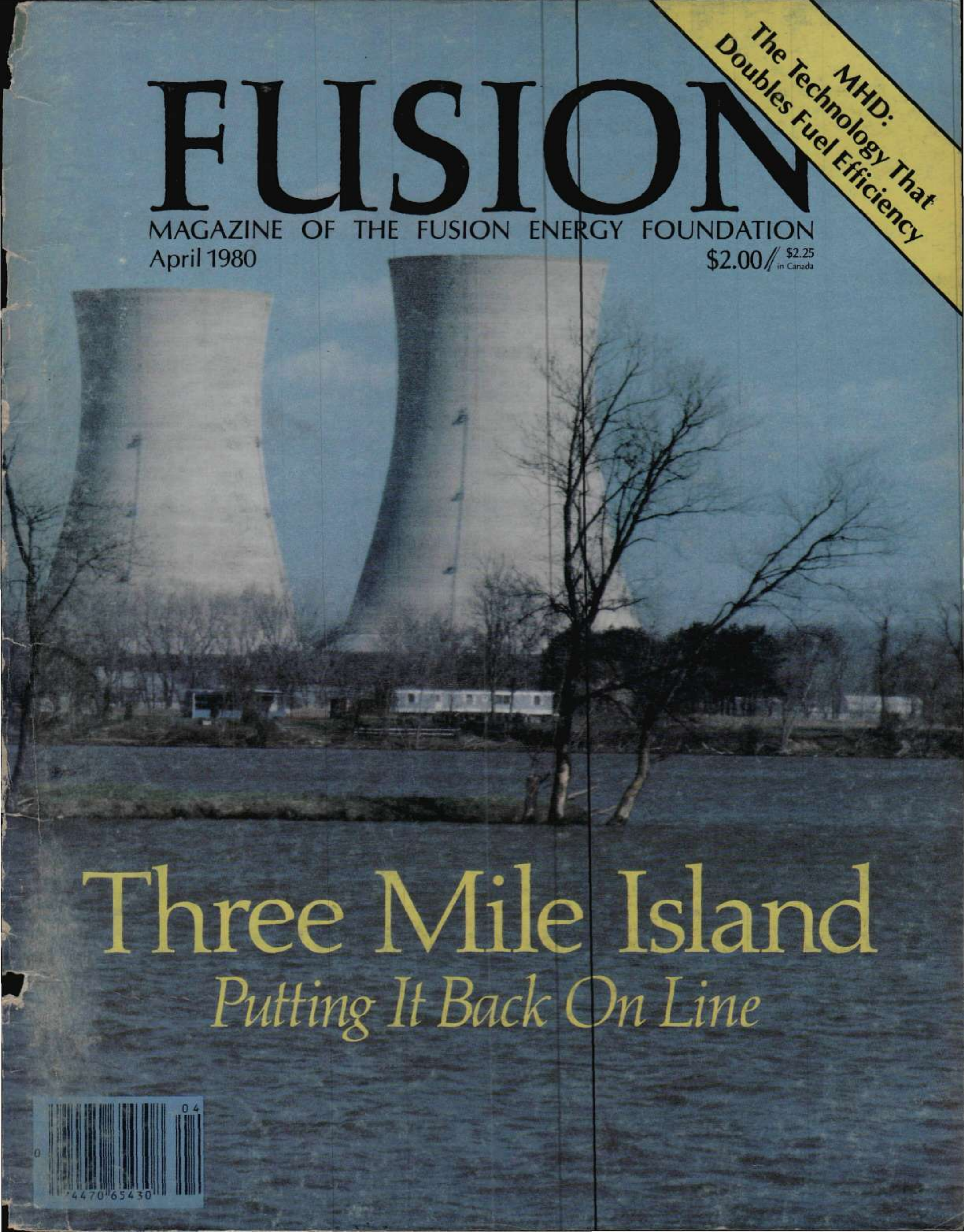
FUSION

MAGAZINE OF THE FUSION ENERGY FOUNDATION

April 1980

$2.00 // $2.25 in Canada

MHD: The Technology That Doubles Fuel Efficiency



Three Mile Island

Putting It Back On Line

FUSION

MAGAZINE OF THE FUSION ENERGY FOUNDATION

Vol. 3, No. 7
April 1980
ISSN 0148-0537
USPS 437-370

FUSION is published monthly, 12 times a year by the Fusion Energy Foundation, 888 7th Ave., Suite 2404, New York, New York 10019, telephone (212) 265-3749.

Subscriptions by mail are $20 for 12 issues or $38 for 24 issues in the USA and Canada. Airmail subscriptions to other countries are $36 for 10 issues.

Address all correspondence to *Fusion*, Fusion Energy Foundation, 888 7th Ave., Suite 2404, New York, New York 10019.

Second class postage is paid at New York, New York and at additional mailing offices.

The FEF publishes a variety of material for the benefit of decison makers and the interested public. The views of the FEF are stated in the editorials. Opinions expressed in signed articles are not necessarily those of the FEF directors or the scientific advisory board.

Fusion's advertising representative in Europe is Karlheinz Holz., Pf. 3329, 62 Wiesbaden, West Germany. Telephone (06121) 440277.

Cover photograph of Three Mile Island by B. Banks, Shostal Associates Inc.

Features

News

Departments

After TMI: 2000 by 2000

One year after the Three Mile Island events of March and April 1979, the truth about TMI continues to lie buried under a mountain of distorted reports from the press and investigative commissions. Because TMI has been used as the lever to continue or escalate the policies that are putting the U.S. nuclear industry out of business, it is critical to restate the basic facts in the case.

(1) There is still no explanation for why two different valves on the back-up steam generator water-cooling system were turned off at the time of the initial steam generator trip-out. The only possible explanation, in fact, is *sabotage*. Yet the FBI and other agencies have not investigated this possibility, except in the most lackadaisical fashion.

(2) Kemeny Commission and Nuclear Regulatory Commission hearings and reports indicated that it took 7 to 8 minutes for the operating crew to discover that the valves were turned off. This contributed both to increasing the heating load in the core and to confusion in the control room about how to handle the indicated core condition.

(3) Had the back-up valves been on, then even the sticking open of the pressure relief valve (attached to the core cooling system) would not have created the conditions in the core that resulted in the temporary cutoff of core cooling water by the operators. The plant probably would have simply shut down temporarily, as has occurred in many other steam generator trip-out cases.

(4) Presidential Commission chairman Kemeny, in fact, referenced the case of the Davis-Bessey plant in Ohio in an article in the December issue of the Dartmouth alumni magazine. There too the pressure relief valve stuck open after the steam generator tripped out. As at TMI, the failure of the pressure indicator correctly to reflect the actual water level in the core was at first not understood by the operators. But within *20 minutes* they did detect and cure the condition. At TMI, with the closed backup valves complicating the situation, it took several hours to find the stuck relief valve. By then radioactive water was on the floor, and TMI was on its way to international notoriety.

Even so, as we reported at the time, there was never any possibility of a "China Syndrome" scenario. This syndrome was invoked after the press and the NRC issued erroneous reports about the possibility of a hydrogen explosion or a "meltdown" induced by a hydrogen bubble.

No review of TMI would be complete without mention of the person the NRC selected to head up its investigation into the TMI incident—Mitchell Rogovin. Rogovin is once again in the public eye because, at the NRC's request, he is reopening the TMI investigation to determine whether TMI officials suspected a "China Syndrome" early on in the incident and did not make their alleged suspicions known. This investigation, like the first, is billed as "fair." Yet, attorney Rogovin is a fellow of and general counsel to the

Institute for Policy Studies, an antinuclear, proterrorist institution based in Washington, D.C. that, among other things, promotes the "decentralization" of the U.S. economy and the rewriting of the U.S. Constitution.

Rogovin is also a member of the New York Council on Foreign Relations, the same group that has called for the "controlled disintegration" of the U.S. and world economies and the destruction of stable oil and nuclear energy supplies—a project euphemistically known as the *1980s Project*. (Rogovin, by the way, is not the only Council on Foreign Relations member involved in the TMI investigations. The author of the project's volume on nuclear proliferation, which called outright for the phasing out of nuclear power, is Kemeny commission member Professor Ted Taylor of Princeton University.)

Ending the Sabotage

The cover story in this issue on cleaning up the TMI mess and revamping the nuclear industry shows what could be done if we ended the sabotage of nuclear power.

The nation has already lost about a decade's worth of progress in the development of standardized nuclear power plants, breeders, and high-temperature gas reactors. The only way to produce the energy needs and new technologies for a growing world economy over the next two decades is to get back on the track of mass production of nuclear plants for domestic use and export. The old slogan of the Atoms for Peace program is as appropriate today as it was in the 1960s: "2000 by 2000."

An 'Aurable Tale

Once upon a time, the world's most advanced technological nation decided that it was too big. So it applied cost-benefit analysis to its military and industrial technology. Soon it became small. This created a problem. The world's second-most advanced technological power was continuing to build nuclear plants, train scientists and engineers, and experiment with all sorts of particle beam weapon systems.

So, the world's formerly leading power invented a new defense called the "aura of power," which was developed by its great thinkers named Strange, Rodney, and Zbig. But after a short time, an "aura gap" developed. They tried hard to fill in the gap with conservation, but that didn't work and so the great thinkers decided to convert what was left of the civilian economy into making old-fashioned weapons.

Then one day the up-and-coming power put one of its leading dissenters into exile because he complained about his country's use of real instead of aura power in a neighboring country. So the scientific academies of the newly small country pulled out their really big weapon: They stopped going to scientific meetings with their challenger.

In the past, they had used these meetings to get a better idea of what their potential adversary was doing scientifically and technologically. It was true that the adversary had some glaring weak spots in its economy and technology but overall it had demonstrated that its scientific academies could produce anything it needed when necessary. Some people on each side even thought that these exchanges would strengthen the hand of the politicians committed to peace and development on both sides.

Despite all this, the great thinkers and their scientific advisors decided that the boycott was after all necessary to fix up the aura gap. Everything went smoothly for a while. Then, one day there was a big display of the nation's new strength and an inquisitive child observing the show pointed out to all assembled, "Hey, there's nothing under the aura."

Calendar

April

7-11
4th Kiev Int'l Conf. on Plasma Theory and Plasma Physics
Nagoya Univ. Inst. of Plasma Physics
Tokyo

8-10
The Three Mile Island:
Technical, Social, and
Economic Implications
New York Academy of Sciences
New York City

8-10
Industrial Innovation Conference
American Association of Small
Research Companies
Baltimore, Md.

8-11
2nd Int'l Conf. on Emerging Nuclear
Energy Systems
Ecole Polytechnique Federale de Lausanne
Lausanne, Switzerland

14-17
4th Int'l Conf. on Nuclear Methods in
Environmental and Energy Research
American Nuclear Society
Columbia, Mo.

17-23
Int'l Conf. on Thermodynamics
and Statistical Mechanics
Int'l Union of Pure and Applied Physics
Alberta, Canada

21-23
American Power Conf.
Illinois Inst. of Tech.
Chicago, Illinois

21-25
4th Int'l Conf. on Plasma Surface Interaction
on Controlled Fusion Devices
Max Planck Institute for Plasma Physics
Garmisch-Partenkirchen, West Germany

28-30
Energy and the Third World
Council for Energy Studies
Vienna, Austria

Calendar items should be sent to *Fusion*, Suite 2404, 888 Seventh Ave., N.Y., N.Y. 10019.

The Lightning Rod

My dear friends,

In these perilous times every armchair in Washington has its military strategist; indeed some not entirely sturdy specimens must accommodate the weight of two, cigars and brandy included. Nor is the shortage of suitably martial seating arrangements for armchair generals unique. Everyone here in the capital has suddenly noticed our nation appears to be short of just about everything required to fight a proper war, except smokescreens and heavy verbal barrages.

Yet, there appears to be a powerful desire to draw lines in the dirt and dare. Why only last week, one of this district's loveliest hostesses complained to me that her best Persian carpet had been ruined by gentlemen digging in their heels and dragging their walking sticks in the most bellicose fashion. "I was inconsolable," she said, "until Henry promised to use his connections to replace it."

So extensive is military mania, that at the annual White House masked ball not only did Harold Brown appear as Genghis Khan and Zbigniew Brzezinski as Napoleon, but Agriculture Secretary Bob Berglund turned up as Attila the Hun and burned the entire South Lawn to prevent it from falling into enemy hands. Moreover, it is said that President Carter himself has taken to signing all communications to his cabinet members with the words, Former Naval Person.

Ah, well...it is perhaps unwise to joke about war. War is a serious business; no one knows that better than I. And once begun, it must be gone through to the very end—long past the mere abstract reckoning out of the winners and losers, at which the armchair strategist excels, to the point where the outcome is indelibly etched in blood and ashes and misery. If there are those who only think to terrify the enemy by expressing the willingness to fight, perhaps delivering a jab or too, let them remember war is not a game....

It is also evident that wars are more successfully fought when those who fight them know what they are fighting for, and thus are willing to cast the entirety of their moral and physical resources into the fray. It was not merely that General Washington took the Hessians by surprise that brought victory, but that our troops were fighting for the freedom of their country, while theirs were fighting for their salaries from King George. Whatever one's opinion of the Russians, it is clear their patriotic fervor has not cooled to the point of fielding a volunteer army of disadvantaged mercenaries to prosecute the interests of their nation.

A people that will not stand up for itself in developing prosperous and upright citizens is not very likely to give a good account of itself on the battlefield, so it is hard to understand why so many distinguished sons of the war party seem so enthusiastic about the economic "necessity" of shrinking our industries, softening our currency, and telling Americans to make less of themselves. Men who treat plutonium reprocessing as a grave danger while glibly proposing a round of nuclear "chicken" in the Persian Gulf ought to be taken seriously only in the necessity to remove them from positions of influence and secure to them the benefit of prompt medical treatment.

If we are menaced, let us take care it is not by ourselves.

Yr. obt. svt.

Benj. Franklin

Notice to Fusion Subscribers

There have been widespread failures in delivery of *Fusion* magazines to subscribers, and we have been investigating these irregularities. At this point, we are confident that computer-fulfillment problems have been reduced and that any delays and nondeliveries are in the bulk handling and mailing process.

We ask your help in tracking down the remaining problems. If you have been experiencing sporadic or chronic problems with missing or damaged issues, let us know the type of problem, what happened, the number of months involved, which months, the condition of the mailing label, and so on. Send us a label, if possible, or the expiration date of your subscription.

Write to: Fusion Energy Foundation, Suite 2404, 888 Seventh Avenue, New York, N.Y. 10019, Attn.: Cynthia Parsons.

Letters

The Politics of The Steam Engine

We continue to receive letters commenting on Philip Valenti's December article "Leibniz, Papin, and the Steam Engine: A Case Study in British Sabotage." In this issue, author Valenti replies to a sampling of the comments. The letter writers' welcome and informative comments on Robert Fulton and the origin of naval steam power will be answered directly in an article on the politics of early American science and technology now in preparation. Suffice it to say here that to the extent that Fulton was a "plagiarist," he was acting as an industrial spy on behalf of the progress and security of the young American republic.

* * *

To the Editor:

The article by Philip Valenti on early steam engines was most welcome, as it fills a gap of which most people were unaware. However I feel obligated to pick a couple of nits from it:

(1) All the evidence indicates that

Thomas Savery was quite incapable of thinking about ship propulsion, and all his "engines" were totally unrelated to propulsion of anything. Hence, I believe that in his 1702 pamphlet he was proposing nothing more than a bilge pump, and his trepidation on this came from his knowledge of how marine architects, etc., resent bright ideas from shoreside.

(2) Valenti ends on a triumphant note about how Fulton picked up the pieces and we all lived happily ever after. Actually, Fulton had a problem. In 1804, Evans got a patent on his "Columbian" engine, and had the audacity to claim the use of high pressure steam in this or *any other* engine, which was as bad as the Savery case 100 years earlier. Fulton fought this on the basis that it only applied to land engines, leaving the main battle to B. H. Latrobe, Chief Engineer of the Philadelphia Water Works. Details of this, and much else of interest, can be found in *Early Stationary Steam Engines in America*, C. W. Pursell, Jr., Washington, D.C. Smithsonian Institution Press, 1969.

Alan Beerbower,
Research Engineer,
UCSD Energy Center
San Diego, Calif.

To the Editor:

I enjoyed most of the December *Fusion*, the first issue of *Fusion* I've seen, but must add some more background to Mr. Valenti's article on the steam engine.

Not enough emphasis was put on the political connections Robert Fulton used to get the steam-powered boat credited to his name for all eternity. Poor Johnny Fitch. He had a commercially successful steamboat that plied the Delaware River beginning in the summer of 1790 at a speed of 7 miles per hour. Unfortunately, the jeers of the dock crowd got too much for passengers and the stockholders who offered free grog and sausages to their customers, and their boat, *The Perseverance*, was stopped at the end of the 1790 season . . . .

In 1793, the directors of the company sent him to France to build a steamboat there (he did receive U.S. patents on his inventions in 1791), but the revolutionary upheaval left the country as no place for radical inventions. He left his plans with either Aaron Vail or Joel Barlow, who were later able to show them to artist/civil engineer R. Fulton.

These items are gleaned from two books—*The Ohio* by R.E. Banta . . . and *Inventors Behind the Inventor* by Roger Burlingame . . . . I hope you can add the story of John Fitch to your steamboat story so you do not do to him what Mr. Valenti says the British did to Leibniz and Papin . . . .

Marshall Johnson
Chillicothe, Ohio

To the Editor:

I found the article "Leibniz, Papin, and the Steam Engine" to be informative and well written. However, I must point out that while Mr. Valenti was setting the record straight with respect to the invention of the steam engine, he is guilty of dissemination of the time-honored myth that Robert Fulton was the inventor of the steamboat.

While the question of the true inventor of the steamboat is one that is difficult to answer, it is clear that Fulton is not that person. Both John Fitch and James Rumsey in this country had constructed fully functional steamboats. Fitch's first effort was sucessfully tested in August 1787.

Furthermore, Symington in 1788 in England constructed a successful steamboat; and as early as 1783, a Frenchman named Claude-Francois-Dorothee, Marquis de Jouffroy d'Abbans, had limited success with a massive steamboat. (See *Steamboats Come True* by J.T. Flexner for details on all of above.)

John Randall
Houston, Texas

Valenti Replies
The Royal Society and The Politics of Priority

The issue of *priority*, as I established in the article on steam technology, involves something entirely different from the question "who was the first to discover or invent X?" We should not be overly concerned to identify which particular prehistoric personality first discovered fire as long as the event did occur and human progress resulted.

The point that must be made clear is how such issues have been used to contain scientific development and cut down the content of discoveries in order to reduce the spread of practical technologies. In its heyday, for example, the British Royal Society thrived on priority disputes. As I shall show here, such disputes have never been mere academic quibbling or jealousies; they have always been a political ploy of institutions, like the British Royal Society, *determined to control* and, if possible, destroy scientific progress.

Consider the most famous priority dispute of all, the one that led to my study of early steam inventions: the Newton-Leibniz Controversy. We English-speaking schoolboys often heard bits of gossip concerning Leibniz's alleged plagiarism of the calculus from the great Newton. A special committee of the Royal Society officially ruled on this issue in 1712, determining that Mr. Newton was indeed the first inventor. To expedite matters, Newton himself wrote the official ruling.

Since all the evidence, as I discovered, is so overwhelmingly on Leibniz's side in this case, why was Leibniz slandered so vilely by the Royal Society in 1712?

Consider the fact that Leibniz was at that time the confidant and teacher of the Electress Sophia of Hanover and that Sophia was next in line to become Queen of England at the death of the then-reigning and sickly Queen Anne Stuart. Consider the fact that Leibniz, a republican, was not likely to tolerate the sort of revival of the Roman Empire that was being plotted behind closed doors at the Bank of England.

I think it's clear that the Royal Society took on the job of concocting some pretext to brand Leibniz a liar, thief, and "dirty foreigner" in order to destroy his political and scientific influence within England. Unfortunately, Sophia died in June 1713, two months before Anne, and Leibniz never had a chance to defend himself personally *in London*.

However, Leibniz had certain significant English-speaking champions, which leads to my second illustrative "priority dispute."

James Logan came to Pennsylvania as William Penn's secretary and remained the intellectual leader of the colony until his death in 1751. He was certainly the most important single intellectual influence on *Fusion* columnist Benjamin Franklin.

Logan and Newton

In 1727, Logan received the third edition of Newton's *Principia,* and was shocked to find that all mention of Leibniz's name had been edited out! He wrote to William Burnet, February 7 that year:

"So now in this third they have done what I doubt impartial men of sober thought and solid judgment, who alone ought in such cases to be considered, will look upon as a yet greater instance of the same infirmity in dropping the scholium to the 2 Lemma between the 7th or 8th Proposition of the 2nd Book wherein Leibniz was named and his Discovery of the differential Method was justly taken notice of....'Tis certain the world was obliged only to Leibniz for the Publication of that method, who was so fair as to communicate it in a great measure to Oldenburg in 1677 when Sir Isaac was so careful of concealing his that he involved it in his letter of 1676 in strange knotts of letters that all the art and skill of the universe could never decipher...."

Logan went on to question Newton's mental competence in a subsquent letter to Burnet, May 10:

"He [Newton] is, however great, but a man and when I last saw him in 1724 walking up Crane Court and ye stairs leading to the Society's room, where I also had the opportunity of viewing him for about two hours, he bent under his load of years exceeding, unlike what they have represented him two years after as in body. Tis but reasonable to expect a Declension elsewhere, so that for his own honour as well as ye Nation's, to which he has been a very great one, had he and Queen Anne both been gathered to their ancestors by the year 1710 before that fierce unnatural dispute broke out between him and Leibniz, which I always believed was blown up by the forces of Society in opposition to the House that had so long employed Leibniz...."

Early Skirmishes

Logan's Philadelphia home, with its library of thousands of classical Latin, Greek, Arabic, and Hebrew volumes and modern scientific and literary works, was the natural intellectual center of gravity of Pennsylvania and neighboring colonies. And Logan's circle more than once battled the Royal Society on the question of priority.

In 1727, with Logan's encouragement, Franklin formed the Junto, "a club established for mutual improvement." Soon after, Thomas Godfrey, a young glazier and self-educated mathematician, asked to borrow Logan's copy of the *Principia* and soon after became part of Franklin's circle.

Godfrey proved to be a brilliant inventor, and soon revealed his invention of an improved quadrant. Logan recognized the importance of this achievement for navigation, and sent diagrams of Godfrey's discovery to the president of the Royal Society, Edmund Halley. We can only imagine the shock waves this generated in London. Could the Empire allow that a barbaric colony, designed merely for looting purposes, had intellectually outstripped the "mother country"?

The next issue of the Royal Society *Transactions* contained an article by the Royal Fellow John Hadley, claiming to have newly invented a quadrant identical to the one diagrammed in detail in Logan's letter! When Logan protested, Halley accused him of *plagiarism.*

In this early skirmish of the American Revolution, Logan mobilized all of Pennsylvania to gather affidavits swearing to Godfrey's honesty. The Royal Society would concede only that Hadley and Godfrey were "coinventors" and awarded both a prize of 200 pounds. However, because of accusations of "drunkenness," the society decided to give Godfrey a clock in lieu of cash.

And just as in the case of the famous misnamed "Halley's Comet" (which is another story), textbooks today immortalize "Hadley's" Quadrant as further evidence of the power of British science.

Philip Valenti

Amory Lovins
From the Ridiculous To the Absurd

To the Editor:

Readers more careful than yourself will have shared my problems with your comments printed after my letter in your January issue. You say, for example, that "Standard energy equivalences show that the energy produced by one nuclear plant is the equivalent of approximately 43,000 barrels of oil daily . . . ." This result can be obtained—but on three assumptions that are both unrealistic and different from those explicitly given in my letter:

- zero transmission and distribution losses (I assumed a nominal 10 percent);
- 100 percent capacity factor (impossible for the off-load-refueling reactors used in the U.S. even if they were perfectly reliable; I assumed 60 percent based on empirical data plus some generous optimism);
- the oil equivalent being calculated is not that whose heat content equals that of the electricity supplied, as I stated, but that which would have had to be burned in a 35 percent efficient power station to supply the same electricity.

Why you would want to do this I cannot imagine. The main effect of U.S. nuclear expansion has been to displace coal, not oil; the oil displaced is tarry residual oil, almost useless for other energy purposes; and since additional electricity can only be used for heating, a purpose for which it is grotesquely uneconomical (even with heat pumps), if you have just built a new power station — nuclear, coal-fired, or oil-fired—you will probably save money by writing it off and never operating it. If one did not build a nuclear plant, one would not build another power station to replace it, but rather provide the same marginal end-use services (heating) in the cheapest possible way; namely efficiency improvements and passive solar . . . .

In short, your comments on my letter consist of one obscure misrepresentation of what I calculated, two absurd technical assumptions, one irrelevant error, one rejection of your own assumption, two supposed paraphrases precisely contrary to my expressed views, and several malicious libels. I do not like being called a liar and am contemplating legal action. You would be well advised to publish this letter in full, with an appropriate retraction and apology.

Amory B. Lovins
Friends of the Earth

The Editor Replies:

We reply in two parts.

(1) All of your laborious computations are based on the absurd assumption that heat is needed only in end use and not to produce electricity for industry, homes, offices, and transportation. What you are really opposed to is the great contribution to humanity of Thomas Alva Edison—the electrical grid.

Your figures and energy economics are of a piece with the recent wild assertion by Professors Jorgenson and Hudson at Harvard (seconded by U.S. Secretary of Labor Ray Marshall), that a doubling of energy prices would result in a 5 percent growth in employment. We have exhaustively analyzed all such labor-intensive scenarios: your type of "soft" or "appropriate" technology offerings, other "conservation"- or so-called renewable-resource-based scenarios, and even the synthetic fuel and "quick-fix" military buildup proposals. The Fusion Energy Foundation's Riemannian model (full results to be published in *Fusion* shortly) demonstrates that such solutions will destroy the economy by about 1990.

No thanks.

(2) On your threat to sue. It's hard enough running a publication without becoming embroiled in costly and time-consuming legal actions. Furthermore, we wish you no ill-will personally.

We will remind you that we know a thing or two about British Secret Intelligence subversion of American and Continental science and industry. We know all about the Bentham-Shelburne operations against the French Academy of Sciences and the Ecole Polytechnique via the antiscience mob of Marat and Danton. The U.S. produced Edgar

Amory Lovins

Allen Poe and Samuel F. Morse as epistemological and counterintelligence agents against such subversion (even if most Americans now know them only as, respectively, literary and technical figures).

Likewise, we know about the British operations against the Göttingen University circle of Riemann and Cantor, as well as the history of the Cambridge Apostles, the Aristotle Society, and especially the antiscience programs of Coefficient Club dropouts Bertrand Russell and H.G. Wells to prevent generalized world technological progress. We know all about World War II and postwar attempts to maintain a nuclear monopoly and control over the U.S. program through the Baruch Plan.

Do you really think that a low-level adopted British propagandist can threaten a bunch of feisty American scientists and engineers like us? Your theories are wrong and most of your facts are muddled. Your proposed policies will kill billions and probably cause a thermonuclear war. Of course, it is possible that you may not be aware of these truths or may not be morally capable of thinking through their consequences.

Your threat to us was mailed from your present home base at the Friends of the Earth in London. We know all about the Friends of the Earth funding by the Aspen Institute, which in turn is under the direction of Robert O. Anderson of the Atlantic Richfield Corporation, which is linked to British Petroleum. We also know how Aspen helped put Iran's Khomeini in power to cut off oil to Western Europe and Japan and to impose Carter's austerity energy policy here in the United States. At the same time, Friends of the Earth was helping to tie up uranium reserves for its London, New York, and Canadian financial backers through its so-called environmentalist activities.

In short, we know how you and your friends are up to your necks in acts of economic warfare against the American republic. While you are publicly engaged in such activities, please at least have the good taste not to talk of using the American legal system that you are otherwise so intent on subverting.

Dr. Morris Levitt

Applause

To the Editor:

A couple of days ago... I happened to get a few glimpses of your magazine *Fusion*, which was being avidly devoured by a fellow passenger on the aircraft. It impressed me as a good "gutsy" intellectually above-average, conservative, and witty journal. I also like its sense of humor!...

Merrill J. King, Jr., MD
Togus, Maine

To the Editor:

Just finished reading the December 1979 issue of *Fusion*. Tremendous!... I am extremely interested in having my whole physics class read this issue and see the importance of what you are doing to overcome people like Jane Fonda....

Edward F. Robinson
Physics Dept., Damien
Honolulu, Hawaii

To the Editor:

I like your publication very much and give it to my students to read (I teach chemistry and physics). I try very hard to get them out of the "Jane Fonda Syndrome."

Keep up the good work.

Lillian Bablanian
Oyster Bay, New York

News Briefs

Edward Teller NSIPS

NAS CANCELS SOVIET SCIENTIFIC EXCHANGES

The National Academy of Sciences announced Feb. 25 that it was suspending all scientific exchanges with the Soviet Union, beginning with a symposium on laser fusion scheduled for March 3 at the University of Arizona. The academy's governing council took this action to protest the Soviets' internal exile of dissident physicist Andrei Sakharov.

"These actions represent, from our perspective, an intrusion upon the human rights and scientific activities of an eminent scientist," the council said.

Other academy-sponsored meetings that were suspended include three planning sessions for symposiums on science policy, physics, and experimental psychology.

Fifteen Soviet physicists were scheduled to attend the fusion meeting.

COMMERCE DEPT. BARS SOVIET SCIENTISTS FROM U.S. MEETING

The U.S. Commerce Department ordered the American Vacuum Society to bar eight physicists from the Soviet Union, Hungary, and Poland from a meeting Feb. 18 to discuss bubble memories, a new computer technology. The Commerce Department also forced the scientists at the meeting to sign a statement pledging not to discuss any information from the sessions with any Soviet-bloc scientists.

Richard Riegert, one of the organizers of the meeting, told the *New York Daily News* that the Commerce Department "claimed that by talking to anyone we would be guilty of exporting technology.... We were told we would have to apply for an export license, which would take two months and would be denied." Riegert said that the meeting participants agreed to sign the Commerce Department pledge because "we were instructed to do it or go to jail."

State Department officials interceded with the Commerce Department to allow the delegation from the People's Republic of China to attend the conference.

TELLER WARNS OPPONENTS OF CIVIL DEFENSE, FISSION

In an op ed Feb. 10 in the *New York Times* titled "On the Brink," Edward Teller warns that the *"absence of* civil defense is *provocative"* because it tells the Soviet Union that the United States is preparing a first strike. Similarly, Teller says that a real peace policy would involve development of nuclear energy resources to avoid world conflict over the oil supply.

Teller contrasts President Carter's nuclear policy, in particular the Carter policy against fuel reprocessing, with that of Anatoly Aleksandrov, head of the Soviet Academy of Science. Aleksandrov, Teller says, "describes nuclear reactors as instruments of peace. He says that the oil shortage will lead to wars. Russians will avoid them, since they will have enough energy from nuclear sources. The wars would only be between capitalist countries. I do not believe in the Kremlin's peaceful intentions; I do believe in Mr. Aleksandrov's good faith."

