promoted by a reduction of daily food intake or by period fasting."

Goodrick, a researcher in aging and care of the aged, was extrapolating from the results of a series of experiments he conducted on rats. According to the Dec. 1 issue of *Science News*, Goodrick found that under experimental conditions rats fed only every other day and allowed access to a wheel, were more active and lived longer and healthier lives than those that were denied access to a wheel and those that were fed every day.



Special Report

U.S. Nuclear Industry: Going Out of Business

The United States will be out of the nuclear business before the end of the 1980s unless there is a radical change in government policy toward nuclear licensing and siting as well as toward the continued operation of nuclear power reactors.

In the last two months, two of the four U.S. nuclear suppliers—General Electric and Babcock and Wilcox—announced that they will be shutting down part of their nuclear plant production facilities because of the sagging demand for power plants. And the situation doesn't look any better for the two other nuclear suppliers—Westinghouse and Combustion Engineering.

Nuclear plants that had been planned by utilities are being either delayed or canceled because of the lower-than-expected growth rates in electricity demand and the frustration the utilities are experiencing in gaining approval in the siting and licensing of nuclear plants.

A similar forecast was put forward as policy in a draft report titled "The Viability of the Civil Nuclear Industry," a summary of which was leaked Sept. 27 in *Nucleonics Week*. Unless substantial economic and political changes take place in the United States, the two weakest nuclear suppliers, GE and B&W, will be out of the nuclear business by 1985 and Westinghouse and Combustion Engineering would follow by 1988, the report said.

The authors of the report are in a position to know. The study was done by Mans Lonnroth of the Secretariat for Future Studies in Stockholm and William Walker of the Royal Institute of International Affairs in London. They prepared the report for the International Consultative Group on Nuclear Energy, which is based in London and is sponsored by the Rockefeller Foundation and the RIIA. In its economic and political scenarios for the 1980s, the RIIA, like its offshoot, the New York Council on Foreign Relations, predicts collapse and disintegration.

Thus, even the projected shortages of oil will not help the nuclear industry, the report stated. Price hikes will only exacerbate inflation and the chances of a recession—no climate for nuclear investment. Their "pessimistic projection" holds that lowered electricity growth rates of 2 to 6 percent per year will characterize the 1980s.

The predictions go on: B&W's future is in doubt due to the fall-out from Three Mile Island. GE has suffered a lack of orders since 1975 and will "probably be out of the nuclear business after the 1980 elections." Combustion Engineering and Westinghouse will have enough work to get through for a few years, but will face difficulties in sustaining design and engineering teams.

Reactor vendors are faced with a 50 to 100 percent over-capacity through the 1980s and there is no way of coping with this over any extended period of time, the report concluded. Even though other studies predict that worldwide reactors will be ordered at the rate of 40 to 50 gigawatts per year, the authors of the draft report claimed that an ordering rate of 15 to 25 gigawatts per year is a "more probable outcome":

"It seems to us that the Western world has around five years in which to improve the prospects for nuclear power if it wishes to remain confident that reactor supplies will be forthcom-

ing. Thereafter, the fabric of the reactor industry in a number of countries would begin to disintegrate, leaving little chance for substantial expansion of nuclear power in the 1990s and beyond."

Nuclear Shutdown

The most recent indications concerning the state of the U.S. nuclear industry started in the second week in September when Babcock and Wilcox announced that they were shutting their plant in Mount Vernon, Indiana because "business got too thin at Mount Vernon to keep that facility going." Six-hundred workers will be laid off. The plant was opened in 1965 when expectations ran high about the role of nuclear power through the end of this century. It was planned to have a capacity to turn out 12 large reactor vessels each year.

B&W is shipping four uncompleted vessels to their plant in Barberton, Ohio, along with components of the steam generator and coolant piping systems, because the orders for these reactors have been delayed. Barberton is not large enough for the assembly of completed plants, but B&W will reopen the Mount Vernon plant only if the orders come through.

One week later, General Electric and Chicago Bridge and Iron, partners in CBI Nuclear, Inc., announced they would be taking in nonnuclear work at their plant in Memphis because of the decline in orders for nuclear power plants. The plant fabricates reactor pressure vessels and does the final assembly.

CBI Nuclear will be trying to pick up oil-related business, such as the construction of offshore platforms, in order to "preserve" their highly skilled workforce. CBI expects to finish the three uncompleted vessels in the pipeline, the two in storage ready for shipment, and the six awaiting installation of internal parts. When this work is completed in mid-1982, that's it. General Electric has had no orders since 1975.

The AEC Planned Big

Going back a few years, the U.S. government did have plans for nuclear power. In 1962, the Atomic Energy Commission began making projections for civilian nuclear capacity to the year 1980. In 1964, 1966, and 1967, it revised its projections upward, noting that public acceptance of nuclear power was greater than it had projected.

"The upward trend is an indication of the unexpected speed with which nuclear power is becoming a major source of electricity in the United States," reported the AEC in its 1967 "Forecast of Growth of Nuclear Power." The upward trend is dramatic. In 1962, the AEC projected 40,000 megawatts of installed capacity by 1980; in 1964, 75,000 MW; in 1966, 95,000 MW and in 1967, 145,000 MW.

According to a May 21, 1979 study by the General Accounting Office, titled "Questions on the Future of Nuclear Power: Implications and Trade-offs": "While nuclear reactors account for only 9 percent of U.S. installed capacity, nuclear power has been the major growth factor for U.S. electricity. Since 1972, nuclear facilities have accounted for over 20 percent of new capacity additions and over 50 percent of the increased electricity output. Nuclear power has also been the largest single growth factor in domestic energy supplies, exceeding coal by 25 percent."

Among nuclear engineers in the field, it was a policy of 2,000 by 2000—2,000 operating nuclear power plants by the turn of the century.

But from the mid-1970s on, those projections have been declining. Utility orders for nuclear power plants peaked in 1973. At the point that policymakers were calling for energy independence in the aftermath of the 1974 Arab oil embargo, the U.S. nuclear industry began to sense its first serious problems. Hoping the environmentalists would just go away, the industry consoled itself with the illusion that the orders from the early 1970s would carry the industry through a "temporary" lull.

Then came the Carter administration and energy policymaking by James R. Schlesinger and the Department of Energy. The latest DOE projections, issued in the past two weeks, see no more than 150 gigawatts of nuclear energy by the year 2000. In addition to the 68 operating reactors, approximately 120 plants are projected and these are already under construction or on order. No more domestic orders can be expected.

The Economic Consequences of a Shutdown

The General Accounting Office report makes it clear that nuclear energy has exhibited the highest growth rate of all U.S. electricity and general energy production in the past half decade. It is equally clear on what the effect would be if little or no nuclear capacity were added in the next decade.

The GAO concludes that if the nuclear growth rate were to continue at the rate of the last five years, in terms of installed capacity, it could increase the U.S. domestic energy supply by the year 2000 by the equivalent of *10 million barrels of oil a day* over 1978 levels. It is doubtful, however, that that growth rate will be maintained, given current energy policy.

Even continuing nuclear growth rates at the current level, the GAO remarks, the growth in electricity consumption will have to be curtailed since supply is, in fact, not keeping up with demand. If nuclear power were to peak at 340 gigawatts, then annual growth

must be held at below 4.25 percent. If it is held at 150 gigawatts (the current DOE projection), then the annual growth rate would have a ceiling of 3 percent. (These figures assume a steady rate of growth in coal availability for electricity.)

The U.S. economy can not maintain a 3 percent per year growth rate for long, before using up existing raw materials and drastically cutting the standard of living of most Americans. Furthermore, the cumulative effects of a drastic reduction in planned operating nuclear power units is already portending serious electric supply problems in the next two to three years.

According to the National Electricity Reliability Council, the United States faces the "grim prospect" of power shortages in the early 1980s. "The prospects for future power supply in the long-term have grown materially worse within the passage of one year," the council wrote in its 1978 report.

Of the base-load capacity planned to be added in the U.S. between 1978-1987, 118 gigawatts are nuclear. More than 50 nuclear units scheduled to be in service through 1987 have already experienced delays, averaging about 1.5 years per unit. Continued "constraints" against the electric supply industry can result in a very serious problem, the council said.

"The consequences of the likely slippage of two to three years in the service dates of planned nuclear and coal-fired plants will be an inadequacy in the supply of electric power starting in the early 1980s and increasing in severity in the years beyond. . . . These shortages will initially cause short-term curtailments of electric power and ultimately lead to some form of rationing with its serious economic consequences," the council wrote.

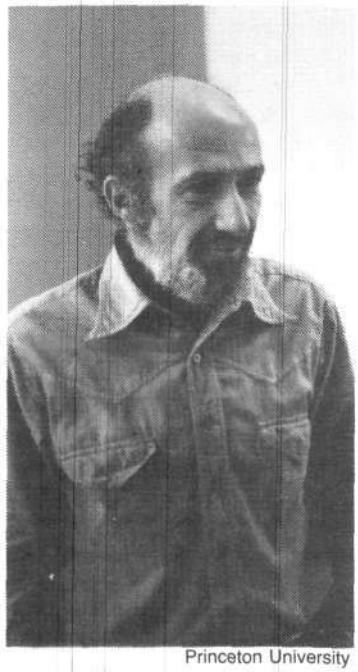
The report further warned that if the situation deteriorates to that point, recovery would take many years. It is inconceivable that an advanced industrial economy could run even for one year in a situation of unreliable and intermittent electricty supplies.

Quite clearly the country can't run much longer without a lot more nuclear power.

—Marsha Freeman

Profile of an Antinuclear Professor

Why Richard Falk Supports Khomeini



Princeton University

A group of Princeton University alumni have demanded that the university's board of trustees fire Professor Richard Falk, a leading antinuclear activist, because he is conspiring on behalf of the Iranian government of Ayatollah Khomeini. Alumni spokesmen Patrick Koechlin and Mark Burdman, an expert on Middle East affairs, directed their demand to the board at a Dec. 14 press conference on Princeton University's New Jersey campus, where they released a lengthy dossier on Falk's career to the press.

"Falk's embracing of Ayatollah Khomeini goes far beyond the indiscretions of radical-liberal academics," said Koechlin, class of 1973. "Falk not only actively conspired for several years to bring Khomeini to power; he continues to support the Iranian government that is in a state of war with the United States.

"What is clear from Falk's own statements is that his commitment is not to Khomeini per se, but to exploit the Khomeini revolution, to impose on the world an environmentalist-terrorist world order. In short, Falk is using his tenured position on the Princeton faculty to commit treason against the United States, while he pushes the world toward an economic and social policy of genocide."

Support for Khomeini

According to the alumni group's dossier, Falk played a critical role in organizing international support for Khomeini, which helped Cyrus Vance and the State Department to undercut the transition from the Shah's regime to a secularist republican or social-democratic government.

Throughout 1978, Falk was the "chairperson" of the U.S. People's Committee on Iran, the American adjunct of a pro-Khomeini network run from the top out of London by leaders of the Bertrand Russell Peace Foundation. This foundation was motivated by the late Lord Bertrand Russell's strategy of using political radicalism as the leading edge of a war against science and progress. Its suppport of anti-Shah activity in Iran's oilfields, as well as in the West, is only one example of its activities along these lines.

Falk went on a "fact-finding tour" of Iran in January 1979, accompanied by former U.S. attorney general Ramsey Clark. It is not known whether Falk accompanied Clark when the latter marched through the streets of Iran shouting anti-American slogans. However, Jan. 31, 1979, two weeks before Khomeini came to power, Falk authored a piece for the *Philadelphia Inquirer* titled "Khomeini is the Future of Iran." The article praised the Khomeini movement as "the first Third World Revolution that owes nothing to Western inspiration."

Antinuclear Policy

As Koechlin pointed out, and as his group's dossier documented, Falk's own writings over the last decade make clear that Falk's primary commitment

is to expolit the Khomeini revolution to impose the environmentalist-terrorist world order he advocates. Falk is an executive committee member of the Institute for World Order, an environmentalist group formed in 1961 at the behest of Bertrand Russell. Falk created a "grass roots" branch of the Institute, the Mobilization for Survival, which has served as an umbrella group for antinuclear demonstrations for the past few years.

A remarkable document authored by Falk in 1978 for the Institute for World Order passionately argues for the imposition of the low-energy, no-technology policies that have been adopted by Khomeini's Iran.

Falk opened his paper, "Nuclear Policy and World Order," with this gameplan for nuclear energy industry shutdown: "Denuclearization will be illusory if a distinction is made between the military and civilian uses of the atom. Denuclearization must, therefore, at some stage—now, rather than later, when it may be too late—involve the total renunciation of nuclear power for whatever purpose and its substitution with other less centralized. . . . sources of energy, such as sun, wind, water, and biomass."

After repeated calls for a "world order" to impose this policy (and a lying swipe at the potentials of nuclear fusion power), Falk outlined a comprehensive approach for imposing a transnational environmentalist world order:

"The prospects for denuclearization presuppose broad social movements within many societies, around a series of interrelated value goals. These goals include some loosening of centralized political controls over national populations. . . . Symbolically and psychologically, the movement against nuclear power must be comprehensive, encompassing its military and civilian dimensions alike, if it is to achieve real mobilizing power. . . . A comprehensive antinuclear movement draws upon the vital energies of peoples devoted to keeping the earth safe and secure for future generations. To repudiate nuclear technology in all its forms would be to withdraw from a nuclear bargain that should never have been struck in the first place. The human species is not so constituted that it can achieve infallibility and societal performance that nuclear safety presupposes."

Falk's 'Ecological Politics'

Behind Falk's antinuclear outlook, the dossier reports, is a social and political philosophy, characterized by a psychopathic hatred for humanity. In 1971, the Princeton professor outlined this philosophy in a book titled *This Endangered Planet: Prospects and Proposals for Human Survival.* The Princeton alumni group described the books as "a blueprint for a world government-directed program of genocide that could serve as Exhibit A for Falk's trial before a new Nuremberg tribunal."

"Man, ants, and rats are among the few principal species that engage in organized aggressive patterns of behavior toward their own kind," Falk wrote. "A comparison should be made" between the behavior of men and the behavior of maggots in a sack of flour. . . ." We, "like these worms," Falk said, "are secreting pyschological and moral toxins."

"To be a man is to be limited and mortal. The rise of the industrial state, and with it, science and technology, has led us to overlook these conditions of finitude and fragility. We have come to accept theories of progress and of inevitable development that look toward an indefinite improvement of the human condition by continuous economic growth made possible by an endless sequence of technological improvements. We have identified an expansion with progress, and we have not acknowledged the existence of any limitations on progress. . . . We [must] rediscover the reality and significance of our finitude. We need to identify and clarify the limits of our planetary existence and plan to live with those limits."

"Man," Falk wrote, "became intoxicated with the power of reason." This must be replaced with "ecological politics."

Destroying the Nation-State

Falk's *This Endangered Planet* takes steady aim against the principal enemy of the transnational ecological politics he is professing: the progress-oriented industrial nation-state. Disruptions, war, and revolution are needed to wipe them away, he postulated:

"National governments and other principal bureaucracies become receptive to adaptive change when their existence is threatened in fundamental respects. Periods of war, civil strife, or economic depression are the most notable examples of governments' acting in the spirit of emergency consciousness. . . . Quietness needs to be challenged by strident displays of the objective circumstances."

As "emergencies" happen more frequently and "catastrophe" looms, Falk sees the United Nations growing from its current status as a "skeletal world government" to a global policy institution to impose "stability." This world government, in Falk's schema, would have as its sole raison d'être the elimination of economic growth and new advanced technologies:

"The essential modification of the world system as it emerges today would involve the elimination of the national boundary as the basic organizing idea for purposes of security, wealth, and loyalty. . . . A needs-conception entails the elimination of national security as a basis of world order and the imposition of restraints upon production in free enterprise economies. In addition, major *distributive* reforms will have to be introduced so that the basic needs of poorer populations can be satisfied without requiring further expansion of the world industrial base. . . ."

The Princeton alumni dossier also noted that Falk is currently hard at work along just such policy lines. He is on the advisory council of the environmentalist "Planetary Citizens" group, a UN-affiliated body. Falk was also a project coordinator of the New York Council on Foreign Relations' *1980s Project* and played a "central advisory role" in the project's findings that the 1980s would be the era of world "controlled disintegration." Falk's signed contribution to the project was one volume titled *Enhancing Global Human Rights.*

—Mark Burdman and Barbara Gould

Readers interested in working with the Princeton alumni group should contact Patrick Koechlin, 25 Cummings Street, New York, N.Y. 10034.

Washington

Postcard Campaign: 'Overwhelming' Response

The response of *Fusion* readers to the postcard campaign initiated in the December issue has been "overwhelming," according to Dr. John Bagley, administrative assistant to Congressman Mike McCormack. Bagley reported that in the two days after Christmas alone, McCormack's office received more than 500 cards.

The postcard urges the Washington Democrat "to introduce legislation that would make a demonstration fusion power reactor by 1995 a national priority and that would increase the 1981 fusion budget to $860 million." The message to McCormack begins: "I am one of the majority of Americans in favor of developing nuclear power and advanced technology to keep our country growing and prosperous."

Fusion magazine selected McCormack as the recipient of the postcards because, as the chairman of the House Subcommittee on Energy Use and Production, he is leading the congressional fight for nuclear power and fusion.

McCormack's staff reports that about 95 percent of the incoming postcards include the return addresses of the senders, and that the congressman is drafting a letter to thank each *Fusion* reader for his or her support of the fusion program.

Postcards are available from the Fusion Energy Foundation and readers are encouraged to have organizations distribute the cards to members.

A news article on the fusion program appears on page 18.

Administration in About Face on MHD

In a surprising move the Department of Energy has decided to submit to Congress a plan for accelerating the U.S. magnetohydrodynamics effort.

According to spokesmen at the DOE in Washington and at the Component Development Integration Facility under construction in Butte, Montana, the accelerated program could produce a commercial MHD demonstration test generator in the 1990s.

The new MHD program plan would double the thermal input for energy conversion for the Butte facility, which is now 80 percent completed as well as for the next-step Engineering Test Facility. If the two test generators are built at 100 megawatts thermal and 500 megawatts thermal, respectively, there would be no need for an additional commercial demonstration facility after the Engineering Test Facility.

The accelerated program would require an additional $20 million for the Butte facility between now and 1984, and an additional $100 million for the test facility which would begin construction in the late 1980s. By the mid-1990s, the new DOE plan estimates that first-generation MHD technology would be available to the utilities. That would place the U.S. MHD effort less than a decade behind the Soviet program, instead of the 20 years it is behind on the current timetable.

The MHD program has gone through a process similar to that of the fusion program in the past five years. In the mid-1970s, top scientists and researchers in the MHD program laid out a timetable for commercial MHD development by 1985. With the establishment of the DOE in 1977, the MHD program (and the fusion program) underwent reviews by Energy Research Director John Deutch, the result of which was that the MHD development timetable was dragged out past the year 2000.

This delay was accomplished both in fusion and in MHD, by adding to the timetable additional experimental machines, even though experts in the field thought the additions would unnecessarily delay the programs.

Under pressure from Congress, both programs have been undergoing second reviews with support from the scientists in the DOE program offices who have insisted that neither advanced energy technology should be put off into the next century.

Congressional Line-up

House Reasserts Nuclear Stand

The House of Representatives defeated a proposed six-month moratorium on granting new nuclear plant construction permits by a near two-to-one margin Nov. 29. Sponsored by Massachusetts Democrat Edward Markey, the proposal was an amendment to the authorization bill for the Nuclear Regulatory Commission's 1980 fiscal year budget.

Although House Interior Committee chairman Morris Udall, an Arizona Democrat, denied it, the amendment was seen as Congress's response to the report of the President's Commission on Three Mile Island as well as an overall House policy vote on nuclear power. The House Interior Committee had approved the amendment, but the leadership of the House Science and Technology Committee led the successful floor fight to defeat the amendment.

Congressman Mike McCormack,

Washington Democrat on the House Science and Technology Committee, minced no words in describing the effect of the proposal. "This amendment is totally negative. It has no redeeming value at all. It simply frightens people. . . . And this attempt comes in the face of the political instability in the Middle East that threatens our supply of oil. I can scarcely believe my ears. . . ."

Sensationalism

"The passage of the Markey amendment would be used by certain sections of the press and media to dramatically harm public confidence in nuclear energy all across the world in the same way they used the TMI accident to sensationalize and exaggerate nuclear hazards," McCormack continued. "What harm was done in the area of Three Mile Island was not done by the Nuclear Regulatory Commission, not by the industry, not by the plant, not by the radiation, but by certain elements of the press and media. . . ."

Congressman Don Ritter, a Pennsylvania Republican and an engineer, also ridiculed the amendments: "Since Three Mile Island, a coal mine caved in in Korea killing 45 people. A massive dam broke in India killing several thousand people. . . . We have 90,000 persons lined up for black lung disease benefits. . . . We are just now learning about the effects of acid rain and the carbon dioxide blanket and the general health effects of air pollution from coal-fired electricity generating power plants. No one has suggested a moratorium on constructing hydroelectric dams, offshore oil rigs, or coal mines. . . ."

Stressing the economic consequences of a moratorium, Congresswoman Marilyn Lloyd Bouquard, a Tennessee Democrat, told the House: "For every delay of each plant, it is going to cost $10 million to $15 million a month. As many as 20 plant applications could be affected by this amendment. That could translate into a total cost of $1.2 billion for a six-month delay. A plant 15 miles from my home cost $600 million to build. If they had been subjected to the Markey amendment when that plant was started, it would cost $1.5 billion today. . . ."

Congress Capitulates On Synfuels Bills

A House-Senate conference committee compromise is likely to push through President Carter's $88 billion synthetic fuels program bill. At this writing, the conference committee says it has "ironed out" the major differences in the two versions of the deadlocked legislation and expects that the House and Senate will pass the bill after the Christmas recess.

The conference committee overrode opposition to the Senate version of the bill, which includes a $20 billion program, with the option of an additional $60 million to be added on in 1985. Outvoted were Congressman Mike McCormack and other members of the House Science and Technology Committee, who had insisted that the technology for coal-based synthetic fuels does not need government-funded R&D but should be commercialized only if industry finds it to be competitive.

During the summer the House passed its synfuels legislation as an amendment to the Defense Production Act that authorized $3 billion in synfuels spending over the next five years. However, this amendment specified that the money was not for government-owned facilities, but for industry incentives and loan guarantees to encourage private investment in synfuel plants.

The Senate version not only allocates much more money but also puts the federal government directly into the energy business by setting up an "independent" synthetic fuels corporation to oversee the projects. The Senate proposal includes joint ventures, cooperative ventures, and totally government-owned plants.

The reported compromise will allow President Carter to buy synthetic fuel for the military under the Defense Production amendment passed by the House until the new corporation proposed by the Senate is established.

—Marsha Freeman

Moving?

Please send us your change of address and the mailing label from a *Fusion* magazine. The Post Office will not forward magazines.

Inside DOE

DOE Readies Oil Conservation

Under the leadership of Energy Secretary Charles Duncan and Deputy Secretary John Sawhill, the DOE is readying the nation for the oil shortages the department expects to hit in 1980.

In mid-December, the DOE announced that it had set state-by-state "voluntary" gasoline consumption targets for 1980. DOE press releases on the targets, however, state flatly that if the states do not meet the targets voluntarily, the targets then become "mandatory."

The authorization for the administration's consumption targets is the recently enacted Emergency Energy Conservation Act. The act will go into effect if the president determines that a severe energy supply interruption exists or is "imminent."

"National gasoline conservation is needed because of the continuing probability of lower crude oil supplies in 1980," a DOE press release states. As Secretary Duncan has been warning since taking office in fall 1979, Iran will not be the only unstable U.S. oil supplier and in "1980 and 1981 world oil demand and supply will be in a very tight balance."

The DOE state gasoline consumption reduction calls for a drop of 7 percent

for the first three months of this year—a drop to a consumption level of 6.8 million barrels per day compared to 7 million in 1979. In addition, Alfred E. Kahn, the chairman of the Council on Wage and Price Stability has proposed a 50 cents a gallon gasoline tax to encourage people to conserve.

Duncan has commissioned Deputy Secretary Sawhill to set up an energy task force to "up-date contingency plans" drafted last spring in response to the cutbacks in Iranian oil. Federal response to energy emergencies has now been moved out of DOE's Economic Regulatory Administration and right into the White House.

At the same time that the DOE is preparing consumption cuts, the Congressional Budget Office has recently completed a study which shows that a reduction in U.S. oil consumption of only 1 million barrels per day would push gas prices up by 40 cents a gallon, cut Gross National Product figures by $6 billion, and add .3 percent to the unemployment rate.

Little Known Facts About the DOE

In its December publication called "Interesting Energy Facts," the DOE makes no mention of nuclear power, fusion energy, or advanced technology. Included, however, is the following item: "Thinking of Having Kids? . . . A baby born today . . . will use during its lifetime 2.1 tons of coal, 2,300 barrels of oil, and 6.4 million cubic feet of natural gas.

***

The November DOE newsletter *Energy Insider* reported at some length on the invited talk of zero-growther Amory Lovins before the Environmental Advisory Committee where Lovins claimed that energy cutbacks need not hurt productivity and that he supported synthetic fuel production. Readers will remember that in January in the letters column Lovins wrote that he agreed with *Fusion* that the synthetics fuel program was economically "stupid."

National

CDC to License Soviet MHD Technologies Here

Control Data Corporation announced at a Dec. 14 press conference in New York that advanced Soviet energy technologies, developed at the Academy of Sciences Institute for High Temperatures, will be made available to U.S. industry through an agreement signed between CDC and the Soviet foreign trading organization, Licensintorg.

The licensing agreement will include more than 30 new processes, many, applications and spin-offs from the highly successful Soviet MHD program.

In discussing the importance of the agreement for the future of American economic growth, Dr. Hajo Onken, vice president of Control Data's Worldtech subsidiary, explained that the Soviet Union has the highest number of research scientists per capita in the world, and has a lot of know-how to offer. "The United States is lagging in the number of innovations needed to maintain and expand our economy," Onken stated, "But U.S. corporations have great capability to adapt basic and applied research to marketable products."

C. J. Knorr, senior vice president of Control Data added that "politics more than economics have controlled trade relationships between the United States and the Soviet Union," and it is "high time to look at our trade with the Soviets without emotion."

Earlier this year the U.S. State Department canceled a Control Data computer sales deal with the Soviets.

The Technologies

The more than 30 technologies that will be offered to U.S. firms exclusively under Control Data transfer arrangements include the use of MHD generators for varied application, as well as the use of technology advancements resulting from the basic and applied research in the Soviet MHD program.

Portable MHD generators, in the 30 megawatt range, have been used in the Soviet Union for seismic studies (earthquake prediction) and in the exploration for raw materials. Control Data recognizes that this application would be useful for U.S. oil and raw materials producers in locating new reserves. In addition, such small units, which can be turned on in a much shorter time than conventional units, are ideal as emergency power systems for hospitals and other institutions.

Portable steam generating systems, developed out of the MHD research, would permit new techniques in heavy oil recovery, drilling in more difficult wells, and in the mining recovery processes of deep sulpher deposits.

In addition, the measurement, control, and diagnostic devices developed so the MHD plasma could be accurately measured at high temperatures applicable in plasma metallurgy, smelting, and in fusion research.

The Soviets have developed new materials and processes to maintain high temperatures and high-speed gas flows. Advanced development with combustors and the successful design of an MHD channel with alternating conductive and insulating areas could further advance smelting and metallurgical technology.

—Marsha Freeman

IEA Nations Nix U.S. Austerity Plan

U.S. representatives met with a stonewall by Western Europe and Japan at the meeting of the International Energy Agency (IEA) in Paris Dec. 10. Both of Washington's major proposals, one dealing with oil conservation and another with international energy-sharing agreements, were brought to defeat, as the West German and Japanese delegations led the Swiss and other nations in votes against them.

The Carter administration had called for European acceptance of an agreement for a voluntary cut in IEA member countries' oil consumption by a total 1 million barrels a day. But the American delegation's argument that the already considerable cut in U.S. oil consumption over the past year should serve as a model for Europe and Japan was summarily dismissed by the West German delegation. They argued that "much of this improvement [in cutting oil consumption] is attributable to the economic downturn in the United States," and it makes no sense for Europe to "plan itself into a recession just to match U.S. percentages."

IEA Control Vetoed

The second Anglo-American proposal at the meeting concerned the granting of increased powers to the IEA to regulate oil flow into the various member economies. U.S. Energy Secretary Charles Duncan cited the recent collapse of an oil deal between the Italian national oil company, ENI, and the Saudi Arabian government (after a manipulated scandal around the deal in the Italian press) as exemplary of the problems that might arise in the near future. Despite Duncan's motivation, this proposal too was voted down.

A Kissinger Project

The IEA was organized by U.S. Secretary of State Henry Kissinger in 1974, less than one month after the Organization of Petroleum Exporting Countries announced its fourfold price increase. Kissinger brought together the 20 members of the Organization of Economic Cooperation and Development, the association of advanced industrial nations, and, riding the crest of a wave of panic at the oil price hike, established the supranational institution on the pretext of combating OPEC.

In 1974, the French refused to join the new IEA, because, in the words of then foreign minister Michel Jobert, it undermined the sovereignty of OECD member nations. France would continue its negotitions for bilateral oil-for-technology deals with OPEC nations, bypassing the control of the London-centered oil multinationals.

Not surprisingly, the French chose the closing day of the December IEA conference to again attack the energy austerity policies of that institution and its prime mover, the Carter administration. Speaking on French radio Dec. 11, French Industry Minister André Giraud roundly attacked the U.S. program for introducing a confrontation with the oil-producing nations.

"The policies Kissinger and others are trying to impose on the Middle East and oil questions are intolerable," Giraud said. "To use Iran to launch a generalized attack on the OPEC nations through the IEA is something France will not engage in."

News Analysis

Soviet Science Chief Rebuts 'Greenies'

A debate over the future of nuclear energy surfaced in the Soviet Union Dec. 18, with an extraordinary press conference given by Dr. A. P. Aleksandrov, president of the Soviet Academy of Sciences. Aleksandrov took the surprise step of attacking by name Soviet scientists who have raised environmentalist objections to the Soviet policy of concentrating nuclear power expansion in heavily populated regions of the country.

"There are no grounds for constricting the development of nuclear power engineering in the Soviet Union. Nuclear plants are very safe," Aleksandrov said, according to Radio Moscow. He included in this statement the Soviet plan for concentrating the plants in the dense industrial western areas of the Soviet Union, where they will account for the entire margin of growth in power production over the next decade.

Questions Shared by East and West

The clash among scientists on the nuclear industry, a central issue for the Soviet economy, is a part of a broader struggle for control of Soviet foreign and domestic policy. Aleksandrov, a member of the Soviet Communist Party's powerful central committee, was taking up a serious challenge from circles inside the Soviet Union associated with the antinuclear zero-growth environmentalist policy outlook of the Club of Rome and the New York Council on Foreign Relations' *1980s Project*, which has prescribed "controlled disintegration" of the world economy in the coming decade.

Although the particular issue recently adopted from the western environmentalists has been nuclear safety, the questions now under debate are more

Tass from Sovfoto

Dr. A.P. Aleksandrov: "Nuclear plants are very safe."

fundamental, and are shared by East and West. Are we doomed by "limited resources" or do science and technology lead us to increasingly more complex, energy-dense, and efficient forms of production? Is advanced nuclear-centered technology appropriate for the developing nations? Do we plan an economy with the "linear extrapolations" of systems analysis, or do we challenge science to solve the problems of development?

The Zero-Growthniks

Since at least the mid-1960s, there has been a concerted effort by the zero-growth U.S. and British think tanks to recruit Soviet policy planners to their point of view. In 1965, McGeorge Bundy, national security advisor to President Kennedy, collaborated with Dzherman Gvishiani, Soviet deputy chairman of the State Committee for Science and Technology, to establish the International Institute for Systems Analysis in Vienna.

The institute has devoted its time and resources to discovering solutions to global crises such as resource and energy shortages, principally by programming banks of computers to divide the world's shrinking real wealth. This approach has made its way into such Soviet policy-making institutions as the USA-Canada Institute, chaired by Georgii Arbatov, and the foreign policy think tank IMEMO, which have emerged as the factional proponents within the Soviet elites for the Club of Rome's zero-growth policies toward the Third World.

The foreign policy corollary of the "appropriate technologies" policy for the Third World espoused by these Soviet institutions is socialist bloc support for "antiimperialist" struggles in the developing sector, including the regime of the Ayatollah Khomeini in Iran and proterrorist factions in the Palestine Liberation Organization. Such a policy precludes Soviet cooperation with the Franco-German thrust for Third World technology and development deals embodied in the European Monetary System.

Nuclear Power is Safe

Aleksandrov's press conference is a strong counterattack against the environmentalists by the pronuclear, détente-oriented Soviet leadership circles led by Soviet President Leonid Brezhnev. One of Aleksandrov's sharpest statements came, when, in response to a reporter's question, he denounced Academician N. Dollezhal. In a September article in the party journal *Kommunist* Dollezhal had proposed that nuclear plants in the future be confined to sparsely populated Siberia. Dollezhal's *Kommunist* article launched classic environmentalist arguments about the dangers of nuclear wastes into the Soviet energy debate. Aleksandrov dismissed Dollezhal as incompetent, "a specialist only in reactor building, not in the broader aspects of nuclear technique."