"Opponents of civil defense and fission reactors should take note," Teller concludes.

KENNEDY RULES OUT NUCLEAR ENERGY IN HIS FUTURE

Senator Edward Kennedy has revamped his lukewarm antinuclear position and now says "There is no role for nuclear energy in my energy future."

The revised Kennedy position was announced Feb. 15 in a statement endorsing the program of the Campaign for Safe Energy, a coalition of New Hampshire organizations opposed to nuclear power. As cited in *Fusion*'s January 1980 "Energy Scorecard for Presidential Candidates," Kennedy had called for a *moratorium on nuclear plant licensing until new safety regulations made it* possible for "nuclear power to move forward again." In his latest statement, Kennedy says "I believe that a plan should be developed to phase out existing nuclear power plants as other sources are phased in."

U.S FARMERS URGED TO GROW MARIJUANA

A lead article in the March issue of *High Times*, a slick prodrug magazine, urges U.S. farmers to begin growing marijuana as a cash crop. Author Pamela Lloyd makes the argument that American farmers have traditionally grown hemp, and she cites the "Kentucky Study," a model plan for marijuana decriminalization written by Gatewood Galbraith. Galbraith, who has declared his 1983 candidacy for Kentucky governor, foresees $30 to $50 million per year per state in tax income on the marijuana crops, which he would earmark for "health programs." Galbraith urges marijuana users, small farmers, and antinuclear forces to "band together in the face of the really devilish and malicious and deadly thing that the government is trying to push down our throats due to the economic interests of a few."

CARTER ADMINISTRATION PUSHES POT INTO DRUGSTORES

At least two government agencies are now pushing pharmaceutical companies to market the active ingredient of marijuana, THC, as a prescription drug. According to *Science News* Feb. 16, the National Institute on Drug Abuse and the Food and Drug Administration have been meeting with the drug companies to urge them to market the drug, ostensibly for the relief of the side-effects of anticancer drugs. Medical experts have argued that other drugs are available of equal potency that have less destructive side effects than marijuana. (See "The Biological Effects of Marijuana," by Gabriel Nahas, M.D. in *Fusion* Sept. 1979.)

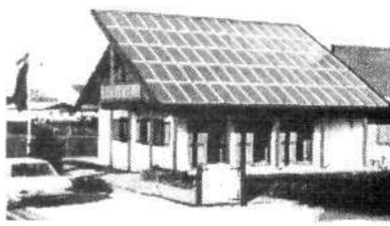
Not surprisingly, the government's strongest ally is the group NORML (National Organization for the Reform of Marijuana Laws), which commented that "moral and social bias should not be allowed to prevent the use of marijuana cigarettes for medical purposes...." NORML sees the medical availability of THC as a first step toward total legalization of marijuana.

Science News reported that the head of the National Institute on Drug Abuse, Robert Willette, said that if all goes well, the public can expect to see THC available by prescription in one to two years.

SOLAR HEATING RAISES RADIATION EXPOSURE

The extra insulation of a solar-heated house may double the annual radiation exposure of its inhabitants, according to Jack Challem writing in the *New Mexico Independent*. The culprit is radioactive radon gas, produced by the disintegration of radium in building materials. As Challem explains, "All building materials that come from the earth...contain trace amounts of uranium and radium. The uranium and radium are impossible to avoid, though their levels in the earth...tend to vary geographically. They are relatively high in the Rocky Mountain states, including New Mexico."

In an average house, which is drafty, the radon gas blows away, but in a solar-insulated home, less of the radon gas can escape. This can double the normal individual exposure to naturally occurring background radiation of 150 millirems, Challem says, noting that this is the kind of increase that would cause an antinuclear riot if it came from a nuclear power plant.



The solar house: radon gas trap?

LOUSEWORT LAURELS TO CHICAGO TRIB ENVIRONMENT EDITOR

Chicago Tribune environment editor Casey Bukro wins lousewort laurels this month for his Feb. 20 article pitting fusion energy against fission energy. Titled "Expert Adds Fuel to the Fission Vs. Fusion Debate," the article warns the public that "there will be radioactive waste problems with fusion plants, just as there are from fission plants...." Exactly two paragraphs in the Bukro piece describe the fusion process. The remaining paragraphs are devoted to discussion of just how many *tons* of radioactive waste it is possible for one fusion plant to make. What Bukro doesn't explain is that this "waste" is actually reactor component parts that contain short-lived, low-level, irradiated solid wastes. These components can be stored right under the reactor when replacement parts are substituted.

Viewpoint

by Philip M. Crane

The Real Disaster At TMI

As we now know, the incident at the Three Mile Island facility was not a disaster; it was a learning experience. Most important, we learned that nuclear safety technology, although not perfect, is more than adequate in preventing hazardous radiation leakage. What else we learned is that the media and government are not friends of nuclear power.

The Media Institute, a nonprofit organization located in Washington, D.C., did an interesting study on how the electronic media covers nuclear power. Keeping in mind that two-thirds of the American population rely on television as their primary source of news information, the Media Institute's findings help to understand current public opinion of nuclear power. Television coverage of nuclear power continues to focus on insignificant "color" rather than factual information on its risks and benefits. By "color" I mean the attention-getting marches and "antinuke" rallies that help up Nielsen ratings, rather than sound scientific evidence.

In light of the fact that seven out of ten "outside" sources or experts on nuclear power interviewed during TMI were, in general, outspoken critics of nuclear power, it is little wonder why the only health consequence of the incident was psychological in nature. More of an effort could have been made to calm the public with facts rather than agitate the situation through speculation.

For American society to survive as we know it, we must produce. We need energy to grow economically; and 95 percent of America's physical scientists, in addition to numerous scientific organizations including the National Academy of Sciences, concur that this energy should largely be nuclear. However, our present administration and Congress do not share this scientific viewpoint, as evidenced by the fiscal year 1981 Energy Budget. The president is clearly not interested in moving the nuclear option ahead, since overall funding for nuclear initiatives has dropped dramatically. The budget reflects President Carter's emphasis on safety through regulatory measures, rather than on developing new technologies such as breeder reactors.

Although no new domestic nuclear plants have been ordered for 1980, the market in foreign countries is thriving. The major American manufacturers continue to develop their overseas markets, where governments are much more receptive to the idea of nuclear-generated power.

How do we get past the barrier of negative pubic opinion that is further reinforced by federal actions? How do we make the public *believe* in the industry's 23-year safety record?

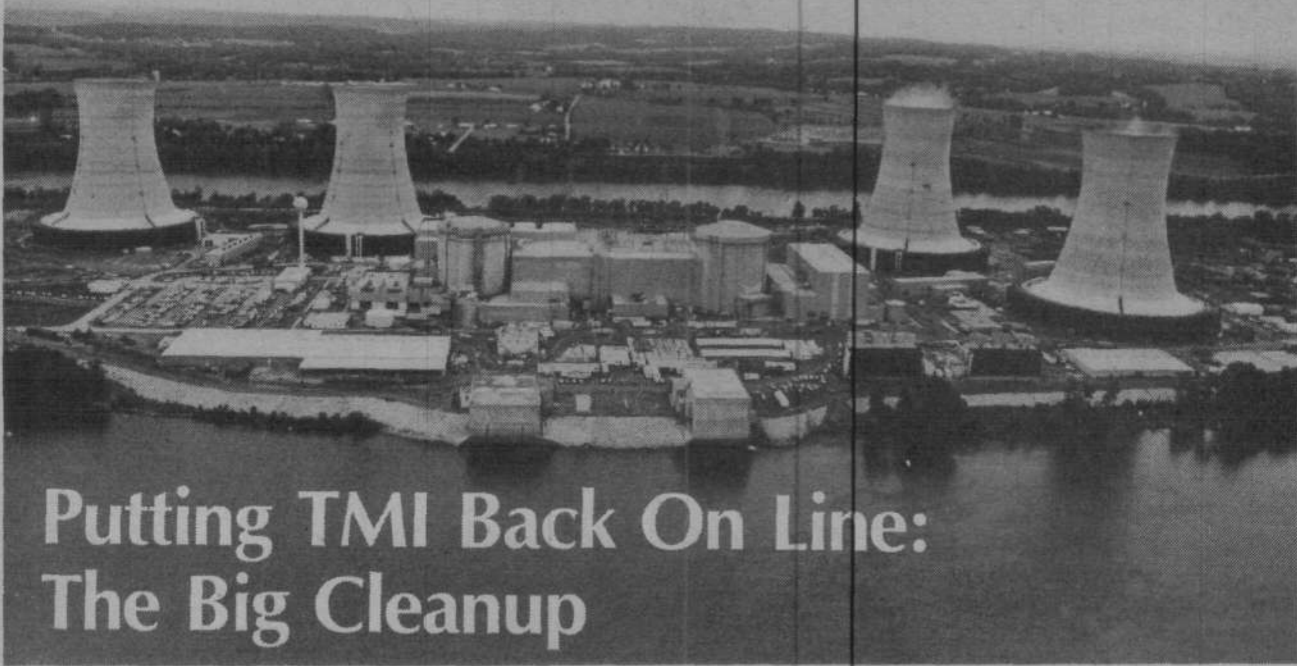
Changing the public's attitude toward the use of nuclear power is one of the greatest challenges the industry and scientific community must face. There is a stridently vocal element in our society that views industry and business with unabashed animosity. This attitude has reached an almost religious moral status and, obviously, is detrimental to the production America and the entire world need.

Elitism of this nature is dangerous. Americans must be deprogramed from this no-growth mentality and reeducated to the idea of progress. Our country must restore a commitment to economic growth and prosperity, to reason, and to material advancement as one of the signs of intellectual and moral progress. Until our nation disregards the no-growth policies that have stifled both our economy and energy production, we will continue to be vulnerable to unpredictable changes in the world's economic and political climate. And this could very well be the real disaster of Three Mile Island.

Congressman Philip M. Crane, an Illinois Republican, is one of the recognized conservative leaders in the House and a contender for the GOP presidential nomination.

'Colorful' TMI headlines: No basis in science.

Nuclear Report



Putting TMI Back On Line: The Big Cleanup

by Jon Gilbertson

This report is based in large part on Jon Gilbertson's extensive interview with Jack Devine, recovery engineering manager for the Three Mile Island Nuclear Power Plant, Unit 2, in Middletown, Pennsylvania. Devine is employed by General Public Utilities Company, the parent company of Metropolitan Edison, the utility that operates the TMI units.

The conclusions and opinions rendered in this report are those of the author and do not necessarily represent the view of Jack Devine, General Public Utilities, or Metropolitan Edison. Fusion *magazine wishes to thank both utilities for their assistance, with special thanks to TMI manager of communications Sandy Polon and administrator of public information David Klucsik.*

Jon Gilbertson, a leading authority on nuclear safety, is the director of nuclear engineering for the Fusion Energy Foundation. He has dedicated this report to the 60 percent of the American population that already supports nuclear power and to that 25 percent that will support it once their legitimate questions are answered.

Nearly one year after the incident at Three Mile Island Nuclear Power Plant, Unit 2, the plant remains shut down, and it will remain shut down for at least another three or four years, until the cleanup is completed.

Unit 2 staff is now involved in the initial stage of cleaning up the radioactive contamination released to the reactor containment and auxiliary buildings during the early hours of March 28, 1979. Simultaneously, the staff is planning the ordering and building of equipment needed to complete the entire cleanup job, including the removal of the damaged fuel. Considering that this is the first time that any commercial power reactor has faced such a massive clean-up problem, the work is progressing very well.

Just across the fence from Unit 2 is TMI Unit 1, a ready-to-operate reactor that has been shut down since it was closed for routine refueling six weeks before the Unit 2 incident. Started-up in 1974, this reactor has one of the best operating records, measured in terms of generating capacity and availability, of any reactor that operated during that five-year period.

Aside from making sure that all Unit 1 storage and processing systems used in the Unit 2 recovery work this past year are again separated out, the only thing preventing Unit 1 from going back on line again quickly is political. All other Babcock & Wilcox reactors of the TMI design that had been shut down for modifications after the TMI incident were restarted months ago and are generating electricity much more cheaply than comparable oil or coal units.

Although this report deals primarily with the status of the clean-up effort at Unit 2, a major concern is to start up Unit 1 as rapidly as possible in order to minimize the replacement costs of electricity to the people of Pennsylvania. These costs are now running about $24 million per month —$14 million per month for Unit 1 alone. In addition, the startup of Unit 1 will help to rebuild confidence in nuclear power in the population around TMI and will provide a much needed boost for the U.S. nuclear industry.

Preventing the Unit 1 startup is expected to be the chief target of the antinuclear environmentalist move-

ment this year—much the same as the environmentalists' attempted shutdown of the construction of the Seabrook, New Hampshire nuclear plant last year. As the replacement costs for the shutdown Units 1 and 2 demonstrate, the antinuclear goal is one that the nation —and the people of Pennsylvania— can ill afford.

In fact, breaking out of today's austerity-inflation spiral depends on securing a stable and economical energy resource. This can be achieved only by expanding nuclear power, building more plants like TMI, and making sure that this nation is committed to developing an even cheaper long-term resource—fusion energy—over the next two decades.

The Safety Question

For those genuinely worried about the safety of nuclear power—and there are many as a result of the hysterical publicity around the TMI incident—here are a few points to keep in mind:

(1) Even though the TMI Unit 2 experienced the most serious incident that has ever occurred in a commercial nuclear power plant, *not one single person was even harmed or hurt.*

(2) The safety systems on Unit 2 worked as designed, and even though some were overridden erroneously by the operators, the safety systems responded by completely protecting the public from significant radiation. The damage was limited to economic damage; that is, cleanup and fuel replacement.

(3) The much publicized story of a possible hydrogen explosion in the reactor vessel followed by a core meltdown was a fiction. As the Nuclear Regulatory Commission admitted, *there never was any possibility of such an explosion*—The conditions did not exist nor could they, since there is no source of oxygen available in the reactor. This story that spread through the media and kept people on edge for several days was completely false.

(4) The antinuclear propaganda film "The China Syndrome," starring Jane Fonda, which appeared just before the TMI incident, led the public to believe that they could expect a core meltdown at Unit 2. The truth is that it is doubtful that any fuel pins melted during the incident—and fuel pin melting and a core meltdown are two completely different things.

(5) The levels of radioactivity released were so low that they posed *no threat* to public health, even in the long run. As several investigations have stressed, even the precautionary evacuation recommendation for pregnant women and small children should never have been issued and was directly a result of false or faulty information from the press or the NRC.

(6) The facts of the TMI incident lead to the conclusion that by any standard of comparison, nuclear power is still by far the safest and environmentally the cleanest form of energy.

The Unit 2 Cleanup

The importance of reporting how the Unit 2 cleanup works is not only to inform the public of what has to be done to get the reactor back on line again, but also to dispel some of the public's fears and myths about the invisible radiation bugaboo.

In nuclear engineering lingo, cleanup is usually referred to as decontamination. Very simply, this means getting rid of the radioactive material that has contaminated the walls, floors, equipment, surfaces and so on of certain rooms or buildings. The cleanup effort is nothing extraordinary. It is accomplished using a standard array of cleaning equipment—high-pressure water and steam sprays, detergent, abrasive sprays, fire hoses, mops, floor polishers, and plain old scrub brushes.

There is nothing unknown about the cleaning process: Radioactive contamination simply has to be scrubbed and washed off like any other contaminant, such as smoke, soot, oil, or a chemical—except that it has to be done carefully and the waste water used has to be collected and eventually processed. People have been cleaning up radioactive contamination for years now —it's been 40 years since the Manhattan Project—and have become very good at it. There are companies that specialize in such cleanup, and many of their staff persons are now working on this effort at TMI.

The point to be emphasized is that many ordinary people—scientists, technicians, and others—work around radioactivity frequently and are not harmed or endangered; nor do they worry about the alleged dangers.

Most of the clean-up workers at Met Ed have volunteered for the job. In fact, most are Met Ed employees who are nonnuclear people—line-men, tree trimmers, secretaries, meter-readers, and so on, who have never set foot in a nuclear plant before. Many more have signed up and are waiting to be called for the cleanup of the containment building.

Where the Radioactive Material Came From

The damage to the TMI reactor fuel and the release of radioactivity from the reactor core was caused primarily by a steam safety relief valve that stuck open for more than two hours. Because the reactor plant operators did not realize that this valve was stuck open during this time, some of the manual protective manuevers the operators took with the cooling water flow caused reactor fuel to overheat and crack open, releasing some radioactive fission product gases and solids into the coolant water.

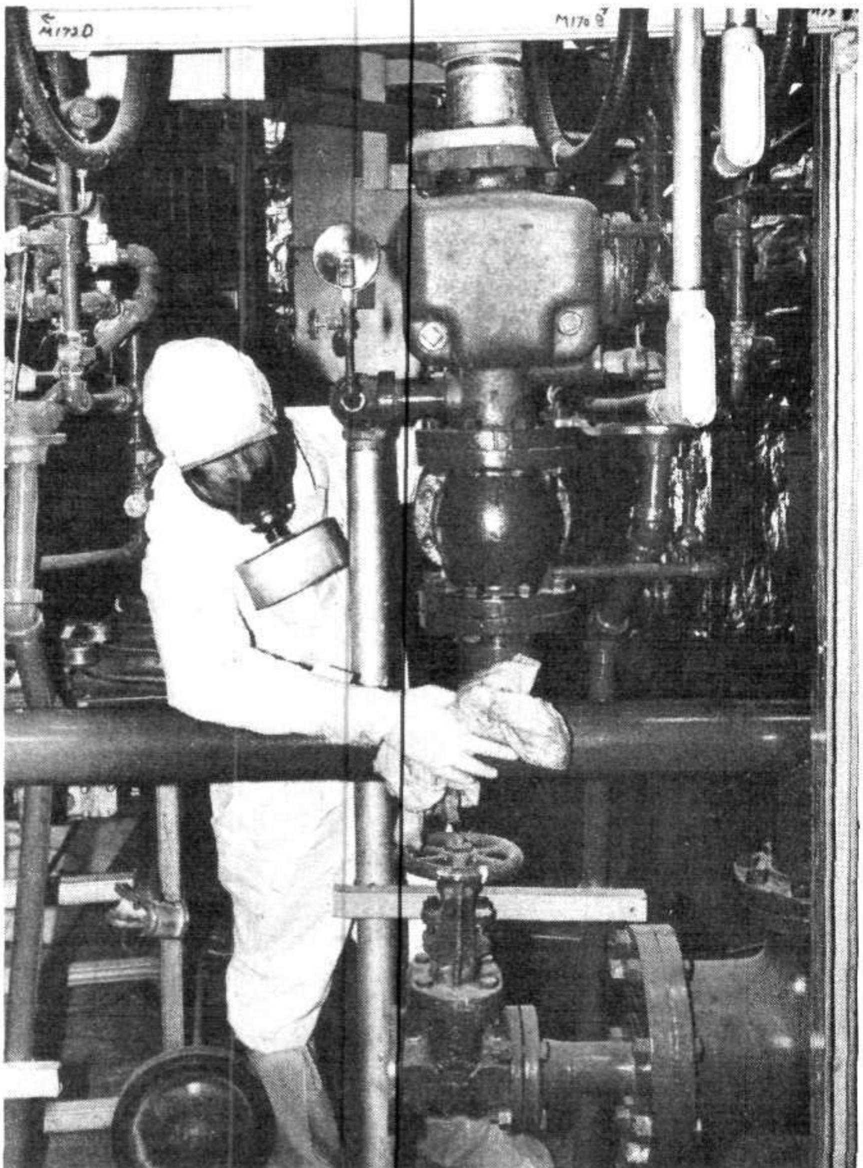
Some of these fission products eventually found their way into the containment building sump area (the floor) when they were blown out of the reactor coolant system through the stuck-open valve, along with the steam-water mixture. The sump pump in the containment building automatically came on during the first hour, pumping some of this contaminated water into the auxiliary building. This is the source of most of the radioactive material in that building. It should be kept in mind that both buildings are designed to contain and handle radioactive material safely and both did perform the job just as designed—with plenty of safety margin left over.

Although the amount of radioactivity that was released, particularly to the containment building, was very large, the actual amount of material involved was very small. Most of the material was in gaseous form and consisted of the noble (inert) gases xenon and krypton, along with some small amounts of iodine gas. The solid material is mostly the elements cesium and strontium.

In total, the amount of gas released to the two buildings could easily fit in a regular-size diver's oxygen tank, and the solid material would fit in a quart milk bottle.

The problem is that most of this material is radioactive; that is, since it was formed as a by-product of the chain reaction or fission process, the material consists of isotopes of these elements that are unstable. Unstable here simply means that the elements are still "decaying" to a stable state by releasing an alpha or beta particle (electron) or a gamma ray. This decay process is called radioactivity.

With every day that passes, the radioactivity problem at TMI is getting smaller. That is, as the unstable elements decay away, the amount of radioactivity decreases and the material becomes easier to deal with and to



Radioactive cleaning: The workers here are mopping the floor and washing equipment in the auxiliary building during clean-up operations. After several applications of this method, the radioactivity was reduced to levels so low that protective clothing and breathing apparatus were no longer needed.

Photographs courtesy of Metropolitan Edison Co.

clean up. These unstable elements decay at various rates, called half-lives—a measure of the time it takes the radioactivity to decrease by one-half. Because it is now nearly one year since the material was released at TMI, the radioactivity levels are considerably reduced from what they were on March 28, 1979.

Although still high compared to what a human being should be exposed to with no protective clothing or equipment, the radioactivity in the containment building is such that a worker can now enter for a short time with proper protection. Such entry is planned within a month. The auxiliary building, on the other hand, which received much smaller amounts of radioactive material during the incident, is almost completely cleaned up now and people can work there in most areas with minimal protection, (just booties and gloves).

The Auxiliary Building

The auxiliary building was the obvious place to begin the cleanup because the levels of radioactivity were lowest there and because the building and its equipment are needed for cleanup of the containment building. There were two types of radioactive material in this building at the start of cleanup last fall.

First, there were normal reactor coolant overflow water and other normal low-level radioactive waste water that had been in storage tanks prior to the March 28 incident. Second, there was water from the reactor containment building floor that had been pumped to the auxiliary building during the first hour after the incident. Most of this water was pumped into spare tanks. However, when these tanks filled up, some of this water spilled onto the floor before the sump pump was turned off. This second type of water is called intermediate-level* radioactive water since its activity is somewhat higher than normal low-level water.

If there had been no overflow spilling on the floor, it would not have been necessary to clean up the auxiliary building, because all the contaminated water would have been contained in the storage tanks. The water spill allowed contained fission gases to escape to the building atmosphere, thus contaminating it. In addition, the spill allowed the solid fission products in the water to be dispersed over the floor and other surfaces reached by the water. After filtering out the gaseous iodine, workers safely released most of the noble gas xenon to the atmosphere in small quantities during the first days after the incident. It was these small releases of xenon gas that the press exaggerated into a "Nuclear Cloud Approaching Harrisburg."

The radioactive xenon that was not released has long since disappeared, since its half-life is only 5.3 days. The solid fission products that are finely dispersed in the water present another sort of problem, because they tend to settle out on all surfaces contacted by the water and remain there even after the water is removed. These radioactive materials—mostly cesium and strontium—have to be removed by hosing, spraying, polishing, scraping, and scrubbing, with most of the work done by hand.

'Releasing and dispersing small amounts of radioactive noble gases safely to the atmosphere is a proven scientific technique. . . .'

The accompanying photographs illustrate this nearly completed operation as it was performed in the auxiliary building. The surfaces were simply cleaned and recleaned until little or no radioactivity could be measured by the very sensitive radiation monitors used.

Processing the Contaminated Water

The more long-term clean-up operation is the processing and storage of the waste water and other contaminated water in the storage tanks. The water that is used as the main liquid in all of the various cleaning processes becomes contaminated with radioactive material as it is removed from the surfaces. This waste water must be carefully retrieved, contained, and stored in tanks just like other contaminated water, since it now has a low-level radioactivity.

At TMI Unit 2, all this waste water, along with other waste water from before the incident, is stored on site and is now being processed. Processing involves separating the radioactive material and other contaminants such as detergents, abrasives, and so forth from the water so that the water can be disposed of or reused in further cleaning operations.

Although the auxiliary building has equipment available to process the small quantities of contaminated water during normal operation, this equipment could not even begin to handle the quantities of contaminated water that exist now. Therefore, it was necessary to install a processing system with a much larger capacity to do the job. This system, EPICOR II, began processing water late in November 1979 and will continue over the coming months.

EPICOR II is processing contaminated water from the auxiliary building where the water is contained in storage tanks. Later it will process water stored in the nearby fuel handling building, for a total 400,000 gallons. Working around the clock at the rate of about 3,000 to 5,000 gallons per day, the job is estimated to take about three months. As of this writing, 125,000 gallons have been processed.

How EPICOR II Works

EPICOR II removes radioactive particles from the water using a series of organic resin filters that work something like a household water softener. The water passes through three large cylindrical tanks where resin beads separate and filter out fission products. This is a proven method that the defense industry has used for more than 20 years.

The system is designed to completely contain the contaminated water; built-in safeguards prevent any leakage to the environment. From the time water enters EPICOR until the radioactive materials are safely sealed off, the process is constantly monitored. Met Ed and NRC personnel on site oversee each key function and continually check air and water samples to assure safe and effective operation.

The only contaminants remaining in this water after processing are small amounts of tritium, an isotope of hydrogen that cannot be removed by these chemical separation processes. However, this slightly radioactive isotope is present only in very small amounts and can be easily diluted with clean water to reduce the tritium concentration to levels far below those allowed by government regulation for discharge to the Susquehanna River.

In any other location and under any other circumstances this is precisely what would be done. However, the antinuclear hysteria generated around the TMI incident has prevented this harmless waste water from being disposed of in the normal manner. As a result, Met Ed has made provisions to store the processed water in special tanks on Three Mile Island. Until the NRC makes a final decision on the case, this water may be used for further clean-up operations in the containment building or it may just remain in storage. Once more, I emphasize that this water, with the proper dilution, is completely drinkable!

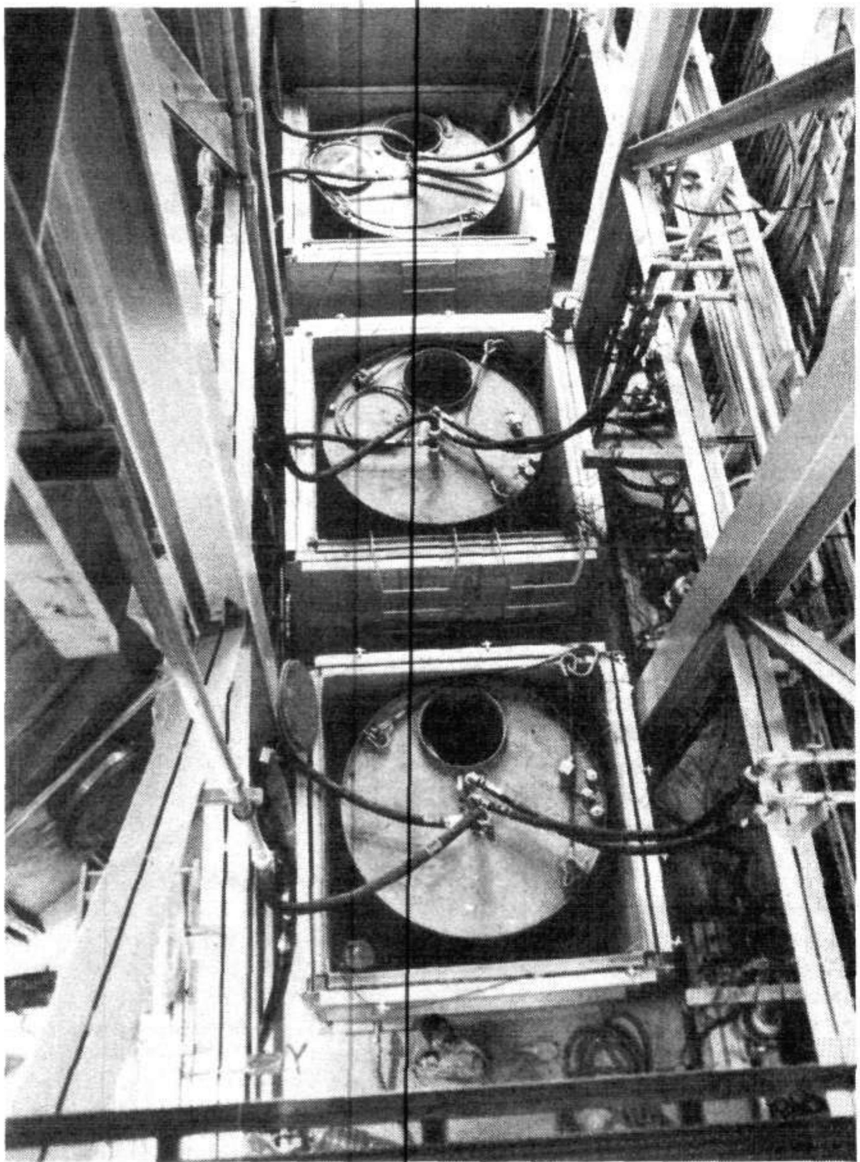
The Filtered-Out Contaminants

The solid resins that are used in EPICOR II to filter out the radioactive material are stored at TMI for the time being in specially constructed storage facilities. There is plenty of room onsite to build sufficient temporary storage for these resins from the entire Unit 2 clean-up and processing operation. The permanent storage of these contaminants, however, will be at one of the low-level waste disposal areas in the United States, probably at Hanford, Washington where TMI has already shipped some solid wastes.

Before this waste can be shipped out, the sludgy resin material must be completely dried and solidified by removing all the entrained water. This will be done at TMI over the next two-year to four-year period, after Met Ed brings on site the appropriate evaporator and drying equipment. These dry solids will then be compacted in steel and concrete containers, placed in heavy shielded shipping casks, and shipped by truck to the off-site waste disposal area, much the same as any low-level solid waste material treated.

The removal and transportation of radioactive wastes from Unit 2 is already underway, with refuse moving by tractor-trailer units to the Hanford Reservation in the state of Washington. Over a four-year period, the auxiliary building cleanup and decontamination of water will require about 250 shipments. The projections for the decontamination of the containment building and the reactor cooling system indicate that about 2,000 to 2,500 shipments will be required for this material.

The current shipments consist of 150 to 160 55-gallon steel drums containing dry, compacted solid refuse from the clean-up operations. Included are radioactively contaminated work clothing, shoe covers, small tools, rags, paper, and other debris. By August 7, 1979, when shipments began, TMI had accumulated some 600 drumloads. Although halted temporarily in November when Hanford was closed for a short period, these shipments will continue for several years—as long as the antinuclear movement demands to permanently close waste disposal sites remain unsuccessful.



Three resin tanks (filters) in place in the EPICOR II system just prior to startup of processing of contaminated water from the auxiliary building.