Aleksandrov also ridiculed a proposal by well-known physicist Petr Kapitza that nuclear plants be built on remote islands, asking how infrastructure costs could possibly be handled.

Environmentalist Footprints

The footprints of the environmentalist offensive in the Soviet Union are also all over the current issue of *Kommunist*. B. Miroshnichenko wrote "Ecology—A Sphere of International Cooperation," which endorsed various Club of Rome-shaped United Nations programs on the environment. Worse, Miroshnickenko called for a "mass education program" to instill what he called "environmental thinking" in the Soviet population.

A companion *Kommunist* article, by N. Kovalskii, elaborated the foreign policy of promoting maximum disarray in the Western countries. Kovalskii identified the environmentalist movement in the West as the most important instrument for the "antimonopoly struggle" of communist parties today.

By contrast Aleksandrov announced in the wake of the Three Mile Island incident last spring that the mass media in the West were employing gross exaggerations and distortions to stop nuclear power. From his press conference and the fact that he was a listed speaker in the closed debate at last month's central committee plenum on the economy, it is clear that Aleksandrov's section of the party is fighting to prevent Soviet policy from promoting that end—for the West or for the Soviet Union.

—Rachel Douglas and Marsha Freeman

An Interview with E.P. Velikhov:

The World Must Go Nuclear

Speaking at the August 1979 United Nations Conference on Science and Technology for Development in Vienna, E.P. Velikhov, the former head of the Soviet fusion program, launched an eloquent call for the worldwide expansion of nuclear power to meet the needs of Third World development.

"One billion people live in darkness in the developing countries; without electric light, their active days are short, and there is little time for education. Lenin's program for the electrification of the Soviet Union, which transformed the lives of the entire population and laid the foundation for the present industrial power of the Soviet Union, must become a prime example for the whole developing sector," the vice president of the Soviet Academy of

Sciences told the UN audience.

Velikhov's remarks to the 4,000 conference participants were particularly important because high-technology development policy was only marginally on the conference agenda; the bulk of the presentations dealt with the "appropriate technology" schemes put forward by the International Monetary Fund and the environmentalists.

Velikhov elaborated on his conference proposal in an interview conducted at the conference by Jonathan Tennenbaum, a European representative of the Fusion Energy Foundation. Excerpts from the interview follow.

Fission Now, Fusion Later

Nuclear energy is very important both for the advanced sector and the developing sector. That means fission now and fusion later. In some developing countries at present there are difficulties in integrating large nuclear plants. But the advanced sector has all the preconditions for a big expansion of nuclear energy: The fast breeder is waiting, the high-temperature reactor is almost ready, the industrial infrastructure is there. The industrialized countries must go for a massive expansion of their nuclear capacity. The delay in high-temperature reactor development in certain countries is very bad.

I agree with you people [the FEF] that the antinuclear movement is very reactionary. People should worry about nuclear bombs, not nuclear power plants. It is the developing countries that pay when advanced countries move away from nuclear energy. If the West gives up its nuclear program, that will kill people in Bangladesh: Oil and gas consumption would rapidly increase, leading to more expensive energy in Bangladesh, which means higher prices for fertilizers and other essential products, and more hunger. . . .

No supranational agency should be allowed to impose economic policies on developing countries. Development policy is a question of national sovereignty. The important thing is that the decisions in each country be made on a scientific basis. When a country needs nuclear power, it should go ahead with it. . . .

Soviet scientists make no division whatsoever between science and technology. Our scientists take responsibility for the economic development of the country. It is very important to improve the status of people involved in economic planning in the developing countries. We are pushing for a greater role and better position for scientists in those countries, to involve them more in planning. This would also counteract the "brain drain," which is a very serious problem in many regions. . . .

Lenin's Policy Example

We think that Lenin's policy for the electrification of the Soviet Union is a prime example for the developing countries. Lenin brought together the best scientists and engineers to plan out the project—50 years ago. By bringing electricity into the countryside, we eliminated illiteracy and extended the active life of the population.

Electrification is extremely important for Africa, for the developing countries generally. The nights, especially in tropical regions, are very long; without electric light, people have little time for education. . . .

Unfortunately, in the world generally there is an artificial, juridical distinction between science and technology. Science is generally open and free to all, but technology is not. [Velikhov was referring here to licensing and patenting practices that are slowing down technology transfers to the developing sector.] We want to approach this problem by going to a higher technological level.

Fusion is the best example. Its development is in the interest of all nations, and fusion technology will belong to everyone.

The INTOR project [the fusion tokamak prototype plant proposed as a joint project of West Europe, Japan, the Soviet Union, and the United States] is going extremely well. All the best people in fusion internationally are supporting the project enthusiastically. The Soviet government is fully, officially behind it.

At the moment we are engaged in a very fruitful, interesting debate internationally on which technologies should be employed in INTOR. The next stage will be preliminary planning, and next year we hope to begin work on the conceptual design.

Fusion News

Hirsch Panel Reports: 'No Scientific

"Fusion research is not technology limited. It's funding limited."

—Dr. Robert L. Hirsch

After two days of deliberations and expert testimony, the Fusion Advisory Panel of the House Science and Technology Subcommittee on Energy Research and Production concluded Dec. 11 that there are "no scientific or technical barriers" to the development of fusion energy by the 1990s. The panel also stated that the only impediments to the U.S. fusion effort were "lack of funding" and "the current Carter administration policy" to delay fusion development for another 40 years.

Congressman Mike McCormack, the Washington Democrat who chairs the subcommittee, put it this way: "The technology is available today to develop magnetic fusion. . . in the 1990s, about two decades earlier than the current Department of Energy plan."

"Fusion has been perceived only as a long-term energy source," McCormack said. "Recent successes in the fusion program oblige us to change that view."

A subcommittee news release characterized the fusion process as "inexhaustible, always available, all-weather, and multipurpose." Fusion is not just another alternative energy source, McCormack said. It is the only energy-dense source that can provide unlimited, cheap, and clean energy.

The Fusion Advisory Panel, convened in summer 1979 by McCormack, represents the nation's leading fusion scientists as well as the top management of U.S. engineering, industrial, and aerospace corporations. The panel heard presentations from some of the leading scientists at the national laboratories and from the Office of Fusion.

Serving on the panel are Dr. Robert

Barriers to Fusion by the 1990s'

Rebecca Harrington

Fusion Office director Edwin Kintner (standing) testifying at the Hirsch Panel hearings Dec. 11. Panel chairman Robert Hirsch is at the far left.

L. Hirsch, Exxon Research and Engineering Company who chairs the panel; Dr. Richard E. Balzhiser, Electric Power Research Institute; Dr. Robert Conn, University of Wisconsin Department of Nuclear Engineering; Ersel Evans, Westinghouse Hanford Company; Dr. T. Kenneth Fowler, Lawrence Livermore Laboratories; Dr. Harold Furth, Princeton Plasma Physics Laboratory; Joseph G. Gavin, Jr., Grumman Corporation; Henry K. Hebeler, Boeing Engineering; Dr. John W. Landis, Stone & Webster Engineering; Dr. Tihiro Ohkawa, General Atomic Company; Robert I. Smith, New Jersey Public Service Gas and Electric Company; and Dr. Alvin Trivelpiece, Science Applications, Inc.

A National Commitment

The House subcommittee has accepted all of the Hirsch panel's findings, including the proposal to add $200 million to the budget for fiscal year 1981 for the accelerated fusion timetable. On Jan. 22, President Carter will submit the administration's 1981 budget request to Congress. Congressman McCormack's staff has scheduled meetings with top-level policy makers in the White House to push for the additional funding for magnetic fusion and a commitment for an "Apollo-style" program for fusion.

"Only the fusion program can be compared to the space program in that, given the national commitment, it is something we can and must do," said Representative McCormack after the panel hearings. McCormack challenged the panel members to take up the task of educating the American public as to the status and potential of fusion energy, as he and his staff take the fight for fusion to the executive and the president.

Fusion by 1995

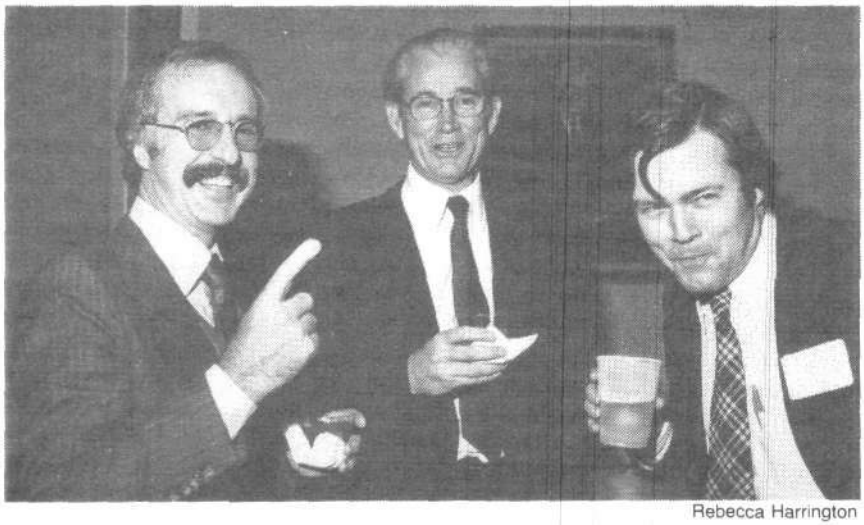
Both Energy Secretary Charles Duncan and Deputy Energy Secretary John Sawhill ignored formal invitations to testify before the panel. But a Dec. 11 appearance by Edwin Kintner, director of the DOE's Office of Fusion Energy, indicates the high level of optimism for the frontier technology that still exists among the Energy Department's scientific and research personnel.

Kintner presented the panel with a detailed program for achieving a commercial magnetic fusion plant by 1995, which he characterized as conservative, not a crash program, but a concerted national effort at solving the remaining technical problems of fusion development.

"Fusion development cannot be ev-

olutionary like the development of automobiles, airplanes, and electric utility plants because the required steps are simply too large," Kintner reported. "The closest similarity is probably to the space program. There are two simultaneous thresholds for space travel: acceleration beyond the gravitational field of the earth and provision of a life-supporting environment in a void. Unless both of these requirements could be achieved simultaneously, man could not travel and function in outer space."

"In a sense there are two similar simultaneous thresholds for fusion," the DOE official continued. "We must create and maintain a burning thermonuclear plasma, and then remove the heat energy at a high enough temperature to convert it to useful power. If we do not do both of these simultaneously, we have not taken a truly meaningful step toward useful fusion power." Kintner told the committee that the price-tag for a research effort in this direction would be $12 billion in 1981 dollars.



Rebecca Harrington

Toasting to "fusion by 1995" at a reception after the Hirsch Panel hearings are (below, right to left) John C. Clarke, deputy director of the Office of Fusion; Alvin Trivelpiece, Science Applications, Inc.; and Charles B. Stevens, Fusion news editor; (above, left to right) Dr. Al Mense, congressional staff member for the House Subcommittee on Energy Research and Production; Congressman Mike McCormack, chairman of the House Subcommittee on Energy Research and Production; and Dr. Stephen O. Dean, chairman of Fusion Power Associates.

Kintner explained to the committee the major advances in fusion technologies on which the effort for commercial realization in 1995 will be built:

Decade for Fusion Technology

"By 1990, it will have been 10 years or more since the following major confinement devices began operation: the Princeton Large Torus tokamak (PLT), which will demonstrate the feasibility of radio frequency heating; the Princeton Poloidal Divertor Experiment (PDX), which will also pursue radio frequency heating and further extend neutral beam heating experiments together with key experiments on plasma shaping and utilization of magnetic divertors for removal of impurities and helium "ash" from fusion plasmas; the MIT Alcator A and C, which will continue to explore the high-density tokamak regime and radio frequency and microwave heating; the Los Alamos ZT-40 Reversed Field Zeta Pinch, which in the light of recent Italian results could provide a proof of principle for this approach; the Lawrence Livermore Tandem Mirror Experiment (TMX) and the Doublet III tokamak at the General Atomic Corp., which will now get the type of neutral beams needed for generating reactor-grade plasmas in a joint program with Japan.

Kintner continued: "The following major experimental devices will have operated five years or more: the Princeton Tokamak Fusion Test Reactor (TFTR), which will actually generate more fusion energy than the energy it consumes with a reactor-grade plasma of deuterium-tritium fuel; the Mirror Fusion Test Facility (MFTF) at Lawrence Livermore Laboratory; the JT-60, the Japanese TFTR-scale tokamak; and the Joint European Tokamak (JET), another TFTR-scale experiment."

Asked by Representative McCormack why the Department of Energy did not respond to requests to testify, Kintner answered that he was not consulted by the Carter administration on energy policy questions. Yet, Kintner's program is the only U.S. energy research program to attain or supersede all of its projected goals on schedule and within budget over the past five years.

Kintner concluded his testimony by pointing out that the potentials of fu-

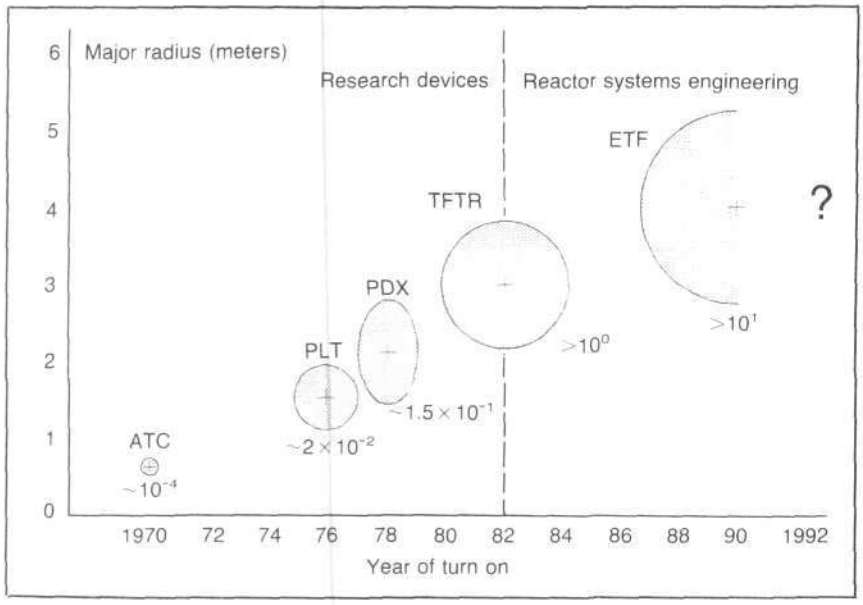
sion were so great—unlimited supply of cheap, readily available fuel, and practicality from an environmental and economic standpoint—and its applications were so broad—generation of hydrogen, synthetic fossil fuels, and fuel for fission reactors, and elimination of fission waste products—that as far as he could see no other large-scale energy system need be built once fusion was fully commercialized.

Limited by Funding

Panel chairman Dr. Robert Hirsch, former head of the U.S. magnetic fusion program, seconded Kintner's testimony on the two most important points. "Fusion research is not technology limited. It's funding limited," Hirsch said, speaking for the panel as a whole. "Fusion research," he continued, "is the only energy program, or for that matter, the only major scientific-technological effort which has achieved its projected goals on schedule within the budget's forecast for specific projections."

Other testimony from the DOE's Office of Fusion Energy emphasized the optimistic prospect for fusion development. Dr. Frank Coffman, director of the fusion office's Division of Development and Technology, pointed out that recent technical and experimental progress had dramatically changed the projected parameters—such as size and cost—of tokamak fusion power plant designs. Reactors can be much smaller with a significantly higher power density and lower capital cost.

The importance of U.S. collaboration in international fusion development efforts was underlined when Dr. Lee Berry of Oak Ridge National Laboratory presented the committee with the initial conclusions of the U.S. Engineering Test Facility design group and the International Atomic Energy Agency's International Tokamak Reactor design group. As Berry related, the international group was the result of a proposal by Soviet fusion director E. P. Velikhov that the international agency construct a tokamak test reactor in an international collaborative effort before 1990. Berry reported that both design groups concur that the scientific data base for constructing a test reactor already exists or will soon and that a scientific and engineering data base could be developed to support a 1990 operation objective if the present level of effort is accelerated.



PRINCETON TOKAMAK DEVELOPMENT 1972-1990

The development of the Princeton Plasma Physics Laboratory tokamak research program is shown here from 1972 to the present, along with projections for future development. The figure was part of the testimony of Dr. Paul J. Reardon, head of the Princeton program for the Tokamak Fusion Test Reactor, to the Hirsch Panel Dec. 10.

The y axis shows the radius of the plasma columns of the various devices. The shaded shapes represent the relative scale of the plasma cross-section for each experiment, and the cross (+) gives the exact radius of the plasma column in meters. On the x axis are the year in which the device is operating and the projected or achieved fusion energy gain, known as Q. Specifically, Q is the ratio of the fusion energy output to the energy input needed to confine and heat the fusion plasma. The last device shown, the Engineering Test Facility, represents the scale needed for commercial fusion power plants.

Report on TFTR

Dr. Paul J. Reardon, program head for the Princeton Plasma Physics Laboratory's Tokamak Fusion Test Reactor program, startled the panel with the news that the Princeton project, which will be the nation's largest tokamak, is within 9 percent of its original budget and three months of schedule.

Reardon explained that when you are involved in developing a missile, plane, or conventional power plant, "you are science-limited" since the basic principles of the technology are relatively fixed and well-known to begin with. "The opposite is the case for fusion," he said. The breadth of the fundamental principals of fusion systems "gives us a lot of elbow room" when it comes to applied technology.

One surprising report by Reardon was that he had no problem obtaining the essential engineering and technical personnel needed for major fusion projects. His experience on the TFTR project was that once the engineers were brought together on site and initiated into an overview of the program, they enthusiastically and quickly picked up the necessary technical competence.

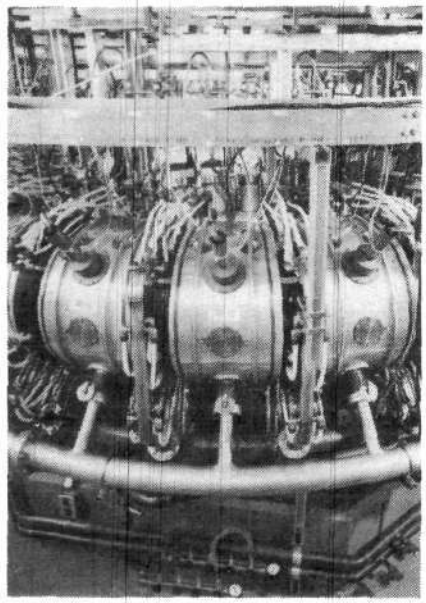
Reardon now faces the difficult task of laying off hundreds of experienced engineers on the excellent TFTR design team, because the TFTR design work will be completed within months and, under present Carter administration policy there will not be another major fusion project initiated for more than five years.

—*Charles B. Stevens*

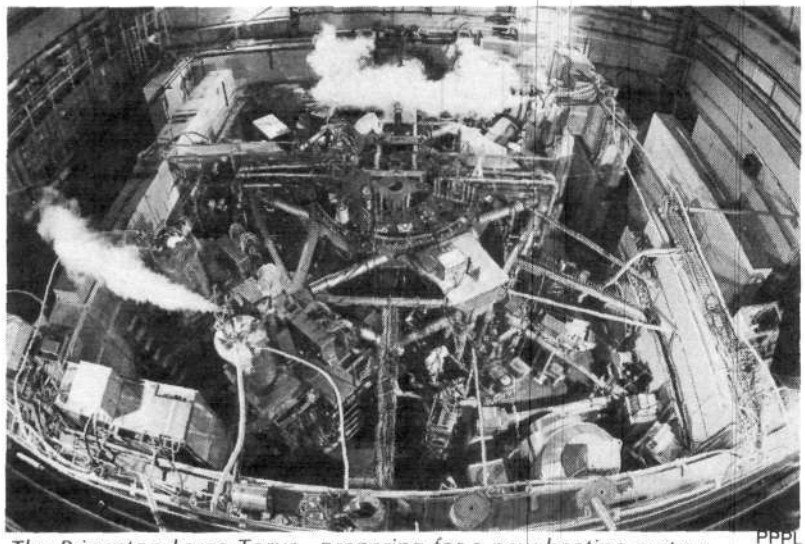
Elmo Bumpy Torus Gets Microwave Heaters

The Elmo Bumpy Torus magnetic fusion experiment at Oak Ridge National Laboratory, an experimental fusion system in which the mirrors are linked together to form a donut shape, has just received new microwave heaters.

The new heaters, which will provide the means to heat the EBT plasma, provide 50 kilowatts of electromagnetic radiation at 28 million cycles per second (28 gigahertz) and operate continuously. The new heating system will allow the EBT to operate continuously, without the engineering problems created by the pulsed-mode plasma heating planned for magnetic confinement systems like the tokamak.



The Elmo Bumpy Torus



The Princeton Large Torus—preparing for a new heating system. PPPL

PLT Moves to New Frontiers

The Princeton Large Torus tokamak, the PLT, which achieved the first fusion temperatures ever in a magnetic fusion device in August 1978, is preparing for demonstration of a new heating system for magnetic fusion—radio frequency heating. In the radio-frequency approach, which will replace the neutral beam heaters provided by Oak Ridge National Laboratory for the August 1978 PLT experiment, radio-frequency electromagnetic radiation will be used to heat magnetically confined plasma. The electromagnetic radiation will interact with the collective motions of the plasma ions and the deposition of heating energy will result.

Initial experimental results are optimistic. Up to 500 kilowatts of radio frequency have been directed into the PLT plasma and it appears that 50 percent of the radio-frequency energy is absorbed by the plasma. Confirmation of these results is expected shortly.

TMX Achieves Hottest, Dense Plasma

Preliminary results from California's Lawrence Livermore Laboratory indicate that the Tandem Mirror Experiment, TMX, has reached plasma temperatures in excess of 220 million degrees Celsius, using 30,000-volt neutral beam heaters. These temperatures were obtained in the two "end-cell" mirror plasmas of the TMX.

The TMX device consists of a long cylindrical plasma with a simple solenoidal magnetic field and two mirrors, one at each end to prevent the plasma from flowing out of the cylinder.

The previous plasma-temperature record was held by the single-cell 2XII Livermore mirror machine, which reached temperatures of 143 million degrees Celsius in 1976, using 20,000-volt neutral beam heaters.

Both experiments achieved densities on the order of 10 trillion nuclei per cubic centimeter.

Although still waiting full confirmation, these initial results point toward an early demonstration of the principles of TMX operation.

NRL Progress Using Thin-Shell Targets

Laser-matter interaction experiments at the Naval Research Laboratory in Washington, D.C. have confirmed the efficacy of the Soviet approach to laser fusion using thin-shelled targets. For many years Soviet laser fusion scientists, such as N.G. Basov, were nearly alone in their advocacy of these hollow spherical targets.

NRL researchers reported that their initial projections of the efficiency with which thin shells could be accelerated with lasers to velocities needed for inertial fusion continue to be confirmed in experiments with thin foils. Instead of imploding a hollow pellet, NRL scientists direct laser beams at a thin foil, 3 to 15 microns thick. This allows them to observe both sides of the irradiated surface and therefore make crucial scientific measurements.

The NRL researchers obtained foil velocities of 20 million centimeters per second with hydrodynamic efficiencies of 20 percent.

U.S.-Japanese Conf. Discusses Spheromak

The rapid growth and sophistication of plasma physics and technology developed in fusion energy research was discussed in a joint U.S.-Japanese Symposium on Compact Toruses and Energetic Particle Injection held Dec. 12-14 at Princeton University.

The main topic of the symposium was the "spheromak," a self-contained tokamak-donut-type magnetic confinement system. Wide-ranging conference discussion, however, represented a first attempt at synthesizing the major advances made in plasma theory over two decades of work on mainline magnetic fusion approaches and directing known results toward realizing compact, technologically straightforward, and economical fusion systems.

The prognosis of the symposium was optimistic, and the prospects for joint U.S.-Japanese work look good.

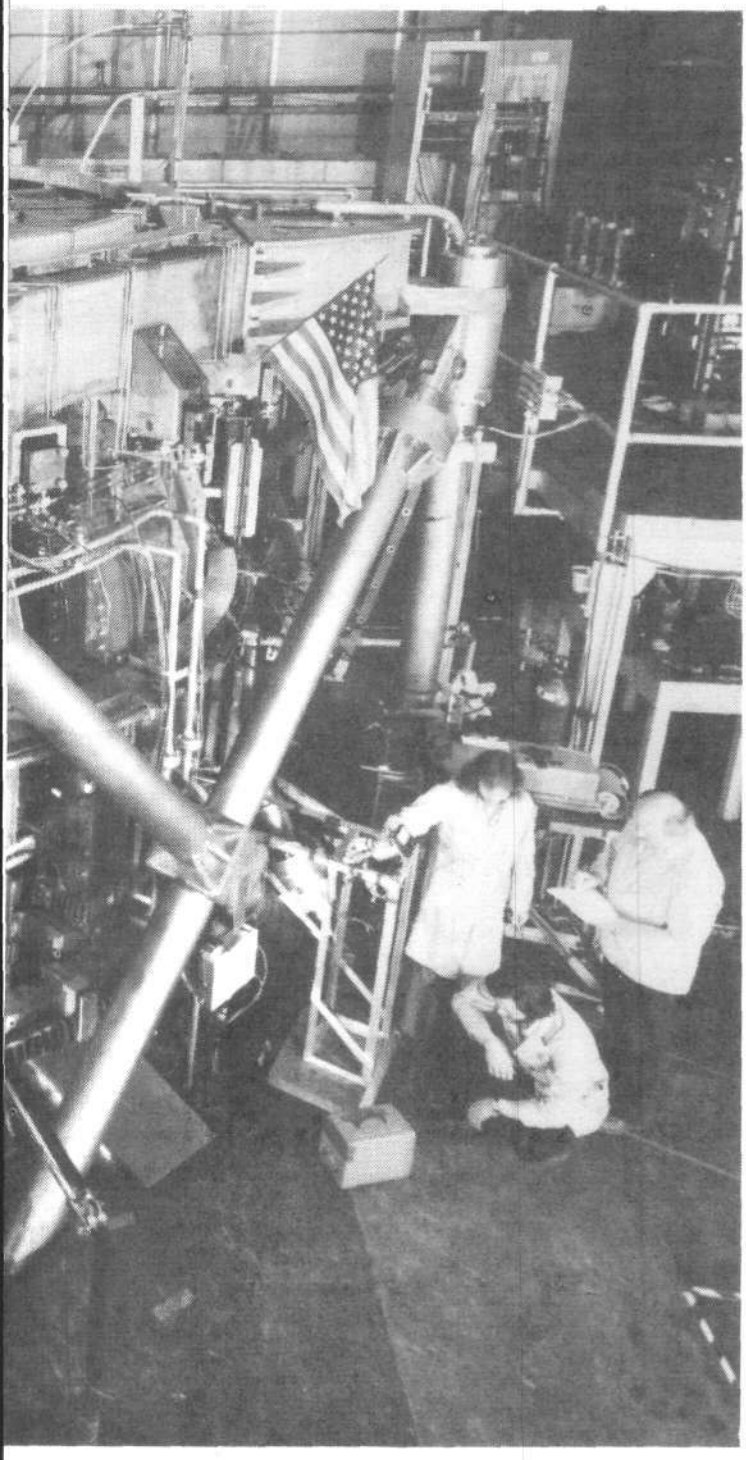
The spheromak system combines the work on tokamaks, mirror systems, high-beta pinches, and technology derived from the proton and electron beam programs of the inertial fusion effort. The result is a self-contained plasma configuration that in most cases is a "force-free" self-organized structure. In this advanced approach to fusion, the plasma does most of the work of generating the magnetic fields that allow fusion ignition conditions to be maintained.

In its most basic terms, the spheromak reflects a realization of the experimental and theoretical work of Dr. Winston Bostick of the Stevens Institute and Dr. Dan Wells of the University of Miami. Both Bostick and Wells have championed the self-organizing plasma approach to fusion for almost two decades.

Dr. A. Mohri of Japan's Nagoya University presented details on existing and planned spheromak experiments which are similar to those Wells has undertaken at the University of Miami. In the experiments described by Mohri, two spheromak donuts are formed, accelerated, and collided together to form a fusion plasma.

Technology

by Charles B. Stevens



There are no scientific or technological barriers to the realization of practical and economical fusion power plants by the 1990s: This is the conclusion of leading international fusion authorities on the current status of fusion as we begin the decade of the '80s. In fact, in the case of the United States—the country best situated to realize this goal, if the level of international collaboration continues—the only barrier to realizing fusion energy by the 1990s is the deliberate Carter administration policy to withhold the funds necessary to keep the research going.

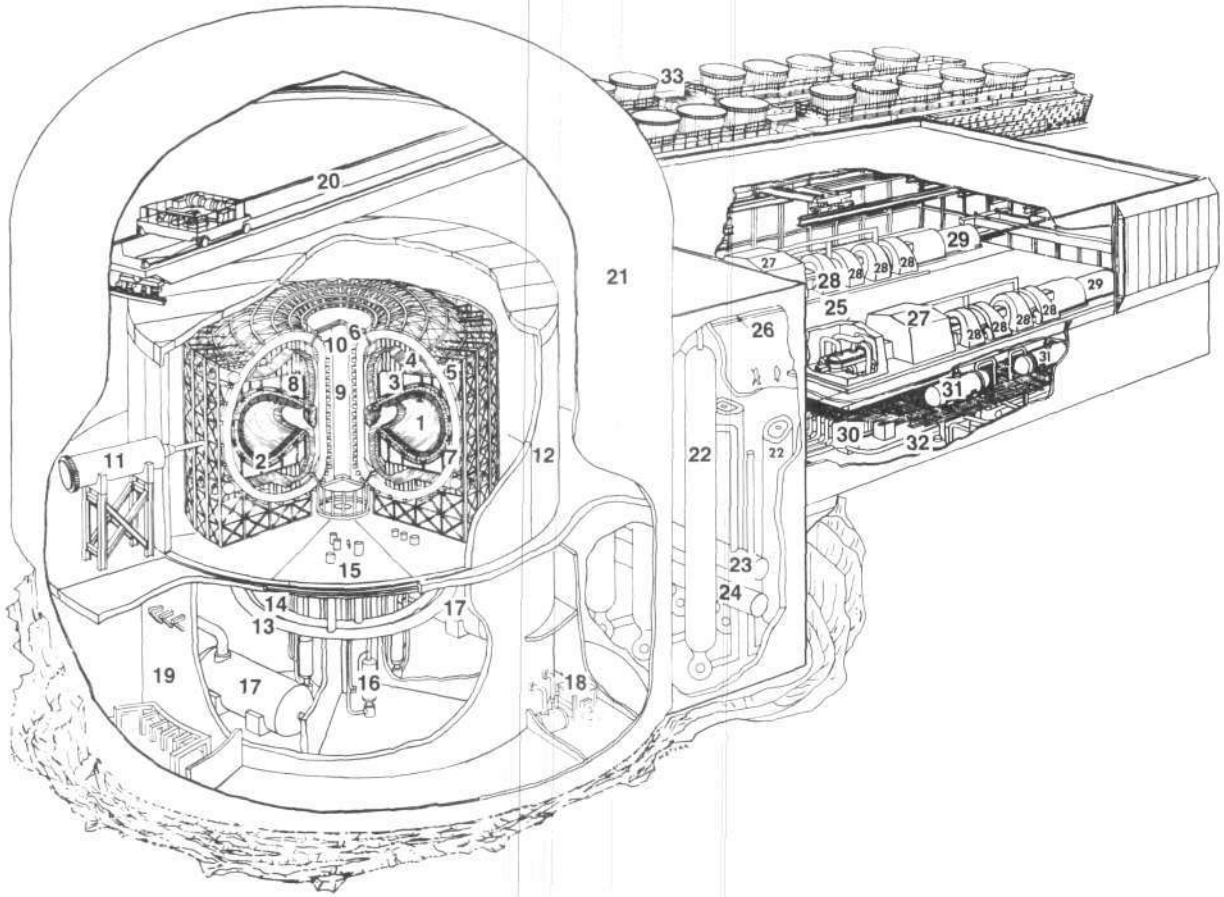
That the U.S. fusion program has gained major ground since this magazine's reviews of the status of fusion in the August and October 1978 issues[1] was amply documented in the Dec. 11 congressional hearings of the House Subcommittee on Energy Research and Production.[2] There Dr. Robert L. Hirsch, chairman of the Fusion Advisory Panel commissioned by the subcommittee, reported the unanimous conclusion of this panel of distinguished scientists: "Fusion research is not technology limited. It is funding limited."

Hirsch, who is a former director of the U.S. fusion program as well as a former director of the U.S. Energy Research and Development Administration's Advanced Energy Systems Division, noted that fusion was the only U.S. research program that had attained or superseded all of its projected goals on schedule and within budget in the past five years. And to make the point concretely, a detailed program for achieving and operating commercial demonstration fusion power plants by 1995 was presented to the panel by Edwin Kintner, director of the U.S. fusion program.

Technology: The Pacing Factor

Virtually every approach to fusion since the 1950s has recently demonstrated the scientific potential of providing the basis for economically harnessing fusion power.[3] Although new theoretical and experimental advances will continue to make possible new variations and approaches that may decrease the technological complexity of realizing fusion energy, the pacing item determining how quickly we can develop fusion is the technological hardware for

The Poloidal Divertor Experiment, PDX, at Princeton Plasma Physics Laboratory.
PPPL



1. Vacuum chamber
2. Blanket
3. Primary shield
4. Divertor chamber
5. Vacuum pumps and exhaust manifold
6. Control field coils
7. Toroidal field coils
8. Poloidal field coils
9. Liquid helium tank
10. Toroidal coil support cylinder
11. Fuel injector
12. Biological shield
13. Blanket steam outlet header
14. Blanket steam inlet header
15. Steam and flibe lines
16. Flibe-TF disengagers
17. Flibe storage tanks
18. Cryogenic system
19. Maintenance hot cell
20. Polar crane
21. Reactor containment
22. Steam generators
23. Hot steam supply header
24. Cold steam return header
25. Very high pressure turbine
26. High pressure turbine
27. Intermediate pressure turbines
28. Low pressure turbines
29. 3,600-rpm generator
30. Steam lines
31. Feedwater heaters
32. Feedwater treatment
33. Cooling towers

Figure 1
TOKAMAK FUSION POWER PLANT

This schematic of a 1,000-megawatt electric tokamak fusion power plant shows a cutout of the reactor building and the donut-shaped reactor. The fuel for this fusion plant for one year would fit into a pickup truck—about .6 ton. In comparison, a coal-fired plant the same size would consume 2.1 million tons of fuel and an oil-fired plant would consume 10 million barrels of fuel during the same year period. The fusion fuel cost for a year's operation would be a few thousand dollars, while the cost for fossil fuel or fission fuel would be between $50 and $150 million.

fusion applications. Even in basic research, technology can be the determining factor in the rate of experimental progress.

To get a better appreciation of the critical role of technology in the fusion process, let's take a look at a proposed fusion power plant (Figure 1). This plant design is based on a concept developed by the Soviets—the tokamak, a Russian word meaning torus (donut) with current, and the most successful and most researched approach to fusion. This plant, which would generate about 1 billion watts of electricity, is comparable in output and physical size to conventional fossil and nuclear fission power plants; its only major difference is that it obtains its heat energy from a fusion reactor.

In the heart of the power plant is a donut-shaped vacuum chamber in which a few grams of hydrogen fusion fuel, consisting of the two heavy isotopes* of hydrogen—deuterium (D) and tritium (T)—are heated to a temperature of more than 100 million degrees Celsius. At this temperature, the fuel is ignited forming the element helium (He) and generating copious amounts of intense energy, chiefly high-energy neutrons (about 80 percent) and high-energy ions and electromagnetic radiation* (light and X-rays).

The relative power output is about 1 to 10 million watts per cubic meter of the fusion vacuum chamber—about the same rate of energy output found in a large coal or oil boiler that consumes tons of fossil fuel per hour. However, the amount of hydrogen fuel consumed every hour by the fusion reactor would be measured in grams.

Even though the vacuum chamber is filled with fusion fuel, it is still virtually a complete vacuum. Just a few decades ago, such a chamber filled with fusion fuel would have been considered the ultimate in vacuum technology.

The other parts of the fusion reactor shown—all of which have undergone constant technological improvements in the past few years—are the superconducting magnet coils* used to confine (or insulate) the hydrogen fuel so that it can be maintained at a hundred-million degree temperature; the blanket and shield that absorb and transfer the fusion energy; the various systems used to heat the hydrogen gas to fusion temperatures; and the fueling system.

Other than the energy storage system, which stores energy for igniting the fusion plasma during start up, the rest of the plant consists of heat-energy transfer systems, turbines, and electric generators that are quite similar to conventional power plants. In more advanced fusion energy systems, however, these auxiliary systems will not be needed because the fusion energy will be directly converted to electricity.

The essential point in looking at these fusion power technologies is that fusion energy is not some fixed resource but a continually advancing technology. In this sense, fusion is the first specific technology to most exactly reflect man's creative capacity for self-perfection.

A brief description of the startup and operation of this fusion power plant will introduce most of the technologies involved in magnetic fusion reactors.

First, hydrogen gas in a 50-50 mixture is pumped into the donut-shaped vacuum chamber. Next, the superconducting external magnets that surround the vacuum chamber are activated by passing an electrical current through them. The electrical power to do this comes from a flywheel-motor generator energy storage system, the MGS.

At this point, a rising electrical current, which also comes from the MGS, is passed through the air core transformer, which is made up of poloidal field coils.* This generates an electrical field that ionizes and then induces a current in the hydrogen gas. This transformer-induced plasma current is transient and can last only as long as the cycle of the transformer—anywhere from a few minutes to an hour. If this were the only source of the needed plasma current, the reactor would have to operate in a pulsed mode, which creates many severe problems.[4]

In the tokamak plant shown here, the problem of pulsed operation has been overcome by the use of a radio frequency generator whose continuous output of electromagnetic radiation interacts with the plasma to generate a continuous plasma current. Thus, this is a steady-state fusion reactor.

The next stage of starting up the fusion reactor is heating the hydrogen plasma to above 100 million degrees. There are various ways to do this: another microwave,* or radio wave* generator whose specific interaction with the plasma leads to heating; neutral beam injectors; plasma guns, which inject large blobs of hot plasma into the tokamak; intense ion or electron beams.* This reactor uses a combination of microwave and neutral beams*; the neutral beams are for startup and the microwave beams are for maintaining continuous control of the plasma during the fusion burn.

As the fusion plasma burns, it generates helium nuclei, which keep the plasma at fusion temperatures as they are trapped within the magnetic bottle. The other product of the fusion reaction, neutrons, are electrically neutral and therefore pass through the bottle to the vacuum chamber wall, the first wall they encounter. These high-energy nuclear particles pass through many centimeters of the chamber wall before they are slowed down and stopped either by collisions with atoms or by actual nuclear reactions in the material out of which the chamber wall is made.

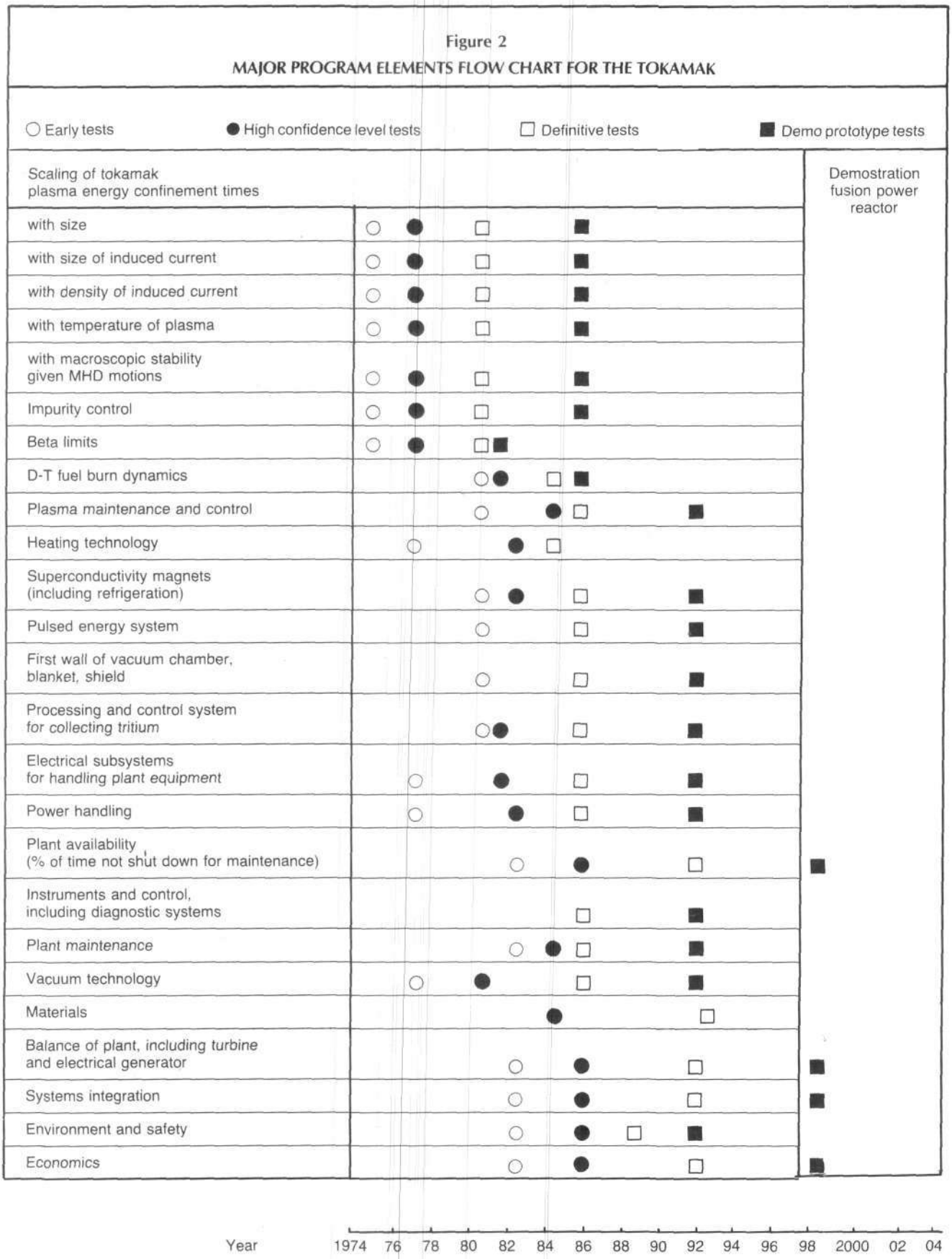
In the case of deuterium-tritium fuel, this is the most important aspect of the fusion plant design. These neutrons deposit most of the heat energy that becomes the electricity output of the power plant, and at the same time they generate nuclear reactions with lithium to breed tritium for fueling the plant. Lithium is maintained in a breeding blanket in the chamber wall in such a manner that it is sufficiently exposed to the fusion neutrons to breed more tritium than that burned up in the plasma. In some reactor designs, there is also a "neutron-multiplier material" in the breeding blanket.

In addition to the breeding blanket, the first wall contains heat transfer tubes. These tubes carry a working fluid, in this case ordinary steam, which cools the wall, thereby transferring the heat energy out of the chamber wall.

*Terms followed by an asterisk are described in the accompanying glossary.

Figure 2

MAJOR PROGRAM ELEMENTS FLOW CHART FOR THE TOKAMAK



Eventually, the steam is used to turn a turbine, which then turns an electrical generator. Ninety percent of this electricity is made available to the public, and 10 percent is used to run the various apparatuses of the power plant, such as the microwave generators, the refrigerators for the superconducting magnets, and the flywheel-motor generator energy storage system.

After burning for several seconds, the initial fusion fuel is completely reacted. New fuel is injected with pellet injectors that shoot frozen hydrogen pellets into the plasma where they are vaporized and ionized and then become part of the fusion plasma. Also, impurities—elements other than hydrogen—from the vacuum chamber or vacuum ducts (which have access to the plasma for the diagnostics and plasma heating systems) begin to migrate into the plasma. These impurities will slow down the fusion reaction by diluting the fuel. More important, the impurities tremendously increase the electromagnetic energy output of the fusion plasma and in this way cool it down.

In this reactor, these impurities are scraped off the surface of the plasma by a divertor. This consists of a "hole" in the magnetic bottle that allows plasma to come directly into contact with a divertor chamber "dump" that collects the impurities.

Other sections of the power plant that function only passively or for plant maintenance are the radiation-heat shield, which protects the superconducting magnets; the tritium processing and cleanup system; the remote maintenance system for repairing and replacing portions of the reactor; and cranes for magnet and reactor vacuum vessel disassembly.

Figure 2 shows the technologies described here and other key scientific elements needed for a tokamak reactor in terms of the U.S. Department of Energy projections for reactor construction.

An Advanced Look at the Fusion Process

Before discussing each of these fusion technologies and their prospects for progress in the 1980s, I will describe the basic fusion process from an advanced standpoint in order for readers to fully understand the importance of each developing technology.

Nuclear fusion is the basic process by which the universe derives its active energy and material. In general terms, the nuclei of lighter elements are fused to form the nuclei of heavier elements and in the process, large amounts of energy are generated. Figure 3 is a schematic of the fusion fuel cycle.

To achieve this, the mutual electrical repulsion of the two positively charged nuclei must be overcome; that is, the electrical potential barrier of the two nuclei must be penetrated. This is accomplished by giving a sufficient relative velocity to the two nuclei so that there is some chance they will penetrate the potential barrier. Since temperature is a measure of the average velocity of a group of atoms, the requirement for barrier penetration can be translated into a temperature condition for the reaction.

The rate at which the fusion reaction will proceed is determined by the density of the fuel nuclei (given in number of fuel nuclei per cubic centimeter) and the probability for a specific fuel to react at a temperature above which the potential barrier can be successfully penetrated and nuclear fusion can take place.

The temperature at which there will be significant amounts of nuclear fusion is the threshold plasma temperature and is given in units of electron volts, eV, a convenient measure of energy or temperature. One eV equals 11,000 degrees Celsius; in energy units, 1 million electron volts, 1MeV, equals 1.6×10^{-13} joules.

The reaction energy generated in nuclear fusion reactions is quite large compared to the energy input. For example, in the case of deuterium and tritium, the heavy isotopes of hydrogen, there is a maximum gain—energy out divided by energy in—of about 1,800.

This energy output shows up in the reaction products. The deuterium-tritium reaction generates a helium nucleus with an energy of 3.5 MeV and a neutron with 14.1 MeV. If a portion of this output energy can be used either to maintain the reacting fusion fuel or to heat other "cold" fusion fuel above the threshold temperature, then there can be an infinite energy gain—as long as the density of the reactant nuclei is maintained. In any case, to achieve significant amounts of fusion energy output, both the original energy used to ignite the fusion fuel and the fusion energy generated must be confined to the fuel at the same time that the density of the fuel is maintained.

There are three ways that the reacting fuel can lose this energy: First, the fuel and its products can simply dissipate; that is, either the fuel diffuses to a very low density at which the fusion reaction is essentially stopped or the fusion products escape the region of the reacting fuel without heating it. (For example, because they are electrically neutral, neutrons propagate over fairly large distances through most materials without losing significant amounts of their energy.)

Second, the reacting fuel thermally loses its energy at a very high rate—faster than it is replaced by either some external heating source or the internally deposited fusion energy—to its physical surroundings (the vacuum chamber wall).

Third, the reacting fuel radiates its energy away in the form of electromagnetic energy, primarily X-rays. This can be caused by the presence of high atomic number impurities like metals from the vacuum chamber wall in the fuel, by high electron densities, or by high-temperature electrons in the presence of strong magnetic field (cyclotron radiation*).

This flow chart depicting time estimates for solving various problems on the way to completing a demonstration tokamak reactor was part of a 1976 study by the U.S. Energy Research and Development Administration. The funding presumed for this schedule was that of Logic III (out of five "Logics"), a moderately well funded fusion program.

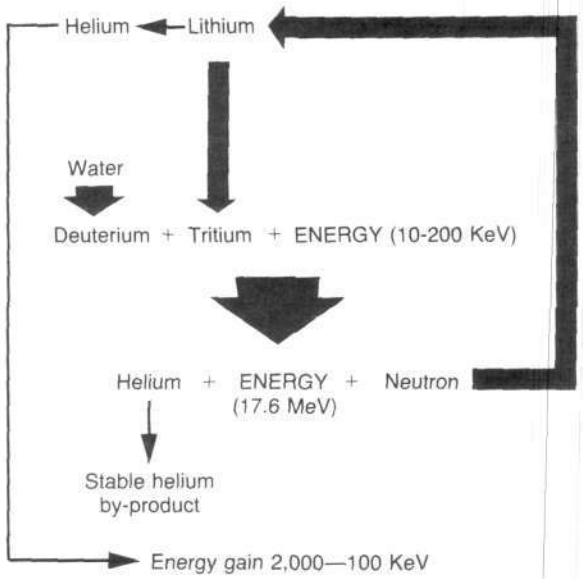


Figure 3
FUSION FUEL CYCLE

This is the fuel cycle for the easiest fusion reaction to achieve, deuterium (D) and tritium (T) fusion. At temperatures greater than 10 keV [10,000 electron volts, which is approximately equal to 110 million degrees Celsius], deuterium and tritium form helium (He) and a high energy neutron (n) with a total energy output of 17.6 MeV (million electron volts). Of this, 3.5 MeV is associated with the He nucleus, and 14.1 with the neutron. The 14.1-MeV neutron reacts with lithium to produce helium (He) and tritium (T). This allows for the maintenance of the tritium fusion fuel, since this hydrogen isotope does not occur naturally on a large scale and must be generated.

These net energy conditions can be broadly summarized in terms of two parameters: temperature, and the product of fuel density and the time over which energy is confined within the fuel. Since at high densities the fusion reaction proceeds at a much greater rate, the time over which significant amounts of fusion energy are generated can be quite small. At lower densities, the energy must be confined within the fuel for longer periods.

For deuterium-tritium fuel, temperatures must be maintained above 4.4 keV, 50 million degrees Celsius, and the product of density and confinement time must be greater than 30 trillion nuclei per cubic-centimeters per second in order to generate minimal net energy. For significant net energy generation, these parameters must be increased by a factor of 2 to 3.

Figure 4 charts some existing and future fusion experiments showing achieved and projected results in terms of these two parameters.

The achievement of fusion energy production is actually the macroscopic reconfiguration of matter and energy in order to have access to microscopic, subnuclear binding forces. In this process the microscopic, subnuclear structure is transformed to a higher-order structure, resulting in a new higher-order macroscopic configuration of matter-energy. More efficient fusion systems are determined by the degree to which this microscopic transformation is used to maintain the process itself and by the degree to which the initial macroscopic configuration reflects the essential features of the overall transformation. In other words, the successful fusion configuration is self-organizing.

Self-Organization

The essential theoretical concept is similar to Georg Cantor's concept of the transfinite and its relationship to mathematical physics.[5] Cantor's concept of physics is that a macroscopic manifold—for example, some existing configuration of matter-energy governed by apparently fixed laws—is essentially determined in terms of transformations in the microscopic (in the infinitesimal of the continuum) in direct relationship to changes in the macroscopic manifold.

For purposes here, higher-order of the transfinite corresponds to higher-order microscopic structures of matter-energy. Just as a higher-order transfinite number permits the elaboration of a new higher-order macroscopic manifold, higher-order subnuclear microscopic structures permit the elaboration of higher-order macroscopic physical manifolds. The more effectively such microscopic transformations are accessed, the more efficient the transformation of the macroscopic is. Therefore, the initial macroscopic configuration must reflect the overall transformation in order to achieve the greatest efficiency. From this advanced standpoint the basic features of fusion systems become quite simple—with plasmas as the most immediate example of this.

Most matter in the universe exists in the plasma state, sometimes referred to by scientists as the fourth state of matter—gas, liquid, and solid are the other three. Plasma is not a single state, but rather an infinite continuum of higher-order states. These higher-order states can be measured in terms of their energy-density, and the efficiency with which the energy is organized and transformed is the most crucial feature of plasma states.[6]

Magnetic Confinement

These theoretical considerations are immediately evident in fusion fuel confinement systems. In the plasma state, matter is ionized; that is, broken up into negatively charged electrons and positively charged ions. Although neutral molecules may still exist within the sea of charged plasma particles, molecular and atomic forces no longer determine the essential relations of the macroscopic structure of the plasma. This leads to a higher-order relationship between the microscopic motions of the plasma particles and the overall macroscopic configuration and energy relations of the plasma as a whole.

For example, the relative motion of the plasma electrons and ions generates magnetic fields, electric fields, electric currents, and electromagnetic radiation. At the same time,

CDC Institute for Advanced Technology, Washington, D.C. and San Francisco

Soviets Announce Commercial MHD Program

by Marsha Freeman

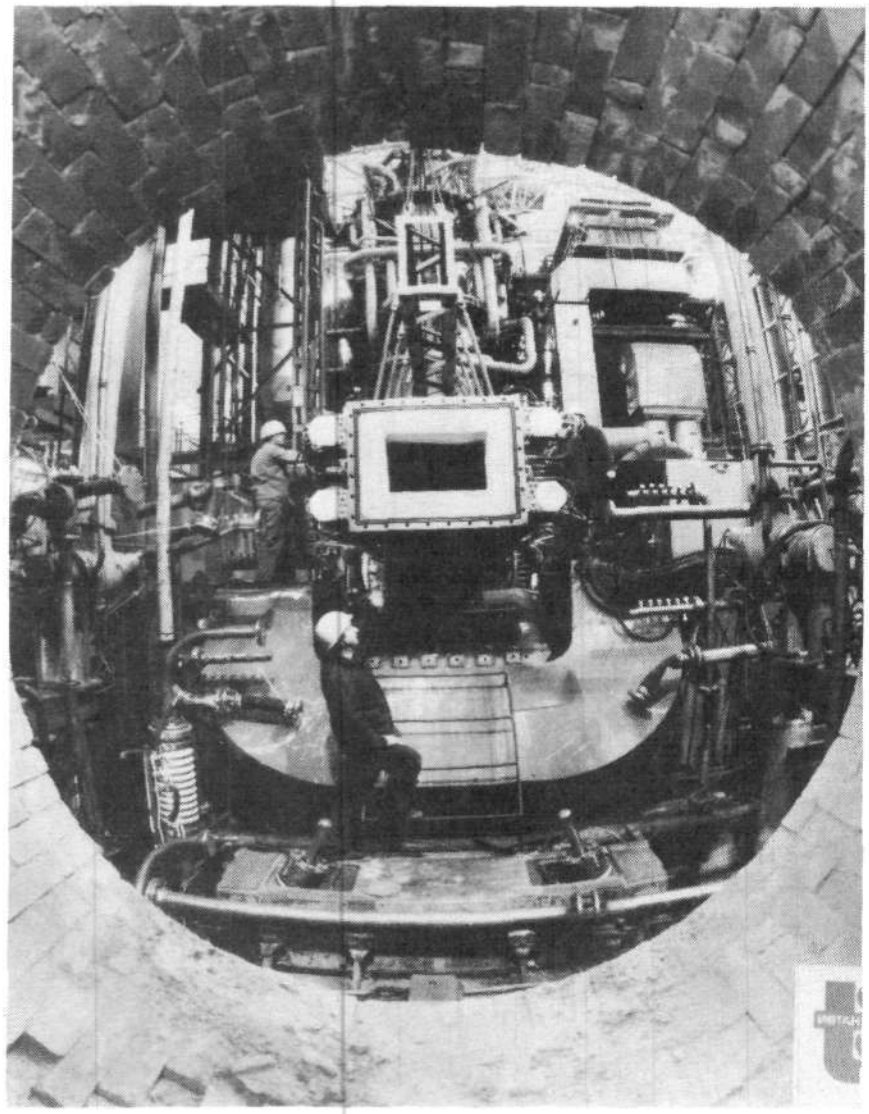
At two December seminars on magnetohydrodynamics sponsored by Control Data Corporation's Institute for Advanced Technology, a delegation of Soviet scientists announced that the Soviet MHD program was entering its fourth phase—the commercial demonstration of the technology. The 18-year-old program is almost exactly on target, with the operation of the U-500 generator expected to begin in 1985.

Although there were no formal presentations on the state of the U.S. MHD programs at either seminar, discussions with the two dozen U.S. researchers and industry representatives in attendance confirmed that during the past 18 years the U.S. program has fallen at least a decade behind the Soviet effort.

Why? The reasons for the U.S. lag can be understood by looking at the philosophy and the organization of the Soviet program, which resembles that of the U.S. Manhattan Project.

At the First International Conference on MHD held in Great Britain in 1962, Academician A.E. Sheindlin, the director of the just-formed Institute for High Temperatures of the Soviet Academy of Sciences, announced that the Soviet Union was embarking on a four-phase research and development program to bring MHD technology to commercialization in 20 years.

At the same meeting, Academician E.P. Velikhov, the deputy director of the Kurchatov Institute for Atomic Energy and one of the most respected Soviet plasma physicists, presented a fundamental analysis of the thermodynamic and electromagnetic instabilities that could be expected under certain conditions in MHD plasmas when applied to thermonuclear fusion.



The MHD channel in the gas-burning Soviet U-25, the world's first pilot MHD plant.

Since that time, parallel efforts in developing direct-conversion MHD technology have continued in both institutes. The High Temperatures Institute, known as IVTAN, has worked mainly in lower temperature fossil-based plasmas (up to 2,500 degrees Celsius), and the Kurchatov Institute has continued work in MHD for fusion. A delegation of scientists from IVTAN was at the two seminars to discuss the Soviet progress.

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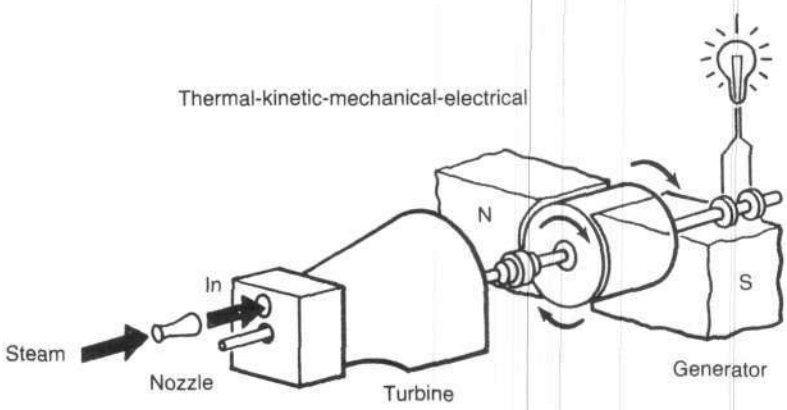
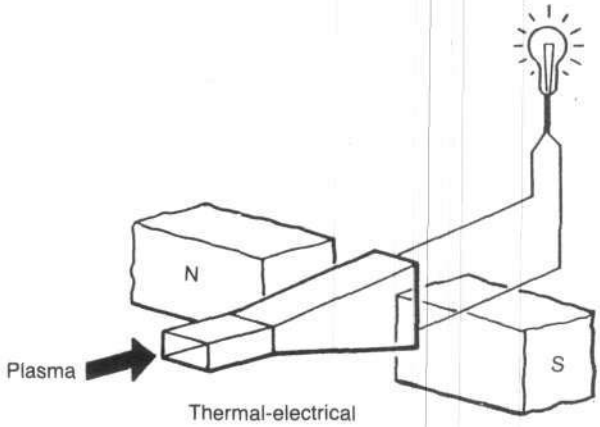


Conventional steam generator



MHD generator

MHD VERSUS A CONVENTIONAL STEAM GENERATOR

In a conventional steam generator, only 40 percent of the energy theoretically available in the fuel ever reaches the transmission lines, because energy is lost in the conversion of fuel to heat, heat energy to mechanical energy, and mechanical energy to electricity.

MHD reduces these three stages of electric power production to one—a continuous process that requires no moving parts. Heat from burning fossil fuels produces a stream of conductive plasma that flows through a long, nozzle-like tube surrounded by electromagnets. The gas stream essentially replaces the armature of a conventional electric generator. This creates a current that is drawn off by electrodes along the length of the tube. Overall, efficiencies may be increased to as much as 60 percent.

What Is MHD?

Magnetohydrodynamic energy conversion will double the efficiency of conventional electricity generators and cheapen the cost of producing power.

MHD is based on the same principle as the conventional generator. According to Faraday's principle of magnetic induction, moving an electric conductor through a magnetic field generates an electric current. In the currently used turbine-generator design, steam is used to turn a turbine that provides the mechanical energy to turn an electrically conductive set of windings through stationary magnetic field lines.

MHD conversion eliminates the mechanical moving parts in this process. In direct MHD conversion, the moving electrical conductor is an ionized gas (with free ions and electrons) that is propelled through a channel surrounded by a magnetic field.

In a fossil-based MHD system, the ionized gas or plasma conductor is the fuel itself, combusted at high temperatures. Potassium is added to the gaseous combustion product as a "seed" to aid the ionization. In MHD-nuclear systems the plasma can be a liquid or gaseous metal coolant heated by the fission process. In fusion MHD the plasma that is the fusion end-product will be directly converted to electric power.

Double Efficiency

An MHD system increases the efficiency of energy conversion by about

50 percent, doubling the existing limit of 35 percent for steam turbine cycles. This is the case even taking into consideration the electromagnetic losses in the MHD generator as a result of interference from induced secondary magnetic fields from the plasma current and other small-scale turbulence problems.

The efficiency of the energy conversion is increased with MHD for two reasons:

First, MHD eliminates the energy loss from the transfer of mechanical (kinetic) energy through huge, rotating pieces of machinery.

Second, the thermodynamic efficiency limit is greater.

This theoretical limit is determined by the temperature difference between the gas let into the MHD system and the temperature of the gas when it comes out of the channel. In the fossil-based MHD designs, this temperature difference may reach 1,500 to 2,000 degrees; conventional steam turbine systems have a much smaller temperature differential—about 600 degrees. (The absolute temperature limit for a conventional steam turbine system is about 800 degrees Celsius, compared to 2,500 degrees Celsius for an MHD system.)

For commercial MHD, the most stubborn problems that remain to be solved are the development of channel and electrode materials that can withstand high temperatures in a highly corrosive atmosphere for long periods of time. In addition, these materials have to withstand near-absolute zero superconducting magnet systems that are in close proximity to hot plasma channels with no leakage of heat or cold.

Initially, it is likely that commercial MHD generators in the Soviet Union will be used mainly as peaking plants run in parallel to constantly operating conventional fossil fuel plants. As reliability and economic feasibility are proven, the second-generation technology, beginning in 1990, will be put on the power grid as baseload plants with steam turbine bottoming cycles that use the out-let gas for conventional power production.

Continued from page 25

Perhaps the most significant difference in the Soviet and U.S. programs is that the Soviets see MHD as a *process*, not a fuel or a technology limited to coal.

At the seminar in San Francisco, Dec. 11-12, Dr. E.M. Shelkov, the deputy director of IVTAN, was interviewed by a reporter from the *San Francisco Examiner*. Since the seminar discussion of the experimental MHD work at IVTAN had centered around the generators now running on natural gas, the reporter asked if MHD would replace nuclear energy.

MHD As a Process

"The question is incorrect," Shelkov said, and he went on to explain that MHD is not a fuel and is not tied to the use of any particular fuel. MHD is a *conversion process*, a way of producing electricity directly from a high-temperature ionized gas without the need for cumbersome and inefficient steam turbines, he said. The Soviets will use MHD conversion with gas, coal, nuclear, and fusion power.

In a seminar presentation IVTAN Professor E.E. Shpielrain discussed the future applications of such direct conversion as well as the history of the IVTAN program. When the Institute began MHD experiments in the early 1960s, he said, they decided to use the clean fuels, natural gas and oil, to do the first simplest component design and engineering.

The first bench-scale experiment was the U-02, which demonstrated that fundamentally the technology could work. In the early 1970s the Soviets completed the gas-burning U-25, the world's first pilot MHD plant. It tested new high-temperature components, such as channels, electrodes, and air preheaters in a totally integrated system that occasionally has delivered electric power into the Moscow power grid.

The third phase in the program, Shpielrain said, was the diversion of a small portion of the U-25 plasma into a by-pass loop in order to test more complex and delicate components required for commercial operation—particularly a superconducting magnet and its accompanying cryogenic system.

The fourth phase will be the U-500, an MHD-steam cycle combined system, that initially will have half the power (250 MW) generated by the MHD system.

All the development so far as well as the planned deployment of the first 10 to 15 gigawatts of MHD power through the early 1990s, will use clean-burning natural gas. At the same time, particularly for the coal-rich region of Siberia, coal-based MHD generators are under parallel development.

Shpielrain explained that last year the small U-02 began simulated coal-burning tests, where ash was introduced into the MHD channel. By 1983, the Soviets plan to burn coal in the U-25B by-pass loop in cooperation with the United States; and by 1990, they will begin design and construction for baseload coal-burning MHD power plants.

Nuclear MHD Underway

Based on the initial experience with natural gas, MHD applications are now under development at IVTAN for use with tomorrow's advanced nuclear plants. The Soviets plan to have the majority of their baseload electric power plants variations of conventional and advanced nuclear technology soon after the turn of the century.

Shpielrain enumerated five advanced nuclear designs, from high-temperature reactors to breeders using liquid metal coolants, that could be the heat-source for MHD conversion. Questions under consideration include the acceleration of liquid metals as the working fluids in situations where they are normally noncompressible, the use of noble (inert) gas working fluids, and combinations of liquid-gas phase changes for the proper flow-rate through the channel.

Both at IVTAN and at Kurchatov, work is continuing toward direct conversion with the ultimate energy source, fusion, continues.

The U.S. Program

The U.S. MHD program has never been conceptually or experimentally organized to deal with MHD as a conversion process.