The Containment Building

Because of its mammoth size and huge surface areas, the containment building is the biggest clean-up job. The cleaning techniques and processes will be much the same as those already employed on the auxiliary building, except that the scale is larger. Met Ed has estimated that as many as 100 people per shift will be working in the containment building during this clean-up, compared to a maximum of 30 per shift for the auxiliary building.

The plan of attack for this building has been nearly all worked out and is expected to go into operation in late February or early March 1980. In fact, some of the initial preparatory steps have already occurred, including sampling and measurements of radiation levels at several elevations of the building and a remote visual inspection by video camera of the interior of the top part of the building. It was found that the radiation levels are much lower than originally estimated and, as expected, there appears to be no equipment damage. For example, the cover glasses on instrumentation panels inside the building do not appear even to be cracked or broken.

The next two steps are to purge the containment building atmosphere in order to eliminate all airborne radioactivity and to send a team inside to conduct a much more detailed inspection and collection of radiation data.

It would be preferable to purge the building atmosphere first and then send in the team, because this would lower the radiation levels in their working environment. However, depending on how long it takes the NRC to give the go-ahead for the building atmosphere purge (see next section), Met Ed may decide to send the team in first. In either case, human entry can be made safely; what will vary are the amount of protective clothing and the length of time in the building.

At any rate, initial entry is now sched-

Radiation Fact Versus Fiction

The antinuclear movement has used the hysteria created around the Three Mile Island incident to add a terrifying tale to its arsenal of scare stories: Even when nuclear plants are operating in safe, routine fashion, the story goes, they emit an invisible but deadly force—radiation.

Last summer, then-secretary of the Department of Health, Education, and Welfare Joseph Califano, announced that 10 persons would die of cancer as a result of TMI's radioactive emissions. Ralph Nader has called nuclear-plant related increases in radiation levels "the modern form of suicide." And Dr. Benjamin Spock has beseeched parents to end nuclear power development in order to stop radiation-related birth defects. Even today, the scaremongers are prolonging the cleanup at TMI by promoting scare stories around the release of harmless amounts of krypton gas.

Fortunately, none of the scare stories has any basis in fact.

The Facts

• According to studies by an ad hoc committeee made up of the Environmental Protection Agency, the Health Education, and Welfare Department, and the Nuclear Regulatory Commission, the average cumulative radiation dose to persons within a 50-mile-radius of the TMI plant was 1.5 millirem—less than 5 percent of that received from one normal chest X-ray.

On average, a person who lives within 50 miles of a nuclear plant receives only 0.01 millirem per year, less radioactivity than is received annually from cosmic rays, the air, the ground, building materials, food, jet flights, or watching color television (see table).

• Extreme doses of radiation over an extended period of time result in a proven increase in cases of cancer. Using the method of *linear extrapolation*, those who predict deaths from TMI's minute emissions of radiation assume that because there were a certain number of cancer deaths after Hiroshima, there will be a linearly calculable number of cancer deaths in the TMI area in proportion to the 1.5-millirem exposure.

AVERAGE ANNUAL DOSES OF RADIATION PER PERSON IN MILLIREMS

Nuclear reactor (50-mile radius)	0.01
Natural background	
cosmic rays	35.00
air	5.00
building materials	34.00
food	25.00
ground	11.00
Man-made sources	
coast-to-coast jet flight	5.00
color television	1.00
chest X-ray (one)	50.00

Sources: Petr Beckmann, *The Health Hazards of Not Going Nuclear*, Boulder Colo.: The Golem Press, 1976.
James J. Duderstadt and Chihiro Kikuchi, *Nuclear Power, Technology on Trial*, Ann Arbor: The University of Michigan Press, 1979.

One flight equals a lifetime's residence near a nuclear reactor.

uled for the beginning of March. This entry will be made by a team of three well-trained engineers and technicians who know what to look for once inside and how to guard themselves from overdoses of radiation. A standby team of three qualified workers will be ready outside the airlock in case of emergency need, and the team inside the containment building will be in constant radio communications with supervisors in the containment service building.

The initial entry personnel would wear several layers of protective clothing, including hard hats, three to five layers of full anticontamination clothing with surgical caps, hoods, rubber boots, outer layer plastic suits, and full raingear, including hat and coat.

The gear they will carry includes breathing apparatus, devices for measuring gamma and beta radiation, air and gas samplers, explosive gas meters, beam flashlights, and two-way radios. The length of time the reentry team can spend in the containment building will depend upon the level of radiation, but could be as long as an hour or more. The team will have two basic assignments: (1) mapping the radiation levels and "hot spots" in as much of the building as is possible under the conditions they find; and (2) assessing the physical condition of the inside of the containment building.

Decontaminating
The Building Atmosphere

Probably the single largest *political* hurdle to clear in the entire clean-up operation will be getting rid of the radioactive gas from the atmosphere of the containment building.

Technically, this problem is the easiest to solve of all the clean-up operations—if normal procedures could be followed. Normally the building air would be filtered and purged at low flow rates, bringing in fresh air from the outside while at the same time discharging the contaminated air to the atmosphere.

The only contaminant now left in the building air of any significant quantity is the noble gas krypton-85. The behavior of noble gases when discharged into the atmosphere is a well-known phenomenon verified by many years of experience. The krypton discharge from the containment building will be completely dispersed when released and will very quickly disappear as it becomes diluted. There are absolutely no unknowns in this operation, and it is completely safe. After filtration to remove any other contaminants, the krypton would simply be purged from the containment building at flow rates that would keep the releases far below those normally allowed by NRC regulation. The total time estimated to complete the job is four to six weeks, depending on the release rates used.

It sounds simple, but it is also the biggest political issue now in the TMI area. Antinuclear specialist Dr. Ernest Sternglass from Pittsburgh University has been called in to argue—contrary to all scientific evidence and known natural phenomena—that no radioactive gas should ever be released to the atmosphere, even chemically inert noble gases. There may be some "unknown way," Sternglass claims, "that it might possibly become concentrated in one small area" and thus be harmful. As a TMI engineer has pointed out, this is like telling someone not to

Another example of this linear reasoning is as follows: Since a person hit by 500 snowballs at once will die from this event, a linear extrapolation predicts that a person hit with one snowball a day for five winters will also die, and similarly, that throwing 500 snowballs at 500 people in one day will kill 1 person, since for every 500 snowball-people-days one death will result.

Another way of putting it is that while large amounts of radiation can kill, like a guillotine, small amounts are no more harmful than scratches on the neck, which are *repaired* biologically and do not lead even a little way toward the same type of death. (Some experiments suggest that small increases in radiation may even be beneficial).

- Ralph Nader made his "modern form of suicide" remark at the University of Colorado in Boulder. The plane flight from Washington to Denver and back gave him more radiation (5 millirem) than he would receive from a lifetime's residence near a nuclear reactor.
- Most of Nader's audience, living in Colorado, receives between 30 and 100 millirems more radiation annually than people living at sea level, because of a thinner atmospheric shield against cosmic rays. That difference is the annual equivalent of what would be produced by 10,000 nuclear plants all located within 50 miles of the alleged victim.
- Because of the rock formations around Boulder, Nader's audience was also subject to an additional amount of radiation 160 times greater than that received from proximity to a nuclear plant. For the same reason, Grand Central Station in Manhattan could not be licensed as a nuclear plant, because the radiation from its granite blocks would violate Nuclear Regulatory Commission standards.
- Dr. Spock's birth-defect warnings refer to the well-known genetic defects produced in animal offspring by heavy radiation exposure of parents. Such effects have never been observed in humans, however, perhaps because they are so negligible as to be beyond detection. Extremely thorough investigation showed that there was virtually no increase in birth defects even in Hiroshima and Nagasaki.
- Every person in the United States receives an average of 25 millirems of radioactivity annually from the consumption of food. This is 2,500 times more than from a nuclear reactor's proximity. A small part of this food-produced radiation is also radiated out of the body. Thus, when Ralph Nader and the antinuclear groups gather to hold a rally, they receive much more radiation from each other than any 2,500 nuclear reactors could provide. As Dr. Edward Teller once put it, "In sleeping with a woman one gets just slightly less radioactivity than from a nuclear reactor. But to sleep with two women is very, very dangerous."

When the facts are in, the best answer to the environmentalists' radiation hysteria remains: "Nuclear power is safer than sex."

open a bottle of coke because there might be some way that the carbon dioxide coming out of the bottle will concentrate in one big bubble around his head and thus suffocate him to death!

The history of the TMI incident has proved that people are often easily duped by stories like this because they are misinformed about the subject or they are afraid of the unknown; anything dealing with radioactivity for most people tends to fall in the class of the unknown.

Releasing and dispersing small amounts of radioactive noble gases safely to the atmosphere is a proven scientific technique and should be approved by the NRC for the Unit 2's containment building decontamination in the immediate future. The longer the decision is delayed, the longer the gas remains stored in a building that is not designed to store such gas permanently, leaving open the possibility of an uncontrolled release of this gas through a leak.

There are also other methods to dispose of the krypton-85, for example: compression and storage of the contaminated air in tanks; cooling the air to very low (cryogenic) temperatures at which the radioactive gases liquefy and can be separated from the air and stored; absorption of the radioactive gases as they are passed through a charcoal bed at very low temperatures.

Although any of these methods will work, they are very time-consuming and expensive. In addition, they could not be implemented for some time because special equipment must be brought in. But again, the most cogent reason for rejecting these alternate methods is that they are not necessary; the filter and purge methods will meet all objectives safely and otherwise better than the others.

Removing and Processing Contaminated Water

There are two sources of contaminated water in the containment building that must be processed before the building clean-up operations begin. These are the 7.5 feet of water on the floor (sump area) of the building and the water in the reactor coolant system (RCS). Approximately 700,000 gallons of water on the floor came through the failed open relief valve during the first 2 hours and 15 minutes after the incident; the 90,000 gallons of RCS water is water normally in the system.

The radioactivity levels of these two sources is somewhat higher than the levels of the water spilled on the floor of the auxiliary building, and for references purposes Met Ed has classified it as high-level* radioactive water. The major radioactive materials, however, are the same—cesium, strontium, and tritium. There are just more of them than in the auxiliary building.

The tentative plan is to do the RCS water first and then the water on the floor, but the order is not critical. To begin the processing, another larger and slightly modified EPICOR II system must be built and installed. This system will use a more efficient inorganic resin, zeolite, that is better suited for large volume, higher radioactivity water. The filter and pump units will be located underwater in the fuel storage pools of the fuel handling building. This will provide all the safety and protection necessary for employees and will make the equipment easily accessible.

'Many ordinary people... work around radioactivity frequently and are not harmed or endangered; nor do they worry about the alleged dangers.'

This equipment will be installed by midsummer so that actual processing can begin in the third quarter of 1980. The combined processing of both these sources of contaminated water should take no longer than six months, so completion should occur in early 1981. The water on the floor, of course, will be removed and processed at the same time, and then put in a storage tank for later reuse or discharge.

The water in the RCS, on the other hand, will be processed and returned to the RCS, because coolant circulation is needed in the reactor until the fuel is removed. Measurements indicate that there is now very little or no leaching of radioactive contaminants into the RCS water from the damaged fuel; hence this water will remain quite clean once it is processed.

Final Cleanup

The final cleanup operations in the containment building will be the washing and scrubbing down of walls and other contaminated surfaces. These cleaning operations are now scheduled to begin in April 1981, and will take more than a year to complete. Several three-men exploratory teams will be in and out of the building many times before cleaning begins and will plan out the work in great detail.

Initially, Met Ed thought it might be necessary to perform some remote control gross cleaning operations prior to sending the actual work crews inside. However, this does not seem to be necessary because the radiation levels are lower than originally estimated. A final decision on this option will be made after the exploratory teams have completed the initial investigations.

A remote cleaning operation would make use of the built-in containment building spray system designed to remove iodine gas from the containment air in an accident. This system would spray water and steam or some combination of water and detergents on the walls to wash off some of the radioactive contaminants. This would reduce radiation levels in the upper part of the building, making it easier for the cleaning crew.

If the remote cleaning step is skipped, a similar gross decontamination will take place using manually directed water and water-steam sprays from hoses. If needed, chemicals and detergents will be used with water, but these are used sparingly because it makes the job of processing the waste water more difficult. The final clean-up step, and the most time-consuming. is the manual mopping and scrubbing down of all surfaces.

After the gross building decontamination is completed and the manual cleaning of the upper part of the building is underway, the operations to begin removing the fuel from the reactor vessel can begin. This is scheduled to start in the last quarter of 1981 and will be completed by the end of 1982, at the latest.

How badly damaged the fuel bundles are is open to question at this time and will not be known until workers start removing them. However, for planning purposes it is assumed that 60 percent of the fuel has received some damage and that at least some of these damaged fuel bundles will not be capable of withstanding their own weight (nearly a half-ton) if pulled from the top by the normal method of removal. Therefore, special removal equipment will be built to be available to provide lift from the bottom of the more badly damaged bundles.

The procedures to be followed are straightforward. First, the overhead polar crane will be placed into serviceable condition. Then the refueling cavity around the reactor will be flooded to cover the reactor vessel and permit the lifting of the reactor head with minimal recontamination of the surrounding area. Initially, the head will be raised only a few inches in order to allow the insertion of lights and video camera equipment to make an initial inspection. This is to ensure that there is nothing hung-up on the vessel head or internals that might be accidently removed when the head is lifted off. After this operation, the head will be completely removed and stored, providing both visual and mechanical access to the top of the reactor core and fuel.

The current plans are to start removing the fuel bundles —the outside bundles first and the center bundles last—until all 177 bundles are removed. As each bundle is removed, it will provide visual access to the adjacent bundles; thus, further assessment of the damage can be made as fuel removal proceeds. The damaged fuel will be stored temporarily on-site in the spent fuel pools, which are designed for that purpose.

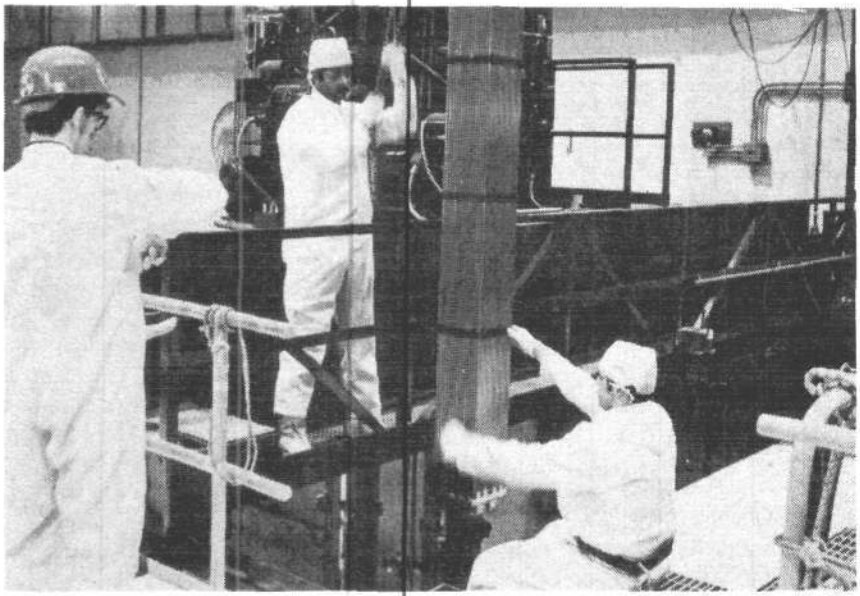
Some of the more seriously damaged bundles might require a special container around them to make sure they stay intact structurally. These bundles eventually will be shipped to a processing-storage depository the same way that spent fuel is normally shipped; in large, specially designed and constructed shipping casks.

After the removal of the fuel, the only remaining clean-up operation is the decontamination of the reactor cooling system (RCS) itself. The magnitude of this job cannot really be known until the fuel has been removed; however, certain assumptions and plans can be made now.

For example, at least some fuel particles—chips, grains, and so on—most likely came out of some fuel pin cladding cracks. It can be assumed that this material, since it is very heavy, is lying at the bottom of the reactor vessel or perhaps was carried into coolant system piping or the steam generators.

To assess the situation, some of the vessel's internal equipment will have to be removed so that a thorough inspection can be made. Assuming that fuel particles and other contaminants were carried into the RCS by the water flow, we can predict approximately how much cleaning and decontamination are required. First, the coolant water, which had already been processed and cleaned up earlier, will be transferred to storage tanks. Then the RCS, including the pipes, vessel bottom, and so on, will be cleaned by remote vacuum cleaner operations to remove all particulate matter. Finally, fission product contaminants that have deposited on the inner surfaces of the RCS—inside pipes, tanks, steam generators, and so on—will be removed, probably by chemical solvents.

The exact decontamination techniques cannot be specified now, but will involve well-known methods and will be accomplished by experts brought in specially for the job. After this cleaning operation is completed, near the end of 1982 and six months after fuel removal, Unit 2 personnel can begin planning to start up the reactor again.



A new TMI Unit 2 fuel bundle moved out of storage on its way to the reactor vessel during the initial loading of the core in early 1978. These bundles, many of which are damaged, must now be removed from the vessel before new fuel can be brought in to restart the reactor.

Putting Unit 2 On Line

The earliest that TMI Unit 2 can be brought back into operation again will be sometime in the fall of 1983, by current estimate. Once cleanup is completed, the staff must inspect, analyze, and prepare for requalifying all the equipment affected by the March 28 incident. This might require the replacement of certain equipment; for example, instrumentation and electronic gear that failed or was exposed to high-levels of radiation such that premature failure might be expected in the future.

There will be an ongoing assessment of potential equipment replacement as access is gained to such equipment throughout the clean-up process. The most that can be said right now is that, other than the reactor core (all fuel bundles), there appear to be no major components or equipment that need replacing. If this continues to be the case, bringing Unit 2 back on line sometime in the second half of 1983 is a firm possibility.

Decontamination and reactivation of TMI Unit 2 will take about four years, but this schedule could vary by as much as six months. The decontamination and reconstruction effort for the Unit 2 reactor containment building will require slightly more than 4 million work hours. About 25 percent will be for craft labor, services, and site supervision and 25 percent for engineering and technical services. The total payroll for this effort is estimated at about $109 million. As much as possible, craft and other labor will be drawn from local labor pools or from Met Ed and other GPU system companies. Between 1,000 and 1,400 persons are expected to work on site during the four-year effort. The normal employment level for TMI is about 600 employees, including contractors on-site.

A recent Bechtel study has estimated that the costs of this entire operation will be about $320 million, including a contingency fund of $80 million. However, the Bechtel estimate does not include the cost of replacing the reactor core. The utility's investment in the core at the time of the incident was about $35 million; taking into account the increased prices of uranium enrichment and fabrication, a new core will cost between $60 and $80 million. Additionally, the utility has added $25 million to the Bechtel estimate to cover further unforeseen contingencies. All told, this brings the estimated cost of decontaminating and restarting Unit 2 to about $400 million. Expenditures to date have been about $106 million.

For planning purposes, Unit 2 restart, if approved, is scheduled for the fall 1983. The present schedule, which would prepare Unit 2 for refueling in spring 1983, does not include consideration of a number of potential delaying factors. Among the more important of these are extraordinary legal or political hindrances, major changes in existing regulations, or wide variations from anticipated conditions in the containment or reactor coolant system. These factors could significantly increase the time and budget requirements for safe cleanup and recovery.

Conclusion

Three Mile Island represents one of the best examples of man's achievements in science and engineering. To me and to most Americans, it is a very beautiful sight to behold. The magnificent cooling towers placed among the reactors, turbines, and other power-generating equipment, and surrounded by the beautiful setting of the Susquehanna River are striking evidence of man's desire to grow, develop, and progress. Whatever lessons TMI has taught us, whatever improvements need to be made in the design and operation of nuclear plants will be made; most have already been made. This is the way it always has been with a developing technology—improve, advance, and develop!

Nuclear reactors are not out of man's control. Man created nuclear reactors to do what we make them do. If we can make them do their job better, *we'll do it. That's what it means to be* an American.

Note

* These categories of radioactivity were established for convenience by Met Ed personnel in order to distinguish the different types of water that must be processed at TMI. The terms should not be confused with the general classes of radiation; that is, high, intermediate, and low-level, which are used industrywide to categorize fission product waste material. Under the industry classifications, all of the TMI radioactive water to be processed would be categorized as low level.

References

1. "Summary—Technical Plan for TMI-2 Decontamination and Defueling," Metropolitan Edison Company, Dec. 12, 1979.
2. "Entry and Decontamination of the Reactor Containment Building at Three Mile Island Unit 2," Highlights of a Planning Study conducted by Bechtel Power Corporation, *Report Number Four*, Metropolitan Edison Company, Aug. 27, 1979.
3. "Population Dose and Health Impact of the Accident at the Three Mile Island Nuclear Station," A Report to the Met-Ed Community, *Report Number Three*, Metropolitan Edison Company, June 15, 1979.
4. "Testimony Before The Subcommittee On Nuclear Regulation of the Senate Committee on Environment and Public Works," A Report to the Met-Ed Community, *Report Number One*, Metropolitan Edison Company, May 10, 1979.

After TMI: Some FEF Recommendations

Since the March 1979 incident at the Three Mile Island Nuclear Power Plant Unit 2, there have been as many as eight official investigations. Although the various reports issued have many deficiencies, omissions, and outright invalid conclusions, there are certain areas concerning the nuclear industry that deserve attention and improvement. These areas include the training of personnel, plant security, technological improvements, and the overall organization of the industry.

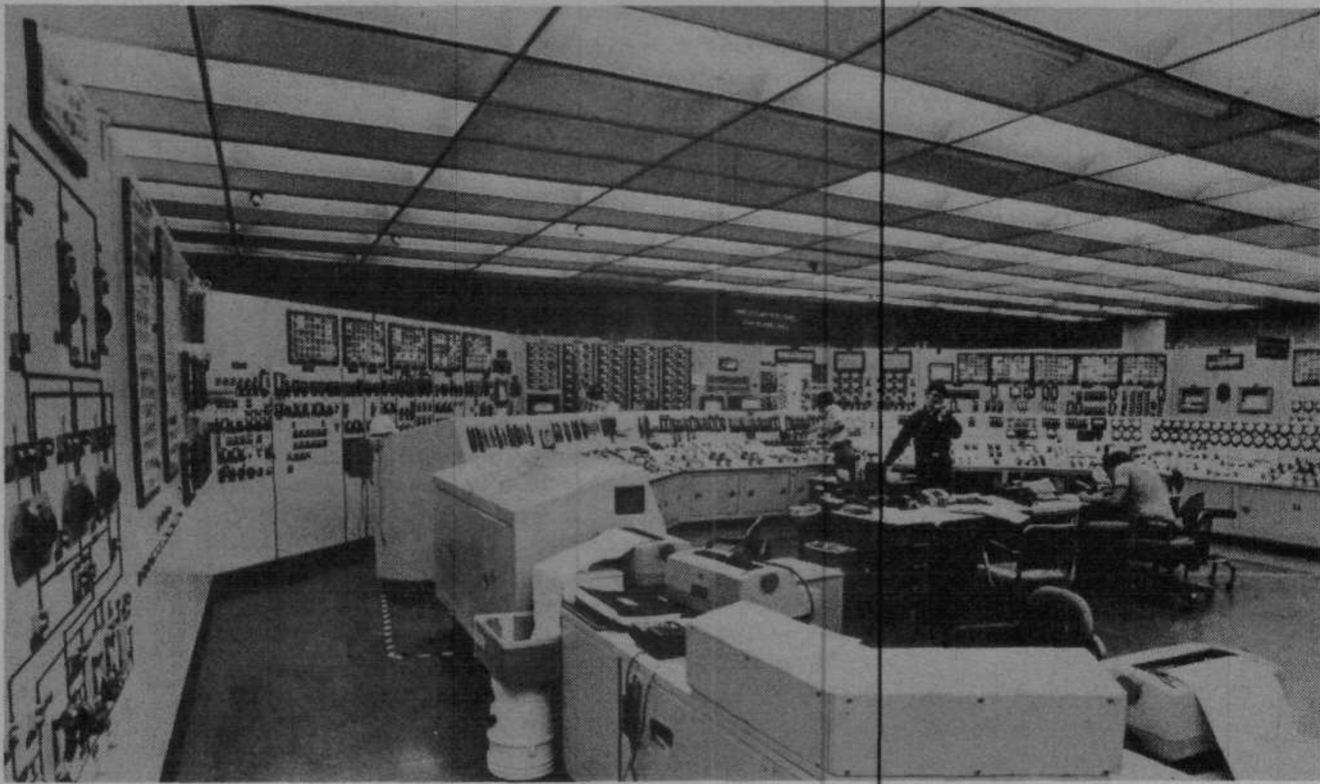
As *Fusion* reported in March (conferences section), the nuclear industry has already begun to deal with some of these issues by setting up a safety institute and by using the expertise of the aerospace industry and the Nuclear Navy to work through problems. Contrary to the mumbo-jumbo coming from the Kemeny Commission report that somehow the human interface with nuclear technology is too complex, it should be emphasized that these are problems that can be solved.

Here is a brief summary of FEF's recommendations in each area.

Training of Personnel

There has been a lot said about whether the operators at TMI Unit 2 were adequately trained for the job. In fact, the operators on duty at the time of the incident were all experienced naval submarine reactor operators and well trained for the job, according to the existing industry standards. Overall, Met Ed's operators, including those on duty, are probably better qualified than the average operator throughout the industry.

Nevertheless, it remains the case that even though operators were legitimately confused during the early 15 to 30 minutes of the incident because, unknown to them, all emergency cooling to the steam generators had been shut off,[1] they could have terminated the incident before fuel damage occurred had they made the correct diagnosis of what was wrong.



The Unit 2 control room during normal power operation in early 1979. The plant is highly automated and when things are running normally, the operators primarily monitor instruments.

In addition, because they did not recognize the fact that the pressurizer relief valve was stuck open, the operators made several significant errors in judgment. In retrospect, probably the most serious error was the shutting off of the emergency core cooling water flow.

Accident Analysis

Overall, the operators were responding to what they thought was happening in a way they had been trained to respond. The problem is that they had never been trained for this particular type of event and, therefore, would not necessarily have recognized what was happening from the information and data they were monitoring.

Someone trained in abnormal plant operation and accident analysis should have recognized that the valve was open; most probably this would have prevented any damage. Therefore, a more thorough operator training program that includes more exposure to abnormal conditions is an important improvement. This is not to say that all reactor operators should become nuclear engineers trained in accident analysis. But such a person should be on site in a supervisory capacity on every shift in an operating reactor.

The more in-depth training of the operators and the on-site safety engineer should be by hands-on nuclear plant simulator classes. All operators are now trained on such simulators; the TMI operators received this training on the Babcock and Wilcox simulator in Lynchburg, Virginia. We recommend classes, however, that would preprogram the simulator to present operators with a wide variety of abnormal operating conditions, rather than just the normal operational circumstances they have been trained for in the past.

Plant Security

Although security at operating nuclear power plants is very good when it comes to preventing some outside individual or group of individuals from entering the plant, this is not always the case with regards to an inside breach of security—that is, a potential inside sabotage operation.

There have been many reported cases of plant sabotage during the construction of nuclear power plants over the past few years. Furthermore, as recent as last May there was a proven case of sabotage of an operating reactor, the Surry II plant of Virginia Power and Light Co. In that case, two employees poured lye on new fuel bundles. After a thorough FBI investigation, which used lie detectors on all employees who had access to this fuel, the two perpetrators were caught and convicted.

In the TMI Unit 2 incident, it is still not known how the emergency feedwater valves were closed prior to the incident. It is known, however, that the valves had to have been closed by some individual or individuals, either by negligence or as an act of sabo-

Continued on page 22

FEF Recommendations

Continued from page 21

tage. None of the investigating commissions was able to resolve this question, nor has the FBI yet been called in to investigate the staff as they were at Surry II.

The most effective way of tightening up internal security within the industry as a whole is to employ stricter screening guidelines and procedures when hiring personnel. For example, no one who is antinuclear or who has been involved in antinuclear-related activities should be allowed to work at a nuclear power plant. If it is necessary to involve the FBI in this screening procedure, as it most likely will be, the government must make this service available to the utilities.

The nuclear industry must abandon the practice of hiring plant security services from an ordinary security service company. Instead, utilities should screen and hire their own security personnel. Alternately, security service companies that provide personnel to nuclear plants must have those personnel screened by the same procedures that any nuclear plant employee is subject to.

Technological Improvements

As in any new and evolving technology, improvements should be made as they are recognized. Nuclear plants are certainly no exception. The most important of the improvements recognized as necessary as a result of the Unit 2 events are:

- Instrumentation to directly measure the water level in the reactor vessel.
- Instrumentation to provide an absolute indication of whether the pressurizer relief valve is open or closed;
- Interlocks on the two emergency feedwater block valves so that they cannot be closed without the operator knowing about it and without requiring the operator to take physical action;
- Visible and audible signals to announce to personnel if either of these block valves is in a closed position (for example, for testing purposes);
- A computerized scanning system of all critical valve positions, flow measurements, water levels, pressure levels, and so forth, to provide the operators with a periodic summary of operating conditions.

Organization of the Nuclear Industry

The primary change that must take place in the organization of the nuclear industry and its regulatory bodies is to put it under the control of a proindustrial development branch of the government. Since the responsibility for the development of nuclear energy changed from the Atomic Energy Commission (AEC), to the Energy Research and Development Administration (ERDA), and, finally, to the Department of Energy (DOE), the development of nuclear power has gone downhill—to the point where it is now near collapse. The DOE is now managed by some people who are patently antinuclear, and even the regulatory agency for nuclear power plants, the Nuclear Regulatory Commission (NRC), has antinuclear leadership at the top. This is like having people who are against air travel, heading up the Federal Aviation Administration!

Responsibility for all nuclear-related research and development should be separated from the DOE and placed under a NASA-style administration. This would include the fusion program as well as all advanced fission reactor programs and support activities for current reactors such as safety, fuel cycle, waste disposal, and so on. As is the case with NASA, this group would report directly to the president and would not be part of another department.

The NRC, on the other hand, should remain a separate body. However, a certain amount of reorganization is needed. The management and the operating staff should consist of technically qualified individuals in nuclear power plant engineering, operations, and safety. The commissioners should also be chosen from the ranks of the technically qualified and should be committed to the job of ensuring a safe expanding nuclear power program. The goal of the NRC should be to achieve a safe, strong, and viable U.S. nuclear industry.

Note

1. Who shut off the emergency feedwater valves is a question that none of the TMI investigative groups answered.

Special Report

Research Gap Is Crippling U.S. Military

"Failure to aggressively pursue technological innovation and provide adequate funding for basic research" is one of the main reasons that U.S. military forces are now decisively inferior to those of the Soviet Union, according to an in-depth study published recently in *Executive Intelligence Review*, an international weekly.

The study, titled "The Erosion of U.S. Military Capability," charges U.S. political figures and civilian and military strategic planners since Robert McNamara's era at the Defense Department with "ignoring the fundamental relationship between economic and technological development and military strength."