In 1966, when forward-looking researchers led by Dr. Arthur Kantrowitz at the Avco Everett Research Laboratory presented a proposal for commercial coal-based MHD development to the

Department of the Interior, they were told that the United States was going nuclear and MHD technology was not needed!

Now, when Congress is faced with deciding which of a smorgasboard of coal technologies to support in an effort to move away from the use of oil, MHD is not even in the top 10. Whatever congressional support there is for MHD research has come from coal-producing states, mainly in the West.

When the Soviets announced in the early 1970s that the U-25 would be delivering power to the Moscow grid, the United States did wake up to the fact that it was falling behind. Under the combination of the detente and high-technology energy policies of the Nixon administration, a renewed effort was begun in MHD and an important U.S.-Soviet cooperation agreement was signed. But this year, for the first time in a decade, the U.S. MHD budget has been cut back. Although it may receive a supplemental budget add-on in the spring that may save important parts of the program, the budget addition does not represent a commitment to develop commercial MHD but a political football between the Executive and Congress.

From Theory to Industry

Another major difference in the U.S. and Soviet programs is a function of the difficulty of putting a demonstrated technology into commercial deployment here. In the past two years, the administration has taken various steps to make that process more difficult.

For example, the civil service reform that went into effect July 1, 1979 specifies that for two years after leaving government service a scientist or engineer is not allowed to work in industry in his area of expertise. As a result, Department of Energy administrators, with hundreds of years of accumulated experience in MHD, fusion, and other highly advanced and specialized fields, are not allowed to bring the benefit of that experience into industry.

By contrast, at IVTAN there is a cooperation and cross-fertilization of ideas and experience in all aspects of the MHD program (from natural gas to fusion), at the same time that the institute supervises every step—from solving the problems in plasma physics to building the commercial machines.

IVTAN has a number of scientific divisions answering questions dealing with theoretical problems in plasma physics, thermal conductivity, thermophysical properties, shock waves, gas dynamics, and mass transfer. Research divisions include new power installations and processes, power MHD systems, geophysical MHD applications, development of new diagnostics, computer technology, and applied superconductivity.

After the theoretical problems have been resolved and the research divisions have applied fundamental developments, an experimental design bureau with the institute begins the engineering work to make practical systems designs. As the pilot project stage moves into commercial demonstration, or an experimental "factory," IVTAN joins forces with the appropriate industry ministry to implement the first-kind technology.

In the case of the MHD U-500, for example, the Ministry of Power and Electrification will work with IVTAN to deploy the technology for commercial benefit. The institute will continue work on experimental "complexes" to link the basic MHD power technology to complementary industrial processes, such as fertilizer production, metallurgical applications, and perhaps at some time, the production of hydrogen. For instance, as part of the Soviet policy to explore all

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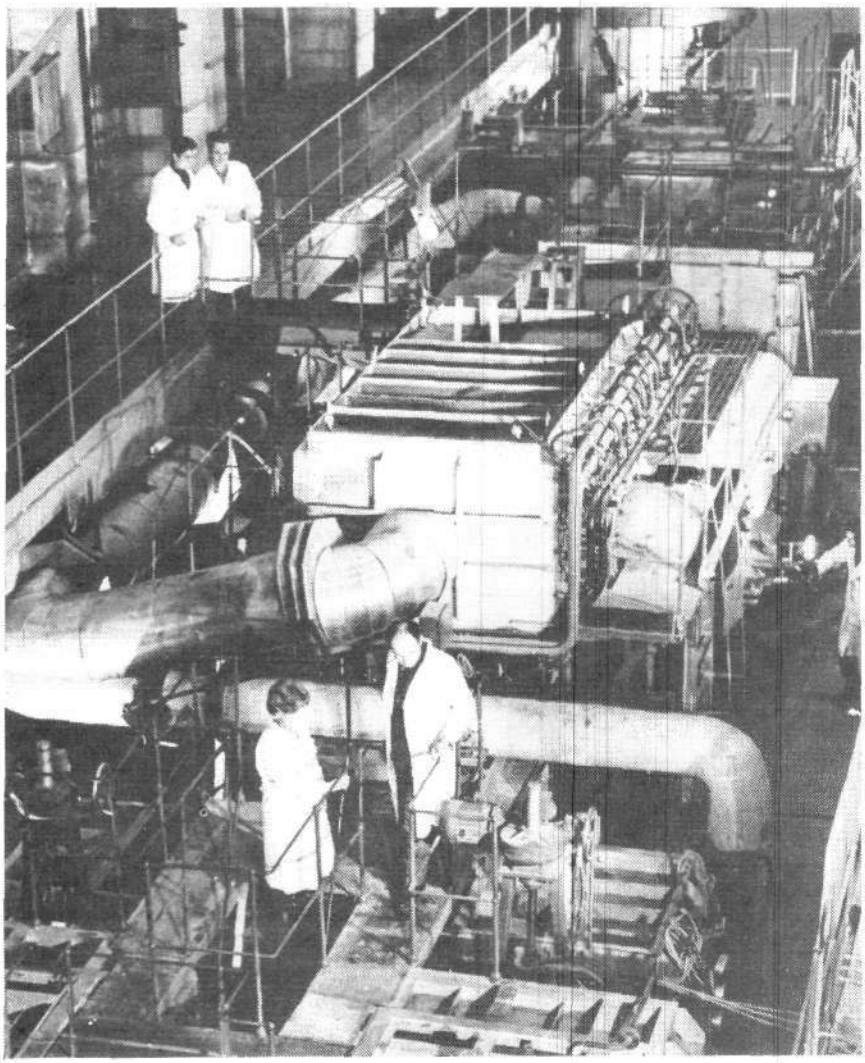


The generator in the Soviet U-02 bench-scale MHD experiment, which used a U.S.-built cryogenic magnet from Argonne National Laboratory in Illinois.

Anti-Drug Coalition, Bogota, Colombia, Dec. 6, 1979

Symposium Founds Colombian Anti-Drug Group

North and South American leaders in the fight against drugs met in Bogota, Colombia for a one-day symposium Dec. 6, that founded the National Anti-Drug Coalition of Colombia. The new coalition unanimously passed resolutions in favor of cooperation with antidrug organizations in the United States, Canada, and Europe. This international constellation, coalition leaders said, will provide the political muscle to defeat the proposed legalization of drugs such as marijuana and cocaine in Colombia, and to create a political climate in which every major candidate for political office is forced to take a stand on the drug issue.

Colombian antidrug coalition spokesman Fausto Charris, a union leader, opened the convention by emphasizing the significance of holding an international symposium on drug abuse in Colombia, which produces more than 80 percent of the marijuana consumed in the United States today. "The mere fact that we are gathered here today," he said in his welcoming speech, "is a blow to the networks behind the international drug traffic."

NSIPS

Antidrug leader Fausto Charris: "Our fight will be for the industrial progress and education that will obliterate the parasitic drug economy."

Symbol: A Nuclear Plant

Charris explained that the driving force behind the antidrug fight is far more than a mere distaste for drugs. It involves a humanist commitment to the development of the human mind as the keystone of society's progress, he said. "This is why the new coalition's symbol will be a nuclear plant, because our fight will be for the industrial progress and education that will obliterate the parasitic drug economy."

The 80 participants in the conference heard three panels debate the medical, economic, and international policy implications of the drug trade. The audience included representatives from Colombia's Health Ministry, Attorney General's office, Defense Ministry, and nearly a dozen public and private health and drug-related organizations.

In the first panel, on the medical effects of drugs, Dr. Ned Rosinsky, Fusion Energy Foundation staff member and member of the U.S. Anti-Drug Coalition presented slides showing the actual physical destruction caused by marijuana. Rosinsky refuted the arguments that marijuana is harmless. He likewise dismissed the unscientific arguments against the use of the herbicide paraquat, which is in fact needed for a successful eradication program.

Four other physicians from Colombia also spoke on the medical evidence against marijuana, and unanimously agreed with Rosinsky's conclusions.

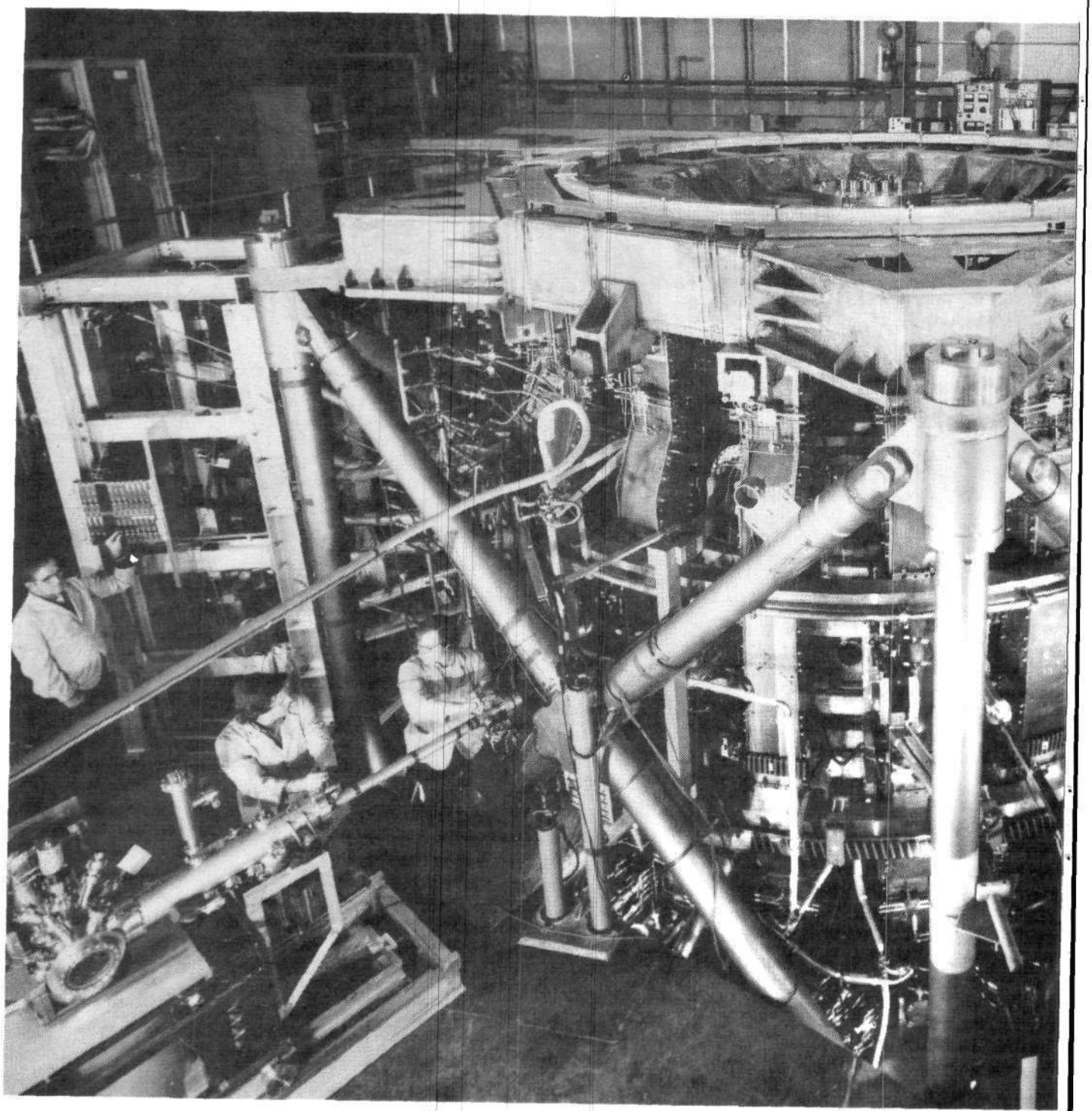
Everyone's Responsibility

The second panel, on the economic and social effects of the drug trade, included Maximiliano Londono, the chairman of the Andean Labor Party, and Salahuddin Muhammad, vice chairman of the U.S. Anti-Drug Coalition. Londono explained the nature of the $200 billion annual international drug-running operation and denounced the proponents of legalization as shabby apologists for this multinational drug empire. Muhammad centered his talk on the moral responsibility that every citizen must take to put a stop to the drug trade and other forms of mental enslavement.

In the final panel, Attorney Max Dean from the Michigan Anti-Drug Coalition explained why legalizing the drug trade would be a travesty against the notion of natural law and attacked U.S. presidential candidates like Senator Edward Kennedy who have called for the decriminalization of marijuana.

Feature articles on the biological effects of marijuana and the U.S. Anti-Drug Coalition appeared in the October 1979 issue of Fusion.

The 1980s: Decade for Fusion



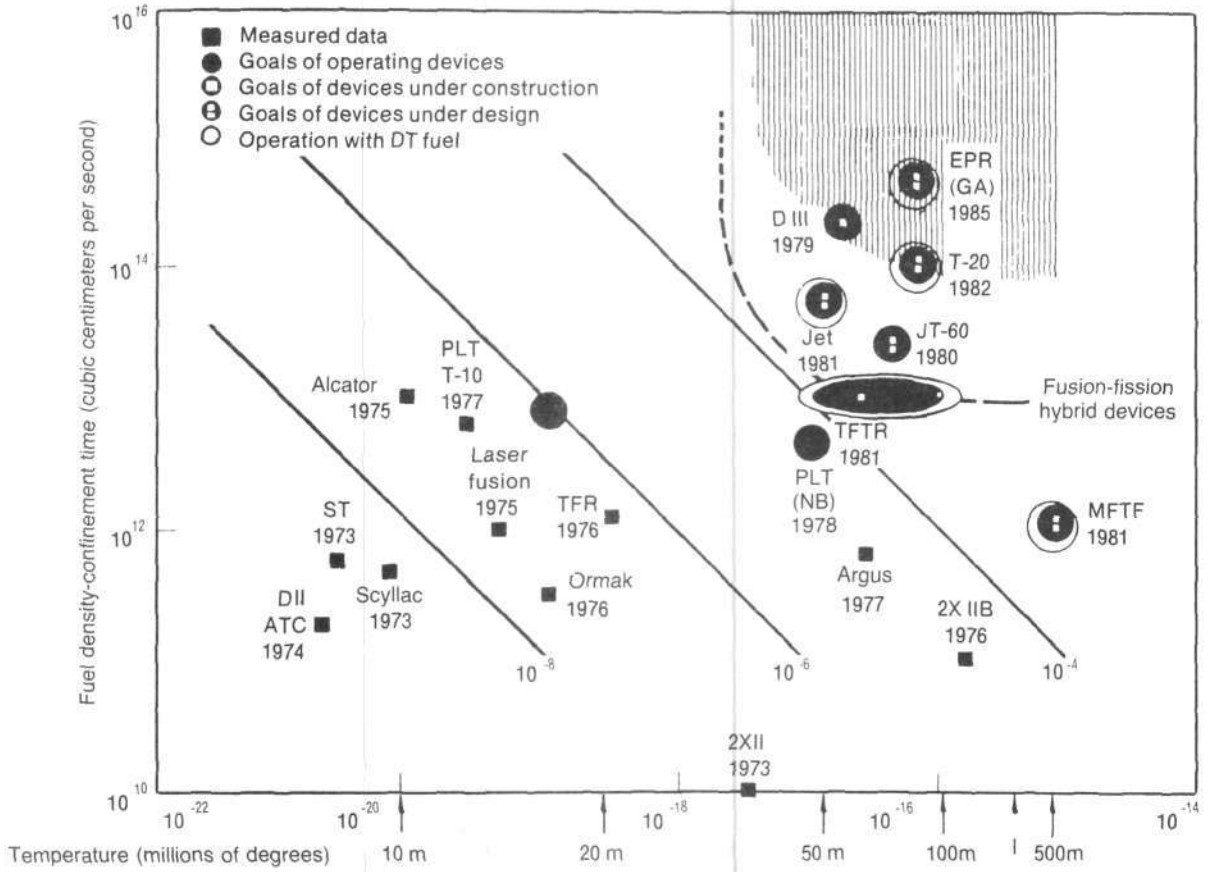


Figure 4
RESEARCH PROGRESS IN FUSION POWER

The current state of fusion research is shown here in terms of already achieved results and projections for planned experiments under construction. Results from the various research projects are plotted logarithmically on both axes. The horizontal axis gives temperature in millions of degrees Celsius, and the vertical axis gives the density-confinement time product in number of nuclei per cubic centimeter-seconds. The hatched region in the upper right-hand corner represents the area in which a pure fusion reactor must operate. The dashed line, also in the upper right, shows how these conditions are substantially lowered for fusion-fission hybrid reactors.

Below the names of the various experiments are the dates of measured results (boxes) or projected results (circles). A guide to the experiments follows: DII is the General Atomic noncircular tokamak, Doublet II, to which DIII is the followup. Doublet III, now on line, is expected to reach near-reactor conditions. ST refers to the first U.S. tokamak, the converted Princeton ST stellarator, which duplicated the initial Soviet tokamak results. ATC was the second U.S. tokamak, also at Princeton, a small device that demonstrated the feasibility of neutral beam and plasma compression heating in tokamaks. Alcator is the Massachusetts Institute of Technology's high-field, small tokamak, which, as seen, holds the record for density-confinement product. Ormak was the third U.S. tokamak to be built, and it demonstrated scaling both in terms of size and neutral beam heating. TFR, the French tokamak, also demonstrated neutral beam heating. PLT and T-10 are the large U.S. and Soviet tokamaks, respectively. PLT, the Princeton Large Torus, achieved temperatures of greater than 70 million degrees with neutral-beam heating. TFTR is the Princeton Tokamak Fusion Test Reactor now under construction, which will be the first tokamak to burn D-T fusion fuel. EPR and T-20 are the General Atomic and Soviet designs for experimental power reactors, respectively. 2XII and 2XIIB represent the results for Livermore's open-ended mirror magnetic system. The Mirror Fusion Test Facility, MFTF, is a Livermore experiment that will demonstrate the feasibility of a number of different mirror approaches to fusion. Laser fusion refers to world results in inertial confinement. Argus was the prototype 2-beam system for the Livermore 20-beam Shiva system now in operation and projected to achieve results equal to the TFTR. Scyllac represents the results from toroidal theta-pinch research.

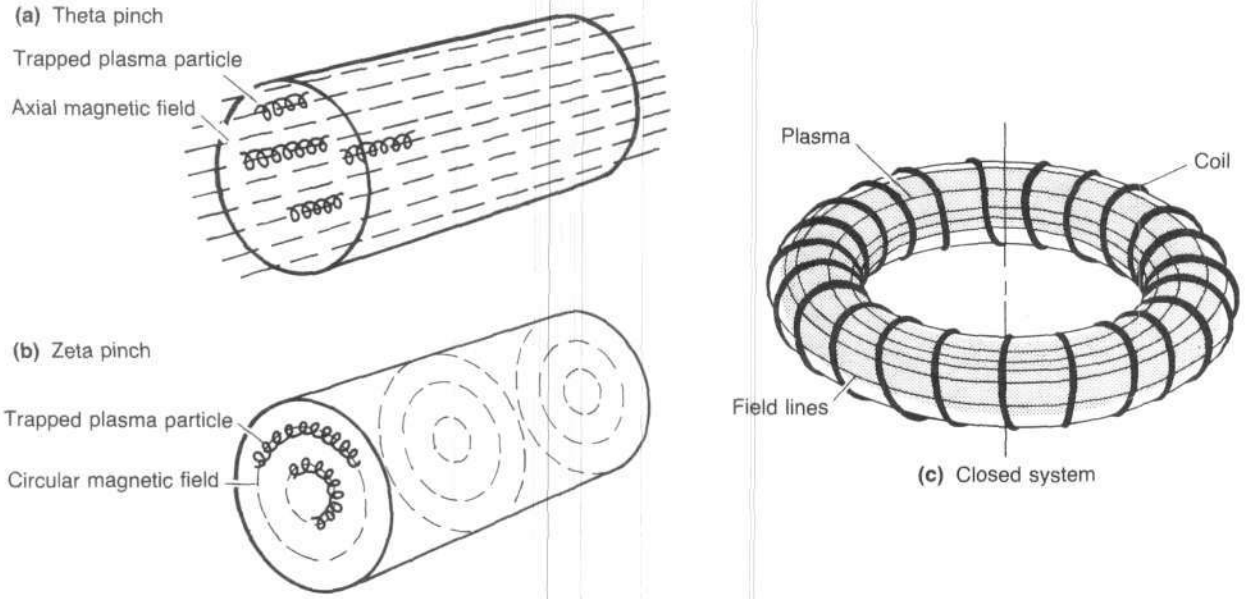


Figure 5
MAGNETIC CONFINEMENT CONFIGURATIONS

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. This generates the 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 the plasma current generating self-compression is called the plasma pinch, and this type of magnetic geometry is called the theta pinch.*

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

The magnetic field configuration 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.*

the existence and configuration of these magnetic and electric fields, currents, and radiation determine the plasma particle motions.

Figure 5 shows how this works. Low-density hydrogen gas is introduced into a cylindrical vacuum chamber. An externally generated electrical field is applied to the cylinder lengthwise, which ionizes some of the hydrogen gas. In response to the electric field, the electrons and ions of this plasma then move in opposite directons toward the ends of the cylinder. In this way, an electric current is induced in the plasma parallel to the axis of the cylinder. This is called the zeta or *z* direction.*

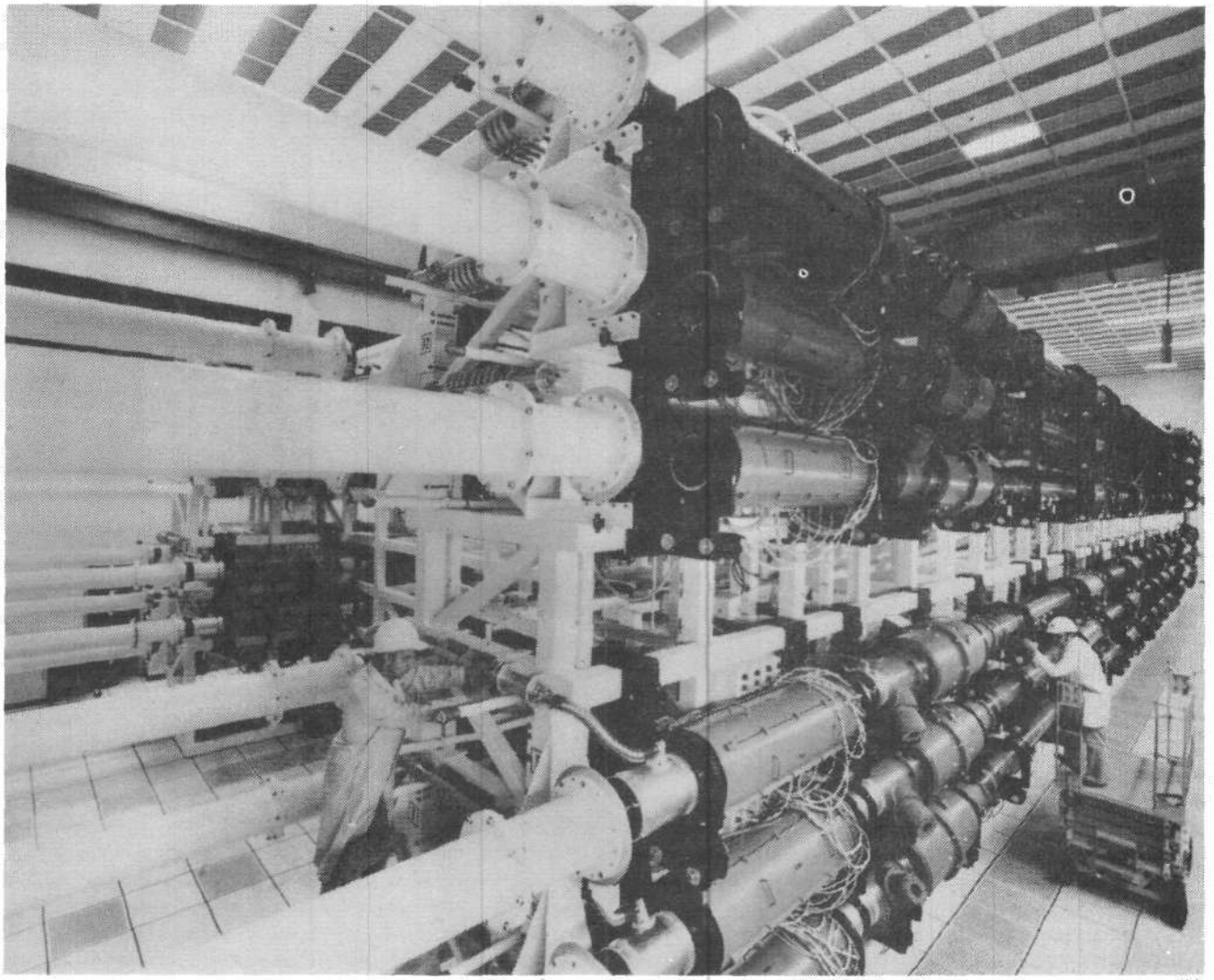
This induced plasma current generates a magnetic field in the circular or aximuthal direction (the short way around the cylinder), called the poloidal or theta (Θ)* direction. The plasma is diamagnetic; that is, it generates a magnetic field that tends to cancel out any superimposed magnetic field. For this reason plasma particles are trapped into spiraling orbits along the field lines of a strong, imposed magnetic field.

Because of this interrelationship, the magnetic field acts as a nonmaterial confining wall. As the magnetic field increases in intensity by increasing the induced plasma current, it "pinches" the plasma column to a greater density. This pinching increases the intensity (current density) of the induced plasma current, thereby leading to a more intense magnetic field.

If this process takes place rapidly, it creates an implosion of the plasma column whose inward motion eventually heats the plasma. This heating leads to a greater energy density of the plasma; that is, a greater gas pressure. In other words, the plasma is able to counteract the inward magnetic pinching forces and a metastable configuration of a magnetically confined and heated plasma is achieved.

This type of configuration is termed the *z* or zeta pinch. If instead of an axially directed current, a circular current is induced in the theta direction, the magnetic field generated would be in the *z* direction and the configuration is termed the theta pinch.

There are two ways to close off the ends of this cylindrical



The Shiva laser system at Lawrence Livermore Laboratory, the world's most powerful laser. LLL

configuration so that plasma does not simply flow out. The magnetic field at the ends of the cylinder can be intensified by putting external magnets at each end of the cylinder, thereby reflecting the plasma particles back into the center of the cylinder, or the ends of the cylinder can be brought together to form a torus or donut shape.

There is an almost infinite variety of plasma-magnetic field configurations that can be formed for sustaining a fusion plasma. The most important distinctions among these configurations are: (1) whether the magnetic fields are internally or externally generated; (2) whether the plasma is primarily heated by internally generated fusion energy, plasma currents, shock implosion, or external heaters such as intense beams of electromagnetic radiation (radio frequency or microwave heating), ions, electrons, high-energy neutral molecules (neutral beam heaters), or preheated blobs of plasma shot from plasma "guns"; (3) whether the configuration is pulsed or steady-state; (4) whether the plasma magnetic field configuration is open-ended as in the case of the linear z-pinch (Figure 5a), and the linear theta pinch (Figure 5b), or closed (Figure 5c); (5) the extent to which the magnetic field is efficiently used to confine the hot plasma;[7] and (6) the geometry of the plasma currents and magnetic fields.

The most important distinction, which determines the difficulty of the technology used in initiating and maintaining a fusion system, is generally how self-organizing the plasma configuration is—to what extent the plasma itself either generates directly or mediates the means whereby it is confined and heated.

For example, externally generated magnetic fields in a steady-state or long-pulse system are limited by the strength of the materials out of which the magnetic coils and structural support are made. This is generally determined by the strength of chemical bonds that are on the order of a few eV. On the other hand, in a plasma the structure generating the magnetic and electrical fields is held together, not by weak chemical bonds, but by the magnetic and electrical fields. Therefore, the use of self-organizing plasma structures removes the technological limitations

on the intensity of the force fields, thereby relaxing the difficulty of the technology involved.

To put it another way: The object is to set up a system in which relatively crude energy input is transformed via the plasma to higher-quality energy (more intense electric and magnetic fields, for example) that, in turn, permit a higher-order plasma structure to be generated. The ignition of fusion energy furthers this type of process because the quality and quantity of the fusion energy generated is much greater. Inertial confinement fusion gives the best example of this.

Inertial Fusion

In inertial fusion the primary force confining the fusion fuel is the inertia of the fuel mass itself.[8] The fusion fuel is heated to fusion temperatures and undergoes significant amounts of fusion before blowing up. To achieve this, the fusion fuel must be compressed to a very high density at which the fusion reaction proceeds at a sufficiently rapid rate.

The first successfully demonstrated net-energy-producing fusion system based on the inertial confinement approach is the hydrogen bomb. An atom (fission bomb) is set off, generating radiation (soft X-rays) that is used to burn off the surface layers of a configuration of fusion fuel called the target. The rapidly expanding plasma produced on the surface of the target—in the same way a rocket works—generates an inwardly directed force that implodes the remaining portion of the target.

When the shock waves* generated during this implosion process converge on the center of the fusion fuel target, they are dissipated and their energy is transformed into heating the compressed fuel and igniting fusion. Because of the high density of the surrounding compressed fuel, the fusion fuel products—in particular the helium nucleus—deposit their energy around the ignited region setting up a thermonuclear burn wave in the compressed, cold fuel.

If the fuel has been compressed to a very high density, then the burn wave propagates faster than the shock waves exploding the target apart. The efficiency of the burn wave can also be enhanced by induced magnetic fields that help confine the energy to the fusion fuel. Arranging the distribution of both the implosion energy and fusion burn

The Scientific Status of Fusion

As this brief survey of recent achievements and expected progress in 1980 shows, the scientific feasibility of the tokamak magnetic confinement system has been demonstrated, and many alternative magnetic systems are not far behind. In fact, the science of magnetic confinement has advanced to the point where confinement systems can be designed almost to specification.

At the same time, it should be understood that the fusion effort is just beginning to scratch the surface in terms of the fundamental principles upon which these fusion systems are based.

Magnetic Confinement

The Lawrence Livermore Tandem Mirror Experiment, TMX, has begun operation with initially good results. As neutral beam heaters are added to the TMX, it is expected to demonstrate the scientific principles of this approach.

The design of the next step in TMX development, an upgrade of the Mirror Fusion Test Facility, MFTF, has been completed and the machine is now under construction. This upgrade, called MFTF-B, would cost about $125 million and would provide reactor-grade plasmas in the TMX mode by 1984.

The Princeton Large Torus, the PLT tokamak, has obtained initial results demonstrating the efficacy of the radio frequency method of plasma heating. Radio frequency heating uses a frequency that correlates with the frequency of the ion spirals along magnetic field lines. (This is called ICRF, ion cyclotron radio frequency.) About 50 percent of the directed electromagnetic energy ends up as heat in the plasma, with up to 500 kilowatts total input. Within the next year, the PLT experiments could fully demonstrate this important alternative to neutral beam heating.

Higher frequency heating experiments using a combination of the electron and ion spiral frequencies, the lower hybrid heating frequency, or LHH, will be initiated later this year.

The Oak Ridge Impurities Studies Experiment, the ISX tokamak, has obtained record plasma betas, and the experimental results indicate that there may be no significant barrier to attaining high beta operations in tokamaks —up to 20 percent. The ISX has also demonstrated pellet injection for plasma fueling.

This year, the ISX is scheduled to carry out extensive studies of microwave electron cyclotron heating alternatives and key experiments in plasma shaping and impurity control, including exploration of reactor-relevant types of divertor configurations.

The operational Princeton Poloidal Divertor Experiment, PDX (shown on the front cover), will provide key experiments in numerous divertor configurations for impurity control with reactor-grade neutral beam heated plasmas.

The Alcator C at the Massachusetts Institute of Technology, which is expected to go into full operation shortly, is the follow-up to the MIT high magnetic, high-density Alcator A—the first magnetic experiment to obtain the minimum density confinement time product needed for breakeven energy production. Alcator C will exceed this breakeven product and carry out extensive lower hybrid heating, ion cyclotron radio frequency, and fueling experiments.

The General Atomic Doublet III in San Diego, a tokamak whose cross-section is shaped like a figure 8, will proceed with the support of Japan to neutral-beam-heated reactor-grade plasmas.

The Japanese JT-60 tokamak at the Japanese Atomic Energy Research Institute, like the European Euratom JET tokamak at Culham, England, will demonstrate the full physics of reactor operation. However, it will do this without actually burning deuterium-tritium plasmas; it will use only hydrogen and deuterium, as will all the ex-

wave energy in the fuel can also enhance the confinement of the energy in the fuel, which increases the burn-up of the fuel itself.

The most efficient type of inertial fusion implosion is one that is *isentropic**; that is, one in which the largest portion of the implosion energy goes into compressing the fuel. This is because the amount of energy it takes to isentropically compress matter significantly is much smaller than the energy it takes to heat fusion.

If the fusion output energy can also be used to compress more fusion fuel isentropically and the thermonuclear burn wave propagates through it, then there can be an infinite gain target.[9]

The fission bomb, of course, cannot be used as a driver in controlled thermonuclear fusion because of its very large energy outputs. For commercial applications, alternate drivers such as lasers or particle beam accelerators must be found. The intense beams of laser light, protons, heavy ions, or electrons are used in the same way that the soft X-ray radiation from the atom bomb drives an implosion.

The chief factors to be considered in such drivers are: (1) the efficiency with which the original beam is generated; (2) the repetition rate at which it can be generated; (3) the efficiency with which it is coupled to the target (how much of the beam energy is absorbed in heating the target surface); (4) the efficacy of the particular charcteristics of the beam and the beam coupling mechanism to the target for driving isentropic implosion; (5) the efficiency with which the particular type of beam drives the implosion itself; and (6) the extent to which the fusion energy output can be decoupled from the beam generator so that it is not damaged.

A U.S. Reactor by the 1990s?

At the hearings Dec. 10 before the Fusion Advisory Panel and the House Subcommittee on Energy Research and Production, Fusion Office director Edwin Kintner and planning and projects director Michael Roberts presented three alternative programs for the U.S. fusion effort: Program A, based on the current policy of "go slow," results in a reactor demonstration in 2010; Program B, a moderately accelerated effort, results in a demonstration reactor in 2000; and Program C calls for an accelerated (though essentially sequential) effort that results in a demonstration

periments mentioned above. A deuterium-tritium upgrade of JET is now being explored.

The Princeton Tokamak Fusion Test Reactor, TFTR (pictured on the back cover), will be the first magnetic fusion experiment to generate burning deuterium-tritium plasmas. The TFTR will go far beyond breakeven with energy gains of 2 to 5 in the hot ion mode. As shown in Figure 3, the TFTR upgrade will come very close to the exact plasma regime needed for the planned Experimental Test Facility.

In general, in the case of magnetic confinement, it appears that the advanced fusion cycle using the high-temperature deuterium-deuterium reaction is as scientifically credible today as deuterium-tritium was five years ago.

Intertial Fusion Developments

Inertial confinement fusion, which is of much greater interest in terms of the fundamental scientific questions involved, has been retarded in the United States by political tampering and interference. For example, a proposal by Soviet scientists for a joint research program on the very promising fast liner approach, which uses electromagnetic energy to compress a metal cylinder containing a fusion plasma (thereby having the advantages of both magnetic and inertial confinement), was sabotaged by the Carter administration.[1]

In fact, it is now official U.S. policy to pursue inertial confinement primarily for its weapons applications. When the DOE's own expert panel on fusion, chaired by Dr. John Foster of TRW, called for increasing the research budget by 50 percent to develop the type of efficient beam drivers needed for actual power reactors, the administration classified the Foster panel report as top secret.

Ironically, these political policies undermine the inertial fusion effort to the extent that classification precludes even the sort of scientific advances needed for weapons applications.

The most significant result of the year has been the rapid development of collective light ion beam generation.

Sandia Laboratories in New Mexico reported achieving million ampere currents per square centimeter with protons of about 1 MeV energy. The deposition of these intense proton beams in matter turns out to be better than expected, and the prognosis for the development of this important driver has been universally acclaimed.

Lawrence Livermore Laboratory has obtained laser fusion target densities with hydrogen 50 to 100 times greater than that of liquid hydrogen.

The final experiments on the **Los Alamos Scientific Laboratory**'s fast liner indicate that the sort of compression velocities needed to ignite fusion can be obtained. Furthermore, Los Alamos continues to make progress with high-density experiments using a carbon dioxide gas laser system.

In the **Soviet Union**, scientist L. Rudakov reported that his prototype electron beam reactor, Angara V, is on schedule and will be completed in the early 1980s. The first module has been delivered and experiments on a new type of electron beam target, a small fast liner, will soon begin.

The Naval Research Laboratory electron-ion beam research team, which pioneered much of the work on collective acceleration, reported significant success in obtaining propagation of intense beams through prepared plasma channels. NRL researchers also continue to make important progress with the design and experimental demonstration of thin-shelled, high-gain inertial fusion targets. Experiments have demonstrated that very high hydrodynamic efficiencies can be obtained in the acceleration of thin foils with laser light.

Note

1. For a specific example of the sabotage of the fusion program, see "The Case of the Fast Liner" by Charles B. Stevens in the March-April 1979 issue of *Fusion*, pp. 47-49.

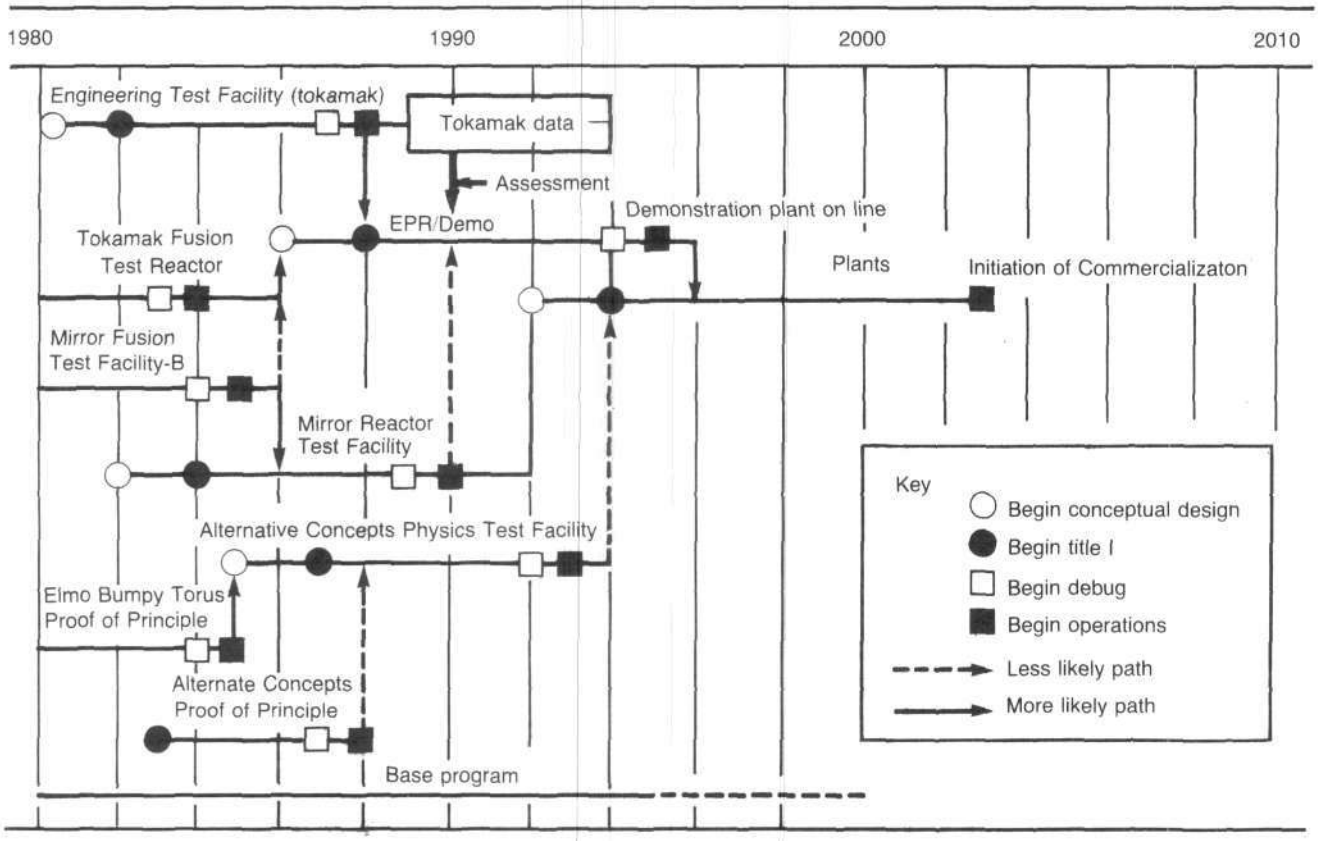


Figure 6
DOE PROGRAM FOR A FUSION PLANT ON LINE IN 1995

This flow chart shows the major elements needed to bring a magnetic fusion power plant on line in 1995 and corresponds to the Department of Energy's "Program C" funding. The type of Experimental Power Reactor or Demonstration Commercial Power Plant, scheduled here for 1990, will depend on data from the Princeton Tokamak Fusion Test Facility, the Mirror Fusion Test Facility B (the Lawrence Livermore upgrade of the MFTF that will be a full-scale tandem mirror configuration), and technology programs. Plants and the initiation of commercialization shown just after the year 2000 anticipate the construction of many fusion reactors, possibly based on different concepts, as the dashed lines indicate.

reactor in 1995. The total cost for Program A was projected at $12 to $14 billion; Programs B and C are projected at more than $15 billion each (all in 1981 dollars).

The accompanying table shows detailed funding proposed for Program C through 1989, and Figure 6 gives a flow chart for the key facilities in this program.

In his testimony, Kintner noted that there are two simultaneous thresholds for fusion—maintaining a thermonuclear plasma and the removal of the heat energy at a high enough temperature to convert it to useful power. "If we do not do both of these simultaneously, we have not taken a truly meaningful next step toward useful fusion power," Kintner said.

This next step would be an Engineering Test Facility, the ETF. Although the ETF would sustain a reactor-grade fusion plasma in all respects, it would primarily be designed as a test bed for developing the technology of fusion power plants.

The ETF in Program C would be based on the tokamak. Therefore, Program C specifies that a "vigorous mirror and alternate concept program are both brought to the plant stage to balance this early concentration on the tokamak." These alternatives would include the Mirror Fusion Test Facility upgraded to the full reactor-grade plasma tandem configuration, the MFTF-B; a Mirror Reactor Test Facility, MRTF; an Alternate Concepts Physics Test Facility, together with several Alternatives Concepts Proof-of-Principle experiments, ACPOP; and a reversed field pinch proof-of-principle experiment, which would probably duplicate the MFTF-B in attaining reactor grade plasmas.

The primary focus of Program C would necessarily be technology development. However, this technology would be universally applicable to all magnetic confinement approaches, so that the first commercial plants could be based on alternative concepts to the tokamak.

Figure 7 gives the schedule for the Engineering Test Facility, ETF, which will provide the demonstration of technology needed for commercial reactors, and its supporting technologies.

The time chart in Figure 7 is based on the moderately

PROPOSED BUDGET FOR THE ACCELERATED FUSION PROGRAM (Program C)

	(FY 1981 in million dollars)								
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Confinement Systems Division (tokamak and mirror branches)										
Elmo Bumpy Torus (Proof of Principle)		15.0	25.0	25.0	5.0	0				
Long Pulse upgrade		20.0	20.0	30.0	30.0	0				
Basic Operations Budget		147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Tokamak Fusion Test Reactor		20.0	25.0	30.0	30.0	30.0	30.0	30.0	30.0	0
Mirror Fusion Test Reactor				5.0	10.0	20.0	20.0	20.0	20.0	20.0
Alternate Concepts Physics Test Facility										
Engineering Test Facility					5.0	10.0	20.0	40.0	50.0	50.0
Experimental Power Reactor										
Alternate Concepts Physics Test Facility (mirror)									5.0	10.0
Applied Plasma Physics Division										
Proof of Principle				5.0	25.0	25.0	25.0	0		
Operations		85.0	70.0	70.0	70.0	80.0	80.0	90.0	90.0	80.0
Reversed Field Pinch reactor		20.0	40.0	40.0	10.0	0				
Development & Technology Division										
Tritium System Test Assembly		2.2	0							
Large Coil Project		9.0	5.9	0						
Neutral Beam/Radio Frequency Heating Test Stand		15.0	10.0	5.0	0					
Blanket and Shield Test Facility		15.0	20.0	15.0	0					
Plasma Maintenance and Control Facility		10.0	10.0	0						
Incremental support for Materials subprogram		5.0	10.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Operations		85.0	85.0	90.0	100.0	100.0	95.0	85.0	85.0	85.0
Fusion Materials Irradiation Test Facility		0	0	0	3.0	6.0	12.0	12.0	12.0	12.0
Planning and Projects Division (construction and associated R&D funds)										
Tokamak Fusion Test Facility		34.4	10.0	0						
TFTR Flexibility Modifications		10.0	10.0	10.0	0					
Alternate Concepts Physics Test Facility (mirror)			10.0	10.0	60.0	110.0	140.0	110.0	60.0	0
Mirror Fusion Test Facility-B		29.1	40.0	40.0	20.0	0				
Fusion Materials Irradiation Test Facility		30.0	30.0	20.0	10.0	0				
Alternate Concepts Physics Test *Facility*— PACE						0	0	50.0	75.0	90.0
R&D						10.0	10.0	25.0	25.0	35.0
Engineering Test Facility— PACE			200.0	200.0	250.0	250.0	200.0	0		
R&D		40.0	50.0	100.0	110.0	100.0	50.0	0		
Engineering Prototype Reactor—PACE							0	0	125.0	200.0
R&D							35.0	35.0	70.0	90.0
General Plant Equipment/Project		7.9 3.5	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
Purchase cost for tritium fuel										25.0
Base costs		603.1	629.3	673.4	666.4	669.4	695.4	675.4	700.4	675.4
Engineering Test Facility/Engineering Prototype Reactor			+200	+200	+250	+250	+200		+125	+200
Actual total			829.3	873.4	916.4	919.4	895.4	675.4	825.4	875.4
Rounded total		605	830	870	915	930	895	675	825	875

Shown are the year by year budget projections for the Office of Fusion's "Program C," the accelerated magnetic fusion program that would put a commercial demonstration plant on line by 1995.

accelerated policy of the DOE, Program B. For the DOE's Program C, which leads to a commercial demonstration in 1995, the 15-month gap between conceptual design and the beginning of construction shown in the figure would disappear. In reality, it would take only five years to design in detail and construct an ETF based on the tokamak. The scientific and technology base already exists, or will shortly be demonstrated.

The schedules for the various technology components in this figure will be elaborated below.

The Status of Fusion Technologies

Materials development. Materials development for the reactor, in particular the reactor first wall, at one time was believed to be the most difficult problem in commercializing fusion power plants. The large flux of fusion-generated 14 MeV neutrons easily penetrate the reactor wall materials, where they generate nuclear reactions and cause damage by colliding with the atoms of the wall materials. Together with the thermal and mechanical stress that results from the pulsed nature of tokamak operation, this leads to extensive degradation of the physical properties of the reactor wall material.

In the early 1970s reactor design studies, reactor power densities were kept low. This led to very large power plants in terms of overall scale (see Figure 8) because of the materials damage in the fusion environment that researchers perceived theoretically. The neutron wall fluxes were projected to be about 1 million watts energy equivalent of neutrons per square meter of wall surface. At this low power loading, the walls were assigned lifetimes of two or three years, after which they would have to be replaced.

With the development of actual experiments using fission reactors and particle accelerators to simulate the actual neutron damage and extensive work by such companies as McDonnell Douglas, Atomics International, Westinghouse, and IBM, together with the U.S. national laboratories, this early analysis was proven to be overly pessimistic. Austenitic stainless steels used in fission reactor designs were shown to have potential lifetimes approaching 10 to 20 years, which led to new reactor designs with much higher power densities—3 to 7 megawatts per square meter of neutrons per year.

The study group of the International Atomic Energy Agency for designing an international demonstration reactor, which includes leading fusion scientists from Japan, Europe, the Soviet Union, and the United States, concluded recently that materials are no longer considered the most significant problem and that known alloys are more than sufficient for test reactors.

This is also the case for the ETF, since it would have to operate only about five years with 1 to 3 megawatt per year per square meter wall loadings. But an aggressive materials development program will dramatically improve the economics of actual commercial fusion power plants. "What is needed," according to the testimony of Frank Coffman, director of the Office of Fusion Division of Development and Technology, "is alloys which have 30 to 40 megawatt-years per square meter lifetimes."

The prognosis for achieving this quality of alloys is very good. The rotating target neutron source accelerator is already operational at Livermore Laboratory and will provide key data with microscopic samples. The much larger Fusion Materials Irradiation Test Facility will become operational in 1984. This large volume neutron flux facility will provide the basis for testing sufficiently large samples for engineering design data and confirmation of end-of-life performance. Current experiments with fission reactors are also continuing. Besides the austenitic alloys, an entirely new family of magnetic ferritic alloys have been realized as potential candidates for fusion power plants.

Tritium processing and control. Tritium is the only significantly hazardous radioactive material in a fusion power plant. It is burned up in the fusion reaction and more of it is generated by reacting fusion neutrons with lithium. Therefore, the processing and handling of tritium is the key area for the environmental safety of fusion power plants.

A reactor-level tritium handling system is under construction at Los Alamos Scientific Laboratory, the Tritium Systems Testing Assembly, TSTA, and is scheduled for completion in 1982. Given the already extensive experience developed in weapons programs and work by such companies as Monsanto Chemical Corp., this fusion technology is well in hand.

Magnetics development. This key area of fusion technology, which the fusion program is now primarily responsible for supporting, promises to revolutionize the electric motor, transportation, transmission, and power-generating industries long before commercial fusion is in full swing, because of advances with superconducting magnets.

When ordinary conductors are used to generate magnetic fields, a large part of the electric power is lost as heat, because of the electrical resistance of the conductor. In the early 1960s, practical materials were developed that exhibited the property of superconduction when lowered to near absolute zero temperatures; that is, conduction of electricity without resistance. These materials can be used to generate intense magnetic fields without significant power losses. Furthermore, the only energy cost for superconductors is the refrigerating system to maintain near absolute zero temperature, which is small compared to the cost of power losses with ordinary conductors.[10]

In the early stages of magnetic fusion research it was believed that economical power plants could operate only with superconducting magnets. But recent research progress has demonstrated that although superconducting magnets are still a key technology, ordinary conductors can be used on many parts of the magnetic coil system of an economical fusion power plant.

A very aggressive internationally based superconducting magnet program is already underway, the Large Coil Project, LCP. In the Large Coil Test Facility, six large superconducting coils of differing designs are being constructed by General Dynamics, Westinghouse, and General Electric in the United States, while Euratom, Japan, and Switzerland are constructing one each. These magnets will be configured and tested in a tokamak-like system. They are about one-half the scale needed for commercial power plants and the ETF.

At the same time, more intense field coils are being developed with more advanced superconducting materials, including work at the High Field Test Facility on the magnets needed for the Mirror Fusion Test Facility.

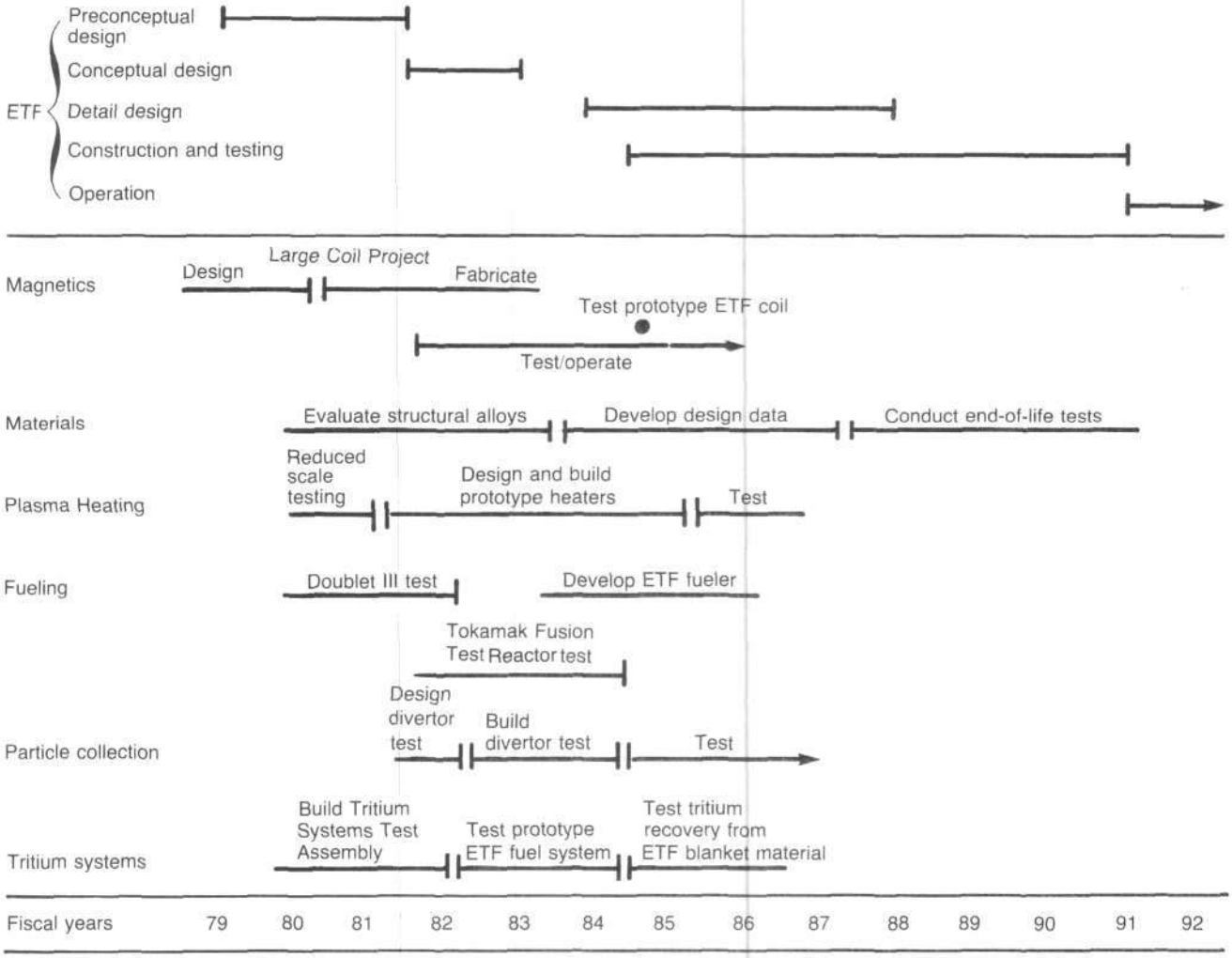
Another key area of technology described as one of the only problem areas for constructing a tokamak fusion test reactor by the International Atomic Energy Agency design group is the pulsed poloidal magnet for inducing the electric current in the tokamak plasma.

Plasma heating technology. The plasma heating technology is well in hand. Neutral beam heating up to reactorlike temperatures has been demonstrated on the Princeton PLT, and an alternative method using radio and microwave electromagnetic radiation is progressing well. Key elements in the heating program are referred to in Figure 9.

Most of the scale-up needed for ETF neutral beams is being achieved now with the TFTR program at Princeton. More efficient positive ion source neutral beams needed for economical reactors are being currently developed in the Soviet Union and at Oak Ridge and Livermore Laboratories. Rf and microwave technology development and testing are also well in hand.

Neutral beam technology demonstrates the tremendous strides in basic plasma technology made over the past decade. The most efficient way to impart energy to matter is electrically. In neutral beams systems ions are extracted from a low-temperature plasma and accelerated electrically to high energies. Because a charged ion beam cannot easily penetrate the magnetic bottle, the beam must be electrically neutralized before it can be used to heat magnetically confined plasmas. This is accomplished by sending the ion beam through a gas cell. The ions exchange elec-

Figure 7
SCHEDULE FOR ENGINEERING TEST FACILITY AND SUPPORTING TECHNOLOGIES



This schedule for the Engineering Test Facility and its supporting technologies shows the ETF in operation by 1991. It presumes funding on the level of the Department of Energy's "Program B" for fusion.

trons with gas molecules to become neutral atoms once again, and they exit the gas cell as a high-energy beam of neutral molecules.

The neutral beam technology program has been sabotaged by the go-slow advanced technology of the Carter administration. In fact, neutral beam development has been so retarded that more money is now spent on operating neutral beams than is spent on its further development and perfection.

Plasma fueling and particle collection systems. The plasma fueling problem is a good example of the rate at which fusion technology and science are advancing. Just a year ago this was considered among the most difficult problems facing fusion reactor designers. But the recent successful demonstration of pellet injection into the ISX tokamak plasma (where a threefold to fivefold increase in plasma density resulted from the disintegration of the solid fuel pellets), as well as maintenance of a stable plasma have changed the whole picture. Plasma fueling technology is now well underway.

This is not the case for particle collection—impurity and helium "ash" removal—systems quite yet. As can be seen in Figure 9, the magnetic divertor approach to this problem is being explored on the Princeton PDX and Oak Ridge ISX.

Basically, in the magnetic divertor magnetic field lines are purposely broken off at the surface of a plasma that permits trapped plasma containing impurities and helium ash to be removed.

The chief problems with this approach are (1) the transport properties of helium and impurities in the overall plasma; specifically, do they migrate to the outside surface where they can be collected; (2) to what extent does the pertubation of the magnetic field divertor configuration disturb the stability of the overall confinement configuration; and (3) how practical is divertor technology, since it leads to major increases in the necessary magnet system and the need for disposing of the energy of the impurities and helium ash that are removed from the reacting plasma.

Both the ISX and PDX will address these questions. In addition, new approaches are under development. These include nonmagnetic removal of impurities and ash with a material wall, a plasma "limiter," and development of plasma processes by the interaction of injected neutral atom beams with the plasma, which leads to the diffusion of particles out of the plasma.

Technology Developments: A Review of 1979

In reviewing the highlights of significant fusion technology developments over the past year, it is important to realize that these advances have been accomplished despite the fact that the fusion operating budget for development and technology has been significantly decreased.

This major decrease in fusion technology just at the time that technology has become the pacing element in all aspects of fusion development is the result of two factors. First, since the inauguration of the Carter administration, the overall fusion budget has been kept at approximately the same level, taking into account inflation. Second, the bold national program inaugurated in the mid-1970s under the leadership of Robert Hirsch led to a U.S. commitment to construct costly facilities. Because the Office of Fusion Energy was unwilling to cut back significantly on the experimental fusion work, the heart of the fusion program, cuts were made in development and technology.

Here are some highlights of the progress made in fusion technology during the past year.

The MIT Nuclear Reactor Laboratory developed a new method for simulating the bombardment of the first wall

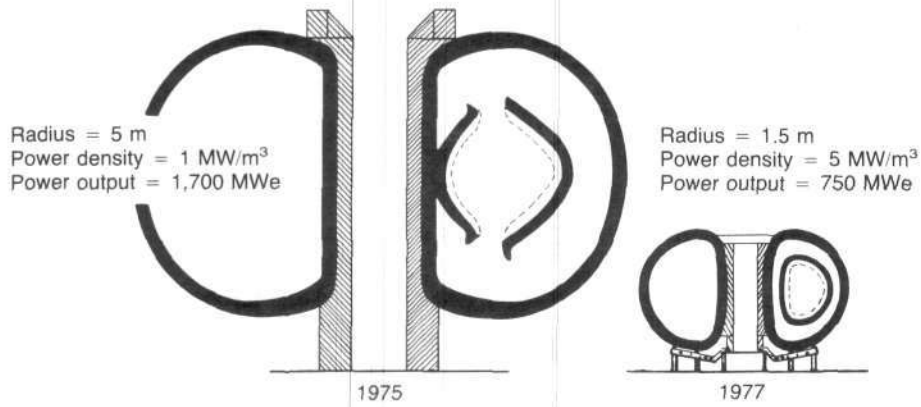


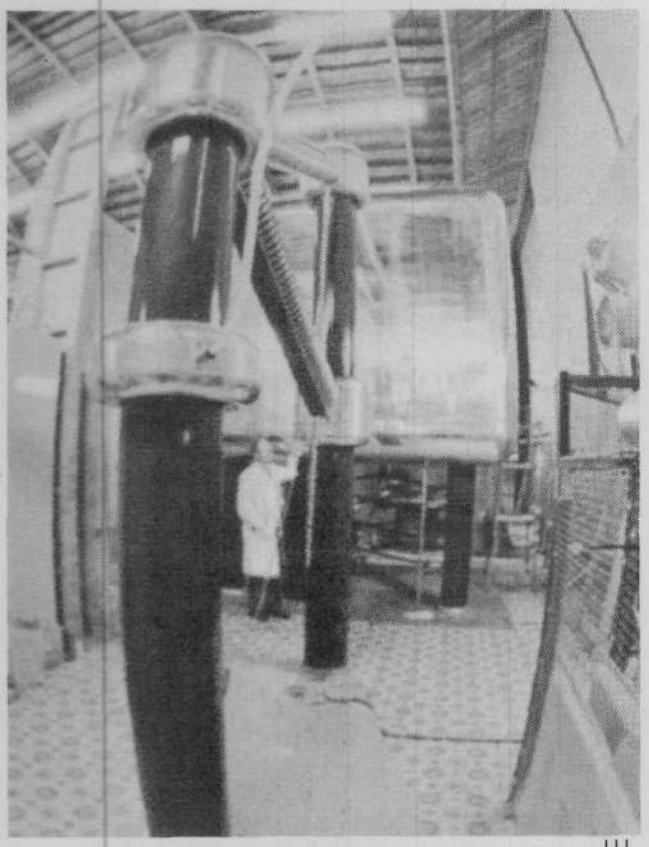
Figure 8
FUSION PROGRESS MEASURED BY REDUCTION IN REACTOR SIZE
The tremendous progress in scientific understanding of the tokamak and advances in materials technology have made possible reduced reactor size and increased power densities. The figure compares cross-sections of the 1975 conceptual design for the University of Wisconsin tokamak design II, the UWMAK II (left) and the 1977 design for the Oak Ridge National Laboratory demonstration power plant, ORNL-Demo.

of a fusion reactor by high-energy fusion-generated helium nuclei and neutrons. This method allows tests that combine near-surface radiation damage and bulk radiation damage in a single experiment. It consists of impinging slow neutrons on a foil coated with boron-10 that surrounds the aluminum or steel fatigue crack specimen, the material of the first wall. High-energy helium ions are generated and bombard the material; simultaneously, fast neutrons produce material damage effects as a result of neutron-atom collisions that lead to displacement of the atoms of the wall material.

The RTNS-II at the Lawrence Livermore Laboratory became operational in November 1978. It is the first irradiation test facility designed specifically for materials research for the fusion energy program and it will provide the most intense source of 14 MeV fusion neutrons in the world.

The fusion neutrons are produced by bombarding a tritium-loaded target with an energetic deuteron beam from an accelerator. The tritium is contained in a thin layer of titanium evaporated onto a copper backing. The target rotates at high speeds, 5,000 rpm, to reduce beam dwell time and is cooled by water flowing within channels inside the target backing to remove deposited beam energy and to prevent rapid outgassing of the tritium as a result of thermal diffusion through the titanium.

One of the two RTNS-II beams has been available to experimenters since January 1979, and an irradiation has been conducted on the kind of fused silica windows that may be installed in Princeton's TFTR. Other studies in progress include radiation damage to superconductors and stainless steels.



LLL

The rotating target neutron source, the RTNS-II at Lawrence Livermore Laboratory.

New alloys. Since the beginning of the magnetic fusion research effort, researchers have avoided using many important alloys in reactor design because they are magnetic; that is, they react to the presence of a magnetic field. It was feared that large magnetic fields in a magnetic fusion reactor would lead to great mechanical stresses in reactor wall and structure if it were made from a ferromagnetic alloy. However, recent systems studies have shown that it may be possible to use ferromagnetic alloys as structural materials in fusion reactors, and this prompted a reexamination of the ferritic alloy system.

Last year representatives of the Liquid Metal Fast Breeder Reactor Alloy Development and Fusion Alloy Development programs met in Richland, Washington to exchange information on austenitic and ferritic steels as well as on nickel-base alloys. The ferritic alloys seem to exhibit much greater resistance to radiation damage than the austenitic alloys, and they also significantly reduce the amount of activation in a fusion reactor environment. Based on the metallurgical and radiation damage information on ferritic steels presented by the LMFBR group, the U.S. Fusion Program is currently completing plans to investigate these alloys under fusion environment conditions. (Of course, this possibility can be realized only on the basis of overall fusion reactor design.)

Radiation damage tests have begun on ceramic materials that will be needed for various electrical components of a magnetic fusion reactor; for example, current breakers, RF insulators, and possibly close-in magnetic field coil insulators. Radiation damage data on magnesium aluminum oxide show that this ceramic material does not swell in a neutron environment of 20 displacements per atom at temperatures of 625 and 800 degrees Celsius. This compares to a 4 volume percent swelling for aluminum oxide under the same conditions. The neutron exposure is roughly equivalent to damage levels expected in experimental power reactor designs.

Important progress in **tritium control technology** was made by Sandia Laboratory in New Mexico, which has developed electron beam or laser release of hydrogen isotopes from surface materials. This has the advantage of heating only the outermost layers and not requiring bulk heating. For single electron-beam pulses Sandia has obtained 100 percent hydrogen release from titanium boron and 90 percent release from 304 stainless steel. This important new technology could be applied to tritium inventory control, clean-up, titanium getter renewal, and fueling.

An **infrared laser** is being used to measure line-average electron densities on the Oak Rige ISX tokamak experiment. Developed primarily for pulsed Thomson scattering measurements* of ion temperature, this system easily follows the rapid time variations in the plasma density more effectively than conventional microwave interfero-

meter diagnostics. As a result, it is the primary density diagnostic on ISX. Further development of these diagnostics will continue; meanwhile, the system is making significant contributions to measurements in fusion research.