As a result, the study says, U.S. attempts to force a strategic showdown with the Soviet Union in the Mideast, Asia, or Western Europe "...given the present U.S. forces structure and capability—or lack thereof—must lead either to forced U.S. withdrawal and a widely perceived strategic setback or to rapid escalation to general thermonuclear war, which, as things presently stand, the United States would lose."

The study includes evidence provided in interviews and testimony from Defense Department officials, scientists, high-ranking members of the U.S. armed forces, and high-technology industrial firms, as well as independent evaluation from military, economic, diplomatic, and scientific experts. Among the contributors were Fusion Energy Foundation research director Uwe Parpart, who coordinated the study, and Steven Bardwell, FEF director of plasma physics, who authored the section on "Research and Development: The Aura of Poverty."

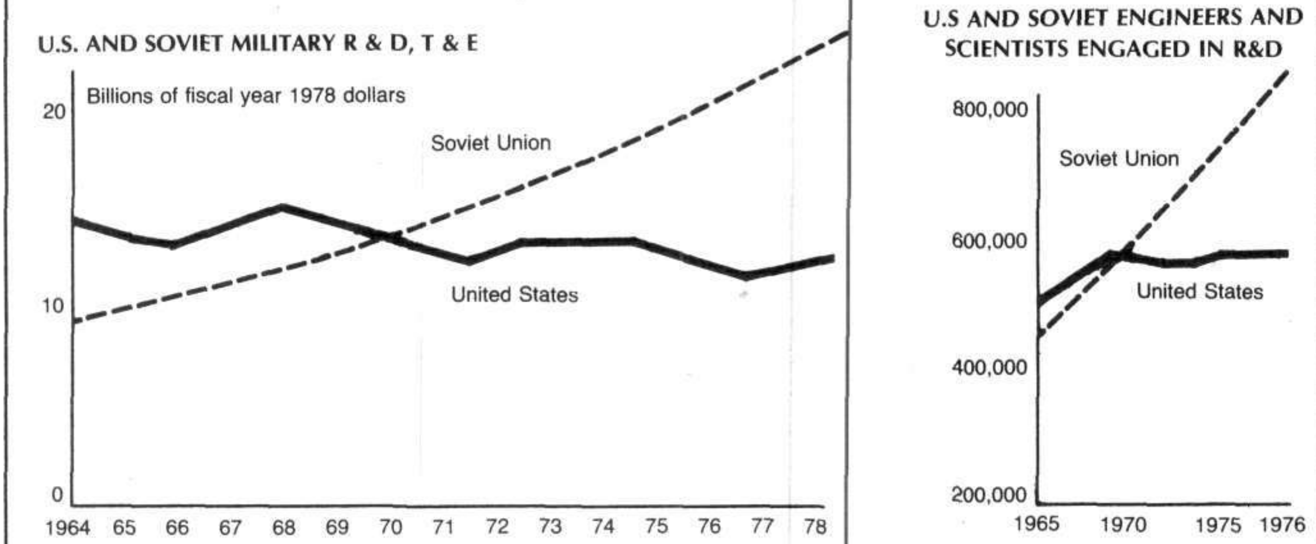
The Present R&D Situation

According to Bardwell, "The underlying feature that defines the whole significance of military R&D is not primarily military; rather it is at root a derived capability based on the society's generalized commitment (or lack of it) to discovery and implementation of the most advanced ideas in every field. It cannot exist in the military field without a broad-based civilian effort, nor can a broad-based civilian effort exist without their being 'spin-offs' in military deployments. That is the simple fact about advanced weapons systems which has escaped our military leaders for more than 15 years.

Highlighting that error, the study reports that in the years between 1965 and 1975, the funding from the Defense Department for basic research fell 50 percent in real dollars. Promised efforts by the present administration to remedy this with 10 percent yearly R&D budget increases have fallen victim to inflation.

Moreover, looking at R&D in the economy as a whole, "the Soviet Union passed the United States in 1968 and now has more than double the number of scientists and engineers involved in research activity" as the United States, the study reports.

Emphasizing that "the health of American R&D is intimately and in-



The figures for Soviet expenditures in military research and development and test and evaluation as well as the numbers of Soviet engineers and scientists engaged in R&D continue to surpass those in the United States.
Source: DOD Annual Report

separably tied to the health of the nuclear industry," the study points out: "In the past 15 years, the industry's new plant orders have gone from 17 in 1965 to a high of 35 in 1972 to a total of *zero* in 1979. . . . Recent industry studies predict that two of the top four producers of nuclear plants will have totally closed their nuclear-related facilities by 1985 and a third will do so shortly thereafter."

A speech given last month by Dr. Harold Agnew, long-time director of the Los Alamos weapons laboratory and now head of General Atomic, a large government contractor involved in nuclear research for civilian power production, is cited to point out that U.S. military capability is suffering badly from a lack of depth in nuclear weapons production facilities, many of which have been closed.

Weapons Systems

What does the weakness in overall industrial-scientific research and development mean in terms of actual weapons systems? The EIR study quotes congressional testimony by Lt. Gen. D. R. Keith, deputy chief of staff for research, development and acquisition for the U.S. Army:

"The past 15 years has seen an erosion of the qualitative advantage in ground forces equipment and weaponry to the point where the U.S. Army is now inferior in virtually every major category of items with which wars can reasonably expect to be won."

Among the categories in which U.S. weaponry is judged to be inferior, according to the EIR study:

- 'The [Soviet] T72 and T64 are probably the world's best operational tanks" [Lt. Gen. Keith].
- "Infantry fighting vehicles are a critical component of mechanized and armored units—especially in European terrain. In this category our M113 is so inferior to its Soviet BMP counterpart that it cannot even accurately be considered a fighting vehicle. It is at least a generation behind . . . . " [Lt. Gen. Keith].
- "The primary U.S. Infantry antitank weapon is the Dragon . . . . [Because of cost] very few U.S. infantrymen have been permitted to fire one . . . . The Dragon is too heavy to fire standing up and if it's fired from a prone position, the blast from the rocket can easily burn off the firer's buttocks . . . .The Soviets have solved this problem at a price roughly one-fifth that of the comparable U.S. weapon" [Lt. Gen. Keith].
- "The Soviets are decisively ahead in the air" [Officials of the West German Defense Ministry].
- "We have likewise been preempted in a combat field we pioneered: heliborne firepower" [Lt. Gen. Keith].

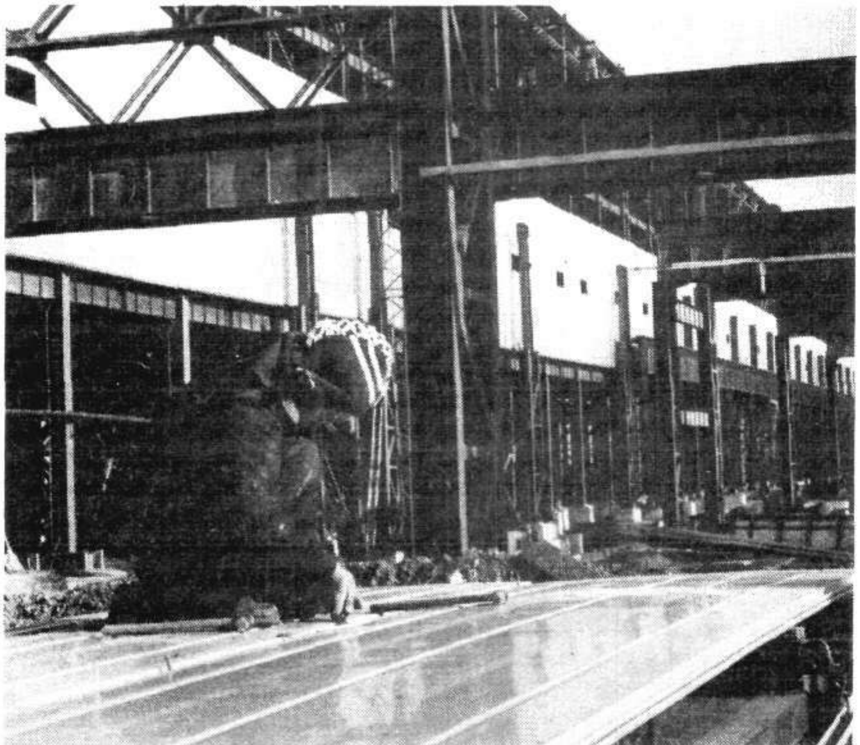


Photo by Peter Hann, courtesy of McGraw Hill World News

'A broad-based civilian effort': Construction work on a Soviet Atommash nuclear power plant in Volgodonsk.

Strategic Missiles

Although the United States has maintained a lead in electronics/precision guidance of strategic missiles, the EIR study says, "the momentum is now with the Soviets. But more important, the USA's own advance—precision guidance—actually destroys the possibility of a limited nuclear war, the only kind for which precision targeting represents an advantage . . . . The Soviet numerical advantage (in weapons, throwweight, and megatonnage of strategic nuclear systems) is at this point about 2:1 over the United States . . . . They are preparing to be able to have a second round of nuclear weapons to use—in contrast to the American conception of a spasmodic, one-shot nuclear exchange.

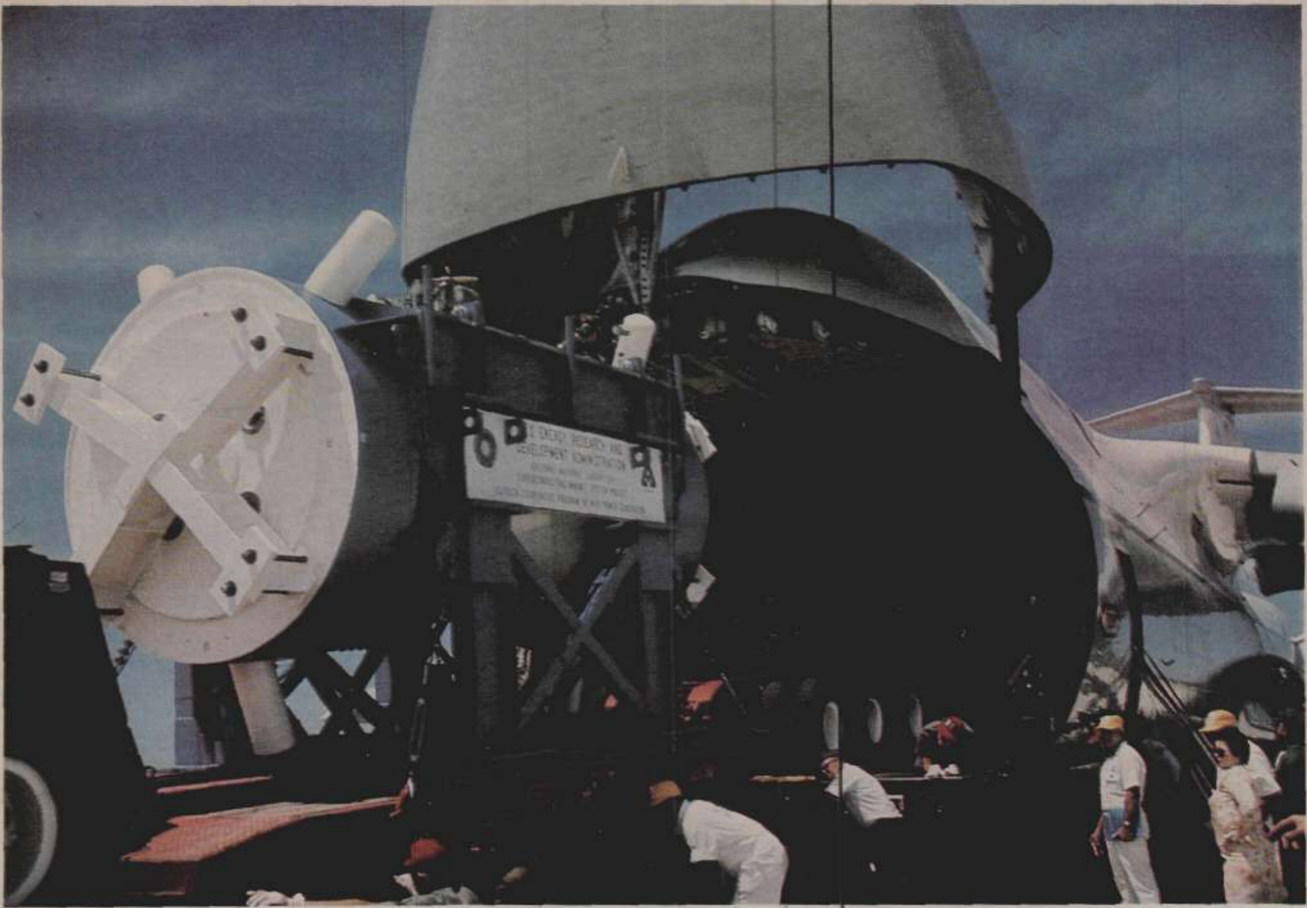
"The American advances in guidance make this scenario the one the Soviets must follow . . . . Since U.S. missiles are now accurate enough that a direct hit on a Soviet missile silo is very likely, and since there is no way to 'harden' a missile site against a direct direct hit, the pressure is for the Soviets to launch their missiles as soon as an American attack is evident. American missiles would be hitting . . . very accurately . . . empty silos."

The Directed Energy Beam Weapon

There has been only one weapons system that has even the remote possibility of changing the military strategic situation in a qualitative way — much the same way the nucleartipped ICBM did 25 years ago—and that is the directed energy beam weapon. This device, if perfected, would be capable of directing an intense en-

Continued on page 58

Magnetohydrodynamics



The U.S. superconducting magnet en route to Moscow for testing in the Soviet U-25 MHD experiment. DOE

Doubling Energy Efficiency by Direct Conversion

by Marsha Freeman

MAGNETOHYDRODYNAMIC direct energy conversion was first observed by Michael Faraday in 1832. He demonstrated that if an ionized fluid is passed across the lines of force of a magnetic field, an electrical current is produced. This method of generating power without any moving parts can be used with any fuel as well as in space and industry, increasing the efficiency (in some cases doubling it) and eliminating environmental problems.

As the best means found yet to take the products of combustion or heat and turn them into the highly organized form of energy in a power grid, it is an important part of the high-technology alternative to the administration's proposals for inefficient and costly synthetic fuel and alternative energy programs.

CONTENTS

MHD: 150 YEARS OF PROGRESS IN ELECTROMAGNETICS

ON JANUARY 12, 1832, Michael Faraday and his assistant stretched a copper wire about 960 feet long across the Thames River and anchored it on each side of London's Waterloo Bridge. A metal plate was attached to each end of the wire and lowered down into the estuary so that the water touched each plate (Figure 1). The wire that was lowered into the water from the bridge toll house then was connected to cups of mercury with a galvanometer wire, and, as Faraday describes it, "the circuit was completed by the water between the plates, which, being in motion up or down, was expected to produce by magnetoelectric induction currents rendered sensible at the galvanometer."

Faraday was indeed able to measure a small current with his crude equipment, but the explanation of how this induced current was created has required the marriage of two fields of physics theory—fluid dynamics and electromagnetism—throughout the last 150 years. As we now know, the induced current that Faraday measured was produced by the interaction of the electrically conductive fluid that results from the salinity of the water, propelled by the natural flow of the river through the magnetic field of the earth.

By March 26, 1832, after continuing his investigations on a smaller scale in the laboratory, Faraday indicated in his diary that he had some appreciation of the relationships among electricity, magnetism, and fluid flow.

Today's large-scale power-generating plant produces an electric current by burning fuel or using fission reactions to produce heat, which turns water into steam. The kinetic energy in the steam is transferred into rotational energy in a turbine, and this mechanical energy then moves the coils of a generator through a magnetic field.

If the electrically conductive coil cuts the magnetic lines of force, this will induce an electrical current in the coil itself. The discovery of this interaction between magnetic fields and free electrons in metal conductors led to the development in the last century of dynamos or electromagnetic generators, which are still the basis of present electric-generating technology.

The MHD Process

The earliest experiments by Faraday and others investigating the more subtle relationships between magnetic and electrical fields, however, considered the question of whether a fluid—either a room-temperature liquid metal or a heated gas—could be the conductor itself, thus replacing the bulky rotating generator machinery with an electrically conductive fluid in motion.

It was discovered that if such a conductive fluid is propelled through a container surrounded by an external magnet system and that magnetic field is perpendicular to the direction of the fluid flow, a force is created that acts on the moving charged particles in the fluid to separate the negatively charged electrons and the positively charged ions. This force, exerted by the external magnetic field, is called the Lorentz force (Figure 2).

This charge separation caused by the Lorentz force creates a potential difference that can produce an electrical

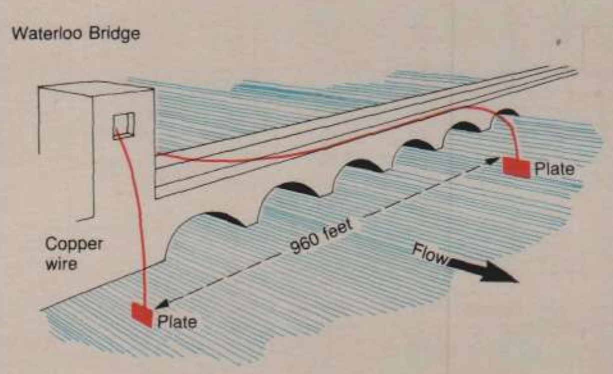


Figure 1
FARADAY'S 1832 EXPERIMENT
Michael Faraday performed the first experiment demonstrating that an electrical current could be produced by direct conversion. The moving charged fluid flow was the saline water in the Thames River; the external magnetic field was that of the earth; and the electrodes drawing off the Faraday current were the metal plates submerged in the river.
Source: Little 1967

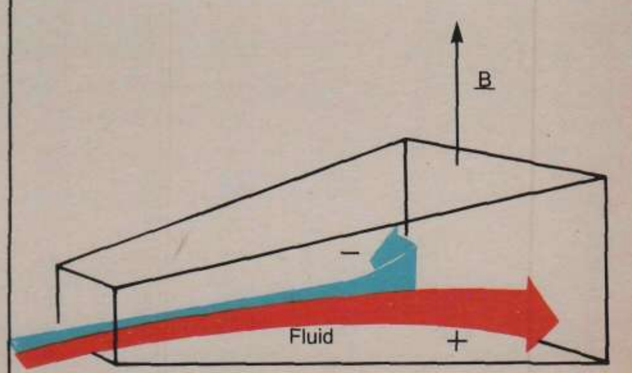


Figure 2
THE LORENTZ FORCE
When a flow of charged particles is passed through a magnetic field, B, that is at right angles to the direction of the fluid flow, it creates a force on the charged particle. This Lorentz force leads to the separation of the particles by charge, positive and negative, and provides the electrical potential by which a current can be drawn off when a load is attached.

current if there is an electrical load to absorb the power that is generated. The load can be a light bulb or any electrical appliance. The current created is at right angles to both the velocity of the fluid and the external magnetic field and is called a Faraday current (Figure 3).

In 1879, Edwin H. Hall, a graduate student at Johns Hopkins University, discovered that there is a more complex relationship, a second-order effect—a drift in the induced current. Hall demonstrated that when a current-carrying conductor (like the MHD fluid) is placed in a magnetic field (which is necessary in order to induce the Faraday MHD current) it produces an electric field in the conductor.

This electric field is proportional to the current density and the magnetic field strength and is at right angles to both the current and the magnetic field. With MHD, this electrical field is perpendicular to the current but parallel to the flow of the fluid. The induced electrical field, therefore, acts to counterbalance the current produced by the external magnetic field and deflects the Faraday current (Figure 4).

The Hall effect, as it is known, produces serious design considerations for an MHD generator (discussed below), because the electrical current is no longer strictly perpendicular to the magnetic field and the flow direction, but has drifted.

In addition to the electromagnetic effects produced by the interaction of the magnetic and electrical fields, there are fluid and hydrodynamic effects to be considered in an MHD system. In 1883, Osborn Reynolds was studying the onset of turbulence in fluids. He reasoned that it would be possible to derive a dimensionless number that would indicate the behavior for any fluid, in terms of the onset of turbulence, as a function of the fluid's viscosity (internal resistance) and inertia.

This would mean, for example, that the flow of air through an orifice will be similar geometrically to that of water through a similar orifice if the dimensions (length and so on) and velocity are chosen to give an identical "Reynolds number." A magnetic Reynolds number has also been developed, which depends upon the parameters of permeability (the ratio of magnetic flux density to the external magnetic field strength inducing the flux), electrical conductivity, velocity of the flow of the fluid, and the length or size of the containing vessel.

Identifying the magnetic viscosity, or Reynolds number, is important in an MHD system to be able to keep the fluid within the parameters of nonturbulent flow. The Reynolds number is the same for any MHD fluid used, from liquid metal to various gases, to ensure that the flow of the fluid maintains the desired characteristics for maximal thermal-to-electrical energy conversion efficiency.

When Faraday did his experiments on electromagnetic induction he showed that it applied to conducting fluids as well as to solids. Aside from the Thames River investigations, most of Faraday's work was with conductive liquid metals, like mercury. By the late 19th century, however, experimenters had switched to power conversion from the thermal energy of compressible gases.

One way to create a fluid (gas or liquid) that is made up at least partially of ionized (electrically charged) particles is to submit it to high temperatures. For the past 50 years, therefore, most investigations of magnetohydrodynamics have been done with ionized gases (plasma) at tempera-

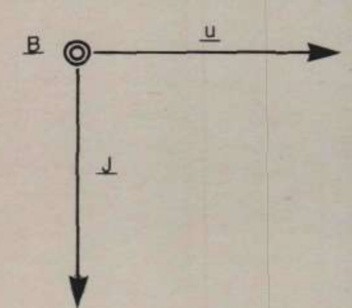


Figure 3
THE FARADAY CURRENT
The Faraday current produced in an MHD channel is the result of the Lorentz force acting on the charged particles in the ionized fluid flow. The current generated is perpendicular both to the direction of fluid flow and to the external magnetic field.

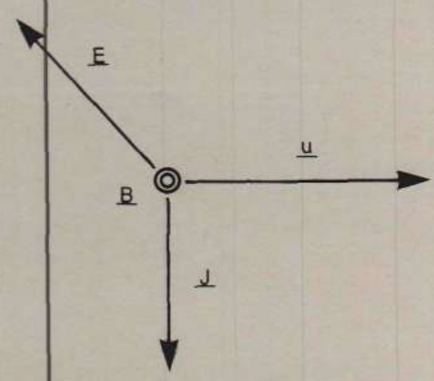


Figure 4
THE HALL EFFECT
The Faraday current creates an electrical field around it that results in a drift force on the current called the Hall effect. Labeled E for the induced electrical field, the Hall effect acts as a "pull" on the Faraday current, J. The magnetic field in the diagram, B, is projected out from the page toward the reader; the Faraday current, the magnetic field, and the direction of fluid flow, u, are perpendicular to each other.

Photo courtesy of Dr. V. Ovcharenko

The channel of the Soviet U-25. The round protrusions on each side are the segmented electrodes. Channel material is ceramic brick.

tures ranging from hundreds to thousands of degrees, and some investigators refer to the study as magnetoplasmadynamics.

Because higher temperatures were needed to ionize gases, the development of high-temperature materials was one of the pacing technologies for high-powered MHD conversion. Gas discharge tubes, where the passage of an electrical current ionizes a gas in the tube, were used to study the properties of conductive gases in the late 19th and early 20th century. Kinetic theory, statistical mechanics, and quantum theory developed in large part as explanations of what was observed in gas discharge tubes.

The major parameters that maximize the direct production of an electrical current in an MHD system are the rate of flow and electrical conductivity of the conducting fluid, the strength of the external magnetic field, and the design of the electric load system in the containing vessel. MHD conversion is an extremely versatile technology, which can be used with any source of heat, any fuel, and in numerous design configurations.

It can produce pulsed power if the fluid flow is pulsed; it can be used for geophysical research; it can be used in portable systems where size and weight are prime considerations; it can provide baseload power generation for utilities or for spaceships; and it can have military applications where large amounts of pulsed or steady power are needed with near-instantaneous start-up.

The 20th Century Pioneers

As early as 1910, patents began to appear for MHD-type devices. Many were vague about the method of ionization or electrical properties of the working fluid, but experimenters persisted in their research.

Between 1938 and 1944, Bela Karlovitz did a series of MHD experiments at the Westinghouse Research Laboratories. No appreciable power resulted because of low gas conductivity and poor field arrangements in the channel. In 1940, Karlovitz patented an MHD device design. A few years later, in the mid-1950s, Dr. Arthur Kantrowitz and a group of young researchers at Cornell University were doing experiments using shock tubes and studying the electrical properties of thermally ionized gases and their interaction with magnetic fields.

Renewed interest in MHD research in the late 1950s was sparked by the Atomic Energy Commission's release of controlled thermonuclear fusion research into the public domain and the development of high-temperature rocket engines under the newly formed NASA space program. The former spurred scientific work in plasma physics, and the latter made materials available that could withstand MHD temperature requirements.

In December 1956, Kantrowitz and Harry E. Petchek presented a paper titled, "An Introductory Discussion of Magnetohydrodynamics," at the Lockheed Symposium on Magnetohydrodynamics, published in May the next year as Research Report 16 of Avco-Everett Research Laboratory. The report summed up the potential of MHD research:

> Interest in magnetohydrodynamics has been spurred primarily by astrophysical problems and by problems associated with the fusion reactor . . . . Another primary source of the current interest in magnetohydro-

dynamics is to be found in the fact that we see in this field the opportunity to unite two disciplines, gas dynamics and electromagnetic theory, which have heretofore had very few points of contact . . . . The result is the prospect of a richness of new phenomena which can only be dimly appreciated at the present time . . . . A little evidence of this new richness has recently come into view, for example, the production of high energy particles in intense pinched sparks as presented by Kurchatov. Another example is the hypothesis of Gold that the sudden commencement of magnetic storms is related to the propagation of a shock wave produced by solar disturbances to the vicinity of the earth . . . . Success in the design of experiments to exhibit a range of magnetohydrodynamic phenomena leads to the hope that practical devices utilizing the anticipated richness of new phenomena in gaseous magnetohydrodynamics will be forthcoming . . . .

Kantrowitz and the team he assembled at the Avco-Everett Research Laboratory immediately began to create and develop devices that would demonstrate the practicality of MHD direct conversion and master the complexity of new phenomena involved in magnetohydrodynamics. By 1959, the Avco Mark I generator was on line, producing a peak power of 11.5 kilowatts and sustaining a power level of 10 kilowatts for 10 seconds.

The early Avco work was supported by a group of utilities led by Philip Sporn, president of American Electric Power Service Corporation. In 1959, Avco completed a three-month study with American Electric Power to evaluate the practical design consideration for an MHD power plant. And in November, Sporn and Kantrowitz coauthored an article on the future of magnetohydrodynamics for *Power* magazine.

Sporn and Kantrowitz described both coal-burning and nuclear plants as areas for development. To get data on high-temperature effects, they studied the reentry of intermediate-range and intercontinental ballistic missiles, which produced quantitative values on the dissociation of materials at high temperatures. This research also gave a picture of heat transfer rates at high temperatures and the effects of additive seeding agents in gases.

The authors stated directly that the theoretical and practical problems of MHD could be solved. They also predicted very accurately that initial MHD devices would obtain a 25 percent improvement in conversion compared to conventional steam turbine systems for baseload power generation and that improved MHD designs would yield 50 percent better performance. Outlining a comprehensive program for research, development, and demonstration for MHD conversion for utility power systems, Sporn and Kantrowitz concluded: "The fact that MHD makes use of a new and heretofore unexplored phase of a well-founded principle leaves open the hope that further development or new ideas will be forthcoming, even though they cannot now be foreseen with certainty."

As this brief description indicates, the door had been opened. Research and experimentation in MHD for numerous applications began here, the Soviet Union, Japan, Britain, the Netherlands, France, and West Germany.

The MHD Technology

MHD electric power conversion is an extremely flexible technology. Generators can be built in the range of 30-megawatt devices for scientific experiments and as portable power sources. (Such devices are operational in the Soviet Union now.) And baseload electric power generation for commercial utility systems will likely use MHD systems with a 1,000-megawatt capacity.

The working fluid in the generator can be combustion products, including oil, natural gas, coal, or chemical rocket fuel, where the fuel is partially ionized in the process of burning at high temperatures. Or at the lower temperatures available from fission reactors, the working fluid can be liquid or vaporized metals such as sodium, as well as noble (inert) gases. With thermonuclear fusion, the nuclear combustion process of fusion will eventually provide a high-temperature plasma as the working fluid.

MHD generators can be designed in either *open-cycle* or *closed-cycle* configurations, depending on the working fluid. If the fluid used is the combustion product of a fossil fuel, the exhaust gas from the MHD generator can have its heat transferred to a conventional steam turbine cycle for additional power generation—an open cycle. With a liquid metal that is heated by an external heat source, such as a nuclear reactor or coal combustion, the working fluid is recirculated after power is drawn off from the MHD generator and is reheated and reused—a closed cycle.

The four major parameters that must be in precise balance for efficiency of conversion and for the production of large power loads are the *electrical conductivity* of the working fluid, the *velocity* of the fluid through the channel or containing vessel, the *strength of the magnetic field*, and the *configuration of the electrodes* to most efficiently draw off the current produced in the generator.

Each of these parameters has expanded the technology and engineering capabilities of industry and, in some cases, has helped create whole new problems and solutions in power engineering.

- In order to bring the electrical conductivity up to required levels in working fluids made up of combustion products, researchers have developed a chemical seeding process.
- To increase the flow rate of a gaseous fluid beyond the speed of sound, nozzle systems are used that compress the gas and then expand it as it accelerates in the MHD channel.
- For baseload power systems, where the magnetic fields must create a Lorentz force large enough to separate enough of the charged particles in the working fluid to make the system economical, researchers developed superconducting magnet systems.
- Finally, working out the complexity of the magnetic and electrical fields in the MHD generator has led to the design and engineering of sophisticated generators that capture only the Faraday current or only the Hall current, or that optimize the system by making use of both.

FOSSIL FUEL MHD SYSTEMS

The area in MHD development that has received the most attention internationally and has the most immediate large-scale potential is MHD conversion in fossil-fuel-based systems to produce power for a utility grid.

The advantage of MHD compared to conventional steam turbine cycles stems primarily from the higher temperatures MHD requires. At these higher MHD temperatures, more electric power can be extracted from the fuel. To partially ionize the fossil fuel so it can be a working fluid in an MHD generator requires combustion temperatures of approximately 4,000 to 5,000 degrees Fahrenheit. The upper limit of turbine generators is about 1,800 degrees Fahrenheit, because of material constraints and the stress of rotating huge pieces of machinery. The exit gas from the MHD generator drops about 2,000 degrees from the inlet temperature, creating a larger temperature differential and therefore a more efficient conversion system.