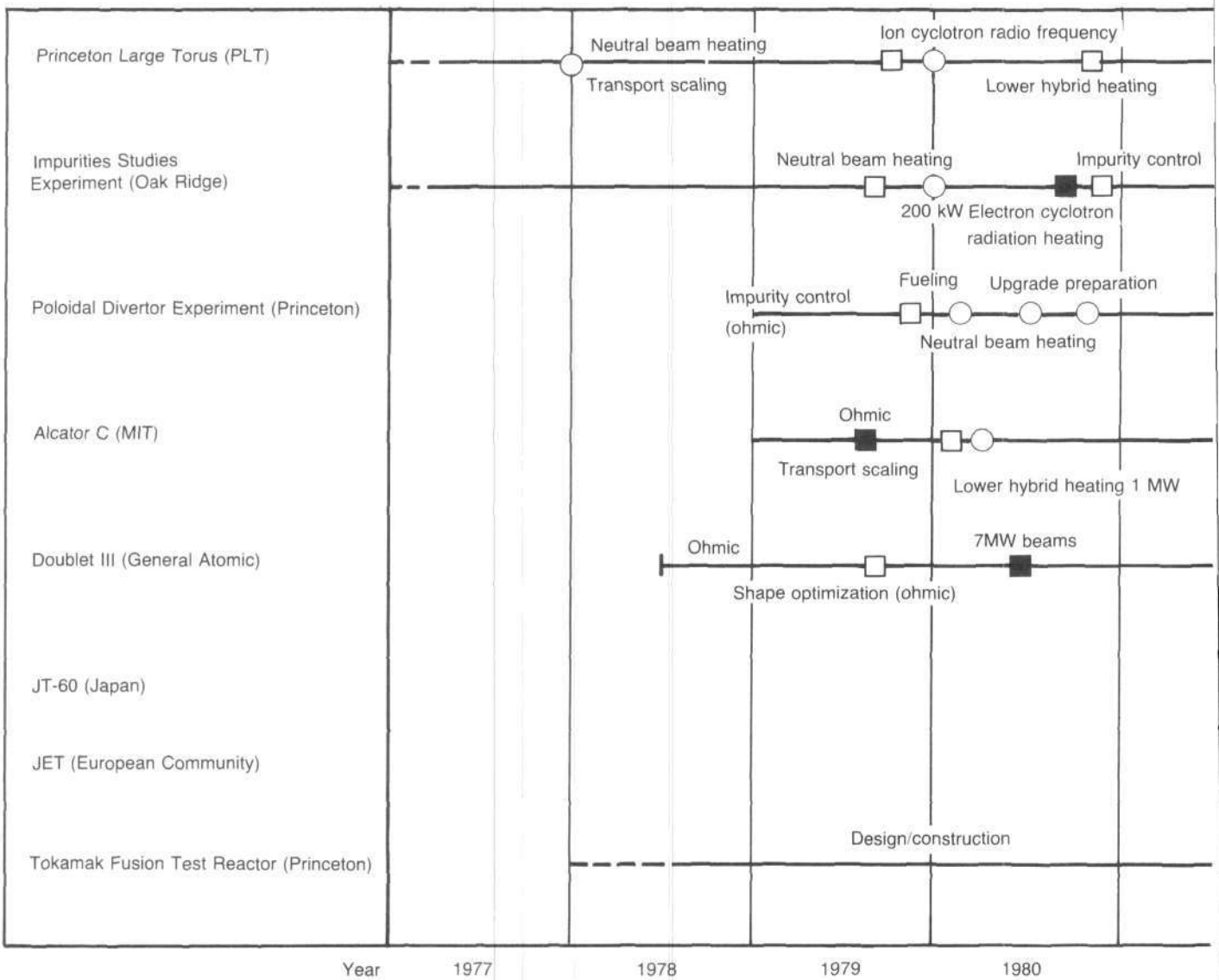
The United States and the Soviet Union have agreed to exchange **commercial steels** for a joint research program begun in September 1979. The United States will furnish 316 stainless steel, which is part of the fusion program at Oak Ridge, while the Soviets will supply a manganese-stabilized steel developed for application in the fission-neutron environment. Irradiation will take place in the Experimental Breeder Reactor and High Flux Isotope Reactor here and in the SM-2 and BOR-60 in the Soviet Union; testing will be coordinated with regard to temperatures, strain rates, and other variables. Progress will be reported every three months and discussed at an annual Materials Working Group meeting.

Experiments on coated plasma limiters, strips of material that prevent the plasma column from touching the vacuum chamber wall in tokamak experiments, have been started on the Oak Ridge ISX-B tokamak. These coated limiters are made with low atomic-number materials and a high heat-resistant coating. Titanium-diboride and boron-carbide coatings on graphite specimens have survived thermal fatigue tests up to 250 cycles, and hydrogen and chemical erosion have been determined to be acceptable for experiments.

A workshop on **sputtering in the fusion reactor environment**, held at Argonne National Laboratory in Illinois in July 1979, concluded after a review of available data that the sputtering* data base at various energies is already relatively well established with little additional data needed in a few well-defined areas.

A workshop on ferritic (martansitic) steels for fusion, held in Germantown, Maryland on July 30 and 31, reviewed the magnetic issues arising from the use of a ferromagnetic material in fusion reactors and concluded that magnetic considerations did not present a major barrier to the use of these materials in fusion reactors. The workshop discussed the DOE fission reactor research and technology programs for cladding, ducts, and steam generators, and the fusion laboratories presented structure design/lifetime calculations.

The group concluded that ferritics have an inherent



advantage over austenitic steels because of higher thermal conductivity and lower thermal expansion. The principal uncertainties are in the fracture behavior (ductile to brittle transition as a function of temperature) inherent in the body-centered cubic crystal structure of the ferritic alloys, as well as fabricability and radiation effects in the fusion environment. The overall promise of the alloy system led to the conclusion that an alloy development program based on these steels should be initiated.

Such a program has been started, and the major participants are the General Atomic Corporation (welding and manufacturing), Hanford Laboratory (fracture, ductile to brittle transition, and fatigue), Oak Ridge Laboratory (design data), Argonne Laboratory (compatibility), and the Naval Research Laboratory (fracture).

The first **dual-beam irradiations** using helium and heavy ion beams to simulate helium content and displacements per atom in the first wall of a fusion reactor have been carried out by Westinghouse. Experiments show that some helium and atom displacement levels lead to large, unexpected swelling in stainless steel at 600 degrees Celsius over a very narrow temperature range.

A second major design review of the Tritium System Test Assembly took place at Los Alamos Scientific Laboratory in February 1979. Seven major subsystems in the final design stage were reviewed, and no significant problems were found. The facility will be completed in 1981 and will demonstrate the tritium fuel cycle and tritium containment and cleanup systems for power-producing fusion reactors.

The initial scoping for the design of the **International Tokamak Reactor**, INTOR, has been completed. This facility will be quite similar to the U.S. program's design for an Engineering Test Facility tokamak reactor, the ETF.

The ETF Design Center at Oak Ridge announced the selection of industrial subcontractors to support the preconceptual design for ETF, now underway. The subcontractors and their areas of involvement are: Nuclear Systems, McDonnell Douglas Corp.; magnetic systems and electrical systems, General Electric Co.; and design integration, Grumman Corp.

The unique 28-billion-cycle-per-second **high power gyrotron**, which is being developed for electron cyclotron heating on the Elmo Bumpy Torus at Oak Ridge, has operated continuously at 100 kilowatts for up to 20 minutes in Feb-

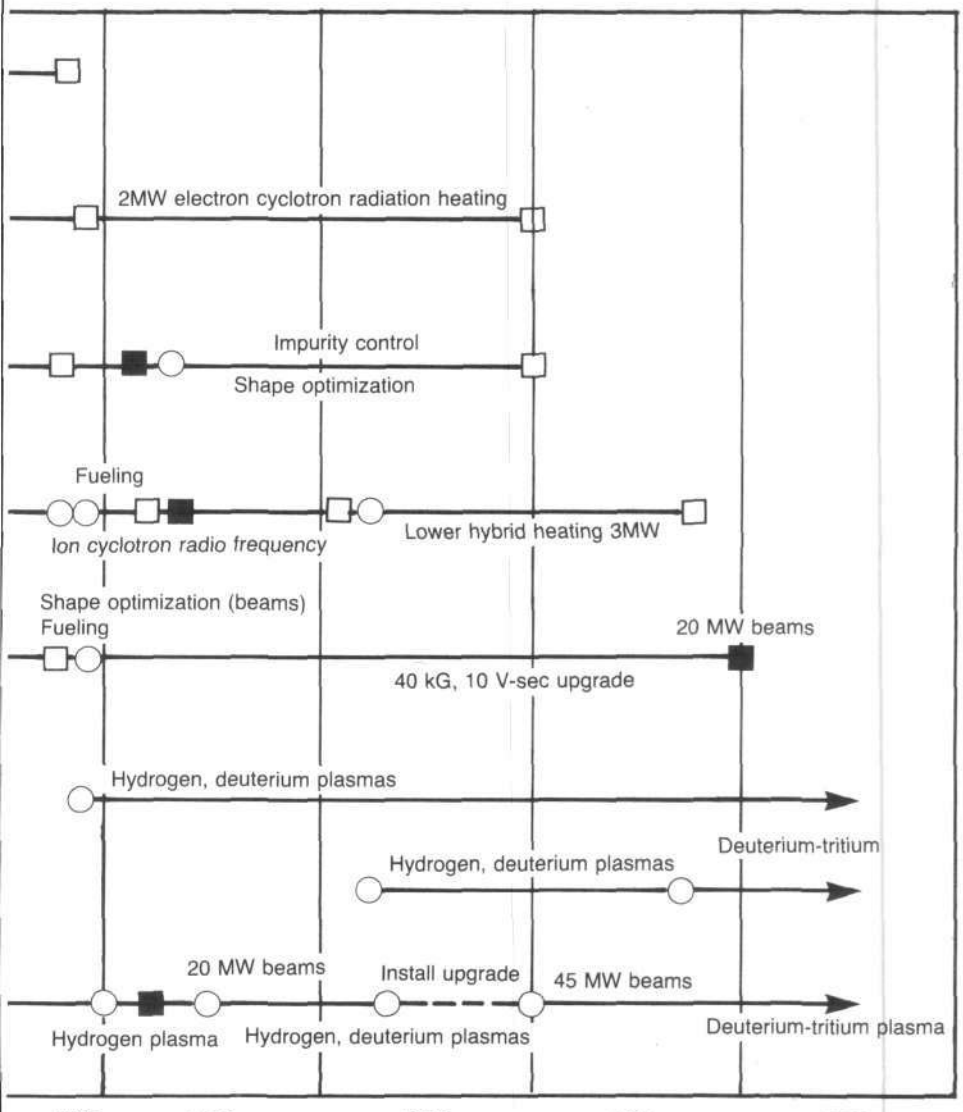


Figure 9
PLASMA PHYSICS BASIS FOR THE ENGINEERING TEST FACILITY
This flow chart shows the schedule for the plasma physics advances necessary to put an Engineering Test Facility on line by 1995. Most of the technologies listed are discussed in the text. Shape optimization refers to the shape of the "donut"; noncircular shapes such as a figure 8 or a "D" are expected to yield higher betas.

ruary 1979. This state-of-the-art microwave generator was developed by Varian Associates. By August 1979, the 28-billion-cycle-per-second gyrotron was pulse tested in a new configuration to about 200 kilowatts and operated continuously at 60 kilowatts for several hours.

The eventual goal is for a tube capable of running continuously at 200 kilowatts for hundreds of hours. The performance of the new configuration appears to be capable of meeting these design goals and also significantly contributing to the development of 100 and above cycle-per-second gyrotrons. Varian Associates and Hughes Aircraft Corp. are working on this latter, major development in the international state-of-the-art for microwave tubes.

The MIT superconducting materials research project has developed new materials and processes with improved mechanical properties for the fusion program. MIT is concentrating on using new processes for fabricating magnets with the high-field superconductor niobium-tin.

Component Development

A beam-direct converter was successfully tested on a one-quarter scale model of the TFTR neutral beam source at Lawrence Berkeley Laboratory. As the electrodes were conditioned from one shot to the next, the gas pressure rise during a .6 second beam pulse decreased and the efficiency increased. After conditioning, the conversion efficiency of the pulse was more than 60 percent at the beginning of the pulse, decaying to more than 50 percent by the end of the pulse. The beam was operated with hydrogen and helium at 100 keV with similar efficiencies.

The McDonnell Douglas prototype TFTR neutral beam source main ceramic insulator was successfully brazed. McDonnell Douglas and Hughes Aircraft Corp. are value-engineering the TFTR neutral beam source so that it can be economically manufactured in industry. The successful brazing of the main ceramic insulator stack represents the completion of the most difficult and uncertain part of the work. The ceramic sections are the largest rectangular ceramic insulators in the world.

The one-quarter scale **TFTR neutral beam source** at Lawrence Berkeley Laboratory has been successfully operated at 110 keV for 1.5 seconds.

The first large **superconducting magnet coil** for the large coil program has been released for fabrication and the Convair Division of General Dynamics has been authorized to initiate phase 3, construction of the large coil. This is the first of six large coils that will be fabricated—three in the U.S. (General Dynamics, General Electric, and Westinghouse) and three abroad (Euratom, Japan, and Switzerland) under an international agreement. The large coils will have a magnetic field capability of 8 tesla (80 kilogauss), an inside bore (shaped like a "D") of 2.5 meters by 3.5 meters, and a weight of 50 tons.

The design and fabrication of the General Dynamics coil will cost about $6.5 million and will be completed in fall 1980. The coils will be tested in a torus configuration in the Large Coil Test Facility now under construction at Oak Ridge National Laboratory.

Phase 2 of the **final design review of the General Electric large coil** was completed, and coil design and the subcomponent verification tests look very good. Upon recalculation of a redesigned high-stress region, it is expected that General Electric will be authorized to begin phase 3, fabrication of the coil. Present schedules call for the coil to be completed by the end of 1980.

The first **quarterly review of the Large Coil Test Facility** was held in June. Construction costs for the facility remain at $26.4 million and the operating funded project is 20 percent complete. The plan calls for the facility to be operational to test the two 50-ton U.S. boiling helium superconducting magnets now under fabrication by General Dynamics and General Electric in March 1981. Construction will continue on the facility to provide a pulsed magnetic field test environment and a capability to test a full six-coil torus in September 1982, when the U.S. forced-flow helium coil and the three foreign coils will be at the site ready for testing.

Argonne National Laboratory developed a **10,000-ampere low-loss superconducting cable** and successful testing of that cable in a 1.5-million joule pulsed superconducting energy storage coil. The cable and coil were designed to model the requirements of the pulsed superconducting coil needed to induce the large current used to stabilize and ohmically heat the plasma in a tokamak. The 10,000-ampere coil with a steady state field of 4.4 tesla has been pulsed more than 1,000 times to produce magnetic field rate changes up to 11 tesla per second.

Industrial Research magazine awarded Argonne its IR-100 prize for one of the 100 most significant technical products of the year.

Reactor-Level Technology

What startled the Hirsch panel most at the mid-December hearings on fusion in Congress, was the unprecedented record that the fusion program has had staying within its budget and staying on schedule to reach reactor-level technology. As several of the industrial members of the fusion panel noted, no major—and no conventional—industrial or technological project has achieved a comparable record in the past five years. With the current rate of inflation, it is usual to see cost overruns of 100 percent and schedule shortfalls measured in years, not months.

The testimony of Dr. Paul J. Reardon, program head for the Princeton Plasma Physics Laboratory's Tokamak Fusion Test Reactor project, the TFTR, debunked skeptical views with a full report on the TFTR, the first industrial-scale magnetic fusion effort.

Reardon told the congressional audience that when you are involved in developing a missile, an airplane, or a conventional power plant, "you are science limited." Although there is a lot of innovation, he said, it has only a marginal impact on the overall operating parameters of the device involved since the basic principles of the technology are relatively fixed and well-known to begin with.

"The opposite is the case for fusion." Reardon said. The breadth of the fundamental principles of fusion systems gives us a lot of "elbow room" when it comes to applied technology.

What Reardon stressed to the congressional subcommittee—and what must be stressed to the general public—is that the U.S. fusion program has already gone most of the distance to reactor-level technology. In the past 10 years, the U.S. fusion program has scaled up tokamaks by a factor of more than 10 in terms of plasma volume. For an ETF or reactor, only a fractional increase beyond this is needed. In terms of energy gain, which is determined by temperature and the density-confinement time product, the TFTR has taken the program forward by a factor of 10,000. For a reactor, only another factor of 10 is necessary.

As for the economics of fusion reactors, the testimony of Dr. Frank Coffman, director of the Office of Fusion's Division of Development and Technology, made the situation absolutely clear.

Recent technical and experimental progress in fusion has dramatically changed the projected parameters of tokamak fusion power plant designs, leading to much smaller reactors with a significantly higher power density. As a result, the projected capital costs—this is the major cost in a fusion energy system since the fuel is virtually free—have been brought down to a level approximately equivalent to those of a nuclear fission power plant of equivalent size.

In summary, the chief remaining question in fusion energy is: When is the nation going to invest in an energy program that has already proven it can provide economical, safe, and virtually unlimited energy by the 1990s?

Charles B. Stevens, director of fusion engineering for the Fusion Energy Foundation, is well known for his coverage of fusion developments.

Notes

1. See the author's "The Current Status of Fusion Research," *Fusion*, Aug. 1978, pp. 22-39; also, "The Coming Breakthroughs in Fusion," *Fusion*, Oct. 1978, pp. 24-57.
2. A news article on the Hirsch Panel appears in the Fusion News section of this issue.
3. See the author's article "The Magnetic Mirror Approach to Fusion Energy," *Fusion*, May 1979, pp. 32-39; and "Laser Fusion: A Review of the Lawrence Livermore Report," *Fusion*, Oct. 1979, pp. 48-57.
4. Among the difficulties in operating a fusion device in the pulsed mode are: the need for storing energy for restarting the fusion plasma; mechanical and thermal stresses due to changes during cycles; complexities of operation (even today it is rare that experimental runs with the same startup conditions lead to exactly the same results of plasma behavior) that call for very sensitive diagnostics for monitoring the plasma and automatic computer control systems; and energy storage between cycles to maintain a uniform electrical output from the power plant.
5. For a discussion of Cantor's work, see Uwe Parpart's translation and commentary on Cantor, "The Concept of the Transfinite," in *The Campaigner*, Jan.-Feb. 1976, pp. 6-68.
6. This concept is fully discussed in Lyndon H. LaRouche, "The Fallacy of Scalar Elementarity," *Fusion*, Nov. 1979, pp. 48-57.
7. This is measured by plasma beta, which is the ratio of the plasma gas pressure to the pressure of the magnetic field. (This is proportional to the square of the magnetic field strength.)
8. The most efficient method of achieving this type of fusion was first developed by Bernhard Riemann in the mid-19th century. See Uwe Parpart, "Riemann Declassified: His Method and Program for the Natural Sciences," *Fusion*, March-April 1979, pp. 24-37.
9. Friedwardt Winterberg, *Atomenergie*, Feb. 1978.
10. Superconductivity is reviewed in detail in William A. Little, "The Prospects of Higher Temperature Superconductivity," *Fusion*, Jan. 1980, pp. 45-53.

Glossary

beam: a stream of particles or electromagnetic radiation going in a single direction.

cyclotron radiation: the radiation emitted by charged particles in a magnetic field as a result of their natural gyration in that field.

electromagnetic radiation: radiation consisting of associated and interacting electric and magnetic waves that travel at the speed of light (examples are light, radio waves, gamma rays, X-rays).

electron: an elementary particle with a negative electrical charge. Electrons surround the positively charged nucleus and determine the chemical properties of the atom.

ion: an atom or molecularly bound group of atoms that has become charged as a result of gaining or losing one or more orbital electrons; a completely ionized atom is one stripped of all its electrons.

isentropic: a process that occurs without change in entropy; for example, in isentropic compression there is no transfer of heat, and hence of entropy.

isotope: one of several species of the same element that have different numbers of neutrons but the same number of protons in their nuclei.

microwave: an electromagnetic wave that has a wavelength between about 0.3 and 30 centimeters, corresponding to frequencies of 1 to 100 gigahertz.

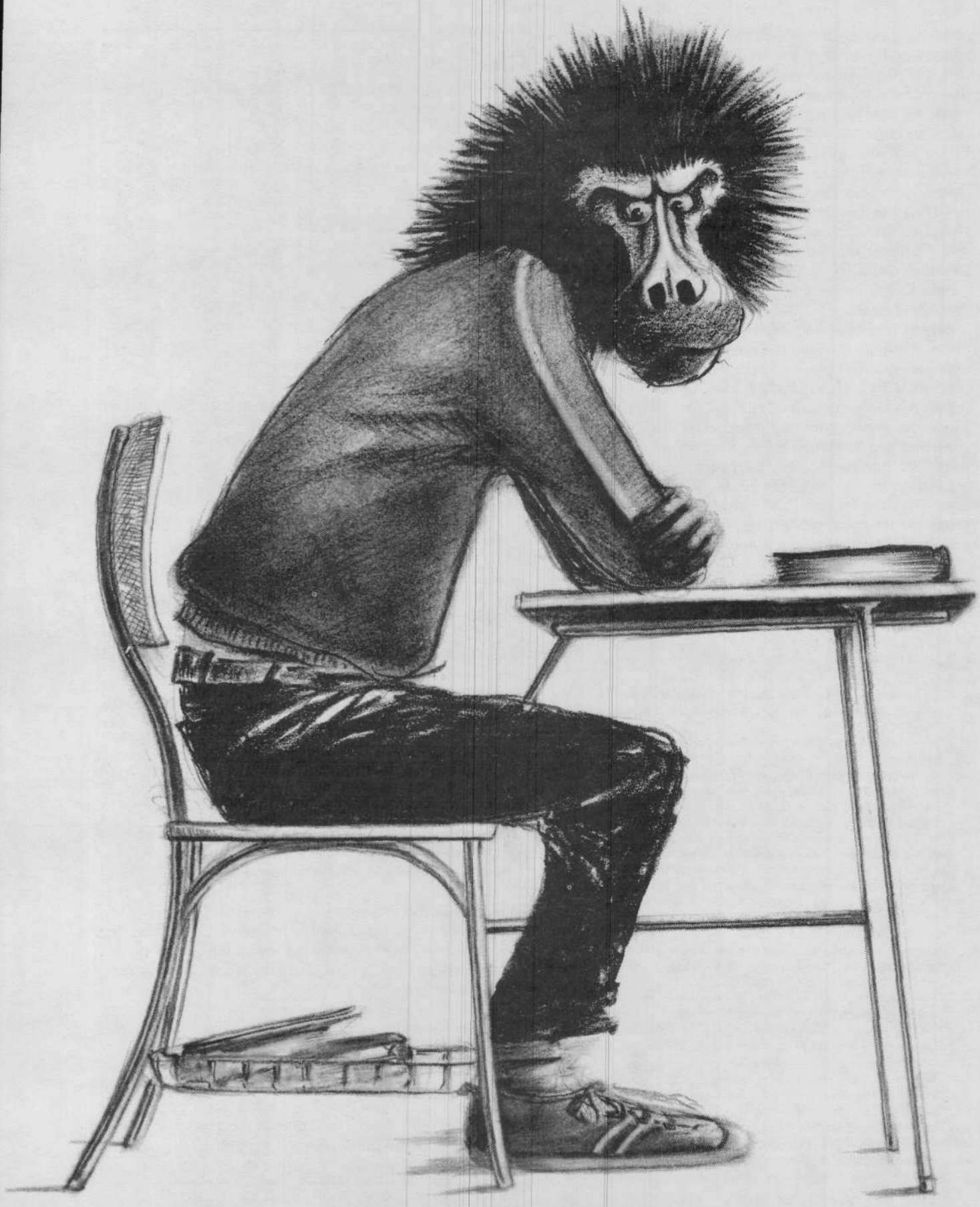
plasma limiter: a material barrier that prevents a magnetically confined plasma from coming into direct contact with the vacuum chamber wall; usually a strip of high-temperature-resistant material such as graphite.

radio wave: an electromagnetic wave produced by reversal of current in a conductor at a frequency in the range of about 10 kilohertz to 300,000 megahertz.

shock wave: the final state of a strong pressure wave that propagates in a compressible medium like a gas; this pressure wave will develop an extremely sharp leading edge, giving it almost explosive properties. A sonic boom is a shock wave.

sputtering: radiation damage to the surface of the containment structure.

Thomson scattering: scattering of electromagnetic radiation by free or loosely bound charged particles; energy is taken away from the primary radiation as the charged particles accelerated by the transverse electric field of the radiation radiate in all directions.



the Science Out of Education

by Mary Gilbertson

The National Science Foundation, an agency set up to promote American scientific excellence, is now contributing to the destruction of science in the United Sates. The story of how that happened is detailed here.

The NSF case is no less shocking, but more comprehensible, if one understands the campaign waged throughout this century to undermine U.S. science and education. Between the wars, slanders of the founding principles of the American republic by falsifiers of history like Professor Charles Beard were combined with outright attacks on science from quarters such as president Robert Hutchins of the University of Chicago. The universities were also targeted to become conveyor belts for the linguistic and systems-theory approaches to science and mathematics developed by Bertrand Russell, the Copenhagen School of Niels Bohr, and the Vienna circle of positivists. This was the equivalent for science as the effect on music of replacing Beethoven with a Moog synthesizer.

It was not until the postwar recession in the late 1950s and the full-scale launching of the environmentalist movement in the 1960s that the public schools were also marked for destruction. At the same time, plans were set afoot to tear apart the tremendous scientific capabilities built up around the work of the Atomic Energy Commission and the National Aeronautics and Space Administration.

Two critical weaknesses in the nation, weaknesses created largely by the financial and philanthropic institutions directing the attack on science, opened the door to the antiscience operation in public education. First was the symptomatic weakness of the dollar and the sagging of the economy. Economic recession created severe budgetary pressure on local school systems as tax revenues lagged behind inflation and rendered state and local administrators more susceptible to accepting the well-funded subversion programs offered by the National Science Foundation.

The more fundamental weakness, which permitted the symptom to go unheeded, was popular ignorance of the basic economic and philosophical principles of the American republic. As the NSF case demonstrates, a correct understanding of science, beginning in our primary schools, is indispensable to the health of the nation. The Fusion Energy Foundation is now engaged in a demonstration project in the teaching of geometry, one step in this process, as another article in this issue describes.

We present the NSF story in two installments: Part one, this issue, outlines the recent history of the NSF and examines in detail one of its horrifying science curricula. Part two, in a subsequent issue, will develop the antiscience epistemology of the NSF as it has been promoted by the work of Jean Piaget, the famed child psychologist responsible for the development of the environmentalist methodology in teaching, with particular emphasis on the new math.

—Dr. Morris Levitt, editor-in-chief

* * *

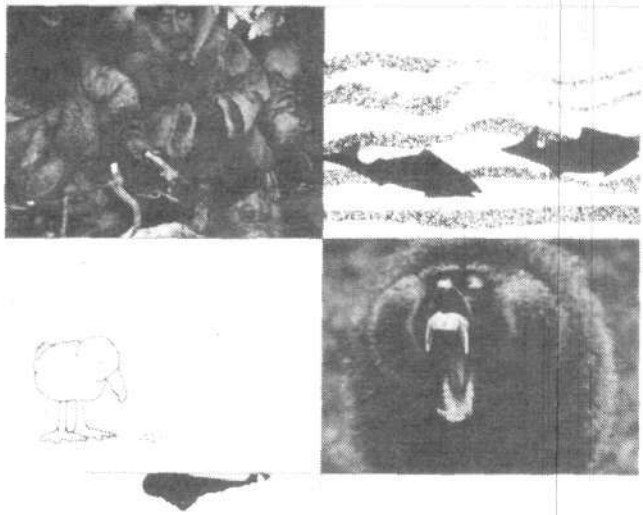
HAS YOUR KINDERGARTEN-AGED child come home from school and announced: "Daddy, nuclear power is bad and solar energy is good," or: "Mommy, your dishwasher wastes energy"? Have you struggled with your grade-schooler over the "new math" or been angered by press and media reports like the September 1979 *New York Times* headline story announcing that math scores for 9 to 13 year olds are plummeting nationally? If so, you're among the millions of American parents who have good reason to be concerned about whether their child and the entire next generation of U.S. citizens are being prepared for the scientific and technological tasks of the next decades.

Under current conditions in most U.S. schools they are not. Instead, America's youth are being prepared for the so-called postindustrial society of the next century in an educational system that has been captured by the antiscience advocates of zero growth. To prepare children for a society in which scientific and technological advance have been abandoned, environmental science and environmentalist thinking have taken the place of physics, mathematics, and even history in American schools.[1]

The National Science Foundation, based in Washington, D.C., has played the leading role in this sabotage, as I shall document. Since the late 1950s when the new math emerged on the educational scene, the NSF has increasingly gained sway over the science and math curricula of American schools.

An official arm of the U.S. government, the NSF is overseen by the Health and Scientific Research Subcommittee of the Senate Human Resources Committee, now chaired by Senator Edward Kennedy. With a current budget of $1.06 billion, tens of millions of which are spent on curriculum development and teacher training, the National Science Foundation today dominates teaching programs in the sciences and social studies nationally.

MAN: A COURSE OF STUDY



The cover of a pamphlet for teachers that discusses the "Man: A Course of Study" curriculum developed by the National Science Foundation. The 23-unit primary school course, complete with films, maps, records, educational games, and other audiovisual devices, takes the culture of the North American Eskimo as its vantage point for a study of human society. "We seek exercises and materials . . . wherein there is a discernible continuity between man and his animal forebears," curriculum planner Jerome Bruner said of the MACOS approach in 1965.

The NSF not only determines *what* your child learns in his first school years about the world and how it works; the course modules and training programs developed by NSF specialists and academics working under foundation grants also determine *how* your child thinks. With the near-universal adoption of the new math by U.S. schools over the past 15 years, this has meant a conceptual holocaust in America's classrooms.

A close look at the NSF lesson plans for the new math and science makes it clear that the lessons have been designed precisely to destroy a commitment to progress in the next generation of Americans. For example, as I shall show, the MACOS science curriculum (MACOS stands for Man: A Course of Study), created in 1962 for fifth and sixth graders, explicitly sets out to develop the notion that man is no more than a sophisticated animal.

As with all the other NSF-sponsored science courses, MACOS establishes the child's classroom experience as the primary reference point for all knowledge. Students are taught that just as a pig discovers the world around him by rooting through his trough with his snout, they can know the world throught their senses. The new math is similarly damaging to the fledgling conceptual powers of grade-school children. The higher notion of mathematics as a tool for examining the ever-changing laws of a developing universe is entirely stripped away, as the NSF new math sponsors freely admit.

MACOS: Man or Animal?

The MACOS program was conceived at a 1962 conference at Endicott House in Massachusetts sponsored by the NSF publishing arm, the Educational Development Corporation, along with the Ford, Sloan-Kettering, and New World foundations, and the American Council of Learned Societies. The most outspoken booster of MACOS was Dr. Jerold A. Zacharias of the Massachusetts Institute of Technology, and the final form of the curriculum Zacharias championed in 1962 has probably done more to destroy science in the American school system than any other single curriculum reform since that time.

Do I exaggerate? The MACOS classroom syllabus and teachers manual speak for themselves on the damaging effects the curriculum has had on both teachers and students.

From Seminar 7, "What is Man?" comes this statement that humans are no more than sophisticated animals:

> Man and seal are both warmblooded mammals. The Eskimo recognizes his kinship with the seal. The differences between the two animals are not great. . . . Almost everything that man does is done by some animal somewhere, but there is no animal capable of doing all the things that man can do.

Seminar 6, "Learning in Animals and How it Differs from Human Learning," concludes that the difference between man and animal is merely the use of symbols, that man has language and animals do not. The teacher is referred to articles on baboons and encouraged to study the work of Jerome Bruner, a colleague of developmental psychologist Jean Piaget, whose theory of learning is the basis of most environmentalist teaching methodologies.

What does the systematic evacuation from the classroom of any notion that it is man's creative powers that have produced scientific progress do to students who are subjected to the MACOS program? Described in the teachers manual is this classroom scene in which fifth graders, imitate Eskimos and are set to debate the fate of an unproductive hunter. It is titled "Models of Knowing and Learning":

> *Student:* Should we choose one place and all hunt together?
> *Teacher:* Of course you should. That way you could cover most of the holes in a seal's range.
> (After the game has been in operation for a while, the teacher came across a group where one child was "starving.")
> *Student:* Teacher, I don't have any food, and Billy he has plenty. Make him give me some so I won't die. We want our group all to stay alive.

Teacher: Well you'd better share immediately if you want to stay alive.

(As the teacher observed one group, she noted out of the corner of her eye one boy reach over and steal some seal stickers from the pile in front of a very successful hunter. The successful hunter has not noticed the missing seal yet. Walking over to the boy she said:)

Teacher: Johnny, you must leave the room because you cheated.

(One boy has been extremely successful in finding seals and has never been hungry in three games. He is rather loud in his braggadocio.)

Student: I got another one. I'm the greatest hunter in the class.

Student: Oh be quiet, you're just lucky. You're not so smart.

Student: I got it figured out. I know the way to do it. It's just that I am smart enough. And you are not. That's why you can't get any seals.

Teacher: I want no unnecessary talking. Play the game and talk only when absolutely necessary.

Excluding The Mind

The development of science and technology, in other words, of the *human mind*, as a definition of the goal of the individual in human society is rigorously excluded from MACOS. Instead, the emphasis is on the most backward, most desperate, and most Darwinian fight for survival. For example, in the seminar for teachers titled "Fantasy and Feeling," the teacher is taught how to get the students to understand that "resourceful" means "environmentally resourceful." The seminar focuses on the Kalahari Bushmen, who live in an area of the world where temperatures of 115 degrees are common and water is very scarce. What happens to old people in such an environment is the essential focus of the teacher training session.

"How can you use a situation to be the basis of the pedagogical objectives of the MACOS curriculum?" the seminar leader asks the teachers. Then a film is shown. Here is a description of it taken verbatim from the seminar booklet, with the discussion conducted by the seminar leader:

> It shows a very dusty, elderly man looking very uncomfortable in the afternoon heat. He motions knowingly to an adolescent boy who routinely pulls his loin cloth aside and proceeds to urinate in the sand at the man's feet; whereupon the man lies down and distributes handfuls of moistened sand over his body with unmistakable expressions of blissful relief. . . .
>
> Out of this unspoken emotion-filled dilemma, I learned, I say, in a very illuminating way, that the Kalahari Bushmen are indeed a very resourceful people: What could be more resourceful in an environment which offers precious little water, but which regularly offers temperatures of 115 degrees, than the trick of turning a young person's urine to an old person's refreshment? And wasn't this a superb stimulus for getting children to ponder the distinctive resourcefulness of 'Man'?"

This lesson for the children on the Kalahari Bushmen is titled: "We Learn Best When We Care Most."

As if the curriculum and the teachers manual did not speak for themselves, the planners of the MACOS project admit that its purpose is not competent science education but how to inculcate in children environmentalist emotions. The "purpose" of MACOS, as its director of teacher education stated in the introduction to the teacher training manual, is as "a laboratory experience" for teachers.

The role of Dr. Richard M. Jones makes this "laboratory" objective clear. Jones is a creator and pioneer of the 20-session MACOS teacher training program, who often led the training seminars personally. According to an entry in the *Congressional Record* during the 1975 discussion of the MACOS curriculum in the House of Representatives, Dr. Jones is neither an educator nor a physical scientist; he is a practicing psychiatrist.[2]

Jones was well aware that the MACOS course material is upsetting to most of the children who have been subjected to it, but he emphasized that it is for just this reason that the program's educational objectives will be realized. "I think we should not feel burdened by thoughts of having practiced medicine without a license," Jones is quoted in a 1975 General Accounting Office report on the MACOS program to Congress.

Of the Kalahari Bushmen film, Jones wrote:

> I knew that the teachers expected in the training session that I would make some capital of the "urination scene." I also knew if I had no more to say than that the scene offered opportunities to engage children's emotions concerning the "anal-urethral" phase, and related issues of holding on, letting go, shame, etc., I would raise doubts concerning my own rule that the confrontation of emotional issues in instructional settings should be means to educational ends and not ends in themselves. . . .
>
> In clinics, issues which we knew to be emotionally charged are raised for the purpose of creating conditions in which emotions can come to be controlled and expressed. In schoolrooms, conditions are created which invite expressions of controlled emotion, for the purpose of imbuing curricula with personal significance.

In other words, just as the MACOS "science curriculum" has nothing to do with science, its "teacher training methods" have nothing to do with teaching—but rather with brainwashing. And from what standpoint are children being indoctrinated?

Other major lesson plans in the MACOS classroom curriculum proceed from the premise that it is normal in certain human cultures for old people and children to be regarded as "useless eaters" and for infanticide and geriatricide, to be practiced.

In seminar 8 of the MACOS training program, "Exploring

Significant Questions," teachers are taught that it is perfectly sound to undertake a study of humanity by studying what is animal:

> As is well known, very many primitive tribes have only a single word to designate members of the tribe and human beings; they alone are fully human, members of other packs are (so to speak) subhuman and killing them is not murder. This primitive type of rat thinking is never far below the surface, even among the civilized and sensitive. Where human beings differ from rats is in their very varying definitions of whom shall be included within the pack.

The 53 sister curricula arrayed around the MACOS program and peddled by the NSF include other obnoxious titles: "Too Many People," "Packaging Humans," "How Much Energy Do We Need?" and "Predicting Human Performance." And from a sex education package developed under the Individualized Science Instruction Program comes this question:

> True or false. A man with a very large, flaccid penis may have an average-sized erect penis.

There has been a public outcry against the implementation of MACOS and related NSF science programs in the schools. But opponents of the environmentalist takeover of science education have gained little ground in the courts and received little favorable press coverage. Most striking is the collusion between the NSF and the U.S. General Accounting Office, which was charged with reviewing the MACOS curriculum in the early 1970s.

The Opposition

It was the dog-eat-dog view of man in the MACOS program that compelled Joanne McAuley to author in 1975 what has come to be known as the "Minority Report" on the MACOS curriculum. McAuley served as a member of a panel of distinguished citizens commissioned by the House Committee on Science and Technology to review the program. The panel submitted a favorable report on MACOS, as did the General Accounting Office, but McAuley raked MACOS over the coals.

McAuley asserted that the psychological effects on grade school children of the MACOS games, and the premises which underlie them, are so devastating as to require schoolchildren to be protected under the Department of Health Education and Welfare's Protection of Human Subjects guidelines for experimental scientific work.

In reviewing the MACOS program in 1975, the General Accounting Office turned down McAuley's request. The GAO didn't deny the charges that the curriculum was destructive, but they excused the NSF from all responsibility to protect school children from the "dangerous emotional abuses" McAuley cited. The GAO's reasoning? The GAO guidelines had been established *after* the MACOS report was introduced into the schools. In fact, the GAO report concluded, "there was little question about the accuracy of the scientific content of the materials in the MACOS curriculum."

Opposition to MACOS continues. In September 1979, a political science teacher and a parent in New York's Nassau County filed suit in a federal court to stop the state from compelling fifth- and sixth-grade children from attending science classes given under the MACOS curriculum. The case is still pending, although National Science Foundation officials claim today that there is "no more controversy" over the program.

The NSF Versus Science

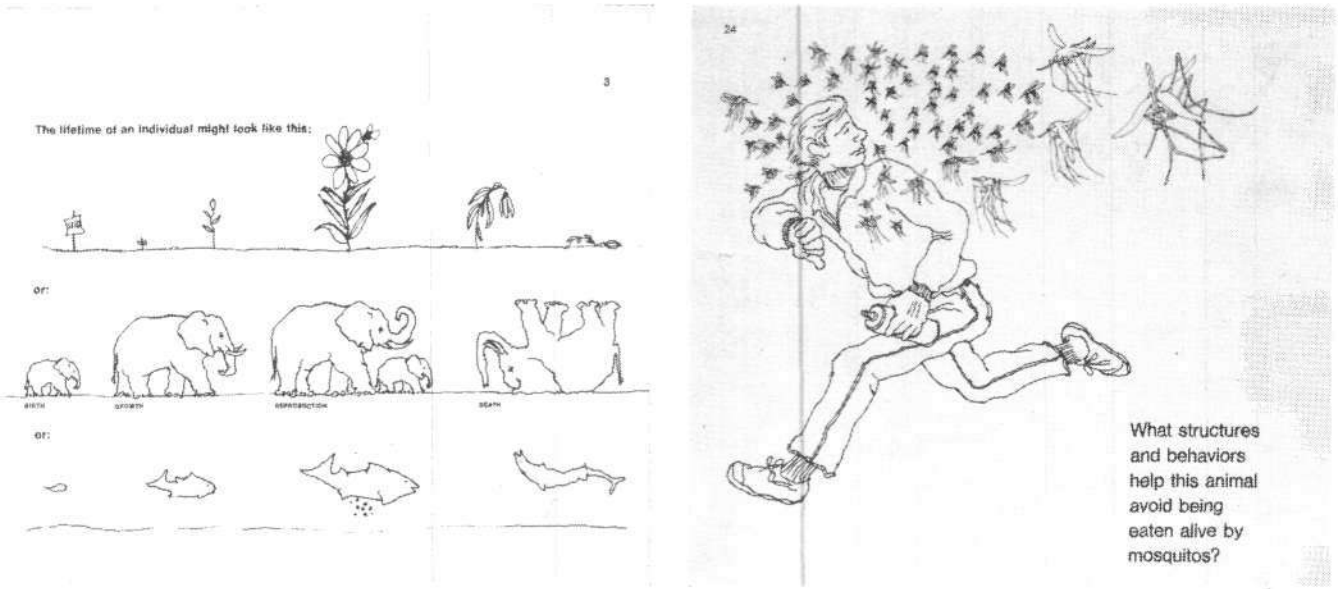
The history of the National Science Foundation's program for destroying American education in mathematics and science shows that it has been supported by the same universities, academics, and private foundations that are today the most outspoken proponents of a move to postindustrial society in the 21st century. Millions of dollars from these conduits were spent on NSF curriculum development for the new math, beginning in 1958. About a decade later came the gear-up for the replacement of science in the classroom with "social" and "environmental" studies.

An inflection point in this campaign for social studies came in 1971, when "curriculum innovators" virtually replaced bona fide scientists as the resource pool for science curriculum development at the NSF-funded Calloway Gardens Conference. According to Joanne McAuley:

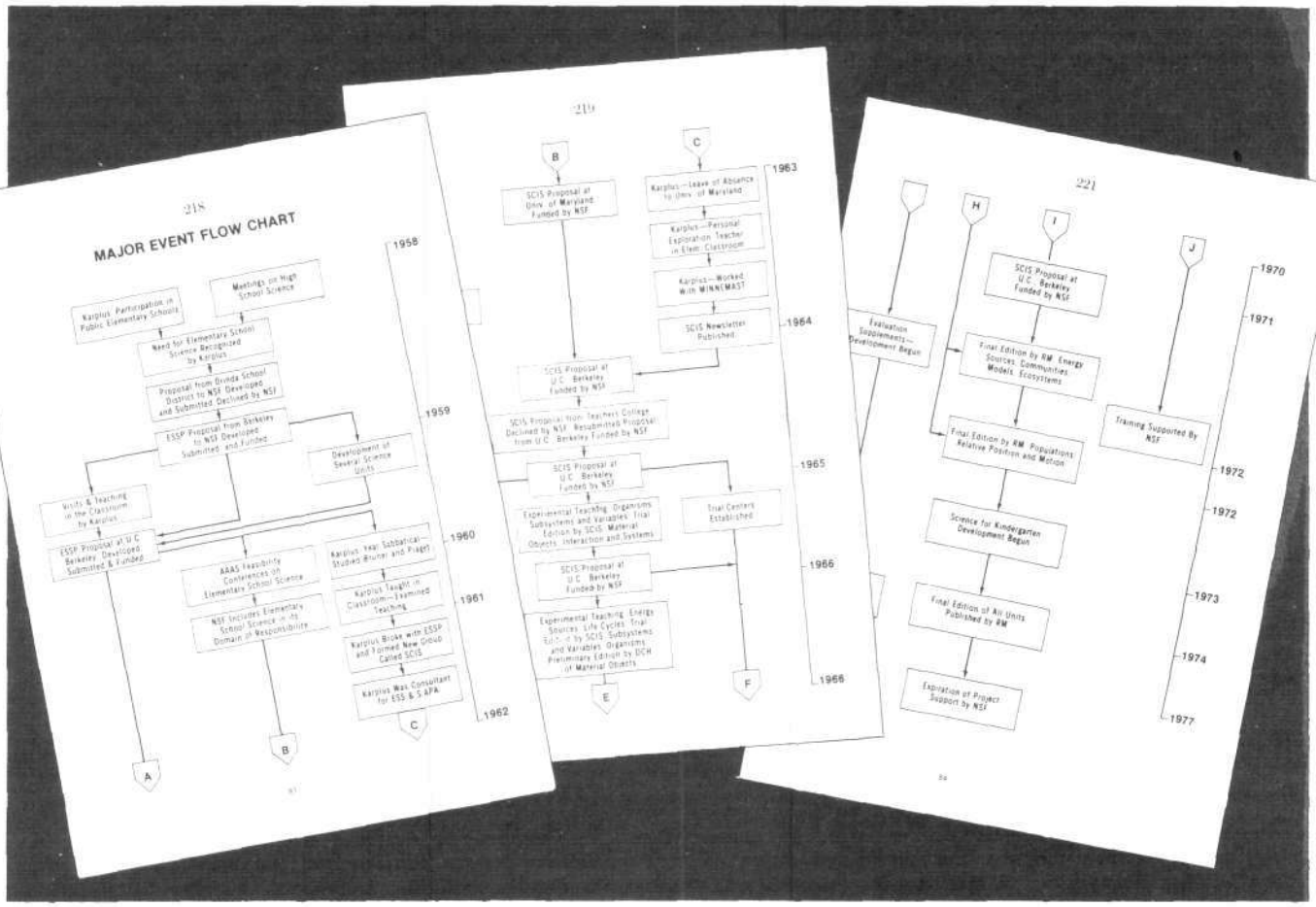
> At the Calloway Conference, Dr. Ernest Burkman . . . brought together a small group of associates whom he selected . . . for the purpose of exploring an alleged need for a totally new approach to science instruction for pre-college students. The report of the Calloway conference, submitted to NSF in January 1972, called for the development of a high school curriculum to include 80 to 125 two-to-three week minicourses with a value orientation covering all physical and social science subjects to replace longer traditional high school courses in chemistry, physics, mathematics, civics, and economics [NSF 1975].

What appalled McAuley and her collaborators in the effort to stop MACOS was the speed with which the new science as sociology course got implemented. As she noted in her "Minority Report" to the House Science and Technology Committee:

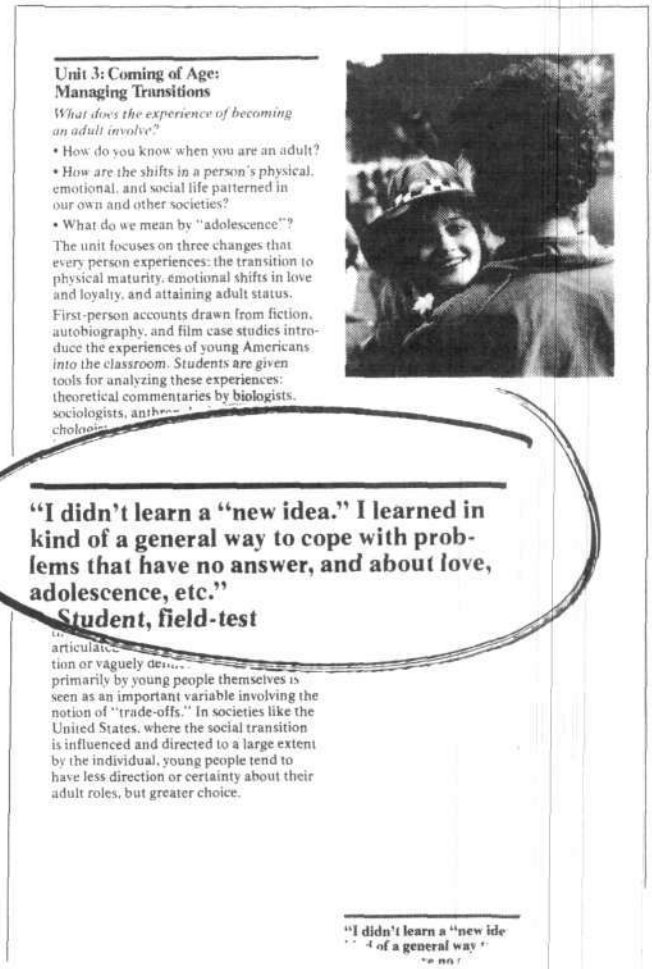
> Without benefit of any evaluation of the Calloway Gardens Conference Report by an independent group not associated with Burkman and with no effort to obtain alternative proposals to fulfill the alleged need from anyone other than Burkman, NSF moved within six months after receiving the initial proposal to approve a start-up grant of $550,000 for the project. I have just learned that it normally takes NSF on the average six months just to process an ordinary $50,000 research proposal, let alone a comprehensive curriculum project to cost in the millions [NSF 1975].



Sample pages from two of the MACOS classroom guides for students stress that the behavior of human beings can best be understood by studying what is animal. Above, the opening of the introductory MACOS unit "Life Cycles"; and a page from a more advanced lesson in "Animal Adaptation."



This "Major Event Flow Chart" is from Appendix 3 of the NSF 1975 Report to the House Committee on Science and Technology. It shows how Karplus's activities dominated the entire development of the NSF elementary school science curriculum, reaching directly to the kindergarten level.



Unit 3: Coming of Age: Managing Transitions

What does the experience of becoming an adult involve?

- How do you know when you are an adult?
- How are the shifts in a person's physical, emotional, and social life patterned in our own and other societies?
- What do we mean by "adolescence"?

The unit focuses on three changes that every person experiences: the transition to physical maturity, emotional shifts in love and loyalty, and attaining adult status.

First-person accounts drawn from fiction, autobiography, and film case studies introduce the experiences of young Americans into the classroom. Students are given tools for analyzing these experiences: theoretical commentaries by biologists, sociologists, anthro- cholog-

"I didn't learn a "new idea." I learned in kind of a general way to cope with problems that have no answer, and about love, adolescence, etc."
—Student, field-test

articulate- tion or vaguely de- primarily by young people themselves is seen as an important variable involving the notion of "trade-offs." In societies like the United States, where the social transition is influenced and directed to a large extent by the individual, young people tend to have less direction or certainty about their adult roles, but greater choice.

"I didn't learn a "new ide- -d of a general way -e no-

Above, a page from the secondary school continuation of the National Science Foundation's MACOS curriculum, which is distributed under the project title "Exploring Human Nature."

Indeed, the NSF has poured millions into its sabotage of U.S. science edcation and has done so with great dispatch. Most educators and many parents are familiar with one or more of the common elementary and secondary level science and math curricula developed by its well-funded brute-force approach. To name only a few, there are: MACOS; Science; A Process Approach; better known as SAPA; the Science Curriculum Improvement Study; SCIS; Exploring Human Nature, EHN, the secondary school equivalent of MACOS; and the School Mathematics Study Group, SMSG, the seminal project for all new math curricula developed and revamped over the 1958 to 1972 period.

The NSF has spewn out hundreds of other curriculum formats that have been picked up by commercial publishing firms for use in the development of their mass-marketed textbooks. McGraw-Hill; D.C. Heath; Harcourt, Brace; Harper & Row; Allyn & Bacon; Holt-Rinehart; and Prentice Hall all work closely with the NSF on textbook development. A curriculum that is too obnoxious for the commercial houses, as MACOS was when it was first released in 1969, is packaged, printed, and circulated by the NSF's own publishing arms, Curriculum Development Associates and the Educational Development Corporation.

How widespread are the NSF programs? A look at the statistics on the use of the MACOS program gives an idea of the success with which these programs have been pushed into the schools. Ten years after its development, MACOS was in use by about 350,000 students in 1,700 school districts in 47 states. According to the NSF 1975 *International Directory* (which the NSF no longer makes available to the public), teachers at 103 teacher training centers throughout the United States were being trained in the MACOS approach, and it was being used extensively throughout the industrialized nations of the British Commonwealth.

Similarly, the new math has spread like wildfire. According to Dr. James Wilson, whom the NSF recommends as the authority on the history of the new math project: "In the 1960s all math text books at the elementary school level went to the new math. . . . Commercial publishing houses all used the NSF experimental text as a basis for their own."

The NSF involvement in teacher training is less well known but no less influential. The foundation trains primary and secondary teachers in its environmentalist curricula in summer and year-round programs. In 1954 there were 27 teachers in foundation programs; by 1966, the foundation had trained a total of 24,000; and by 1978-1979, the NSF had 13,000 teachers a year involved in its direct training programs. Of course, this does not take into account the number of teachers who are involved in the hundreds of college courses funded—to the tune of $48 million in 1978-79 alone—by the NSF.

Enter Robert Karplus

How did we get into this mess?

To answer the question that must be on many parents' minds, it is necessary to examine the epistemological roots of the academic designers of NSF curricula like MACOS.

The case of Dr. Robert Karplus tells much of the story. In the late 1950s, Robert Karplus, a physics professor at the University of California at Berkeley, began to attend the proliferating meetings of U.S. educators and scientists to discuss the inadequacy of high school science education. During this period, Karplus and a group of his colleagues at Berkeley submitted a proposal to the NSF for teaching elementary science in the Orinda-Union school district of the state. The proposal was turned down, because, according to the 1975 GAO report, "the NSF felt that it would be wise to wait until a comprehensive curriculum program had been formulated before considering small-scale variants like the one proposed by Karplus."

But the Berkeley-based reformer did not give up. In spring 1960, Karplus submitted a second proposal to the NSF under the title of "Elementary School Science Program," ESSP. The project was funded, and shortly thereafter, Karplus left for a sabbatical at the University of Vienna.

While Karplus was in Vienna, he immersed himself in a

study of child psychologist Jean Piaget and his colleague Jerome Bruner. Piaget is the leading voice of this century against the humanist tradition in education, and his influence never disappears from Karplus's later work. Not coincidentally in this process, Vienna is the center of the "systems analysis" and "linguistics" approach to mathematics and science that is responsible for institutionalizing the antiscience educational structure in which Piaget's ideas could flourish.

A full analysis of Piaget's methodology will appear elsewhere. The essence of his epistemology, however, can be seen from these brief quotations. In his 1966 work, *Mathematical Epistemology and Psychology*, Piaget asserts that human knowledge is not a product of the mind but of the senses, and he explicitly takes the side of Plato's chief historical enemy Aristotle:

> The "rational nature" of man is only a derivative....The subject and the object of knowledge are separate....Aristotle's schema of "environmental reaction," αντζπεριστασζς, must have been part of the common sense of the Greeks....On this point, as on many others, Aristotelian physics marks a return to ordinary thought rather than a continuation of the aspirations of Platonist mathematics [p. 307]....

Perhaps the most graphic summary of what such a methodology means for American youth can be seen from this brief quote from an earlier radical Aristotelian, Jean-Jacques Rousseau. Rousseau, who worshiped the "noble savage," had a world outlook just like Piaget's—based on the immediate exigencies of the environment. In his book *Emile for Today*, there is a chapter titled "The Scientific Study of Emile" that might have come straight out of the MACOS curriculum:

> It is through the senses that we come to the intellect. The senses must be our guide in the first operations of the mind. I do not wish my pupil to go into a laboratory with its array of apparatus. The scientific atmosphere kills science.

This is the essence of Karplus's Viennese training.

While Karplus was abroad, the ESSP had continued at Berkeley under the interim direction of his colleagues. In 1961 when he returned from Vienna, Karplus had a falling-out with the other program directors over the epistemology of science education, and by 1962 he had completely disassociated himself with their work. Immediately thereafter, the Piaget-indoctrinated innovator established the Science Curriculum Improvement Study (SCIS) under generous financing from the National Science Foundation. Within less than a decade, the foundation had turned over virtually its entire elementary science program to Karplus. The NSF spared no efforts in pushing Karplus's new science programs into the schools. By 1975, according to the GAO report, Science Curriculum Improvement Study materials were used "to some extent in almost all states . . . ."

The 1950 Act of Congress Establishing the National Science Foundation states that the purpose of the new institution is to "develop and encourage the pursuit of a national policy for the promotion of basic research in the sciences." Nowhere in the act does it state that the NSF is empowered to enforce the antiscience view of the postindustrial-society factioneers on a generation of our nation's children.

Karplus's curriculum revolution set the stage for making America's schoolrooms into incubation centers for the environmentalist terrorist mobs of tomorrow. Both Rousseau and Piaget, as the brief excerpts from their writings show, attempted to replace creative scientific work, beginning at the grade-school level, with the "touchy-feely" approach to understanding science through "common sense." On their model, the National Science Foundation curricula force students to think of science as what they can see, touch, smell, taste, and hear in their immediate environment, rather than as an advancing understanding of the universe that is available to them through the development of their minds.

"Hands-On"

This is known in teacher workshop lingo as the "hands-on" approach, which has nothing to do, however, with traditional scientific laboratory experimentation. Extracts from NSF training manuals and reports explain the method:

> The SCIS project is focused on developing a framework of fundamental scientific concepts that are related to the student's own experience with natural phenomena.

John Dewey, quoted in Seminar 10 of the MACOS Teacher Training Manual:

> Mathematics, even in the higher branches, when undue emphasis is put upon the technique of calculation, and science, when laboratory exercises are given for their own sake, suffers from the same evil separation of body from mind . . . .

David Butts discussing the curriculum in Science: A Process Approach:

> Emphasis on process implies a corresponding deemphasis on specific science content.

These so-called alternatives simply formalize at the early educational level the distortions that have increasingly

intruded into scientific practice itself. Both the "hands on" empiricism and the contentless "process" approach ignore the way that higher conceptions are actually developed and the developing contents of those conceptions.

What this means in the classroom comes through in this report from a thinking seventh grader in a New York City private school:

> My NSF course forces me to see science from the idea of common sense. I was told that I could put a large number of paper clips on the body of a paper airplane and watch what happens. Of course, I knew that it would fall down. My teacher told me, like I was supposed to get excited about it, that "common sense" had taught me how an airplane works.
>
> I got mad at the teacher and told him; "no, it's not common sense that's telling me how an airplane works. There's science involved in how an airplane works. What is that science? When I was three years old, I used common sense. Don't make me think like a three-year-old. I'm twelve. I want to use my mind!"

This seventh grader knows his intelligence was insulted. He may even understand that an antiscience outlook is being forced on him and his fellow students in the classroom. What would probably shock him, and most parents, is that his science curriculum was designed, and his teacher was trained—both under NSF auspices—to deliberately turn his generation away from genuine scientific pursuit.

Mary Gilbertson, a Fusion Energy Foundation staff member, was a high school teacher for 10 years.

References

National Science Foundation Curriculum Development and Implementation for Precollege Science Education. 1975. Report to the Committee on Science and Technology, U.S. House of Representatives, 94th Congress, first session. (Washington: U.S. Government Printing Office 61-5790). The most relevant sections of this report are the "Minority Report of Joanne McAuley to Accompany the Report of the Science Curriculum Implementation Review Group," the "Report by the General Accounting Office," "Report by the National Science Foundation," "Commercial Curriculum Development and Implementation," and "Appendix 4," which lays out the role of University of California curriculum reformer Robert Karplus.

Man: A Course of Study—Seminars for Teachers. 1969. (Cambridge, Mass: Education Development Associates and Washington, D.C. Curriculum Development Associates).

Piaget, Jean. 1966. *Mathematical Epistemology and Psychology.* (The Netherlands: D. Reidel). For the most egregious attack on Plato and the development of mind see the chapters "The Set Theorists: Cantor and Zermelo," Platonism As a Real or Illusory Intuitive Vision: The Nominalist Critique," "The Platonist Interpretation of Mathematics," and the "Interpretation of Mathematics by the Laws of the General Coordination of Actions."

Notes

1. The NSF has not kept its "greening" of science a secret. In 1971, in his congressional testimony, Dr. Humphreys, the NSF assistant director for education, stated that the 1972 budget for the NSF included "the development of introductory courses in science that are organized around social problems rather than by scientific disciplinary approach. . . ." By 1979, the NSF director of research in science education, Dr. Hannapel was able to tell this author that "There is a proliferation of courses not like physics or chemistry or math as we know them in the secondary and in the elementary schools."
2. The NSF emphasis on the importance of evaluating the *psychological effect* of the MACOS curriculum was apparently not known to parents, teachers, or students. It was only in the *Congressional Record*—not the NSF publications—that I could find the fact that the MACOS curriculum was officially evaluated by the Washington School of Psychiatry in 1970. The emphasis on the psychological evaluation of the NSF-funded new math curriculum is also shocking.
3. For readers who regard it as far-fetched that the epistemological nature of a science curriculum determines the ontology of a generation, read the 1947 book *Princeton Bicentennial Conference on the Future of Nuclear Science* edited by Eugene Wigner. At that conference P.M.S. Blackett and others proposed and discussed the formation of a U.S. National Science Foundation. Blackett was a main organizer of British American operations-research and systems analysis and is an advocate of the H.G. Wells "science for the elite only" policy.

An Interview with Dr. Uwe Parpart

Teaching Geometry to Develop the Mind

At the beginning of the fall 1979 school term, Dr. Uwe Parpart, Fusion Energy Foundation director of research and a mathematician, undertook a series of experimental geometry classes with grammar school children in New York City under the auspices of the Humanist Academy. Within three months, the series was successful in introducing the basic notions of analytic geometry to the youngsters and developing what Parpart characterized as a "geometric intuition" necessary to their scientific studies as a whole.

This interview with Dr. Parpart was conducted by Christina Nelson Huth.

* * *

Question: What age group are the children who have been participating in your experimental class series?

The children range in age from about six to eleven years, that is from second grade to fifth grade primary-school age. There are about 12 to 15 children representing this age range in each of the classes, which have been going on weekly for about three months.

Question: What has been accomplished up to this time?

We've gotten to the point where we are beginning to deal with the basic concepts of analytical geometry, along with a discussion of the concept of the integral. These two things, at a certain point, have to go hand-in-hand.

Question: How have you brought such young children to such an advanced point?

Basically, I designed the class series to emphasize at each point the fundamental relationship between the process of the construction of geometric figures, and the way in which geometric configurations are exemplified by physical action. The basic idea is this: if one looks at geometry axiomatically [Figure 1], it tends to be entirely divorced from any relationship to physics. What I was trying to accomplish was the opposite. I wanted to show the unity of geometry and physics and, in the broader sense, the way in which geometric considerations are involved in all scientific enterprises.

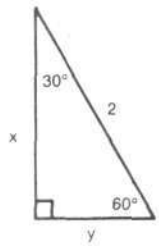
The children got their first sense of the direction I was trying to go in when I told them the story of how Johannes Kepler, the outstanding astronomer and physicist of the early 17th century, had put an end to international "wine wars" by developing a system of equations that could accurately measure the amount of wine contained in the irregularly shaped wine barrels of merchants from different parts of Europe. Kepler's development of the notion of the integral was an important step toward Leibniz's development of the calculus.

Question: Can you describe how this was accomplished in the classroom setting?

We concentrated on the method of construction of various geometrical figures and the coherence of the method of generation to the way in which certain types of physical actions are generated.

In one of our first experiments, we sat down to build—or invent—the instruments necessary to construct various

Side Relationships



y = 1
(Because the length of the side opposite the 30° angle in a right triangle is half the length of the hypotenuse)

$x = \sqrt{3}$
(By the Pythagorean Theorem,
$x^2 + 1^2 = 2^2$
$x^2 = 3$
$x = \sqrt{3}$)

Figure 1
THE AXIOMATIC APPROACH TO GEOMETRY
In this review lesson, high school students are encouraged to memorize geometric theorems.

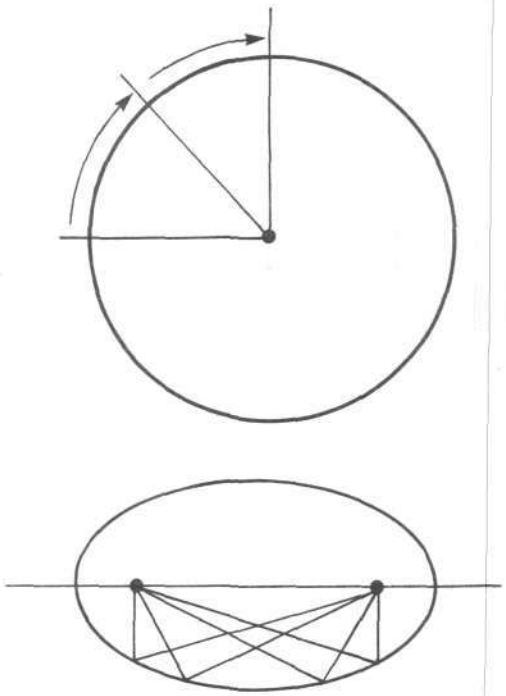
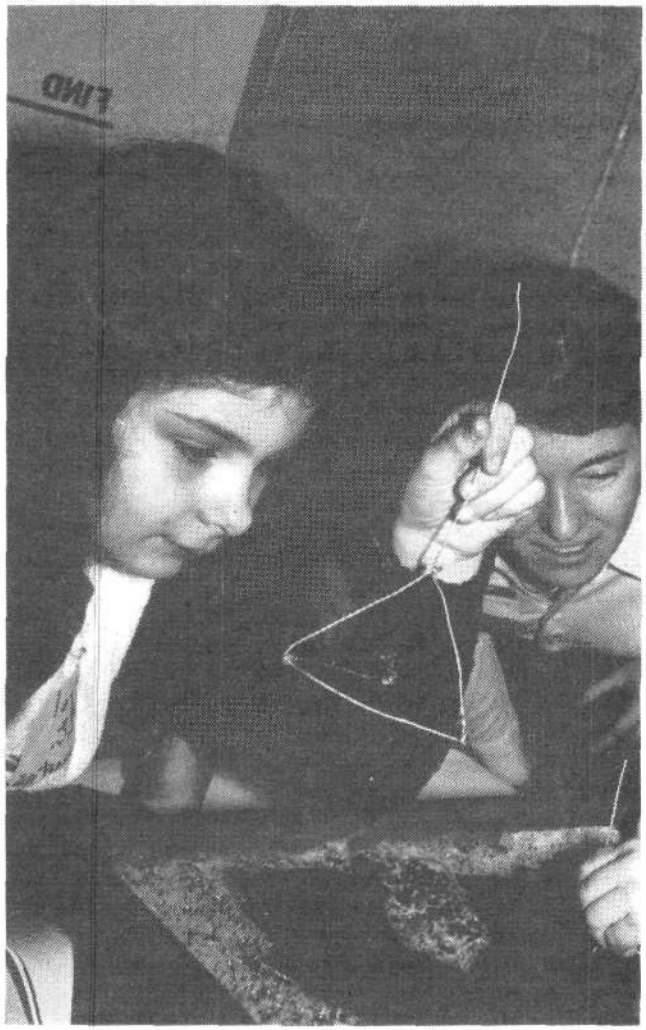


Figure 2
CONSTRUCTING THE CIRCLE AND THE ELLIPSE
Using string, pencils, and notebook paper, the children in Dr. Parpart's experimental geometry classes invented the means to construct geometric figures, starting with the circle and the ellipse. In the process of construction, the children discovered that the circle results from the movement of a line, fixed at a central point, across a plane, and the ellipse from the progression of a series of triangles across a plane.



figures. Rather than simply defining a circle as "the geometric locus of all points that are an equal distance from a given point," as is done in most high school geometry classes, we took a piece of string and a pencil, invented a compass, and drew circles on notebook paper. The formal "locus" definition of the circle was made clear to the children in this process.