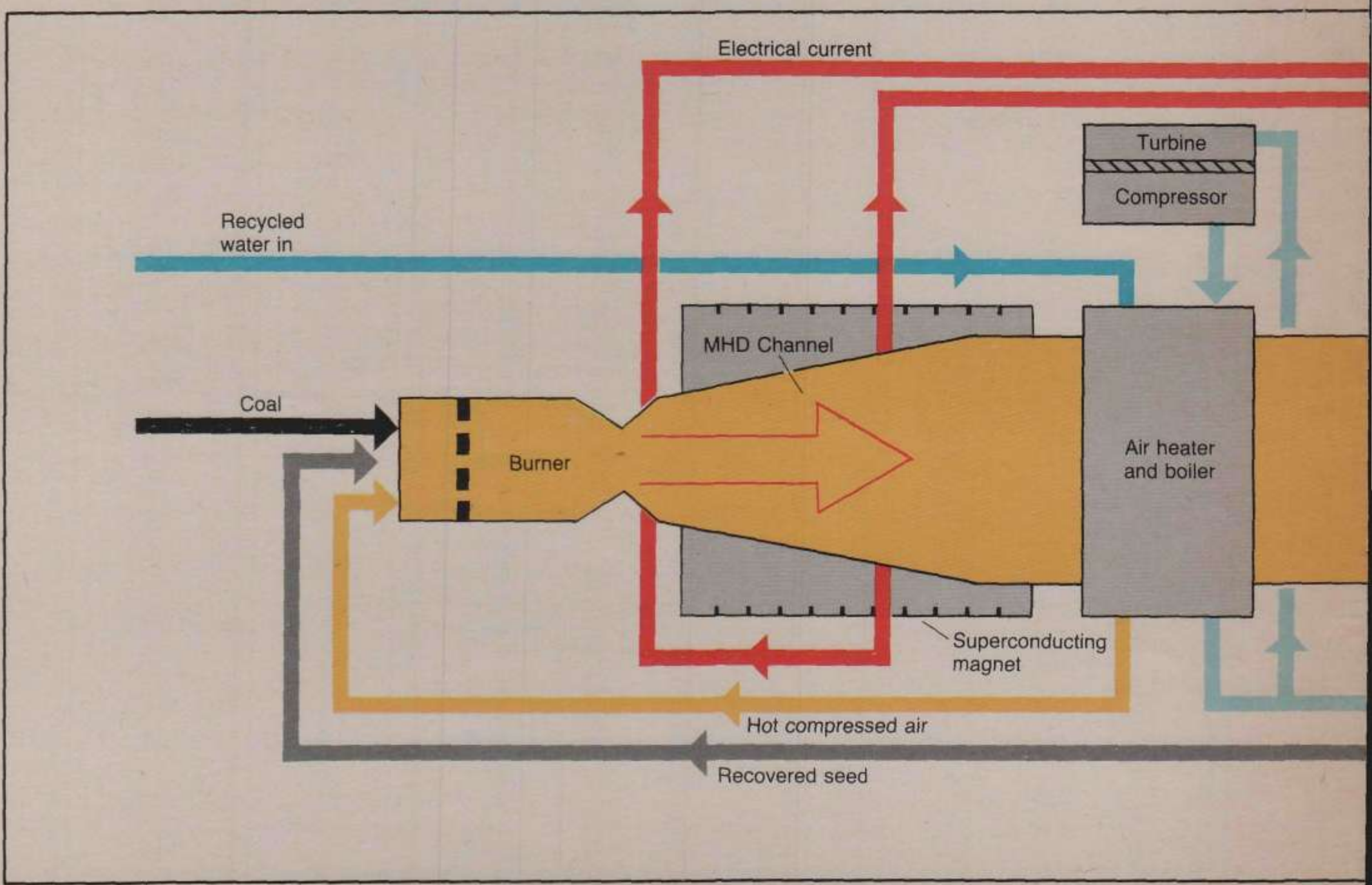
A first-generation MHD coal-fired plant is projected to achieve a cycle efficiency of 48 to 52 percent. This compares quite favorably with the current steam turbine cycle efficiency of 35 to 40 percent. Second-generation MHD generators are expected to convert up to 70 percent of the thermal energy in the combusted coal to electric power.

In terms of fuel consumption, this means that an MHD conversion system would extract nearly twice as much electric power from each unit of fuel as the present technology can. Therefore, although some of the components of an advanced MHD system would be more expensive than off-the-shelf steam turbines, the fuel cost would be about half.

The most cost-effective use of MHD with coal is to design the MHD power train as a topping cycle for a steam turbine plant. In such a system, the exit gas from the MHD channel would transfer its heat into a steam cycle (Figure 5). First-generation MHD technology would most likely be based on 50-50 thermal input to the MHD and steam cycles; more advanced designs would shift the balance to 70 percent MHD.

The cost of conventional coal-fired plants has been rising steadily since the early 1970s because of increased constraints on releasing pollutants into the atmosphere. Taking these higher costs for current technology into account, a 1978 projection put the cost of delivered power from an MHD system near 32 mills per kilowatt-hour, compared to 45 mills per kilowatt-hour for a conventional plant with the same capacity.

Another reason the MHD cost would be lower—in addition to the increased efficiency of conversion and attendant lower fuel costs—is that MHD is an environmentally excellent system. The fuel combustion temperature is so much higher in an MHD system that the combustion is more complete. This reduces particulate emissions from



the system by more than 90 percent. No gadgets are required to capture these pollutants.

To increase the electrical conductivity of the fossil combustion gases, potassium is added in the combustion process. Experimenters have found that the potassium seed chemically bonds with any sulfur in the coal, reducing sulfur dioxide emissions by 99 percent in the MHD plant and thus eliminating the need for costly stack gas scrubbers.

Nitrogen oxide emissions also can be reduced by decreasing the amount of air in the combustor. It has been found that the sharp 2,000-degree drop in temperature from the inlet to the outlet of the MHD channel decomposes the nitrogen oxides. Other options are actually to increase the amount of fixed nitrogen produced in the system for chemical recovery.

MHD systems can also greatly reduce the heat a power system releases into the atmosphere or water coolants. The thermal pollution problem in large-scale power generation generally requires that a power plant be located on or near a body of water. With a first-generation design MHD topping cycle, 60 percent of the thermal energy is converted to usable electric power, compared to 40 percent in conventional coal burning.

The need for pollution control devices for steam-cycle coal plants has also decreased plant availability or reliability—by 6 percent between 1966 and 1976. The Electric Power Research Institute estimated that each 1 percent decrease in plant availability leads to a loss of $1 million in replacement power costs or for the use of older, less efficient operating units. An MHD system would cut down on this kind of loss.

An MHD cycle is an inherently more reliable conversion system than a steam cycle because the MHD generator has no moving parts. Therefore there is no serious problem expected in designing and engineering MHD baseload units that will operate for the 6,000 hours required. Repair and maintenance can be performed by keeping major spare parts, such as channels and electrodes, in stock and by having an easily removable magnet system.

The basic open-cycle coal-fired MHD generator system that uses exhaust heat for the steam turbine bottoming cycle has three major systems: the fuel combustion unit, the MHD generator, and the bottoming cycle. The last is already operating technology; the challenge in the MHD system has been designing new components for the generator.

Electrode Designs

There are three basic MHD channel designs under development to maximize power output from the complex interaction of the magnetic and electrical field configurations in the channel (Figure 6).

The first and simplest design is a Faraday generator that draws off the current produced by the Lorentz force, but does not make use of the Hall current produced or the

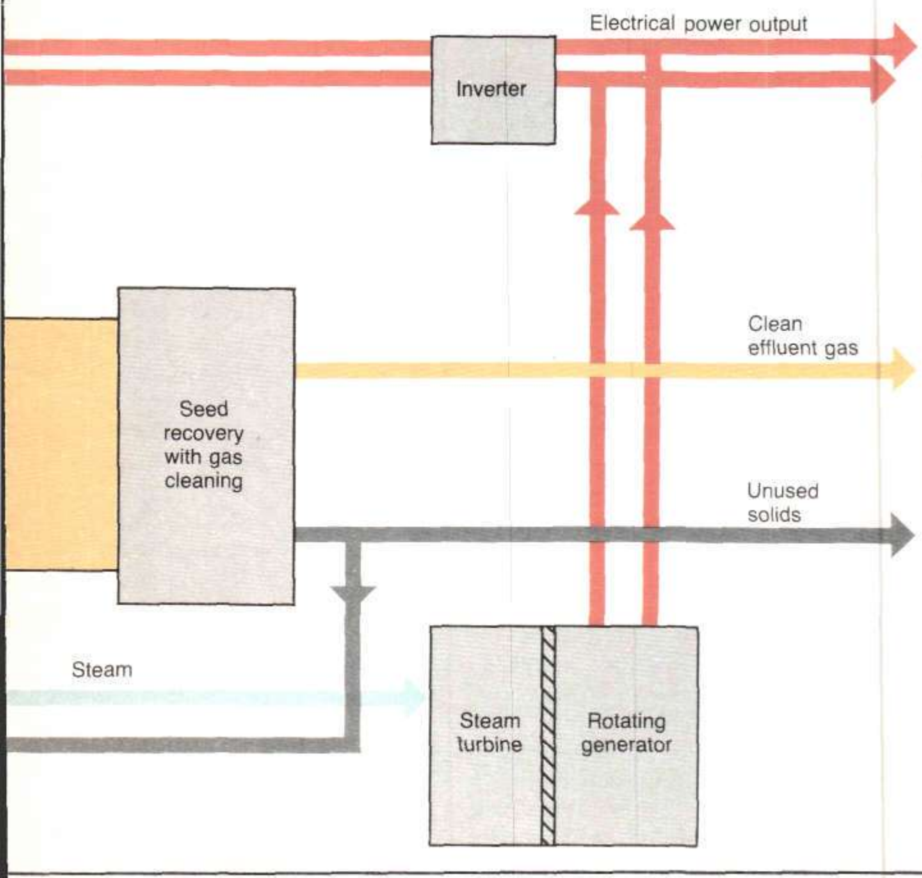


Figure 5
COMBINED MHD AND STEAM TURBINE OPEN-CYCLE SCHEMATIC
In this schematic of a coal-fired MHD open-cycle system designed by Avco Everett, the coal is combusted with the seed and then accelerated through the MHD channel. The power generated through the channel goes through an inverter so that current can be put on the AC power grid. Water is heated in the boiler with the waste heat from the MHD generator, as is the air returned to the coal burner.

The steam produced goes into a conventional turbine; the remaining gas is cleaned and the seed is removed to be recycled. The cleaned gas is then vented into the air as effluent and the steam turbine-generator system produces power to supplement the MHD generator power.

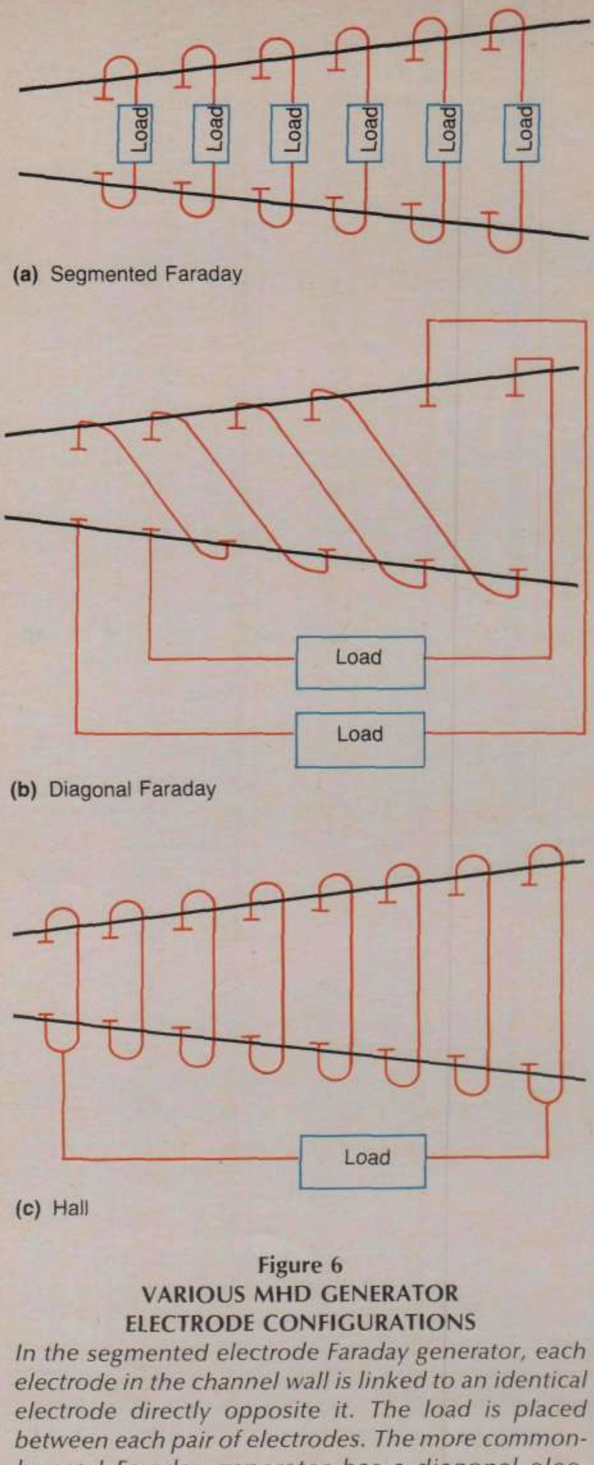


Figure 6
VARIOUS MHD GENERATOR ELECTRODE CONFIGURATIONS

In the segmented electrode Faraday generator, each electrode in the channel wall is linked to an identical electrode directly opposite it. The load is placed between each pair of electrodes. The more commonly used Faraday generator has a diagonal electrode hook-up. The load is between opposing electrodes at opposite ends of the channel and the current drawn off is the Hall-drifted Faraday current. In the pure Hall generator configuration, the load is connected between the input and output electrodes, but the Faraday current crossing the width of the channel is short-circuited.

drift of the Faraday current in the generator. If the electrodes along the channel wall are one connected sheet of conducting material, the Hall current produced parallel to the flow of the working fluid will short out the electrodes. To mitigate the Hall effect, as early as 1959, experimenters at Avco and Westinghouse developed segmented crossed-field Faraday electrode configurations, which are individually insulated.

Hall generators were also designed and tested at the beginning of the 1960s, but again, by shorting out the Faraday current a significant amount of potential power is lost.

The most recent and most promising design for the electrodes in MHD channels appears to be a series of segmented diagonal electrodes that capture the drifted Faraday current most efficiently. Here the load is created between the inlet and outlet ends of the channel, but the electrode pairs are placed in the path of the electrical field from the Hall effect.

Another problem area has been the development of electrodes that could withstand both the temperature and corrosive environment of the hot coal gas.

One discovery in 1971 at the University of Tennessee Space Institute MHD facility was that coal slag deposited on the channel walls "coated" the copper electrodes being tested, thus solving that problem. This effect was later verified on the Avco Mark VI power flow train.

A second solution to lengthening the life of the electrodes was suggested by Dr. Edward Scannell, formerly the director of the MHD program at Reynolds Metals. Scannell has patented gaseous or plasma electrode designs, and electrode development work continues at General Electric, Reynolds Metals, Westinghouse, the Massachusetts Institute of Technology, and Avco.

Combustion Temperature

The main determinant of the electrical conductivity of the gaseous working fluid in a coal-fired MHD system is the temperature of combustion. This temperature can be appreciably increased by preheating the air used in combustion. The three methods of providing air preheat in the system are independent burning of a clear fuel to provide heat; direct use of the MHD exhaust gas recycled back into the combustion chamber; or use of the MHD hot exit gas through a heat exchanger system to indirectly preheat the air.

Burning a separate fuel just to preheat the air clearly would be uneconomical and is not being considered for a commercial system. The most economical technique would be simply to recirculate the heat from the MHD exhaust gas. Until now, however, an economical way has not been developed to use these "dirty" gases, which include seed material and other combustion leftovers, without clogging and creating other problems in the air preheating system.

Fluidyne Corporation in Minneapolis is working on the development of air heaters for directly and indirectly fired MHD systems. In 1978, Fluidyne recorded 900 hours of operation on a high-temperature (directly fired) regenerative heat exchanger simulating the conditions of a directly fired coal-burning MHD system.

For the production of commercial power plants this direct air preheat technology will have to be developed further; meanwhile indirectly fired air preheaters are being used in most experiments by taking the exhaust heat through a heat exchanger.

The Soviet 500-megawatt commercial demonstration facility plans to raise the combustion temperature by adding oxygen to the combustor—an off-the-shelf preheat technology. This would be grossly expensive in a commerical system, and the Soviets plan to use direct preheating in their commercial units.

Magnetic Field Strength

In addition to the electrical conductivity of the gas and the electrode configuration, the third major determinant of MHD efficiency is the strength of the magnetic field. Conventional water-cooled magnet systems cannot exceed field strengths of more than about 3 tesla (a tesla is 10,000 gauss). A baseload MHD power plant will require magnets in the range of 5 to 7 tesla.

To provide such field strength without the magnet needing more power than the plant produces will require superconducting magnets. The world's first MHD generator operating with a superconducting magnet system was the ETL Mark V in Japan. The 5 tesla magnet is used for studying the integrated operation of superconducting magnets and MHD generators and is designed for long-duration tests.

In 1977, Argonne National Laboratory fabricated a 40-ton superconducting magnet that was crated and shipped to Moscow for testing on a bypass loop of the Soviet's U-25 installation. A larger, 24-foot long, 14-foot high superconducting magnet went into construction in 1978 by General Electric and the Massachusetts Institute of Technology. The $7 million project will generate fields high enough for MHD.

Scientists led by Dr. Robert Eustis at Stanford University are studying the effects of high magnetic fields on plasma in MHD devices. Tests on their M2 generator have measured the pressure and fluctuation levels at field strengths of 2.4 tesla. These measurements are important, because excessive electrical fluctuations could lead to a degradation of power output. The fluctuations are measured in current and output voltages.

Fossil Fuel Experimental Generators

Avco has conducted a series of experiments on MHD generators of increasing size since 1959 to test channel and other components. Avco's first generator, the Mark I, was built by Dr. Richard Rosa, now at the University of Montana. It reached a peak power of 11.5 kilowatts and sustained a power level of 10 kilowatts for 10 seconds. The channel was 20 inches long, with 40 separate pairs of electrodes.

The Mark II, built in 1960 with support from American Electric Power Services Corporation, reached a power level of 1.5 megawatts using the combustion products of alcohol and oxygen. The channel was 5 feet long; the magnet system was rated at 32,000 gauss (the earth's magnetic field is .5 gauss); and the flow rate was 6 pounds per second.

The Mark V, operational in 1965, ran on the same fuel and was supported by the utilities, the U.S. Air Force, and the Advanced Research Project Agency of the Department of Defense. The military's interest in the experiment was to demonstrate the feasibility of a large, rocket-driven MHD generator for space power applications. The flow rate was brought up to 100 pounds per second and the Mark V reached a power peak of 32 megawatts for 1 to 2 seconds. Of that, 8.5 megawatts was used to power the magnet system.

By the mid-1970s, Avco's Mark VI was on line using oil-fired combustors but simulating coal-firing by injecting ash into the fuel. In February 1976, the Mark VI ran continuously for 95 hours at 200 kilowatts with slagging on the channel walls. New electrode designs produced a uniform current distribution over the electrode surface and ceramically lined channel walls were used.

Two years later, the Mark VI ran for 250 hours at 220 kilowatts with electrodes clad with platinum for longer last. The machine reached a power peak of 500 kilowatts.

The Arnold Engineering Development Center in Tullahoma, Tennessee has been in the MHD business since they built the LORHO generator in 1965. Similar in size to the Mark V built by Avco, the LORHO used rocket engine combustion products and produced a power of 20 megawatts. This was used to power the wind tunnel at the center for aerodynamic and aerospace-related experiments.

More recently, the Arnold Engineering Center has built a demonstration facility for high performance, short-duration testing that is near baseload parameters. This includes an enthalpy extraction rate of 15 to 20 percent. (Enthalpy extraction is the amount of total heat that is removed from the MHD fluid and is one measure of the efficiency of conversion in the generator.)

The facility will have an inlet temperature of about 3,000 degrees Kelvin, a magnetic field of 6 tesla, and a maximum power output of 50 megawatts. The dual-mode test facility will provide testing for water-cooled magnets up to 6 tesla pulsed for 30 seconds, or 3.5 tesla magnets in steady-state operation and is expected to provide important magnet data.

The aerospace companies were the first to have experience in combusting fuel in temperature ranges approaching those for MHD. TRW and the Rocketdyne division of Rockwell International are now developing coal combustors for MHD use.

In addition, the Pittsburgh Energy Research Center, operated by the Department of Energy, is doing design and testing of multistage combustors. The Pittsburgh center is testing a 5-megawatt thermal two-stage coal-fired combustor, and in 1978 it reached a milestone by demonstrating 95 percent slag removal in the combustor system. This will greatly improve the operating environment for the downstream potassium seed and heat recovery equipment, giving it a cleaner combustion product to work with.

The first MHD generator to run with a seeded combustion was the Westinghouse machine in 1960. More recently, the University of Tennessee Space Institute MHD program has been doing tests on directly fired coal-based systems for seed recovery techniques. Their experiments have shown that 90 percent of the potassium seed will most likely be recoverable, a critical factor for the economical operation of a power system.

Closed-Cycle Fossil MHD

In addition to the binary, or open-cycle coal-fired MHD systems, described here, there has been recent interest in using the combustion heat from burning coal in a closed-cycle plasma or noble gas MHD generator.

Up until the early 1970s scientists had assumed that the use of noble gases (argon and helium, for example) for closed-cycle MHD systems would be heated by high-temperature nuclear reactors. By the mid-1970s, however, MHD scientists realized that these reactors would not be commercially available in the near future because there was no national effort to develop them. Therefore, interest turned to using fossil-fired heat sources.

There are a number of advantages to this closed-cycle plasma design. First, ionizing the argon gas can be done at temperatures in the range of 2,000 to 3,000 degrees Fahrenheit instead of the 4,000 to 5,000 degrees needed for the open-cycle system. Second, the clean argon gas is a less hostile environment for the electrodes and channel walls than the dirty coal gas. Experiments have demonstrated a very favorable enthalpy extraction rate of 24 percent, which gives encouraging economic projections for commercialization.

The major developmental problem is that a heat exchanger operating in the range of 2,000 to 3,000 degrees Fahrenheit and with a corrosive coal combustion heat source is needed to transfer the heat to the argon gas. The heat exchanger requirements are not very different from those needed for the directly fired air-preheater in the open-cycle system, and experimenters are optimistic that the problem can be solved.

One ingenious design for such a high-temperature heat exchanger is the ceramic pebble bed heat exchanger. The heat released from the burning fossil fuel is accumulated in ceramic pebbles and transferred to the argon gas as it passes through the heat exchanger. A small prototype of the pebble bed has been constructed here, and the Soviets have developed similar technology for their MHD program. General Electric's Space Science Laboratory in Valley Forge, Pennsylvania has had a closed-cycle program since 1972, with experiments beginning in 1975. Closed-cycle plasma fossil fuel systems are also being pursued at the NASA Lewis Laboratory in Cleveland, Ohio and at Eindhoven University of Technology in the Netherlands. At Eindhoven a 5-megawatt-thermal experiment aims at 20 percent enthalpy extraction rates. In the United States, GE has tested a 2.7-megawatt heat exchanger with an 1,800-degree Kelvin outlet temperature for the argon gas.

For these closed cycle fossil systems, ionization instabilities and the economics of the heat exchanger system will have to be traded off against the cleaner working fluid and lower temperature advantages.

NUCLEAR MHD SYSTEMS

Conventional nuclear fission plants and advanced breeder and high temperature plant designs and processes do not produce a "combustion" product made up of charged particles. Therefore, the neutron heat from the fission reaction has to be transferred to a working fluid that can be easily ionized for MHD direct power conversion. There are two main approaches underway to solve this problem, and some more advanced ideas have been developed in conceptual design.

The first approach was described above in relation to a fossil-fuel heat source—the use of a noble gas as the working fluid in a closed-cycle arrangement. Until the mid-1970s this approach was still considered most appropriate for linkage with a high-temperature nuclear heat supply, with a projected working fluid of helium or argon seeded with cesium. Efficiencies of 50 to 54 percent were calculated with a 2,000-degree Kelvin inlet temperature.

Although the commercial development of the high temperature gas-cooled reactor has been written off by the Carter administration, studies are continuing, particularly in the Netherlands and in Japan, for noble gas plasma systems with nuclear power. MIT has been experimenting with an unusual disk-shaped MHD generator configuration, and the Japanese are continuing work with a device called Disk II. This disk-shaped geometry is a simple Hall-effect device using an argon plasma, which has a single load rather than dozens of separately connected electrode pairs.

While international attention turned more toward the liquid metal fast breeder reactor as the next generation of advanced nuclear technology, MHD systems using a variety of liquid and gaseous metal as working fluids came under serious consideration. Until 1974, the major application of this use of MHD conversion had been in space power systems, but now it has turned increasingly to commercial power generation.

Liquid Metal MHD

The major U.S. work on liquid metal MHD, known as LMMHD, has been at Argonne National Laboratory in Illinois, concentrating on the development of the intricate MHD generator. Experiments at Argonne began in 1972, and small experimental devices are in operation.

The main difficulty in using a liquid metal as the working fluid for MHD is that it is basically noncompressible and, therefore, cannot be accelerated appreciably through the MHD channel by itself. To solve that problem, researchers have devised various two-stage LMMHD systems.

The major advantage in LMMHD is that the liquid metal is a highly conductive fluid and, therefore, very large electrical currents are expected in the LMMHD generator. In addition, the use of liquid metals in fast breeder reactors and in fusion reactors avoids the liquid metal-to-water interface of a steam turbine power-generating system.

Power conversion from a liquid metal system can be attained at considerably lower temperatures than those

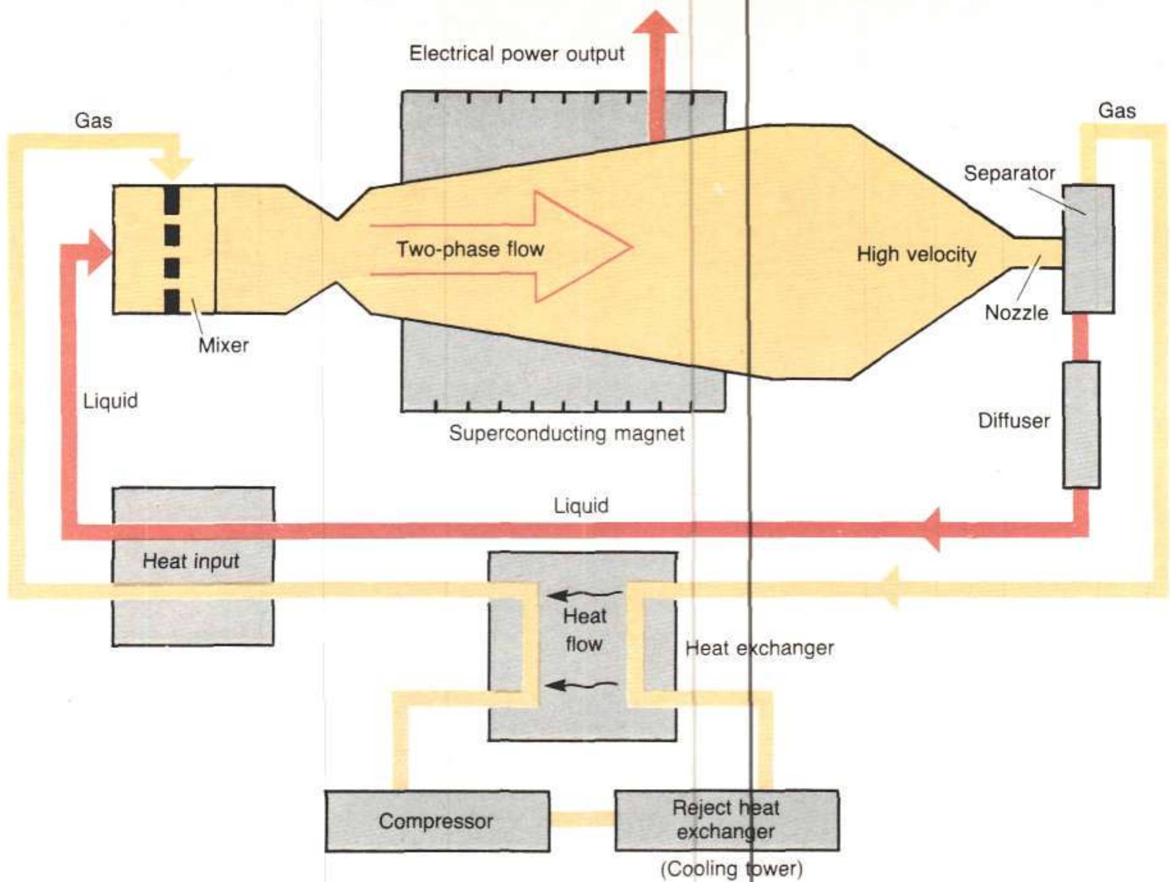


Figure 7
LIQUID METAL MHD POWER SYSTEM

In the liquid metal MHD system, heat is applied to the gas working fluid and to the liquid metal. They are then mixed together before entering the MHD channel. After power is extracted in the MHD channel, the two-phase flow is accelerated to a high velocity so that the gas and liquid can be separated. In this design, the gas is drawn off and taken through a regenerative heat exchanger in order to return the remaining energy in the gas as heat input to the cycle. The liquid metal is taken through a diffuser, where its velocity is slowed and its pressure increased; after heating it is returned to the mixer.

Source: Argonne National Laboratory, *Magnetohydrodynamics Energy Conversion*, October 1979.

needed with the noble gas plasma designs, and experiments at Argonne on devices approximating the design parameters of a commercial system have been in the range of 400 to 1,000 degrees Fahrenheit. Commercial systems using the heat from breeders would go as high as 1,360 degrees Kelvin.

In a basic LMMHD design, the inert gas is the primary working fluid, which expands through the nozzle into the channel, driving the liquid metal mixed with it across the magnetic field (Figure 7). The liquid metal, the electromagnetic fluid, has a high heat content and the expansion occurs at near-constant temperature, so that the liquid acts as an "infinite-reheat" for the gas.

Much of the heat remaining in the gas after the MHD conversion can be recaptured after it is separated from the liquid, recouped in a regenerative (direct) heat exchanger, and fed back into the mixer. The heat could also be used in a steam or gas turbine bottoming cycle.

The Argonne results reported at the 18th Symposium on Engineering Aspects of MHD in June 1979 were very encouraging. The ambient temperature 20-kilowatt-electric LT-4, running on a sodium-potassium liquid and nitrogen gas mixture, has operated at current densities at or above those needed for practical power systems with power levels of 32 megawatts per cubic meter.

The efficiency of conversion measured at this low temperature was greater than 60 percent, and the experimenters are confident that conversion efficiencies of 80 percent are possible with improved efficiency expected from machine scale-up.

In 1977, Argonne researchers began experiments using the liquid-gas mixture as a "foam." The foam is produced as a stable, homogeneous mixture with a high ratio of gas volume to total volume. It is created in the mixer and destroyed in the separator, with a lifetime of tenths of a second as it goes through the MHD channel. Argonne is

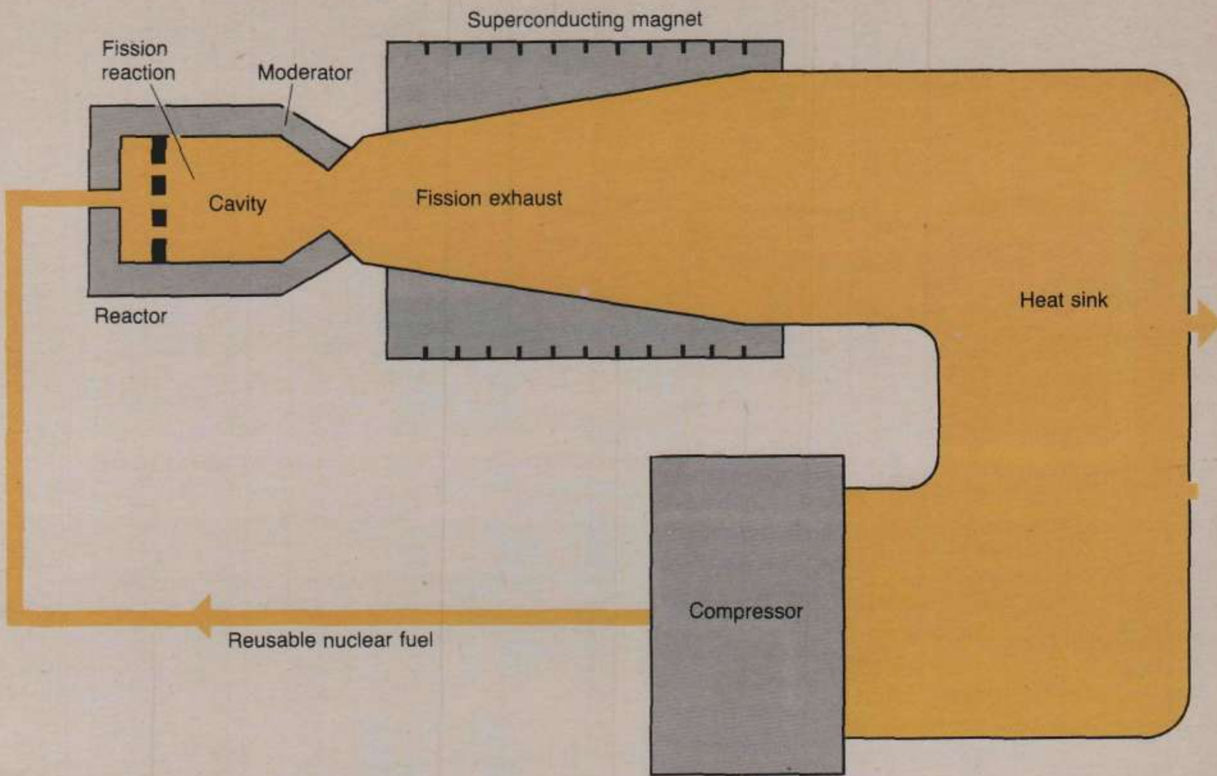


Figure 8
NUCLEAR CAVITY REACTOR WITH MHD CONVERSION
An externally moderated or cavity reactor would use the exhaust from the nuclear fission process as the working fluid for MHD direct conversion. In this simple design, heat from the MHD generator's exit gas could be used in a heat exchanger system to provide a bottoming cycle for the system. The design provides for the reuse of the nuclear fuel.

Source: Rosa 1968

testing various surface-active agents or powders to produce the foam, and the next step will be testing the foam in an experimental generator.

The high-temperature HT-1 at Argonne is the world's first such LMMHD device. In tests with single-phase (liquid sodium) and two-phase (liquid sodium and nitrogen) flow, the HT-1 has operated for a total of 325 hours in the ranges of 400 to 1,000 degrees Fahrenheit.

Studies on the magnetic field effects in LMMHD generators are ongoing at the Department of Nuclear Engineering at Osaka University in Japan. Because the Faraday current generated by the liquid metal conductor is much greater in LMMHD than in combustion plasma MHD systems, the Hall effect produced by the electrical field of the Faraday current is also greater. The Japanese are studying pinch effects in the fluid and formation of bubbles in the flow in a two-phase device.

The Soviet MHD program the world's largest, is pursuing all possible applications of MHD conversion with advanced nuclear heat sources. These studies are conducted at the Academy of Sciences Institute for High Temperatures and at Kurchatov Institute for Atomic Energy.

A group of Soviet scientists in the United States late in 1979 reported that four or five varieties of liquid metal combinations are being considered. These include all-liquid single phase systems; liquid metal with vapor injection, where part of the liquid metal is vaporized and injected into the liquid through a vapor jet; two-phase systems, similar to those in the United States; "foamy" varieties of the two-phase system; and other promising advanced designs, including one (described below) where the nuclear fuel becomes the working fluid.

Nearly all LMMHD systems under development look very promising, and in the United States the only pacing parameter has been the unavailability of the breeder reactors and high temperature reactors to use as the heat source. The near-collapse in U.S. advanced nuclear research in the last decade, however, has not completely discouraged scientists from conceptualizing advanced generations of fission reactors designed to be more readily adaptable to MHD conversion.

Financial support for such research here, as well as in other countries, has come largely from the military. For example, the LMMHD research at Argonne (like the first U.S. light water reactors) is supported by the Navy, and the military R&D agencies of other nations are involved in advanced nuclear and energy-conversion research.

The Cavity Reactor

Before the last decade's demise of advanced nuclear research, Richard Rosa, one of the most creative scientists in the MHD program, wrote a book that included his ideas for next-generation MHD-nuclear technology. Rosa, who built the Mark I at Avco, proposed gaining ultrahigh temperatures in nuclear reactors.

One of his designs was for a cavity or externally moderated reactor (Figure 8). If a sufficient amount of uranium fuel in the form of a liquid, gas, or dust is injected into the cavity mixed with a propellant or working gas, the reactor can attain very high temperatures in the fuel-gas mixture. The melting point for uranium is about 1,400 degrees Kelvin, and if that temperature were attained, the fuel itself could be used as the working fluid with chemical additives to increase its ionization. The density of the fuel injected determines when it becomes a self-sustaining fission reaction or reaches criticality. The moderating material could be beryllium, carbon, or heavy water, Rosa proposed.

Other researchers have attempted to adapt the cavity reactor to rocket propulsion, but a basic problem is that expensive nuclear fuel would be thrown overboard with the propellant because criticality requires more fuel in the reactor than is consumed in any finite period of time.

In a closed-cycle baseload generating system for commercial power, however, the nuclear fuel and working gas would be mixed together, injected into the channel, and passed out of the reactor through the MHD generator still mixed together. It is thought that the gaseous uranium molecules would condense at some point in the cycle, after which the fuel and gas would be handled separately. In any case, the nuclear fuel remains within the system and is reused.

The basic cavity reactor design could be used for many propulsion or power-generating systems. The fundamental increase in efficiency as a result of the higher temperature limits would be its main advantage.

Inductive MHD Conversion

Recently, Dr. Erik Witalis of the National Defense Research Institute in Stockholm, Sweden has been looking into the possibility of improving and resurrecting some "old" ideas in MHD to apply to advanced nuclear MHD generation. In a 1979 paper, Witalis considers the advantage of *inductive* compared to *conductive* MHD conversion.

All the MHD designs discussed so far are based on using electrodes to draw the Faraday current or the MHD current caused by the Hall effect from the conducting working fluid. One of the key limiting factors in the efficiency of conversion is the electrical conductivity of the fluid, which can be improved by the use of high-field superconducting magnets.

In addition, the most popular diagonal channel designs require power conditioning of the drawn current because the voltages are not the same across the entire length of the channel. The current produced in the channel is direct current and has to go through an inverter system before it can be put into the alternating current grid system.

An induced current is produced when the interaction of the gas (or conductor) and the external magnetic field are nonstationary; that is, either the flow is subjected to an oscillating magnetic field or the steady magnetic flux is "pushed" by an oscillating or pulsating gas flow. A potential difference is created at either end of the conductor by the oscillations from the changes in motion of the field of flow. If the flow is pulsed, the induced current can be captured and drawn off from the magnet.

Witalis refers to work done in 1957 by S.A. Colgate and R.L. Aamodt, who proposed an inductive MHD power system from a "truly unsteady gas flow, namely an enriched uranium metal vapor flow oscillating through an MHD generator channel between two gas core reactor cavities, or perhaps better referred to as explosion chambers."

Witalis describes the concept as follows: "The idea was that a density build-up in one chamber would make the fissile gas there go gently critical, explode, push the highly ionized fission gas through the generator to the other chamber with an ensuing similar density build-up, etc. Under the name of the 'Poof-Poof' reactor, the concept was often taken as a joke during the 1960s."

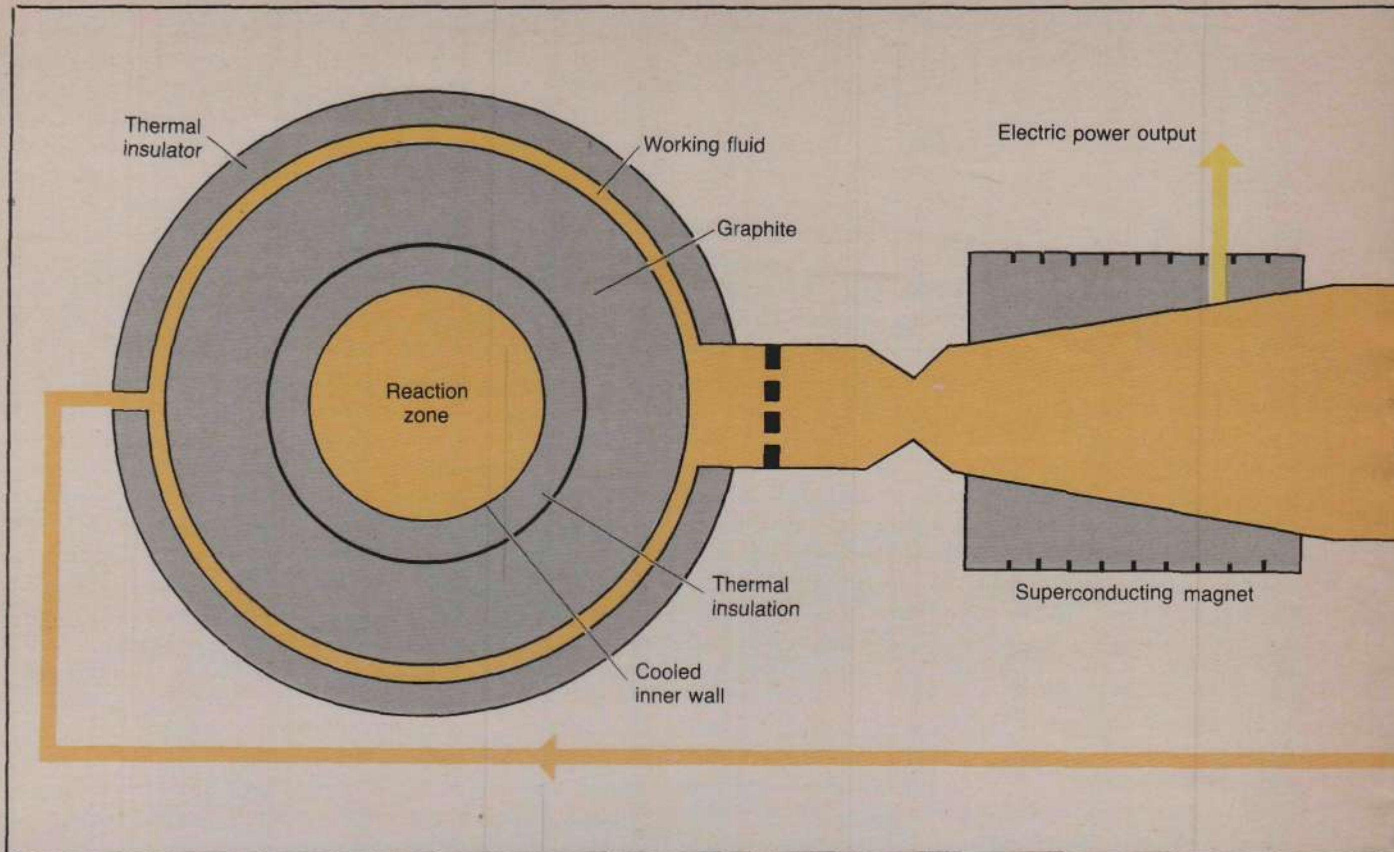
In the mid-1970s, Soviet Academician E.P. Velikhov developed a similar idea using microexplosions from thermonuclear reactions initiated by laser radiation or focused charged-particle beams (discussed in more detail below).

Witalis has continued to investigate the potential for inductive MHD with advanced fission reactors, and in his 1979 paper proposes a modified Colgate-Aamodt scheme. To increase the electrical conductivity of the fluid, which has a much higher requirement for inductive than conductive MHD, he suggests the use of uranium-fluoride compounds as fuel for gas core reactors. In addition alkaline salts could be added to the gas flow as seed, increasing the thermal ionization at comparatively low temperatures of 1,500 to 2,000 degrees Kelvin.

Witalis includes the unique idea that metal dust seeding might be used to further increase the electrical conductivity. He proposes that "essentially, each metal particle will be surrounded by a cloud of thermionically emitted electrons." In other words, the temperature would not be high enough thermally to ionize the metal particles themselves, but "free" electrons in the metal particles could be "boiled off" at the projected temperature of 2,500 degrees Kelvin.

As Witalis notes, the theory of increasing conductivity by metal dusting is very complex and "experiments on it in MHD power contexts are scarce."

But such applications of direct conversion theory to wholly innovative nuclear technology would revolutionize the efficiency and therefore the economics of converting the heat from nuclear power to usable electricity. The only reason that innovative advanced energy conversion systems have not been experimentally or commercially developed is that advanced nuclear technology has been stymied for political reasons.



FUSION MHD SYSTEMS

At the turn of the next century when commercial fusion power begins to be available, the ideal MHD system will be in sight—an energy-producing process whose combustion products are charged particles that can be directly converted into electric power via an MHD system. The first-generation fusion plants using deuterium-tritium reactions will produce 77 percent of their energy in the form of neutral particles and most of the remaining energy in alpha particles (positively charged helium).

Advanced fusion fuel systems using deuterium-deuterium reactions will produce 70 to 80 percent of their energy in the form of charged particles. Even with the first-generation reactors, however, MHD conversion is feasible with any fusion geometry—magnetic confinement or inertial confinement.

Discussions of fusion-MHD were part of the first MHD conferences. At the initial symposia on the engineering aspects of MHD beginning in 1960, fusion scientists from the Princeton Plasma Physics Laboratory and the Lawrence Radiation Laboratory briefed the conference on developments in fusion, both in plasma physics and in engineering. Throughout the late 1960s and early 1970s, as significant advances were made in the heating and confining of fusion plasmas, conceptual design studies for fusion-MHD systems were elaborated here and in the Soviet Union.

There are two basic fusion conceptions under study for direct conversion. The first is the steady-state fusion reaction, typical of the tokamak, mirror, and other major experimental designs. The second is a pulsed fusion design, which has important applications for advanced weapons research and which the Soviets have taken a keen interest in. Speculation about the possibility that the Soviets developed an antimissile beam weapon in spring 1977 raised the question of whether pulsed fusion-MHD designs were used to produce huge pulses of electric power.

Steady-State Reactions

Basic design work on steady-state power production has concerned tokamak fusion devices, but similar methods would be applicable for all deuterium-tritium fusion power plants.

Using the closed-cycle MHD conversion system described above with an inert gas as the working fluid, higher fusion temperatures could increase the ionization potential and thus the conversion efficiency of systems already designed for lower-temperature nuclear reactors. One such possibility has been described by Kantrowitz and Rosa and is shown in Figure 9.

This coupling of a conventional MHD system to a fusion reactor would use a graphite blanket around the reaction zone to absorb neutron and X-ray energy and to heat a suitable working gas such as helium. Because the graphite

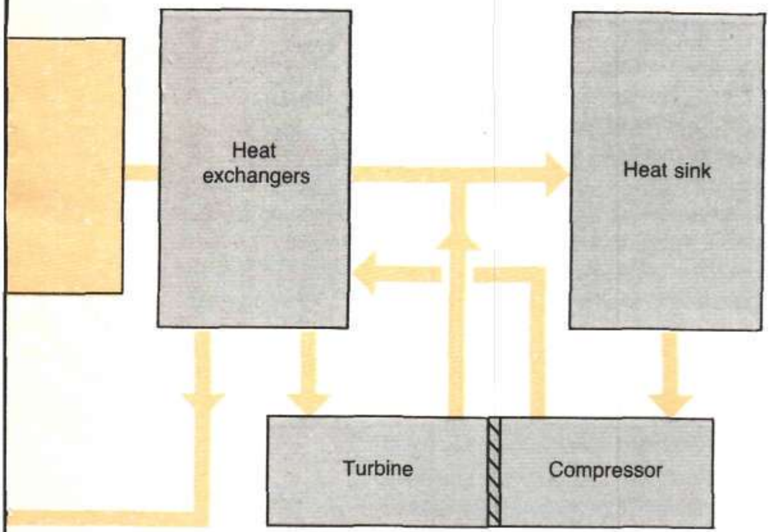


Figure 9
A CONVENTIONAL MHD SYSTEM WITH A FUSION REACTOR
The heat a fusion reaction generates can be used in a closed cycle MHD conversion design that is identical to that of a high-temperature nuclear reactor. In this design the reaction zone is surrounded by a graphite blanket that transfers the fusion heat directly to the noble gas coolant. The excess heat in the working fluid can be extracted by a heat exchanger after the MHD cycle and the fluid is recirculated and reused.
Source: Kantrowitz and Rosa 1975

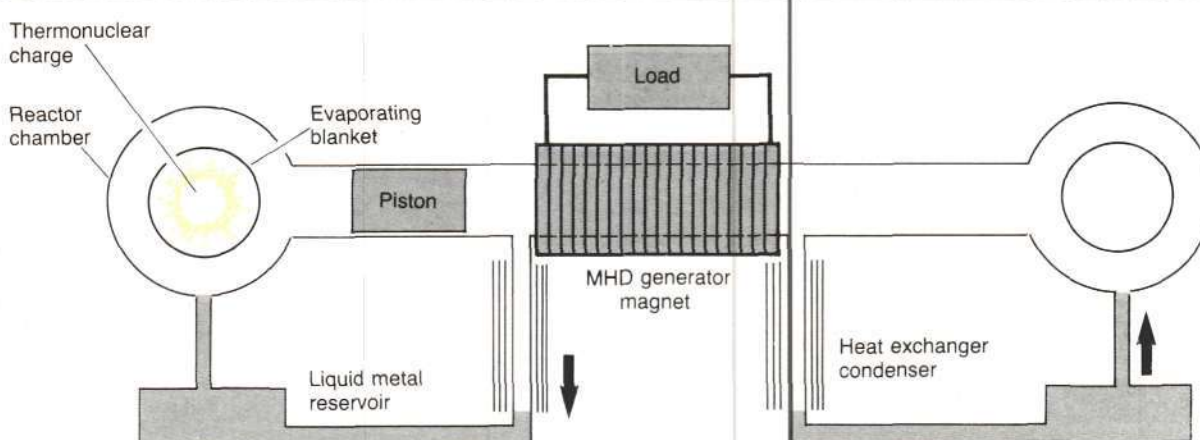


Figure 10
MHD GENERATOR FOR PULSED THERMONUCLEAR REACTIONS
In Soviet Academician E.P. Velikhov's dumbell-shape design for MHD direct conversion with a fusion reactor, an evaporating blanket of a liquid metal like lithium vaporizes when the fusion reactor takes place in one of the reactor chambers. The accelerated hot vapor pushes a metal piston past a solenoid to the other reactor chamber. The kinetic energy is transferred into electrical power, which is drawn off through the solenoid, or load, that separates the two reactor chambers. Another fusion reaction in the second reactor chamber then sends the piston back. In this closed-cycle system, the liquid metal vapor is caught, condensed, and then recycled through the liquid metal reservoir back into the reactor blanket to be revaporized.
Source: Freeman 1977

does not have to contain fission products and because it maintains good structural properties up to 2,800 degrees Kelvin, such a system should be able to operate at high temperatures for long periods of time.

A helium outlet temperature of 2,500 degrees Kelvin seemed reasonable in this design, and preliminary calculations showed an overall cycle efficiency of more than 60 percent.

Rosa and James R. Powell at Brookhaven National Laboratory designed basic fusion-MHD systems combined with gas turbine or steam boiler cycles that yielded projected efficiencies up to 75 percent. They also examined the possibility of producing pulsed power in this system by circulating only the helium coolant-working fluid when the reactor was in between plasma burns.

The Soviets have studied variations on the same MHD technology for fusion, looking in more detail at the nonequilibrium aspects of the ionization of the noble gas at such high temperatures. Their estimates of conversion efficiency were between 52 to 55 percent in a preliminary, nonoptimized system design.

Pulsed Reactions

Although this application of conventional MHD techniques will most likely be the first direct-conversion technology used with deuterium-tritium commercial fusion power plants, a much more intriguing idea has come from work at the Kurchatov Institute by E.P. Velikhov, who has been interested in bulk pulsed-power from fusion reactions. This technique uses the induction conversion described in the Witalis research and probably has significant implications for advanced weapons technology.

Velikhov describes both the conductive and inductive pulsed fusion-MHD design in a paper in the April 1974 issue of *Atomnaya Energiya*, titled "MHD Conversion of Energy From Pulsed Thermonuclear Reactors." He assumes that the fusion explosion will produce approximately 10 billion to 1 trillion joules of energy, the equivalent of 2.5 to 250 tons of TNT. The working fluid for Velikhov's dumbell-shaped reactor chambers is an alkali metal vapor, either lithium, potassium, or sodium, which surrounds the thermonuclear charges as an evaporating blanket (Figure 10). The blanket vaporizes as a result of the fusion explosion, providing the force in the plasma to drive a metal piston from one chamber through the MHD channel to the other chamber. The liquid metal vapor that condenses after the power extraction and temperature drop is recycled through the liquid metal reservoir back to the reactor blanket to be revaporized with the next explosion.

The piston is partially slowed down by the magnetic field surrounding the channel and it compresses the magnetic field in the solenoid. The energy is inductively transferred to the magnet system where the load is attached.

Velikhov has projected that this inductive design would produce an average electrical power of approximately 15 gigawatts with efficiencies greater than steam turbine systems. More important than the efficiency is the possibility of creating huge bursts of electrical power from fairly compact highly energy-dense fusion reactions.

SPACE APPLICATIONS

The earliest conferences on MHD discussed papers and research into direct conversion for extraterrestrial applications, including MHD propulsion, on-board power generation, and plasma processes. Much of the early advanced MHD research in liquid metal systems and high-temperature applications, in fact, was begun in the late 1950s with an eye toward full-scale manned solar expeditions.

Although the goals and funding for the NASA space program were modified and long-term human space flight was removed from the agenda, the space program and its laboratories and contractors have continued to play an important role in MHD research.

A conference held at the NASA Lewis Research Center in Cleveland, Ohio on "Plasmas and Magnetic Fields in Propulsion and Power Research" in October 1969 discussed the importance of MHD and fusion plasma research on propulsion and power systems for aircraft and spacecraft. New or improved propulsion and power concepts and systems were needed, Wolfgang Moeckel explained in his introduction to the proceedings:

> The fact is that we are still rather poorly prepared, from the propulsion standpoint, to undertake the exploration of space. Man has reached the moon, and there is some talk about going to the stars. But we are still quite inadequately endowed, even conceptually, with propulsion systems suitable for exploration of our own solar system. The trip times are excessive, even to the near planets, if we are limited to propulsion systems now in use or in the development stage.

The longer-term technology that NASA scientists were pinning their hopes on was plasma propulsion from thermonuclear fusion systems. In the nearer term, however, they were experimenting with electric rockets using complex interactions of electric current and magnetic fields to accelerate a plasma in an MHD-type configuration (Figure 11). Because the accelerated plasma could provide the power for the rocket thrust, the system was described as "magnetoplasmadynamic (MPD) arc thrusters."

NASA Lewis reported at the conference that it had tested steady-state radiation cooled MPD thrusters at power levels from 100 watts to 40 kilowatts. Using ammonia as the propellant, the thrust was developed primarily by magnetic nozzle effects. The data showed that most of the ion acceleration occurred in the magnetic nozzle region. In summarizing their results, the scientists reported that they had fair success in making plasma measurements and that the complexity of the phenomena required more diagnostic study for a better understanding of the device's operation.

At the same conference, other NASA-Lewis researchers reported on progress in closed-cycle MHD work for power-generating applications for utilities, concluding that such systems, primarily those coupled with nuclear reactors, would be optimal for on-board power in space.

During the late 1960s and early 1970s, Richard Rosa de-

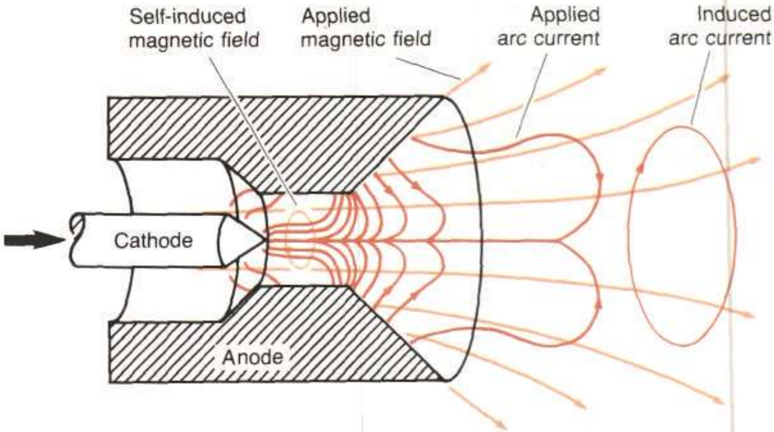


Figure 11
MPD ARC THRUSTER FOR SPACE PROPULSION
The complex design of this advanced concept for an MHD space propulsion systems proposes using the arc currents and magnetic fields from the MHD generator to propel a spacecraft. The design was developed by NASA in 1969, but was not engineered after the manned space program was downgraded in the late 1960s.
Source: NASA 1970

veloped an application of his nuclear cavity reactor for space propulsion. This complex system involves heating the liquid hydrogen by the exhaust heat of an MHD generator using a nuclear heat source. Electric power produced in the MHD generator would provide additional energy input to heat the propellant and provide onboard power.

The heated propellant can be further expanded by use of a turbine powered by the MHD generator. Since the primary optimizing criterion for a space-power system is weight, the compactness and weight-to-power ratio gained in an MHD system make it very appropriate for spacecraft applications.

PORTABLE POWER SOURCES

A unique characteristic of MHD power generation is that the generator can be nearly any size, although efficiency is lower in smaller power units. Efficiency is not the primary consideration, however, in portable applications—for emergency, stand-by, or mobile requirements, including temporary power for scientific experiments in isolated areas.

Soviet Academician Velikhov began an experimental program in 1973 to operate a series of small, portable MHD generators. Called the Pamir series because they were designed and built for conducting scientific geophysical experiments in the Pamir Mountains, these portable MHD generators are commercial, operable MHD systems.

Velikhov applied his experience with MHD to the needs of geological scientists. For years geologists had been probing the earth by drilling boreholes into the earth's crust to measure movements in order to predict earthquakes. The scientists had studied seismic waves, but these carry information only on the elasticity and mechanical properties of matter—"appropriate for billiard balls, but not the earth," as a Soviet scientist put it.

It was known that electromagnetic sounding methods would yield additional information but this technique was limited by the strength of the sounding signal from the generators used in the experiments. Natural earth currents and interference from industrial power production required the operation of self-contained generators that could produce a strong, independent signal.

In 1973, the Kurchatov Laboratory sent the Pamir MHD generator from Moscow to begin operation as part of the equipment of the Institute of Physics of the Earth of the Soviet Academy of Sciences. The initial experiments showed that changes in the electrical conductivity of the rocks of the earth's crust begin two or more months before a strong quake.

According to Soviet computations, 30 to 50 such MHD apparatuses could adequately cover all of the seismically active regions of the Soviet Union. The series of sounding units would have to be linked through a computer bank to process the recordings of the network of receivers and to monitor any changes recorded. This system could effectively forewarn the entire nation of an impending serious earthquake.

The Pamir MHD generator, described as a "self-energizing" machine, is fueled with solid rocket fuel. The electric power for the copper coil magnet is started by a bank of capacitors carried along. When the fuel burns and the plasma flow begins, the magnet is fed electric power inductively. This increases the field strength, which, in turn, increases the electric power converted. The increased power refeeds the magnet, and when the feedback system reaches the required power level, the load is connected to the electrodes in the MHD channel and the power is drawn off conductively. This power then provides a pulsed electromagnetic signal that is transmitted to electrodes buried in the region of the earth where measurements are desired.

When the power is drawn off by the external load, the magnet loses power. Since it is only running for 1 to 10 seconds at a time, a strong magnetic field can be obtained without external cooling of the magnet; it has a couple of

Figure 12
THE SOVIET PAMIR MHD GENERATOR

Shown in the photograph are the Soviet portable MHD generator, the condensers, and other pieces of equipment on site in the Pamir Mountains. The MHD generator was moved by truck to various places in the mountains to do electromagnetic soundings for earthquake prediction.

Source: Velikhov, E.P. et al. 1975. "Factors Influencing the Self-Excitation of Pulse Type MHD Generators" in Proceedings of International Conference on Magnetohydrodynamic Electric Power Generation (Washington, D.C. June 9-13, 1979).

seconds to cool off when the power is being pulsed out to the earth.

The first Pamir generator produced a 1 to 10 second pulse of 10 to 15 megawatts and the magnetic field reached between 3.5 and 4.0 tesla. The data collected at that power pulse would be equivalent to taking readings for three hours with a continuous power source of 10 kilowatts. The areas measured by the generator pulse stretched 20 to 30 kilometers, and dipole cables (equally and oppositely charged) connected to the generator's electrodes could receive signals up to 40 kilometers away.

The Pamir signals can measure the electrical conductivity or magnetic radiation in various distances from the point of measurement. The entire MHD generator weighs about 8.5 tons, most of which is the copper magnet (Figure 12).

The Urals Experiment

In 1975, the Soviets conducted a series of experiments in the Ural Mountains to learn more about varying depths in the earth, especially deep faults in the earth's crust. This information can be quite valuable, since many faults are in fact "channels" that bring ore-bearing melts up from the depths to near the surface.

New, more powerful MHD generators were able to penetrate 40 kilometers below the surface—the entire thickness of the earth's crust in the Urals. The signal was stably registered as far away as 70 kilometers and the device was started with an automobile engine. Scientific studies done in collaboration with the Geophysical Institute of the Ural Scientific Center of the Academy of Sciences found a decrease in electrical resistivity by a factor of more than 100 at depths of 35 to 40 kilometers. Further work will determine whether this is a local phenomenon or is general to the Urals region.