For the construction of an ellipse, we invented an "ellipse-maker," also from pencils and string. With these two constructions under their belts, the children were ready for a discussion of the fact that a circle is constructed by the motion of a straight line over the area of the circular disc while an ellipse is constructed by the motion of a continuously changing triangle over the surface of the ellipse [Figure 2].

The basic point was to get at the "locus" definition of each of these geometrical configurations from the standpoint of defining the method of construction and by understanding the kinds of instruments necessary for this construction. The important thing here is that the children understood that the geometrical figure itself was not primary, but only the trace of a process—the process of construction.

Philip Ulanowsky

In these photographs, Margaret Acheson, Willie Bardwell, and Emmaia Gelman, students from Dr. Parpart's geometry class at the Humanist Academy, demonstrate to visiting adults the varying geometries of soap film surfaces that appear on three-dimensional geometric figures.

I carried through this conception in introducing solid geometrical figures into our experimental work. I used the familiar plane figures to demonstrate the construction of three-dimensional figures through rotation; for example, a circle when rotated creates a sphere, a triangle creates a cone, an oblong shape a cylinder, and so on. This was an opportune time both to discuss pottery wheels and industrial lathes, specific inventions with which the children were familiar, and to point out the relationships among physical action, the specific geometrical figures, and the invention needed to produce it.

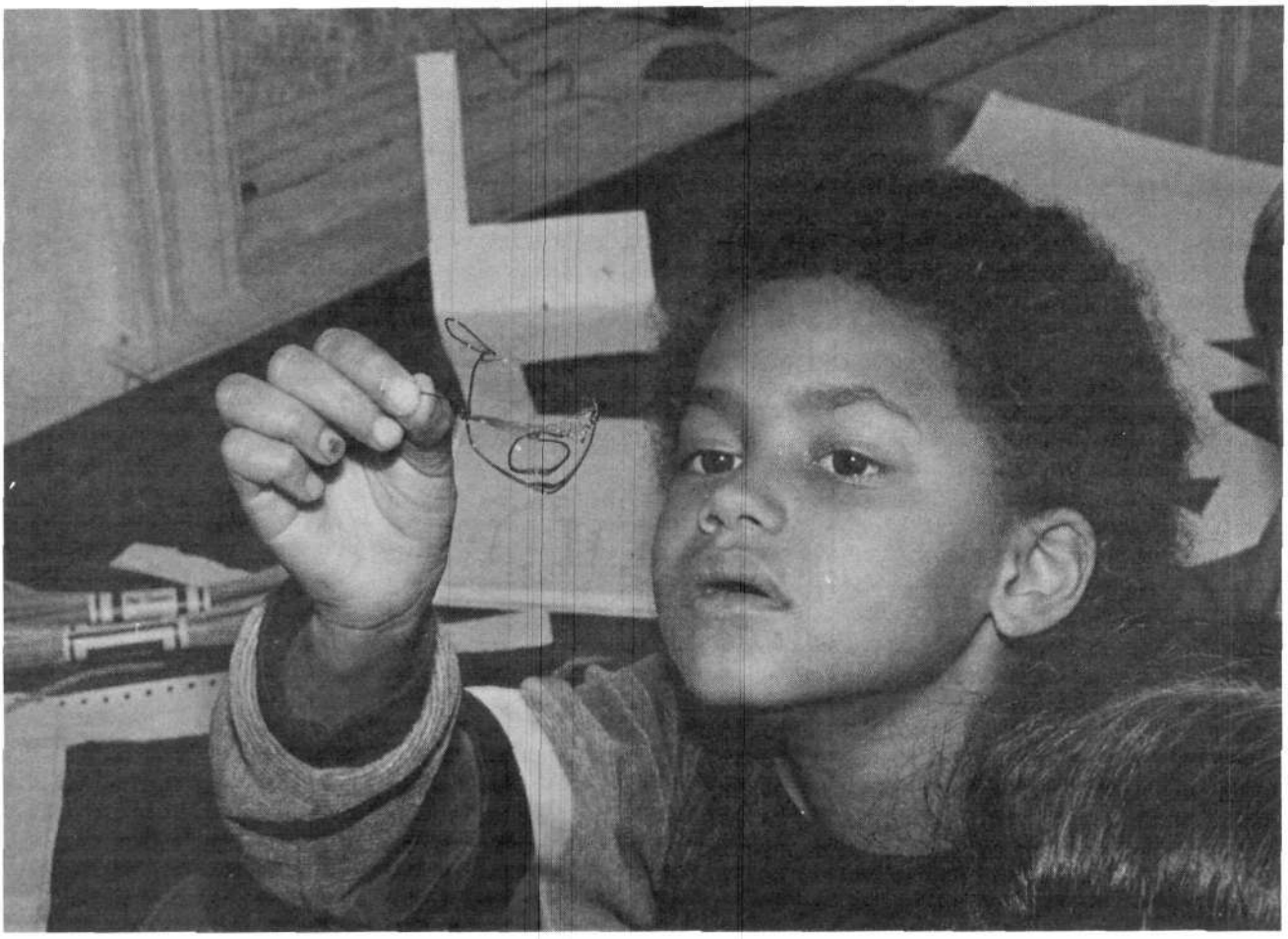
After this basic introduction to geometrical shapes from the standpoint of their construction, I tried to give the children a better sense of the relationship between different configurations. We began working extensively with conic sections. The children made cones from modeling clay, cut through them at different angles, and compared the shapes they had created. We also mimicked this process with conic projections—using a cone and a background light to project circles, ellipses, and parabolas onto a screen.

Question: I understand that you developed this pedagogical approach on the basis of the work of the late-18th century French mathematician-engineer Gaspard Monge?

As a matter of fact, I introduced some of the basic ideas of descriptive geometry, as they were developed by Monge, into the classes at about this point. Monge invented an advanced method of communicating the basic elements of an object to be constructed in three dimensions, an achievement the French military considered to be of such primary importance for its operations that Monge's work was classified for 30 years.

The children were particularly excited about the military and engineering implications of Monge's work. Shortly thereafter, we began a series of field trips, and the kids went to work doing different projections of the George Washington Bridge, building scale-model bridges, and working from scale-model drawings to construct model buildings and so forth to specifications. The basic idea here was, again, to get a feel for how the method of construction relates to plane geometrical figures and to get a sense of looking at things from the standpoint of identifying the most efficient method of accomplishing a certain task.

Geometry, if it is taught properly, provides the basis for



good development of the capability for spatial interpretation of what is known in physics as the "least-action principle." This is acutally what Monge had accomplished by his descriptive geometry: finding the most efficient method to build the bridge by synthesizing and resynthesizing the relationships of the geometrical forms involved in the construction.

Question: Have you referred to other mathematicians or physicists in elaborating your approach?

Felix Klein paid a lot of attention to curriculum development for the teaching of geometry and I have reviewed his work. He developed a program with the stress on process-conception instead of the axiomatic approach. He wrote a good deal on how to teach geometry—to a somewhat older age group around the high school years—emphasizing constructions and model-making.

Question: *Can you elaborate on how your geometry curriculum develops the children's understanding of basic physical principles?*

The principle of least action is fundamental to physics. We tried approaching it geometrically, by examination of the minimal surfaces involved in a construction. This brings up a very complex mathematical problem—known as the plateau problem—that is involved in determining the minimum surface connecting a given curve in space. My approach to this category of problem with the children involved *the construction from pipe-cleaners and wire of* three-dimensional geometric figures that we then dipped into soap film. The children were encouraged to guess at the geometry of soap film surfaces that would appear on their pipe-cleaner structures, and then compare their guesses with the results after dipping.

Question: *What is the difference between your approach* and the way geometry is taught in the schools today?

In most classrooms, students memorize a set of axioms—*and this is called a course of study in geometry. This, of* course, leaves the students without any appreciation whatsoever of the relevance of geometry to problem-solving in other fields and more often than not, it stunts their creative faculties.

My class series was designed not to teach geometry, but to develop a quality of mind—call it "geometric intuition" *if you will—that will be indispensable to the children's* learning elsewhere.

Lockheed Proposes Experimental Liquid Hydrogen Aircraft

The development of a series of freight and passenger planes fueled by liquid hydrogen is the next step for the airlines industry, say top engineering and management executives at California's Lockheed Corporation.

"A hydrogen-powered aircraft is potentially the biggest step in aircraft efficiency we could take," Lockheed senior vice president Willis M. Hawkins told an international conference on Hydrogen and Air Transportation held in Stuttgart, West Germany in mid-September 1979. "It is a whole generation ahead of the best airplane we know how to build today and promises an advance even more important than when we moved to reciprocating jet engines."

The urgency of the new development was made clear when Hawkins, speaking two months later to a November meeting of England's Royal Aeronautics Society, explained that within the next 15 years, the aerospace industry will have to find new fuels for air transportation. Of all the available candidates—synthetic jet fuel, methane, and liquid hydrogen—Hawkins stated that his preference is hydrogen.

Supersonic Flight

Lockheed engineers have developed conceptual designs to use liquid hydrogen as fuel in subsonic planes (those slower than the speed of sound), supersonic aircraft (those faster than the speed of sound, 760 miles per hour), and for possible hypersonic planes, which would travel at least five times the speed of sound, or 3,700 miles per hour.

Subsonic and supersonic aircraft would burn liquid hydrogen using liquefaction, handling, and storage technology developed by the National Aeronautics and Space Administration for the Apollo project. But at hypersonic speeds (for example, planes traveling from Los Angeles to Tokyo in 2.3 hours), air resistance would create heat and a serious problem for the aircraft.

The Lockheed design would use liquid hydrogen to cool the outer surface of the plane. The hydrogen, warmed up in this process, would then be used as a gas in the engine. According to a Lockheed study performed for NASA, the conventional airplane engine would need little modification to burn either liquid or gaseous hydrogen.

The advantages to using liquid hydrogen instead of synthetic jet fuel produced from coal are that, first, it will be cheaper even with today's hydrogen-producing technology. Second, it is three times as energy-dense as fossil-based fuel; therefore, it is much more efficient.

An Experimental Hydrogen Fleet

G. Daniel Brewer, manager of hydrogen studies for Lockheed, has developed a proposal, put forward in various publications and presented at the September conference in Stuttgart, for the construction of an international fleet of experimental liquid hydrogen planes.

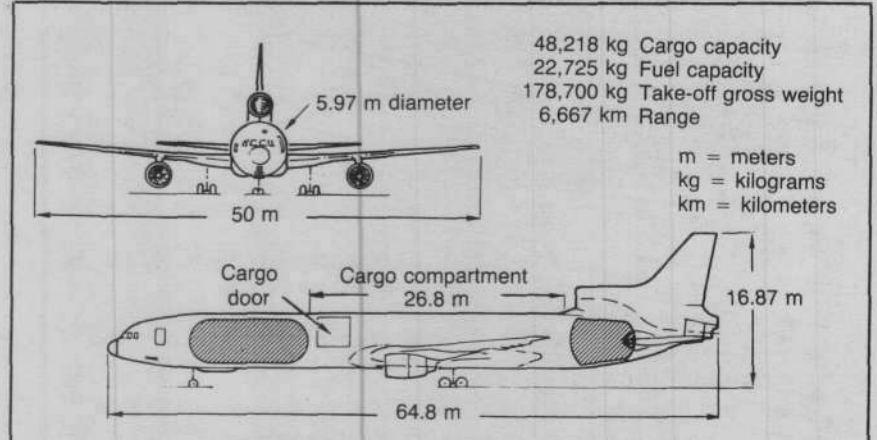
The first four of this next-generation airplane would be used initially for air cargo. They could be converted to joint cargo-passenger aircraft after a two-year technology testing period. Brewer has proposed that the design could be a modified version of the Lockheed TriStar (see figure) with commercial operations beginning as early as 1986.

To meet this schedule, critical technologies development, such as hydrogen pumps, fuel containment systems, and engine modifications, would have to begin immediately. Brewer has suggested that an initial network of hydrogen-suitable experimental airports should be built in Pittsburgh, Frankfurt, Birmingham, England, and Riyadh, Saudia Arabia. These airports would include the capability to produce hydrogen, liquefy it, and fuel one airplane a day with about 20 tons of liquid hydrogen fuel.

The Lockheed executives have remarked that the development of advanced technology, and indeed even the continued commercial deployment of nuclear technology, has been stymied by politicians who pay too much attention to "myopic" environmentalists.

Hawkins told the Stuttgart symposium: "A medium that burns as consistently as hydrogen and that burns with almost absolute purity, is a medium that humankind will find hard to resist no matter how stubborn or irrational our politicians may be."

—Marsha Freeman



Lockheed's L-1011 TriStar, the cargo airliner the corporation proposes to modify for use of liquid hydrogen (LH_2) fuel. Inset: Overall dimensions and characteristics of the proposed LH_2 freighter.

Books

Can the U.S. Afford Trucking Deregulation ?

Trucking Deregulation:
A Disaster Worse Than Vietnam
Executive Intelligence Review
Special Report
New York: New Solidarity
International Press Service, 1979
64 pp. $10.00

On May 25, 1979, 267 people died as a DC-10 commercial airliner crashed onto the runway of Chicago's O'Hare Airport. Only after the Chicago tragedy did the public become aware that something has gone terribly wrong with the nation's airline system. What had gone wrong was deregulation.

After rounds of investigation, industry officials reluctantly admitted that deregulation had spurred a stiffened competition among career companies, foreshortened service on low-density routes, and most important, cutbacks in servicing and safety checks.

Will the deregulation of the U.S. trucking industry championed by Senator Edward Kennedy have a similar—or worse—effect on the U.S. transport system and economy? Yes, say the editors of the *Executive Intelligence Review*, who have recently released this special report on deregulation. They have calculated that the outcome of dereg would be "a disaster worse than Vietnam."

The report, released in November, is prefaced by Kennedy's opponent for the Democratic Party's 1980 presidential nomination, Lyndon H. LaRouche, Jr., a contributing editor to the review. LaRouche explains: "Every part of our economy depends upon regulated trucking service into every part of every community in the United States. If trucking companies are driven to concentrate on the most profitable or relatively least unprofitable routes, both local, smaller communities and

whole sections of major cities will either lack trucking service or will be obliged to bid at prices way above national averages for main traffic routes. Whole communities will be driven out of business. . . ."

An American Success Story

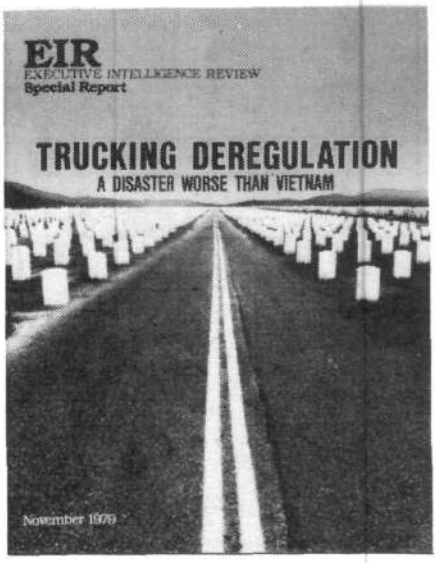
The trucking industry today is an American success story. The highly skilled unionized American trucker can move a shipment of goods 600 miles door to door in a day and a half, setting a record no other nation can match. This accomplishment stems from the decades-long fight of the International Brotherhood of Teamsters to organize the industry in cooperation with both government and industry. By contrast, the unregulated British trucking industry moves a median shipment 63 miles —in four days.

This may be just what Senator Kennedy and the deregulators have in mind for the United States, says the report. Under the proposed deregulation plans, the toll for the entire economy over the next five years would would be an estimated $100 billion.

This charge against the economy's ability to grow, large enough to cause economic disaster, would yearly amount to: at least $7.2 billion in lost efficiency; $4.4 billion lost due to reduction of service to rural communities; $5.1 lost in cuts in the wage scales of unionized Teamster workers; and $5.5 billion in higher insurance costs as a result of higher accident rates. The toll in human life, as a 100,000-man army of overworked, often drug-taking independent truckers takes over the highways, in eight years' time would be as high as the casualty rate of the Vietnam war.

The Free Enterprisers

Who would argue in favor of such a prescription for economic disaster? The "free enterprise" ideologues of the Brookings Institution, the American Enterprise Institute, the Heritage Foundation, and the Mont Pelerin Society, says the report. And, of course, the mouthpiece of these institutions, Senator Edward Kennedy. In his preface, LaRouche termed this campaign for trucking deregulation: "literally un-American; it represents an effort to introduce into the United States the same Adam Smith doctrine which the



American Revolution was fought to free us from. . . . British intelligence-controlled conduits, such as the Heritage Foundation, are engaged in vigorous efforts to convince us we must wreck the American System so that we might be more like the bankrupt, collapsing economy of Great Britain. . . ."

The Starport Concept

For readers who want more than the report's thorough analysis of how the trucking industry works and how deregulation would destroy it, a final chapter lays out a bold new program for an upgrading of the national transportation grid. This program, centered on the Starport conception of ingrated transport nexuses, features computerization of railroad terminals, containerization of the entire transport system, production of piggy-back railroad cars, and a vast expansion of the national air cargo system.

The *Executive Intelligence Review* report, although filled with documentation, facts, and figures, is good reading and will raise compelling questions for the attentive reader. Can America afford to let its trucking industry slip back into the hands of the organized crime drug-runners? Is the provision of adequate transportation service into smaller communities to be considered a national priority or not? Can the U.S. economy withstand an economic disaster worse than Vietnam?

—Christina Nelson Huth

Books Received

Electric Automobiles. Warren Hamilton, New York: McGraw-Hill, 1979, 425 pp., $24.50.

Physics of High Temperature Plasmas. George Schmidt, New York: Academic Press, 1979, 365 pp., $29.50.

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AEE Directory of Professionals. Atlanta: Association of Energy Engineers, 1979, 280 pp., $24.50.

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Future Developments in Telecommunications. James Martin, ed. Englewood Cliffs, New Jersey: Prentice Hall, 1977, 668 pp., $34.95.

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Poisoned Power, John Gofman and Art Tamplin, Emmaus, Pa.: Rodale Press, Inc., 368 pp., $9.95.

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Technology—Fire in a Dark World, Perry Pascarella, New York: Van Nostrand Reinhold Co., 1979, 172 pp., $12.95.

Government, Technology, and the Future of the Automobile, William J. Abernathy and Douglas H. Ginsburg, eds., New York: McGraw Hill, Inc., 1980, 483 pp., $29.95.

Japan As Number One—Lessons for America, Ezra F. Vogel, Cambridge, Mass.: Harvard University Press, 1979, 272 pp., $12.50.

Song of the Sky: An Exploration of the Ocean of Air, Guy Murchie, New York: Ziff Davis Publishing Co., 1979, rev. ed., 438 pp., $12.95.

The Discoverers—An Encyclopedia of Explorers and Exploration, Helen Delpar, ed., New York: McGraw Hill Inc., 1980, 471 pp., $29.95.

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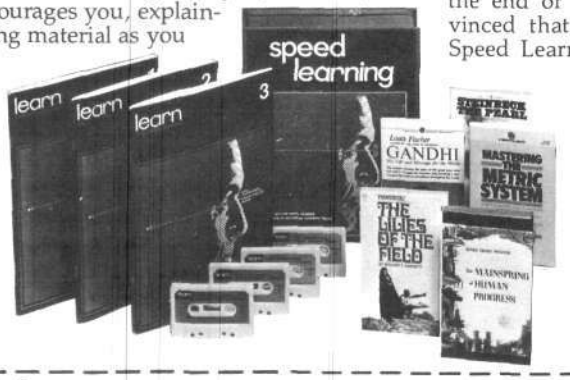

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Conferences

Soviet MHD

Continued from page 28

avenues of MHD applications, E.P. Velikhov, now vice president of the Academy of Sciences, still conducts experiments on portable MHD generators in geophysical exploration and earthquake prediction.

In economic terms the U.S. policy on MHD is even more difficult to understand.

In discussing the U-500 and the cost of its components, Shpielrain showed how the cost of the binary system (a combined MHD-steam turbine cycle) will be competitive with today's conventional fossil fuel plants because of the cost reductions that will accompany mass production. Furthermore, each unit of power produced will require only half as much fuel, because the efficiency will be approximately double.

The Soviets have said that they do not understand why the U.S. MHD program has been narrowly defined as a "coal technology" program or why there has been no sustained government commitment to commercialize the technology. (Most U.S. researchers, in government programs and in private industry, do not understand it either.)

As the Soviets demonstrated at the CDC seminars, MHD direct conversion has many applications, in addition to baseload power generation and other high-temperature spinoffs, that could affect power and industrial engineering in dozens of fields.

The immediate application of MHD, which the Soviets are pushing ahead with, will *double* the efficiency of coal-burning electric power plants and is part of an overall program to phase out oil and go nuclear.

Although President Carter mandated in July 1979 that by 1990 U.S. utilities must phase out all oil-burning power plants, neither MHD nor nuclear power are being made available to the utilities. As a result, most utilities will convert to burning coal with conventional technology in a program that will cost in the tens of billions of dollars.

The increased price of delivered electric power that will accompany this conversion to coal will not be because coal is a more expensive fuel. The price rise will result from the decline in productivity in the switch from oil to coal and from the drain on capital resources of utilities that will have to divert spending from investment in new, more efficient technologies like MHD.

In contrast, by 1990, the Soviet Union expects to generate 10 to 15 gigawatts of electric power in a system that will cut the cost of electric power and that will be a step along the way to applying MHD to nuclear systems.

And beyond 1990? After the year 2020, thermonuclear stations will be used everywhere. "The fuel is unlimited and the technical problems are difficult and very complicated," Shelkov affirmed. "Nevertheless, after 2020, such types of stations will be in wide use."

A news article on the U.S. MHD program appears in the Washington section.

New York Academy of Sciences, Dec. 17-21

Nonlinear Dynamics: Stopping Short of Riemann

by Dr. Jonathan Tennenbaum

Why has the scientific community so far failed to master the methodology that guided Bernhard Riemann in his fundamental scientific work 150 years ago? The importance of posing this question should not have escaped anyone attending the week-long conference on nonlinear dynamics, held December 17-21 in New York City under the auspices of the New York Academy of Sciences.

The conference itself was evidence of a growing realization that the study of essentially nonlinear phenomena, particularly in hydrodynamics and plasma physics, is the crux of scientific progress today. Yet, aside from certain advances in developing a geometrical, nonstatistical approach to nonlinearity, in fact very little fundamental progress has been made in understanding nonlinear phenomena in physics since Riemann's original work on shock waves.

At the same time, however, the conference reviewed remarkable progress in experimental techniques—from the breathtaking Viking photographs of Jupiter's turbulent atmosphere, to applications of lasers to Doppler effect velocity measurements in fluids, to rapidly improving computer simulation techniques. Given the wealth of empirical data now, there is no doubt that what is standing in the way of fundamental breakthroughs is chiefly the lack of a suitable methodological approach.

Among the most fruitful of recent developments has been a far-reaching reevaluation of classical statistical theories of fluid turbulence such as the Kolmogorov "5/3 law," which approximately describes the distribution of energy among different size scales of vortical motion in fully developed turbulence.

First, as Dr. Steven Bardwell emphasized in his review of the LaJolla conference on coherent structures in turbulent flow (*Fusion*, Dec. 1979), recent empirical and theoretical work has shown that many turbulence phenomena are dominated by an "inverse energy cascade"—characterized by the coalescence of small-scale vortices into larger vortices and the emergence of large-scale ordered flows out of initially "chaotic" turbulence—rather than by the dissipative energy cascade presupposed by standard statistical theories.

Second, and most surprising, recent work on the hydrodynamic phenomenon called "intermittency," reviewed by Uriel Frisch, Eric Siggia, and Hassan Aref at the conference, has revealed

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In the course of his nationwide campaign for the Democratic Party nomination, now focused on the February 26 primary in New Hampshire, Mr. LaRouche has gained widespread recognition as the foremost proponent of nuclear energy. However, LaRouche's international leadership role in science goes much deeper.

For example, LaRouche's breakthrough contributions in economic science have made it possible for the first time to demonstrate directly the necessity of scientific and technological progress, and to identify those areas of research where advances are most urgently required. His fundamental contribution to the methodology of science has also made it possible to specify some of the most fruitful approaches to the solution of basic problems in plasma physics and biology.

Those of us who are working professionals in the scientific and technical areas of production, research, and education know that the erosion of our country's scientific base cannot be permitted to continue. The ongoing attrition of our R&D and training programs and the lack of a sound national science policy not only is hurting us, our students, and our colleagues, but also threatens our national security.

Lyndon LaRouche has taken his stand on behalf of the scientific community. Now it is time for us to reciprocate.

We urge you to join in endorsing Mr. LaRouche's candidacy, in giving financial support, and in building Scientists and Engineers for LaRouche into a vital part of his campaign.

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that even when the dissipative energy cascade dominates, an ordering process nevertheless occurs at the *microscopic level*. What happens is that in the breakup of larger-scale into smaller-scale vortical motion, the energy of turbulent motion is not dissipated uniformly in the medium. On the contrary, the energy concentrates itself on a very "thin" submanifold called a fractile set.

This shows up in extraordinarily "bumpy" spatial variations in observed fluid velocities (hence the term intermittency). The phenomenon is also closely related to the process of concentration of wave energy into shock front surfaces in the formation of shock waves. In both cases, the interaction of the actual spatial geometry of motion and the flow of energy in phase space is key to understanding the process.

The power of a geometrical approach to nonlinear phenomena was further demonstrated by papers of D. Montgomery, Harold Grad, J. Moser, and E. Trubowitz at the conference. While Montgomery uses geometrical invariants of MHD plasma dynamics to derive new, nonquiescent plasma regimes in magnetic confinement, Grad focuses on the key phenomenon of *spontaneous change of magnetic field topology* in a plasma.

Rejecting all-too-widespread tendencies of mathematical physicists to cling to standard existing mathematical techniques at the expense of a physical reality that leads beyond them, Grad has created a new geometrical approach to nonlinear partial differential equations. Although present techniques are generally hopelessly inadequate for explicitly solving such equations, the presentations of Moser and Trubowitz, dealing with special nonlinear problems that have been completely solved, suggest the beautiful and rich structures whose discovery is awaiting the development of more powerful mathematical methods.

However, it is unlikely that the essential hindrance to fundamental progress in understanding nonlinear phenomena lies in the mathematical domain per se. For, as Riemann emphasized in his work on shock waves (See the article by Uwe Parpart in *Fusion*, March-April 1979), it is not the idealized mathematical fluid of the Navier-Stokes equations of motion that is the proper focus of our attention, but *real physical* processes—insofar as real processes, as opposed to mathematical structures as currently understood, are dominated by the continual generation of *singularities*, ambiguities corresponding to the action of a higher principle of ordering than that subsumed under a given mathematical description.

The Weakness of the Conference

This is exactly the crucial point of epistemological weakness in the work presented at the New York conference. For example, why were the phenomena of cavitation and sonoluminescence (the formation of gas bubbles and emission of light from "hot spots" in turbulent fluids where highly nonuniform energy distribution triggers local phase changes) not examined as crucial empirical data in the discussions on turbulence? Evidently because the phenomenon of phase change in the fluid medium (for example, evaporation in the case of cavitation) appears from the point of view of the Navier-Stokes equations as an "added-on" serious complicating factor in the mathematical treatment.

From a physical point of view, however, the potential for local phase change (or change of geometrical structure on the microscopic level) is intrinsic to real media and must play an important role even when actual phase change does not predominate. It would be wrong to expect that the scientific study of actual nonlinear phenomena in physics must necessarily be more complicated than solving the Navier-Stokes equations. Quite the contrary: We know that the physical singularities that destroy the ideal mathematical fluid of the Navier-Stokes equations are instrumentalities of that universal ordering process—negentropy—that makes the physical universe conceptually graspable by the human mind.

In that sense, *real* physics must be simpler than mathematical physics, especially when we focus on those physical contexts where, as in fusion research today, we ourselves intervene to create new ordered phenomena.

Dr. Tennenbaum, a mathematician, is an FEF representative in Europe.

Letters

Continued from page 4

ed that a small group of outspoken individuals can have a profound effect on the course of energy in the world. The father of the atomic age once said that the question of atomic energy will be decided in the village square . . . . I have attempted to do this with my song.

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To watch nuclear power die
With no comprehension
You demanded decision
Shut all nuclear plants down
If the chair came before the bulb
You'd say down with electricity
Peace, and love
How long can you keep up this scam
With this modern day boogie man
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With your short sighted intervention
Spreading half truths and doubts
Will it open your eyes when the lights go out?
You attack safety that is second to none
In 30 years it hasn't injured anyone
Back up with money your attack
Carry for a change the financial impact
You are afraid of what you don't understand
Darkness scares the child and not the man
You shout things you know nothing about
Good intentions I have serious doubt
If radiation is the angel of death
Sun bathing is detrimental to your health
You can't hide from the facts of life
Even solar energy has its price
If it wasn't nuclear it would be coal
Protesting seems to be your favorite role

George Green
Phoenix, Arizona

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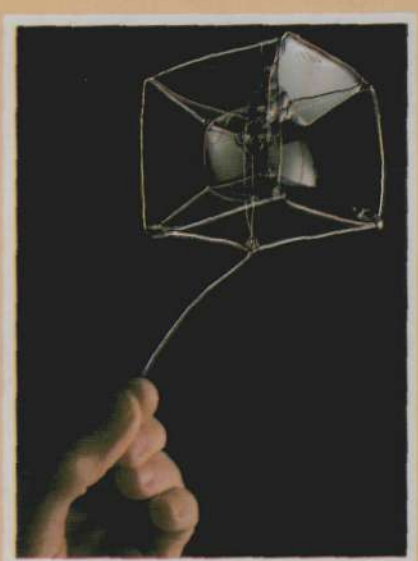
In This Issue

THE 1980s:
DECADE FOR FUSION TECHNOLOGY
As the top fusion scientists have made clear, the only bottleneck to building U.S. commercial fusion reactors by the 1990s is inadequate funding. In our cover story, Charles B. Stevens reviews what is in store for fusion technology in the 1980s.

Cover design by Christopher Sloan; front cover photo of the PDX tokamak courtesy of the Princeton Plasma Physics Laboratory. Construction work on the Tokamak Fusion Test Reactor nearing completion at the Princeton Plasma Physics Laboratory.

THE NATIONAL SCIENCE FOUNDATION:
TAKING THE SCIENCE OUT OF EDUCATION
Will there be enough U.S. scientists to run a commercial fusion program in the 1990s? Not if the National Science Foundation's environmentalist science courses continue to corrupt our youth, according to this exposé by Mary Gilbertson. Instead of science, the NSF has instituted courses such as MACOS—Man: A Course of Study—where children learn that man is just a smart baboon.



TEACHING GEOMETRY TO DEVELOP THE MIND
In a remarkable series of classes for the Humanist Academy, FEF director of research Dr. Uwe Parpart has succeeded in introducing the basic concepts of analytical geometry to grammar school children. This interview with Parpart and the pictures of his students show how a curriculum can be designed to create a quality of "geometric intuition" that aids in developing children's creative faculties.

A geometric shape made by soap film on a three-dimensional figure constructed from wire in Parpart's geometry class. *Photograph by Philip Ulanowsky.*