Electrical conductivity variations in rocks is an indicator that is sensitive to changes in depth, temperature, and the moisture saturation of the rocks and therefore, to the porosity and fissuring of the rocks. This means that the MHD studies will make available entirely new qualities of data for studying major and minor geologic variations.

The Urals MHD device generated 50 megawatts of pulsed power producing an induction field up to 3.5 tesla in the channel. The pulse duration in the electromagnetic loop (the cable and electrodes) is about 1.5 seconds. There are 40 tons of aluminum in this loop.

Most recently, Velikhov and colleagues carried out an extraordinary series of experiments at the Barents Sea. The saline seawater was used as the conducting loop of the system and the current went through the sea from one electrode to the other. The MHD apparatus was placed on an isthmus connecting the Sredniy and Rybachiy Peninsulas with the main body of the entire Kola Peninsula and the electrodes were placed in the sea.

The current bent around the shoreline of the two peninsulas. In order to carry the current to the water "loop," it was necessary to lay two cables weighing a total of 160 tons, but the water loop carrying the electromagnetic signal covered an area of about 5,000 square kilometers. To make such an emitting loop from aluminum (instead of water) would have taken 7,000 tons.

A network of observation stations was organized to register the signals from this unique system and process them. Collaborating in the project were the Institute of Geology and the Polar Geophysical Institute of the Kola Affiliate of the Academy; the Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation; and the Scientific-Production Division of the Soviet Geology Ministry.

The project probed virtually all of the Kola Peninsula. The scientists found that the electromagnetic signal apparently "sticks" to bodies of ore, which immediately become visible as in medical X-rays. This discovery provides efficient means for locating bodies of precious minerals without poking any holes into the earth.

In the United States, scientists conducting research in high power MHD systems, at the Aero-Propulsion Laboratory at Wright-Patterson Air Force Base have been doing preliminary designs and experiments on developing lightweight, high-powered portable MHD generators. The overall goal is to develop the technology for power ranges of 10 to 300 megawatts with operating times from 1 to 10 minutes. The experimenters are now in phase two of a projected four-phase program. This phase concerns combustor performance testing, detailed component design, and component modeling.

Since the Soviet scientists are demonstrably ahead in this aspect of MHD technology development, the U.S. Air Force researchers have proposed that the United States collaborate with the Soviets on geophysical experiments.

Other Applications

Other important applications for relatively small and portable MHD generating systems include commercial peak power use, which is normally quite expensive for utilities. In periods of high demand, small and generally inefficient power-generating units are brought into service to meet demand peaks. These systems burn expensive petroleum or natural gas because these fuels can be stored and transported easily. A small MHD system, which could be on standby, would reduce peak power costs considerably because it burns less expensive coal.

In emergencies, the most important criterion is start-up time. If, for example, the power on the grid should fail, an MHD generator could provide emergency power for a hospital within minutes of ignition. There is no delay waiting for fuel to be burned, water heated to produce steam and turn turbines, and so forth. The MHD generator could go from cold start-up to full power in seconds.

Short-term MHD power could also be provided to remote regions for critical usage or to supplement baseload power systems in operation.

INDUSTRIAL APPLICATIONS

The nitrogen oxide pollutants in an MHD system could be turned into raw materials for vital chemicals by optimizing their production in the combustion process. Simply by increasing the air in the coal combustion process, more nitrogen is "fixed" or chemically combined with oxygen, making available a valuable fertilizer component.

If the air is increased 20 percent the nitrogen oxides in the exhaust gas can be as high as 4,800 parts per million, which is high enough for economical recovery. A chemical-recovery plant located adjacent to the MHD power plant thus could produce fertilizer and also capture the sulfur dioxide pollutant to produce industrially useful sulfuric acid.

Studies have demonstrated that this combined system would be economically feasible, and the Soviets may include such a chemical recovery technique with one of their first-generation MHD power plants.

Another important aspect of MHD power production for industry is that it produces both electricity and high-quality heat. Reynolds Metals has been interested in the possibility of linking MHD to aluminum processing because cheap hydroelectric sources are being exhausted in the Northwest, and the cost of electric power greatly affects the cost of producing aluminum. For example, approximately 2[illegible]0 million BTU's are required to convert 1 ton of bauxite ore to aluminum, compared to 27 million BTU's for steel.

In a 1978 study, "Investigation into the Commercial Application of First Generation MHD Power Plants to the Aluminum Industry," Reynolds described the potential for cogeneration to provide the direct current power and the high temperatures for process steam that would meet the requirements for the Bayer process of converting bauxite to aluminum. Although Reynolds showed that the plants would be a "perfect match," the government MHD program has not funded any R&D into this promising application.

Most industrial processes that require large amounts of electric power need direct current, which means MHD has a unique role to play. Studies have been done on applying MHD power systems to other metal smelting processes, and most show that MHD would increase the efficiency of these processes significantly. From all indications, additional industrial applications for MHD would certainly be developed as it became clear that the commercial MHD technology would be available.

HOW SOON?

For the past decade the answer to the question of when the commercial feasibility of MHD technology would be demonstrated in the United States has been political, not scientific or technical.

Avco put the world's first power-generating MHD device on line in 1959 and then successfully solicited the support of utilities to build larger machines aimed toward eventual commercial use. In 1966, Avco and American Electric Power Services Corporation raised $13 million to begin the construction of a 30 megawatt-thermal (14 megawatt-electric) pilot plant. They proposed that the Office of Coal Research at the Department of the Interior add another $10 million to build the MHD generator. When the Interior Department rejected the proposal, it slowed MHD research through the early 1970s.

In the 1960s, the federal government did most of its energy-related research through the Atomic Energy Commission, which was mandated to develop all forms of nuclear energy. Optimism about the future of nuclear power led some to believe that the increased efficiency and reduced cost from MHD coal systems would not be needed. Of course, even with a proper full-scale U.S. nuclear development program coal would have to provide a significant percentage of electricity into the next century. Nevertheless, as a result of this line of thinking the U.S. MHD program became segmented into separate application areas. Unfortunately, this meant that the overall importance of developing MHD technology to make it available for coal, nuclear, advanced nuclear, and fusion, was lost in the scientific community—and certainly on Congress and the executive branch.

The Soviets have historically taken the opposite approach to MHD research. The Soviet philosophy is that solving the scientific and engineering problems in MHD would be important for direct energy conversion applications for hundreds of years. As a result their MHD effort (outlined in detail by this author in the February issue of *Fusion*) has been broad-based and non-fuel-specific.

The government's rejection of the Avco proposal demoralized the U.S. MHD community all the more when the Soviets announced the next year that they were going ahead with a 25-megawatt pilot plant, aiming for a 500-megawatt demonstration facility by 1982. But the U.S. MHD community kept up the pressure on government policymakers, and in 1969 the federal Office of Science and Technology conducted a complete MHD study.

However, the results of the study, published as a report titled "MHD for Central Power Generation: A Plan for Action," simply justified the individual research projects already ongoing under the Office of Coal Research. The program plan, developed by Office of Science and Technology head S. David Freeman, did not put forward a path for getting to the pilot-plant device researchers in the field judged necessary and appropriate. (Interestingly, Freeman has since played an antitechnology role as head of the Tennessee Valley Authority, and, as *Fusion* reported in the March 1980 issue, he was instrumental in bringing the antinuclear movement to Sweden.)

Other events soon spurred Congress and the president to reconsider the potential for MHD development. At the April 1971 international meeting on MHD in Munich, West Germany, the Soviet delegation announced that their U-25 experimental facility at the Institute for High Temperatures in Moscow was operating. Two months later, President Nixon's energy message to Congress outlined a program to demonstrate commercial fission breeder technology by 1980 that included some supplementary funding for fossil fuel R&D projects. Although MHD funding was not significantly increased in terms of implementing a pilot-plant-sized experimental program, the direction of the Nixon program created an opening for the scientific community and the utilities to lobby and educate the policymakers on the proper policy perspective.

In November 1971, the MHD Power Generating Study Group at MIT published a report on a study it carried out for the U.S. Office of Coal Research—"Open-Cycle Coal-Burning MHD Power Generation: An Assessment and Plan for Action." As a result of the study, the Office of Coal Research granted Avco, MIT, and the University of Tennessee Space Institute to begin design work on central power MHD.

But funding for the MHD program was still pitifully small. In a 1972 article John Dicks, the head of the University of Tennessee MHD program, notes that the fiscal year 1971 budget for these central power system studies was only about $3 million and that small experiments in universities and industry were still the entire program because of the lack of funding. "The present funding is too small to make any appreciable difference" in the overall program, Dicks stated.

If the program were funded as a national priority, Dicks estimated that a 1,000-megawatt demonstration plant could be on line be 1982. Nevertheless, despite the fact that the United States was demonstrably at least five years behind the Soviets in developing MHD, the formulation of a definite timetable for commercial demonstration had to wait.

A boost to the progam came in 1974, when president Nixon and presidium chairman of the Supreme Soviet N. Podgorny signed a bilateral agreement on energy that authorized cooperation in a number of areas, including MHD. This confirmed the earlier discussions on bilateral MHD cooperation involving plans for the delivery of a U.S. superconducting magnet and long-endurance MHD channel to be tested in the Soviet U-25. The United States had no device of that size at the time the agreement was signed.

Although the U.S.-Soviet agreements on MHD provided additional opportunities to test key U.S. components on a large facility, as Watergate blossomed in Washington the administration spent less and less time on formulating national energy policy. This left the initiative for the MHD program to Congress and to the scientific and technical experts in the government program and in the labs. The utilities, organized under the umbrella of the Electric Research Council (the predecessor to the Electric Power Re-

Photo courtesy of Dr. W. D. Jackson

The first meeting of the MHD Joint Committee in early 1974 in Moscow. From left to right are: Dr. V. Ovcharenko; Academician A.E. Sheindlin, the Soviet committee chairman; the Soviet interpreter; Dr. E. Shelkov, deputy director of the Institute for High Temperatures; Dr. S. Pishchikov; Dr. Arthur Kantrowitz, Avco Everett Research Laboratory; the U.S. interpreter; Dr. William D. Jackson, Office of Coal Research and U.S. chairman; and Professor Jean Louis from MIT.

search Institute) also continued financial support for the program. And the same year, Senator Mike Mansfield, a Montana Democrat, introduced legislation to immediately begin the planning and design for an MHD Engineering Test Facility, ETF—a bill that president Ford later signed into law.

During this period, while the program plan for large-scale experimental MHD facilities was being hashed out, other coal conversion processes were proposed on the basis that demonstration facilities could be built more quickly. These other technologies, including coal gasification, were a political response to the 1974 OPEC oil embargo and had no scientific regard for actual cost, efficiency, or harm to the environment.

A workshop at the Electric Power Research Institute headquarters in Palo Alto, California in 1974 pulled together the previous technology assessment reports on MHD and formulated a program plan to demonstrate commercial feasibility as quickly as possible. Cochairing the meeting were Paul Zygielbaum from EPRI and William Jackson from the Office of Coal Research. Represented at the workshop were utilities, industrial research organizations, and engineering and university programs.

The workshop report published in June 1975 had as its stated goal the demonstration of commercial application of MHD in an Engineering Demonstration Plant operating on a utility grid by 1985. A plan was needed, the report said, to tie together all the small, separate ongoing experiments and to state goals and decisions that had to be made if the U.S. program were ever to overcome the endless process of bench-scale models and indecision.

Each step toward commercial MHD demonstration was outlined in complete detail, including component testing, integration facilities, funding levels, technology development needs, and critical decision points.

In the same year, the Energy Research and Development Administration was created with a division for MHD, and William Jackson was selected to head the program. Also in 1975, a study by NASA, the National Science Foundation, and ERDA was completed—the Energy Conversion Alternatives Study, ECAS. A comparative study of 11 specific energy conversion technologies, including both open-cycle and closed-cycle MHD, ECAS had two teams, one from General Electric and a second from Westinghouse, evaluate the economic and technical feasibility of what appeared to be a smorgasbord of competing conversion possibilities.

Both evaluations found that open-cycle MHD would provide the highest conversion efficiency—between 40 and 54 percent. The cost of electricity, all projected on first-generation technology, would be in the range of 27 to 48 mills per kilowatt-hour, only moderately higher than the reference case for conventional steam generating plants (Figure 13).

The ECAS design studies, however, had assumed that only 45 to 53 percent of the output of the plant would be from the MHD cycle and that the capital costs for various components varied by orders of magnitude depending upon the supplier. These included some of the most expensive components, such as superconducting magnets, air preheaters, and high-temperature materials. These considerations would significantly up the capital cost for the assumed 1,000-megawatt MHD plant but would not affect most of the other technologies considered, which used mainly off-the-shelf components.

MHD Experimental Results

The ECAS evaluation that the nation should make a commitment to develop MHD was reinforced by good results from various MHD experiments in 1975.

- The Avco Mark VI ran for 100 hours, indicating that intractable electrode durability was improving.
- An electrode module built here and tested on the Soviet U-02 facility ran for 127 hours, indicating the same point.
- The Soviet U-25 achieved a rated power of 20.4 megawatts for 30 minutes and operated for 100 hours at an average of 2 megawatts. The U-25 tests were especially important because all the inverters and power conditioning equipment had been hooked up to the experimental generator and it delivered power into the Moscow grid, demonstrating utility compatibility.
- In Japan, the Mark V ran for 1 hour at 350 kilowatts with a superconducting magnet. This demonstrated the technical compatibility of a channel with a plasma heated to thousands of degrees surrounded by a magnetic system kept near absolute zero.
- The MIT disk generator achieved an enthalpy extraction rate of 16 percent, reaching toward the 15 to 20 percent range required for commercial application.

The technical results from the experiments and the economic go-ahead from the ECAS study put the MHD community in an all-systems-go position. After nearly a decade of delay, the 1975 ERDA program plan had a stated goal of commercial demonstration before 1990.

ERDA's projection was to have a Component Development Integration Facility on line in Butte, Montana by 1978, where key parts would be tested and integrated into a single flow train. This would be a 50 megawatt-thermal device. In 1982, the plan was to have a 250 megawatt-thermal device, the Engineering Test Facility, to run for 1,000 to 2,000 hours, demonstrating endurance and efficiency. In 1989, a Commercial Demonstration Plant on the order of 1,000 megawatts-thermal would finally demon-

CAPITAL COST COMPARISON BETWEEN THE FIRST COMMERICAL MHD PLANT AND MASS-PRODUCED MHD PLANTS (in millions of rubles)

Component	First MHD power plant	Mass-produced MHD-plants
MHD generator	36.9	14.0
High-temperature air preheaters	25.2	11.8
Inverter substation	16.0	11.2
Air separation unit	5.6	0
Steam generator	12.0	9.0
Instrumentation, control, and auxiliary	27.6	13.5
Compressor room	3.0	5.0
Total cost	129.3	64.5
Standard components	27.0	27.0
Total plant cost	156.3	91.5
Power of MHD unit	500MW	535MW
Specific capital cost	310 rubles/kw	183 rubles/kw

The Soviets expect that the cost of building a 500-megawatt commercial MHD generator will be cut approximately in half when the units are produced on assembly line. One of the chief cost savers will be the use of directly fired air preheaters. The costs are presented in millions of rubles, which cannot directly be converted to dollars because plant costs are calculated differently here and in the Soviet Union. The mass-produced MHD units will be cheaper than comparable gas-burning steam cycles in use in the Soviet Union today.

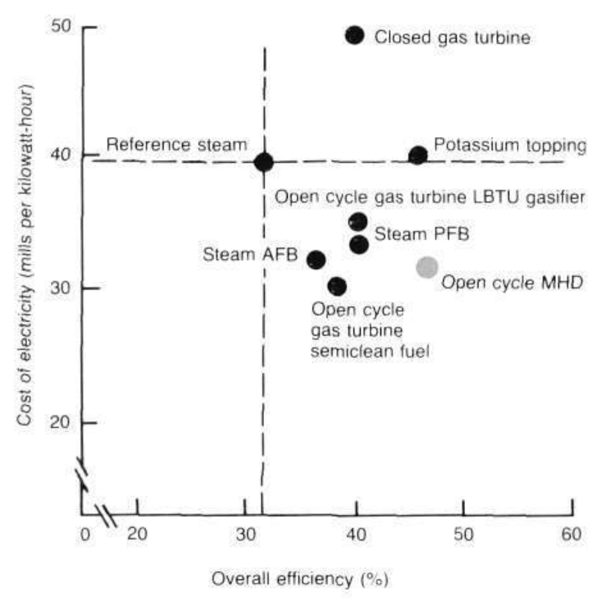


Figure 13
ADVANCED ENERGY CONVERSION SYSTEMS

The Energy Conversion Alternatives Study completed in 1976 produced a series of comparative graphs on the performance of various energy conversion technologies. As shown here, open-cycle MHD was projected to have the highest overall efficiency of all the technologies studied. The open-cycle gas turbine system used a semiclean fuel (that is, not coal) and was projected to have a slightly lower cost of electricity than an MHD system.

Source: NASA 1976

strate full-system reliability and environmental impact. It would deliver power to a utility system and make the technology market-ready.

Systems studies for commercial deployment were underway by STD, Gilbert Associates, and the Ralph M. Parsons Co. In May 1976, ground was broken for the Component Development Integration Facility in Montana and most people in the program, many of whom had devoted 20 years to MHD research, felt that the effort was finally on the home stretch.

Enter Schlesinger

But 1976 was a presidential election year. When the new administration took office in early 1977, James Schlesinger was making energy policy. He organized the new Department of Energy in October on the basis of his belief that there was an energy crisis that no technological "fix" was going to solve; therefore, MHD, fusion, and other advanced technologies were under the gun.

Under the new department organization, the Office of Energy Research was created with Dr. John Deutch as its director. Within weeks, Jackson was unceremoniously removed as head of the department's MHD division. At the same time, energy secretary Schlesinger approved a plan for the new Office of Energy Research to review the MHD program.

The ad hoc MHD review board submitted its interim report to John Deutch at the end of January 1979.The review board, none of whose members knew virtually anything about MHD, states as its first finding that the objective of developing MHD for a gain in efficiency is "recognized as important in the DOE Coal Strategy; but the Strategy considers MHD to be at a lower priority than programs offering more immediate solutions to environmental constraints and energy supply." The "other programs" are left unspecified.

Throwing the ECAS results out the window, the report states, "MHD is not obviously economically superior to other advanced concepts that may require less development and could be on line sooner." Further, the report specifies in doublespeak: "The technological status of MHD does not yet warrant a decision to commercialize MHD. . . . Operations in a commercial power plant environment should not be treated as equivalent to achieving the technological and economic requirements for commercial acceptance."

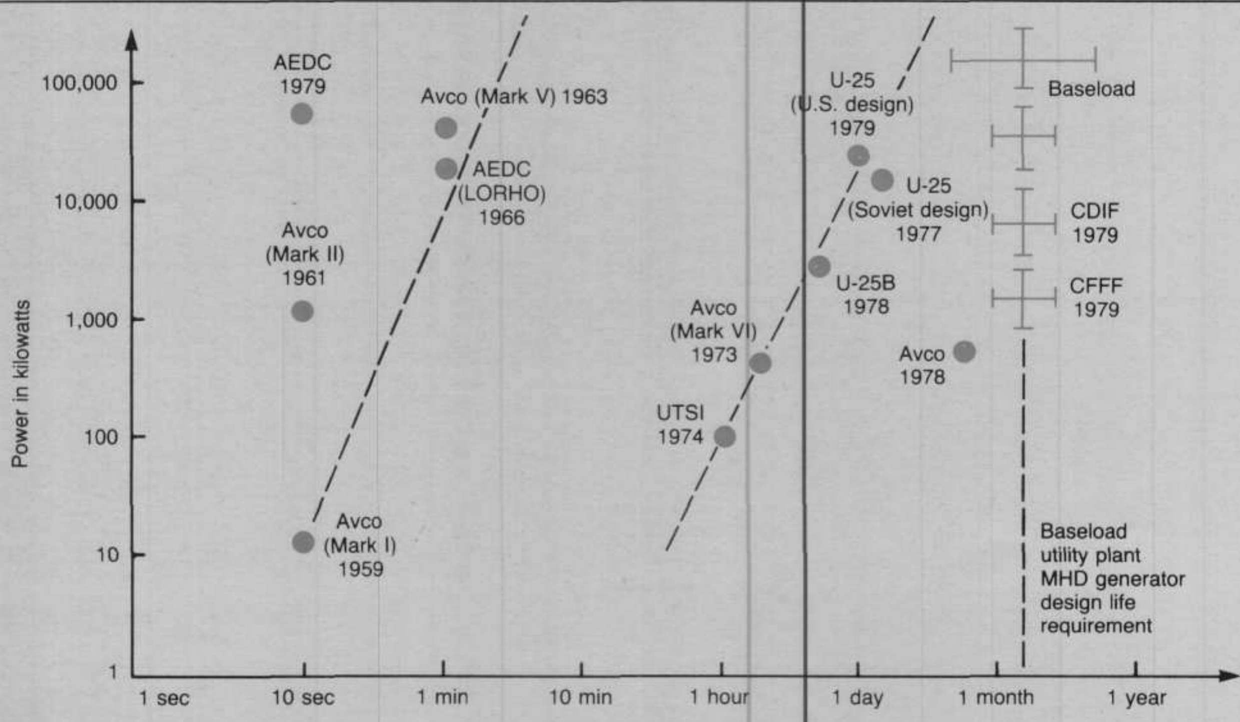


Figure 14

PERFORMANCE PROGRESS IN MAJOR MHD GENERATOR EXPERIMENTS

Since the first Avco Mark I generator in 1959, significant progress has been made in the amount of power generated and length of continuous operating time. The experiment at the Arnold Engineering Development Center (AEDC), under construction in 1979, will reach power levels attained thus far only in the Soviet U-25. The longest continuous operating times are projected for the Coal Fired Flow Facility (CFFF), the Component Development Integration Facility (CDIF), and the Engineering Test Facility (ETF). The U-25 (U.S. design) refers to the channel built here by Westinghouse and scheduled for delivery to Moscow for testing on the U-25.

Noting that "some contractors" in the MHD program advocate accelerating the decision on designing and beginning construction of the ETF by up to three years, the review board evaluates the department's plan to begin design in 1984 and construction in 1985 as too ambitious; it should be stretched out at least two more years, the report says.

The review board also recommended that the program be "redirected to support a broadbased development effort aimed at long-term success rather than early demonstration of possibly uneconomic systems. Compromising technological goals in order to maintain or accelerate schedules should be avoided." In other words, like today's doublespeaking DOE critics of the fusion program, fusion will be solved only in larger machines, but it's obviously too risky to build these now, since they may not work.

George Fumich, the program director for fossil energy under the secretary for energy technology launched a scathing attack on the review committee's findings in a June 1979 memorandum to Deutch:

> . . . The report recommends a program basically different from the one DOE is pursuing. Strong emphasis is placed on generalized research and development subjects rather than specific design and engineering needs. The consequences of adhering to such a change would undoubtably transform the MHD program from an object-oriented, end-item related program to one of broad MHD-related scientific investigations. In my judgment an approach as the one inferred would make it virtually impossible to ever justify an Engineering Test Facility (Pilot Plant) to our Administration and the Congress. The results of the above would cause inordinate delays in the MHD program and increase in program costs. . . .

The Future

The original EPRI program outline for MHD published in 1975 has not been kept, because of technical and management problems. There are serious materials problems that have to be solved. Coal is a dirty and difficult fuel to take through a process as delicate and sophisticated as MHD.

But the major reason the nation has not met some of the goals set for MHD development is that there has been no national commitment to make commercial MHD development a priority in advanced fossil fuels conversion processes or in any other of its potential applications. What's worse is that the administration is justifying these delays by instituting the Schlesinger line—less energy for more money. Advanced nuclear technologies are shelved to make way for the uneconomical synthetic fuel and coal gasification programs, along with the administration's new energy resource—conservation.

As for why this is the case, let's look at the only statement with some truth to it in the 1979 ad hoc review of the MHD program: "The political influence on the entire MHD program, whether real or not, is perceived to be real and has devastating effects on the management and execution of the program."

Ever since the possibility opened up of getting government support to build the first larger-scale component facilities in 1974, MHD has been tossed around Capitol Hill like a political football; decisions are made not on the basis of reaching the program goals but on how bits and pieces of the program can garner support from blocks of voters. This atmosphere of political haggling over the progress of the research and development has demoralized the scientists and engineers involved, many of whom have been working for 20 years to solve the physics, chemistry, and design problems of MHD.

What is absolutely clear from the scientific and technological facts is that once the nation decides that it needs to develop MHD direct conversion technology and put it on line in the next two decades for fossil fuels, the breeder, and advanced nuclear plant configurations, we'll do it.

Marsha Freeman, director of industrial research for the Fusion Energy Foundation, is also energy news editor for Fusion *magazine. She frequently lectures and writes on MHD.*

References

Astrakhantsev, G.V. et al.1977. "Induction Sounding of the Earth's Crust in the Urals Using an MHD Generator." *Proceedings of the Academy of Sciences of the USSR*. 237:808-811 (Sept.).

Engineering Aspects of Magnetohydrodynamics. 1962. Proceedings from the Second Symposium. March 9-10, 1961; Proceedings from the Third Symposium, March 28-29, 1962; Proceedings from the Sixteenth Symposium, May 16-18, 1977; Proceedings from the Eighteenth Symposium, June 18-20, 1979.

Electric Power Research Institute. 1975. "An Overall Program for the Development of Open Cycle MHD Power Generation." Palo Alto, Calif. EPRI-SR-12. (June).

Freeman, Marsha. 1977. "MHD: From Nuclear Explosion to Electricity." *The Science Behind the Soviet's Beam Weapon*. New York: Campaigner Publications.

Hals, F. and Jackson, W.D. 1969. "MHD Power Generation—Economic and Environmental Implications." *Proceedings from the 10th Symposium on Engineering Aspects of Magnetohydrodynamics*. (Mar. 26-28).

Jackson, W.D. 1976. "MHD Electric Power Generation: Prospects and Issues." *Proceedings from the Ninth Fluid and Plasma Dynamics Conference*. AIAA. (July 14-16).

Kantrowitz, A. and Petschek, Harry E. 1957. "An Introductory Discussion of Magnetohydrodynamics." Avco Everett Research Laboratory Research Report 16. (May).

Kantrowitz, A. and Rosa, Richard. 1975. "MHD Power Generation." *The Physics Teacher*. 13:455-464. (Nov.).

Konovalov, B. 1977. "By Rocket Into the Depths of the Earth." *Izvestia*. Nov. 16, p. 4.

Levi, Enrico. 1978. "MHD's Target: Payoff by 2000." *IEEE Spectrum*. (May).

Little, Noel C. 1967. *Magnetohydrodynamics*. New Jersey: Van Nostrand Company, Inc.

NASA. 1970. "Plasmas and Magnetic Fields in Propulsion and Power Research." Cleveland, Ohio: Lewis Research Center. NASA SP-226. (Oct.).

NASA. 1976. Energy Conversion Alternatives Study—ECAS—General Electric Phase II Final Report. NASA CR-134949. (Dec.).

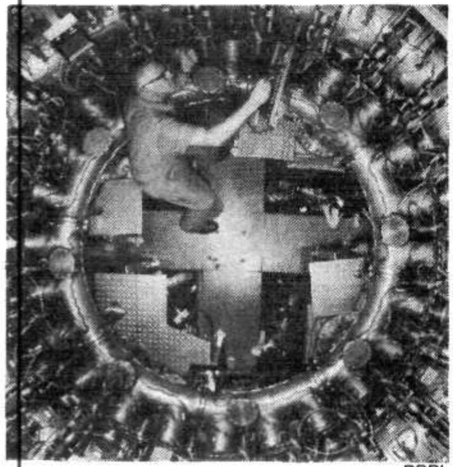
Petrick, M. and Shumyatsky, B.Y. 1978. *Open Cycle Magnetohydrodynamic Electric Power Generation*. Argonne, Ill.: Argonne National Laboratory.

Sheindlin, A.E. and Jackson, W.D. et al. 1976. "Magnetohydrodynamic Power Generation." *Status Report*. Paris: Nuclear Energy Agency.

Sheindlin, A.E., Jackson, W.D. et al. 1979. "Magnetohydrodynamic Power Generation." *Natural Resources Forum*. 3:133-145.

Witalis, Erik. private communication.

The Economics of Fusion Research



PPPL

by Dr. George A. Hazelrigg, Jr.

EDITOR'S NOTE

It is striking that this econometric study by Dr. George A. Hazelrigg, Jr., which starts from the standpoint of classical cost-benefit and "cost of information" methods, arrives at the same conclusion as the Fusion Energy Foundation's Riemannian model study, which is based on a study of capital investment and productivity effects: Namely, that an aggressive fusion research and development program is essential for the nation's economic health.

George Hazelrigg is a pioneer in the economics of the impact of energy technologies. Currently director of systems engineering for Econ, Inc., a consulting firm, he has been involved in a several year long study of the economics of research and development in long-term energy alternatives—especially fusion—for the Department of Energy. A specialist in the economics of research and development, Hazelrigg was on the staff of the space and mechanical sciences department at Princeton University for several years.

Fusion will publish the results of the FEF study of the economics of fusion in an upcoming issue.

* * *

NO ONE SERIOUSLY DISPUTES the fact that it is nice to have a plentiful supply of energy to heat homes, provide transportation, support industry, and so on. Few people take issue with the notion that the less they pay for the energy they consume, the better off they are. Unfortunately, these very simple concepts suddenly become very complex when it comes to setting and pursuing long-range energy goals.

On the one side, scientists and engineers are quite adept at adding up energy supply quantities and costs and comparing these to demand projections. The handwriting is on the wall: Inexpensive fossil reserves are dwindling; they are concentrated in geographical locations that, given the present political situation, are not in the best interests of the United States; and their continued, intensive use leads to potentially serious environmental harm. At the same time, however, these individuals are quick to point out that cost-effective alternative energy sources can be developed, given time and money: the breeder reactor, fusion, geothermal energy, and certain forms of solar energy.

On the other side, however, sit the economists and politicians. The politicians must raise the funds to support long-range energy R&D and they must do it by taking the funds away from other potential uses. Their interests are served by assuring high returns on investments in the short term, despite the fact that most politicians recognize the need for long-term economic stability.

Economists enter the picture because they are asked for advice by the politicians. When such requests involve long-term energy alternatives, the responses appear to have less than overt enthusiasm. Economists argue, quite correctly, that R&D on long-range energy alternatives should have a positive marginal (incremental) return on investment compared to investments in short-range energy alternatives and in nonenergy activities.

Such economists look at fusion, for example, which may not be a commercially available technology prior to the year 2010, they add to that 20 years more before a significant impact is made in the marketplace, and then, according to Office of Management and Budget edict, they discount all benefits at 10 percent (at which rate a dollar benefit received in the year 2030 is worth less than one cent received today). Their prompt conclusion is that fusion R&D is not worth the price. To bolster their argument, they can easily point out that few, if any, taxpayers alive today will ever derive a significant amount of energy from fusion, even if the R&D is successful.

Why would anyone want to support, to the tune of tens of billions of dollars, research that is unlikely ever to benefit them?

It is certainly easy to get enmired in the notion that long-term energy R&D will not help solve energy problems in the short term so, first things first: Solve the short-term problems, then turn to an examination of long-term alternatives. Of course, the problem with this logic, a problem that R & D advocates have long argued, is that there will always be short-term problems and, in fact, without seeking long-range solutions, the short-term problems are likely to get worse rather than better. Thus, it appears that the technical and economic communities are at loggerheads, the former insisting that energy abundance is merely a matter of time and research and the latter often insisting that it is uneconomical to conduct the research.

Is it possible to rectify the differences between these groups?

A Framework for Economic Evaluation

The development of long-range energy alternatives, essentially, is *an investment of resources* (capital and labor) in the present to obtain benefits in the form of cleaner, safer, more economical energy in the future. Because of the time delay between the investment and the return on investment, these quantities, even if expressed in terms of deflated or constant-year dollars, cannot be compared directly to each other. To dramatically illustrate the time value of money, consider which of the following two alternatives you would prefer: a million dollars handed out at the rate of a dollar per year for a million years or a hundred dollars today. Even if the payments were adjusted for inflation, few people would choose the million dollars. For purposes of comparison, therefore, future costs and benefits must be adjusted to their present value by the relationship

$$PV = \int_0^T b(t)e^{-\int_0^t \rho(\zeta)d\zeta}\,dt$$

where *t* is time, (typically in years, with today taken as $t = 0$) and *T* being the limiting date of concern, *b(t)* is the benefit stream (costs may be expressed as negative benefits) and $\rho(\zeta)$ is the discount rate or the rate at which future revenues decrease in present value. In general, ρ is a function of time, but most practical analyses use the assumption that ρ is a constant. Since ρ drives the exponential term in the above equation, its value has a profound effect on one's percep-

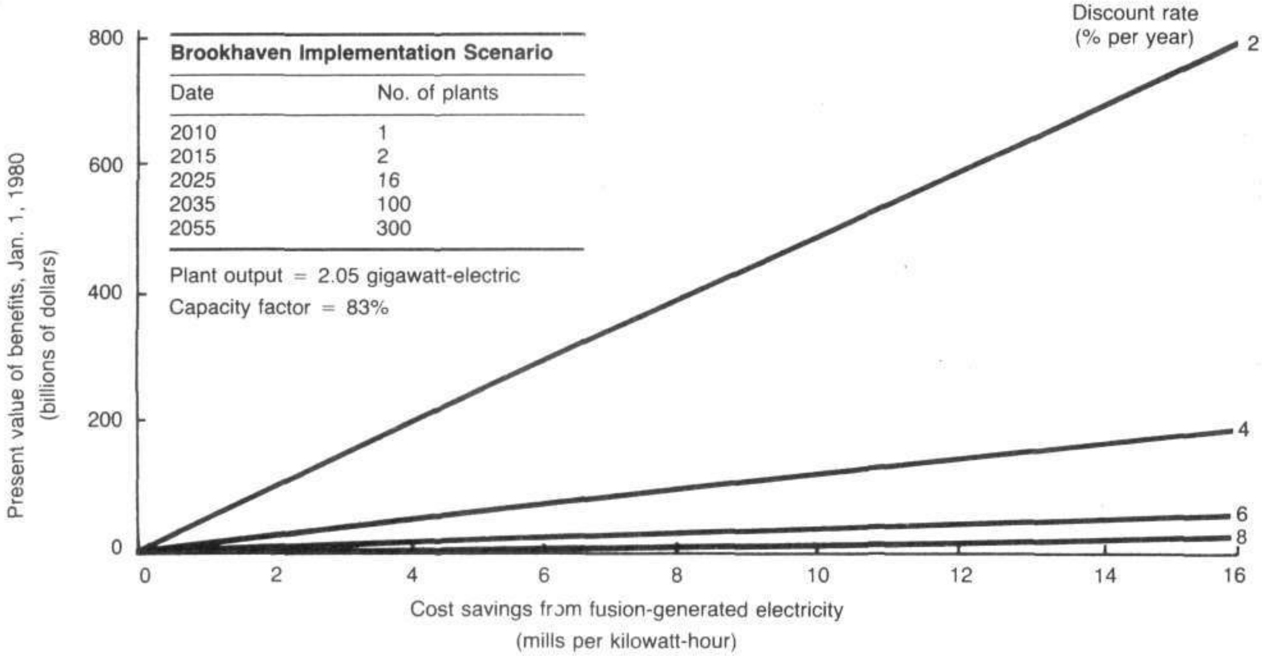


Figure 1
EFFECT OF DISCOUNT RATE ON PERCEPTION OF FUSION ENERGY IMPLEMENTATION BENEFITS

Faced with a choice between consumption today and investment in a venture that will return something in the future, one would choose the investment only if one perceived that it held greater value than could be achieved from immediate consumption of current resources. The tradeoff between current and future consumption is determined by the discount rate, which determines how fast goods consumed in the future diminish in value relative to goods consumed in the present, inflation aside. Thus, an economist prefers to compare costs and benefits of a project only after correcting for the differences in time when they occur. This may be done by adjusting all costs and benefits to their "present value."

The figure shows how one could perceive the benefits of fusion research as a function of the discount rate and cost savings that fusion would allow over alternative energy sources, assuming that a commercial fusion technology is implemented according to the Brookhaven schedule shown, beginning in the year 2010. Because of the long-term nature of fusion research and the exponential effect of the discounting process, the discount rate has a profound impact on one's perception of the benefits derived from fusion energy or, for that matter, any long-range energy alternative.

tion of the benefits of a long-term R&D project. Figure 1 illustrates the dramatic effect that the discount rate has on perception of benefits that might be attributable to fusion.

The discount rate affects much more than one's perception of how future benefits compare to immediate benefits; it also affects one's perception of annual benefits. To be consistent, one should charge off capital expenses at the same discount rate that is used to evaluate benefits. Figure 2 shows how capital charges depend on discount rate and illustrates how sensitive one's perception of costs, especially for capital-intensive activities, can be to this variable.

Finally, based upon one's perception of costs, the extent and rate of market penetration depend strongly on discount rate. Use of a low discount rate, say 2 or 3 percent, can lead one to believe that a capital-intensive technology such as fusion will rapidly capture a large market and produce large benefits, while use of an 8 or 10 percent discount rate to analyze the same technology would lead to the conclusion that it offers no benefits. Clearly, the discount rate is a major issue here.

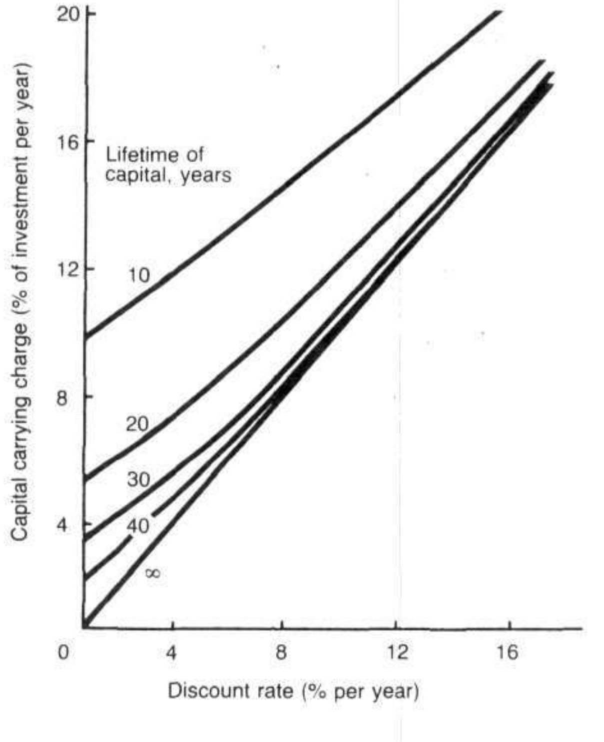


Figure 2
LEVELIZED ANNUAL COST OF CAPITAL
Capital equipment has a lifetime that extends beyond a single accounting period. The cost of such equipment is generally recovered by a capital carrying charge applied across the useful life of the equipment. This figure shows the effect of the discount rate on the capital carrying charge for equipments with different useful lifetimes. Overstating the discount rate causes one to overstate the capital carrying charge and, thus, biases choices to alternatives that are less capital intensive.

A second major issue for R&D on long-range energy alternatives is that by its very nature, such R&D is fraught with uncertainty. There are uncertainties on the schedule by which the R&D effort is conducted, the cost of the R&D efforts, and, most fundamentally, the outcome—success or failure—of the effort. A common evaluation approach has been to estimate the benefits of an R&D program, downweight these benefits by an estimate of the probability of program success, and compare this result to the estimated program cost. Unfortunately, any particular long-range alternative generally has a rather low probability of success; thus, the result of this procedure is that the estimated program benefits are downweighted substantially. It is interesting that although this procedure, widely referred to as benefit-cost analysis, downweights benefits by probability of success, no such weighting is applied to the R&D costs. It is assumed that all R&D funds are committed at the outset of the program with no options open but to wait until the funds are spent and see how the program turns out.

This is not a reasonable model of a long-range R&D program.

In general, long-range R&D programs consist of a sequence of research phases, each with specific activities, specific goals, and associated costs. Each research phase is separated from the previous phases by a decision—the decision to pursue it. Thus, the decision to pursue a particular research phase is only a decision to commit to incurrence of the costs associated with that phase, not the costs of an entire R&D program. As the decision is made to pursue each successive R&D phase, uncertainty in the outcome of previous phases has been resolved and the probability of success is commensurately higher. In essence, R&D is a process of sequential reduction of uncertainty; it is the purchase of information, and it must be evaluated that way.

The third major economic criticism against long-range energy R&D is that it does not solve today's problems; it may benefit future generations, but it does nothing for us now. Arguments to the contrary have focused mainly around the notion that R&D provides technology spinoffs that occur along the way to the end objective and that these spinoffs spawn new industries of benefit in the shorter term. Opponents of the spin-off argument claim that it is more cost-effective to develop the spun-off technologies directly without ever funding the mainline project. In any case, the spin-off argument is weak, and it is the wrong argument.

The nature of long-range alternatives is that they offer to become the major sources of energy at some time in the future, 50 or 100 years from now. They do not provide energy today. Today's energy derives from a pool of resources—oil, gas, coal, uranium—that is widely recognized as being exhaustible, that is, for which production costs will certainly increase substantially in the not-too-distant future. In general, the holders of a limited resource, be they monopolists or cartels such as OPEC or society at large, would choose to allocate the resource across time (intertemporally) in a manner that provides them with the greatest possible derived benefit from the resource. But since the future value of a resource such as oil depends on the future existence or nonexistence of alternative resources and since the future existence of alternatives depends on R&D today, the current optimum consumption rates for today's available resources depend on the nature and extent of current R&D activities.

To state the issue another way, suppose there would never be a substitute for crude oil. Then the value of crude oil, reflected by its price today, would be very high because of its future uses. On the other hand, if one could reasonably expect that in, say, 30 years substitutes for crude oil would be available, this expectation would reduce the future value of oil and, hence, also today's price. This effect applies even if the expected cost of the substitute is sub-

Table 1
REPORTED AND ACTUAL (FULLY ADJUSTED FOR INFLATION) PERFORMANCE RECORDS BY INDUSTRY FOR 1977 FOR 1,600 COMPANIES

	Performance Records (millions of dollars or percent per year)					
Industry	Reported Earnings ($)	Actual Earnings ($)	Reported Return on equity (%)	Actual Return on equity (%)	Reported Return on assets (%)	Actual Return on assets (%)
Agriculture	2.92	–0.75	5.69	–0.86	9.03	4.47
Mining	13.51	0.97	6.72	0.29	8.20	3.88
Drilling and exploration	24.89	7.10	14.47	2.40	17.96	9.97
Builders and construction	17.33	7.01	16.55	4.27	12.69	7.59
Food	32.22	13.38	13.02	3.50	14.69	8.46
Tobacco	129.11	92.12	14.44	8.37	15.38	12.21
Textile and lumber	17.56	1.38	11.83	0.49	12.59	4.84
Printing	18.53	9.73	14.59	5.72	18.47	12.02
Chemicals and drugs	63.24	23.50	14.54	3.42	15.14	8.19
Refining and roofing	293.22	28.15	13.33	0.68	18.11	9.15
Rubber and plastics	14.03	–4.90	9.25	–1.81	11.22	4.34
Glass, clay, and cement	22.84	2.58	12.70	0.76	11.99	4.87
Iron and steel	11.08	–35.79	2.83	–4.00	3.56	–1.23
Hardware	8.08	1.09	14.15	1.13	15.19	6.92
Machinery	45.74	15.80	16.44	4.14	17.87	10.38
Electric	28.92	8.31	15.06	3.04	14.32	8.11
Cars, trucks, and aircraft	79.13	32.12	16.43	4.38	16.19	9.41
Instruments	35.53	19.00	14.70	6.03	18.52	11.96
Jewelry and toys	6.72	0.40	12.06	0.46	14.52	7.17
Rails	84.22	15.82	8.64	0.72	7.61	3.08
Transportation	17.29	–7.20	13.46	–2.41	9.54	2.19
Communication	232.13	–30.51	12.00	–0.51	11.35	3.54
Utilities	49.98	16.04	11.28	1.37	9.70	4.81
Wholesale	10.05	3.73	14.60	3.80	12.68	7.92
Retail	20.34	6.90	12.80	2.69	12.81	7.16

Actual earnings of U.S. corporations differ significantly from those reported on profit-and-loss statements, as a result of inflation. This table shows the effect that inflation has had on 1,600 companies.

stantially higher than the current price of crude oil. The reason is that oil is a limited resource and therefore its production cost is sure, at some point, to rise above the cost of the substitute. It follows that R&D that provides a credible expectation of future energy alternatives yields a significant and important benefit to society today.

Thus we see that one's economic perception of long-range energy alternatives is quite sensitive to one's use of the discount rate and to how one perceives that he is benefited by the R&D process. These issues bear a deeper examination.

The Discount Rate

In 1968, the U.S. Congress Subcommittee on Economy in Government of the Joint Economic Committee held hearings on the social rate of interest (the discount rate) for federal decision making; and in June 1969, the Bureau of the Budget (now office of Management and Budget or OMB) issued Circular A-94 on discount rates and procedures to be used in evaluating deferred costs and benefits. Therein OMB advocates a 10 percent real (corrected for inflation) rate of interest. The principal argument for the use of this rate is that it corresponds to the before-tax rate of return obtained by private-sector investments. It was reasoned that the government should undertake a project only if it could obtain a rate of return that is at least comparable to the rate of return that would be obtained by the private sector.

Private-sector rates of return are available from corporate profit-and-loss statements. Unfortunately, not fully accounted for was the fact that profit-and-loss statements are prepared under Internal Revenue Service guidelines that do not take inflation into account. Thus, during periods of relatively high inflation, corporate profit-and-loss statements provide a distorted measure of real rate of return for these reasons:

(1) Payments to the firm are made with dollars that have less purchasing power than the dollars outlayed to cover costs, because of lags between incurring costs and receiving revenues.

(2) The value of corporate capital assets such as plant and machinery appreciate over time in current (nominal) dollars. Failure to correct for this leads to overstatement of the returns on assets.

(3) Depreciation allows a firm to deduct the cost of a capital asset over the lifetime of its use. This depreciation allows corporations to treat as a cost assets withheld with which new capital equipment can be purchased to replace old worn equipment. Under current tax laws, however, the amount allowed for depreciation is based upon the original purchase price and not upon the inflated replacement cost. Thus, current tax laws allow for inadequate depreciation; firms end up "living off" accumulated capital stock, paying taxes on it, and distributing fictitious profit from it, without this showing on the accounting records.

(4) Firms hold cash assets and inventories that nominally appreciate over time as a result of inflation. These nominal gains are recorded as profits from which taxes must be paid, but they are not real, since nothing additional has been produced or gained in real terms.

All these phenomena lead to overstatement of real private-sector return rates reported by corporations. As Table 1 shows, correction for these four effects drastically reduces the perceived rate of return on private-sector investments. Furthermore, these rates of return are on investments that include some degree of risk; thus, one could expect that they include marginal payments to entice investors into risky investments. It is not all that easy to estimate the portion of return on investment that should be written off as risk premium, although a few knowledgeable executives have estimated that it is on the order of 2 percent; that is, of a 6 percent return on investment, 4 percent could be viewed as risk-free. Another approach, however, is to examine the rate of return on an investment that, for all practical purposes, is risk free; namely, U.S. Treasury bonds.

Rates of interest on Treasury bonds, corrected for inflation have varied from about –3 to +3 percent over the past several years, but tend to be on the positive side at 1 to 2 percent. Treasury bonds, however, probably underestimate the true cost of money because:

(1) They are a relatively liquid investment and investor preferences for liquidity distort the bond market.

(2) Federal regulation of interest on savings accounts and other so-called safe investments distorts the bond market.

Table 2 summarizes the above arguments. Return on assets bounds the discount rate on the high side and return

Table 2
ACTUAL RETURNS ON ASSETS, EQUITY, AND TREASURY BONDS, 1974-77

Year	Return on Assets*	Return on Equity*	Return on U.S. Treasury bonds
	Percent Per Year		
1974	6.3	0.5	–3.0
1975	5.1	–0.6	0.3
1976	5.9	1.1	2.0
1977	6.1	1.2	0.4

*Asset-weighted averages for 25 industries

An appropriate discount rate for the evaluation of federal projects is bounded on the low side by the real (corrected for inflation) rate of return on Treasury bonds and on the high side by real corporate return on assets. The record over recent years points to a discount rate in the range of 3 to 5 percent.

on Treasury bonds bounds it on the low side. It would appear that a valid discount rate would be in the range of 3 to 5 percent with current economic conditions favoring the lower value.

The Value of Energy Research

The fundamental purpose of R&D is to obtain (buy) information that will be of value in making decisions at some time in the future. Accordingly, the value of the information provided by R&D activities is related to the potential value or worth obtained by choosing the best alternatives at each future decision versus the value obtained by choosing other alternatives and the probabilities of obtaining each possible alternative with and without the R&D activities. A simple example serves to illustrate this concept.

Suppose a decision maker is offered the opportunity to wager on the flip of a coin. The only permitted wager is $75 that the coin will land heads. In the event that the coin does land heads, the wager pays $100 ($25 net winnings). Clearly, this bet has negative expected[1] earnings if a fair coin is used. In this case, on the basis of expected-value, a decision maker would not choose to enter the wager. But suppose instead of a fair coin, the coin is selected at random from a set of coins, one-third of which are fair, one-third of which are two-headed, and one-third of which are two-tailed. Since in this set of coins, the number of heads equals the number of tails, there is still a 50-50 chance of heads on any particular flip and, without better information, the expected-value decision maker still would not enter the game.

If on the other hand, the decision maker could determine which type of coin was selected before he places his bet, he might choose to enter the wager. He obviously would choose to enter the wager if he knew a two-headed coin had been selected. This he might determine if he could purchase "test flips" of the coin prior to placing his bet.

Knowledge that the coin chosen is two-headed is worth $25 to the decision maker—the amount the decision maker could win using that knowledge. Knowledge that the coin chosen is either fair or two-tailed is worth nothing since the decision maker would, in either case, choose not to place a bet. Thus, the expected value of determining the type of coin chosen is $8.33—the sum of the values of the knowledge that the coin is of each type weighted by the probability (one-third) that the coin is of each type. An expected-value decision maker would be willing to pay up to $8.33 to know which type of coin had been selected.

Imperfect statements about the type of coin would be worth less than $8.33 to the decision maker. For example, knowing that a single flip of the coin resulted in a head gives the decision maker the knowlege that there is zero probability that the coin chosen is two-tailed, a one-third probability that it is a fair coin, and a two-thirds probability that is is a two-headed coin. Similarly, two flips both resulting in heads improves the decision maker's knowledge to an 80 percent probability that the coin is two-headed.

Clearly, on the one hand, the more test results that the decision maker obtains, the more confident he can be when making the decision to take the wager. On the other hand, if each flip has an associated cost, the number of flips the decision maker would choose to purchase would generally be quite small.

In order for information to be of value, it must be used in making a decision that has a nonzero probability of providing a positive payoff. If the cost of the information is less than its value, the decision maker is justified in purchasing it. In the case of fusion R&D, for example, each R&D activity derives value if it leads to improving the set of decisions that lead to a commercial fusion technology.

The key point here, however, is that the value of a research project, such as the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory, is the value of the information it produces, not the value of the end product—here fusion-generated electricity. Also, this value must be compared to the cost of the research project in question, TFTR, not the cost of an entire fusion R&D program. Because at the end of each discrete R&D activity one has the option to terminate further work on the concept, the economic value of energy R&D, properly measured, must be at least as great as a simple benefit-cost analysis would show and, in general, will be significantly higher. The example given above shows that R&D can have a positive economic value even when the expected benefits of a project are negative.

Nonrenewable Fuels Benefits

The value of nonrenewable fuels, as stated above, depends on their intertemporal allocation; that is, on the rate, over time, at which they are consumed. The consumption rates of these fuels, in turn, are determined by their prices, and strong economic forces act to push prices toward the level that maximizes the values of the fuels. The problem of optimal nonrenewable resource depletion was originally studied by Hotelling[2] and more recently by Weinstein and Zeckhauser,[3] among others. Kalymon[4] and Pindyck[5] have considered the problem as it applies to OPEC in particular.

Both discrete and continuous approaches have been used; but the continuous or variational approach is convenient for discussion here.[6] Consider resource depletion from the point of view of the resource holder. The objective function is to maximize the sum of all future net revenues generated by the sale of the resource, discounted to the present,

$$\text{Max} \int_0^\infty e^{-\rho t}\, q(t)\, [P(t,q) - C(t,q,Q)]dt$$

where t is time, ρ is the discount rate, q is the production rate, P is the price, C is the average per unit production cost and Q is a variable relating to the total quantity of the resource either recovered to date or remaining to be recovered. It is assumed here that consumption equals production and that there is no storage of the produced resource. Then P and q are directly related to each other, P (t,q) is referred to as the demand function. P is the control variable by which the resource holder allocates his resource, but for purposes of solving the above problem it is easier to use $q(t)$. Also, since $C(t, q, Q)$ becomes difficult to estimate as the resource is depleted, it is easier to take Q to be the quantity of economically recoverable resource remaining. The above maximization is then subject to the constraints:

$$\left.\begin{array}{l} q(t) \geq 0 \\ Q(t) \geq 0 \end{array}\right\} \text{ for all } 0 \leq t < \infty$$

Given ρ, $P(t, q)$, $Q(t=0)$ and $C(t, q, Q)$, this problem can be solved yielding the optimum price for the resource as a function of time. It is interesting to note that the economic value of the resource to the resource holder is lessened if the holder sets the price either lower or higher than the optimum price.

Now suppose that the government funds an R&D effort to develop an alternative energy source that is expected to become available τ years in the future. Because of the uncertainties inherent in R&D, however, τ is likely not to be a known quantity. Rather, τ might be expressible only in the form of a probability distribution. Up to the date τ, demand for the current resources is unaffected by the R&D effort. After τ, however, $P(t, q)$ is affected by the availability of the alternative. Let $P(t, q)$ be the demand function after availability of the alternative. The maximization problem now becomes

$$\text{Max} \left\{ \int_0^\tau e^{-\rho t} q(t) [P(t,q) - C(t,q,Q)]dt + \int_\tau^\infty e^{-\rho t} q(t)[P^*(t,t-\tau,q) - C(t,q,Q)]dt \right\}$$

subject to the same constraints as above. Availability of the alternative after time τ, so long as $Q(\tau)>0$, assures that $P^*(t,t-\tau, q) \leq P(t,q)$. Thus, the value of the resource is diminished by credible R&D activities leading to the development of alternative energy sources. The optimum reaction of a resource holder to the initiation of such an R&D effort would be to lower the price he sets on his resource. Any other course of action would cause him added economic penalties.

Figure 3 illustrates the potential impact of an R&D program on optimal OPEC oil prices. The base case occurs if no R&D is pursued on alternatives. The alternative resource development case occurs for an R&D program that has a 90 percent chance of producing a successful alternative energy technology that could ultimately reduce demand for OPEC oil by 75 percent. The time of availability of the alternative, τ, is taken to be a gamma-distributed variable with the earliest possible τ taken to be 1995 and the most likely value of 2005. It is assumed that after availability of the new technology, 20 years is required to penetrate 50 percent of its potential market. This R&D effort is seen to reduce optional OPEC prices by about 1.5 percent. Although this percentage is small, integrated over total oil imports it becomes a very substantial sum.

The same logic applies to consumption of domestic energy resources. R&D on future energy alternatives provides a rationale for continued economic growth, both in the energy sector and elsewhere, relying on currently available resources today with the expectation of a transition to alternatives in the future.

There are likely to be two related benefits of energy R&D that are not captured directly by this model and have not been quantified to date. The first is that R&D on long-range alternative energy sources creates economic forces that act to stabilize prices of current resources against abrupt short-term fluctuations. Without R&D on energy alternatives, if energy suppliers cut back production below the optimal rate, they merely defer some of the revenue stream that the resource generates. With the expectation of future alternatives as a result of R&D, however, production cutbacks result in a loss in (undiscounted) value of the resource in addition to deferral of the revenue stream.

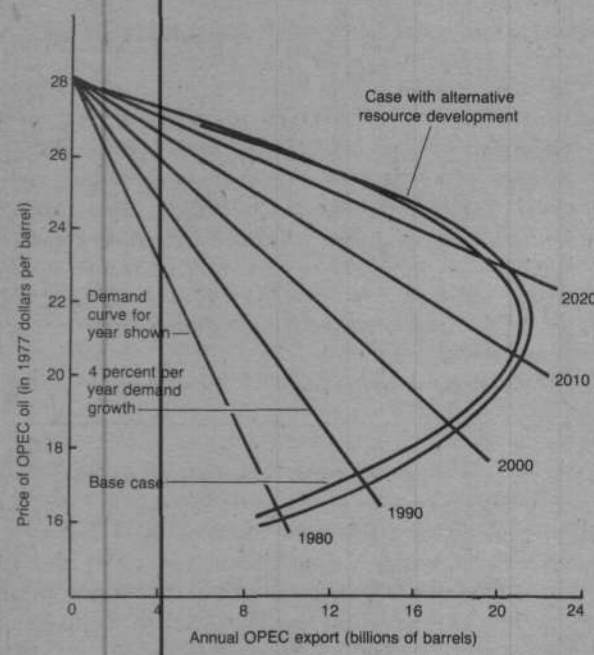
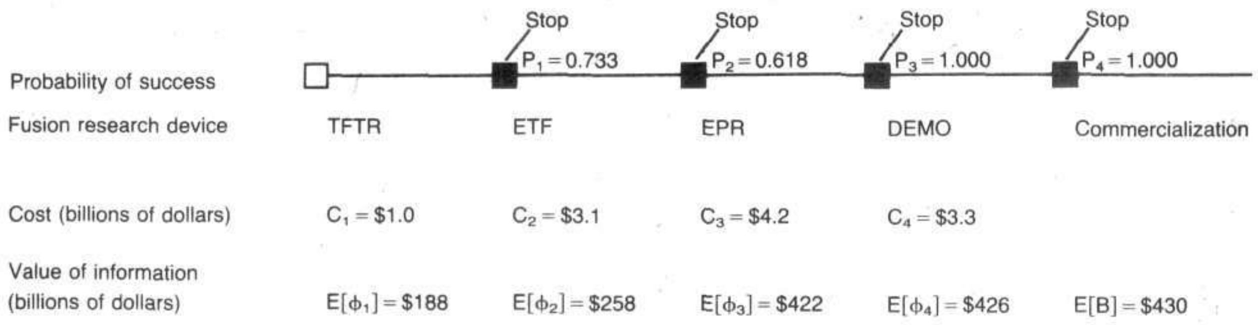


Figure 3
THE EFFECT OF ENERGY R&D ON OPTIMAL OPEC PRICES

The value of a nonrenewable resource such as oil, either to the holders of the resource or to society at large, is maximized by setting its price as a function of time to achieve an intertemporal consumption pattern that accounts not only for present supply and demand, but also for current expectations of future supplies and demands. Thus, if oil had no potential substitutes, it would be valued rather highly. On the other hand, R&D on long-range alternatives such as fusion that could substitute for oil at some time in the future lowers the expected future demand for oil; hence, such R&D changes oil's optimal consumption pattern, reflected by its price, over all future time including the present. It follows that R&D on long-range energy alternatives yields immediate benefits in the form of altered fossil-fuel consumption patterns. This benefit alone provides a substantial rationale for long-range energy R&D.



Note: All costs and values are present values referenced to Jan 1, 1980.

Figure 4

ANALYSIS OF THE VALUE OF THE TOKAMAK FUSION TEST REACTOR

Research on long-range energy alternatives should be viewed as a process of buying information. In the simplest context, that information is used to decide, at a sequence of key decision points, whether or not to proceed with the program as planned. Since R&D is a process of buying information, it should be evaluated in terms of the value of the information it produces. Information can be evaluated using decision theory and a process referred to as backward induction. The decision-tree shown here provides a basis for evaluating the information that could be produced by the Tokamak Fusion Test Reactor. It shows that the net value of the information produced is likely to be on the order of $188 billion. Compared to the approximately $1 billion cost of TFTR, this looks like an excellent investment.

*ETF is Engineering Test Facility, EPR is Engineering Prototype Reactor, and DEMO is Demonstration Reactor.

The second effect energy R&D can have is to aid in obtaining a balance of trade. Since some $70 billion of U.S. imports is energy and since the value of these imports depends upon U.S. energy R&D, with increasing levels of R&D reducing the value of energy imports, it follows that increasing energy R&D activities credibly leading to long-range alternatives effectively results in an improvement in the balance of trade. In fact, the establishment of a major long-range energy R&D program may be one of the quickest means of positively affecting the current negative balance of trade.

The Economics of Fusion Research

Fusion is a classic example of a long-range energy alternative that holds a potential for meeting worldwide energy needs cleanly, safely, and economically for at least millions of years into the future. Yet, it is not likely to be commercially available for some 20 to 35 years. Thus, it is easy to examine the economics of fusion and conclude that fusion research is not economical. A more careful examination, however, tells quite a different story. Use of a 3 percent real rate of interest and the High-Field Compact Tokamak Reactor design of the Massachusetts Institute of Technology shows that fusion potentially can supply energy at prices competitve with the most economical plants in operation today. The present value of the resulting consumer surplus provided by such a system commercially available in the year 2005 is several hundred billion dollars, exclusive of the short-term benefits discussed above.

A tokamak commercial fusion technology could be developed through a sequence of R&D phases beginning with the Tokamak Fusion Test Reactor and proceeding through the Engineering Test Facility (ETF), Engineering Prototype Reactor (EPR), and Demonstration Reactor (DEMO) phases. After the DEMO phase, the technology, if successfully demonstrated, is commercialized and provides a direct economic benefit to society.[7]

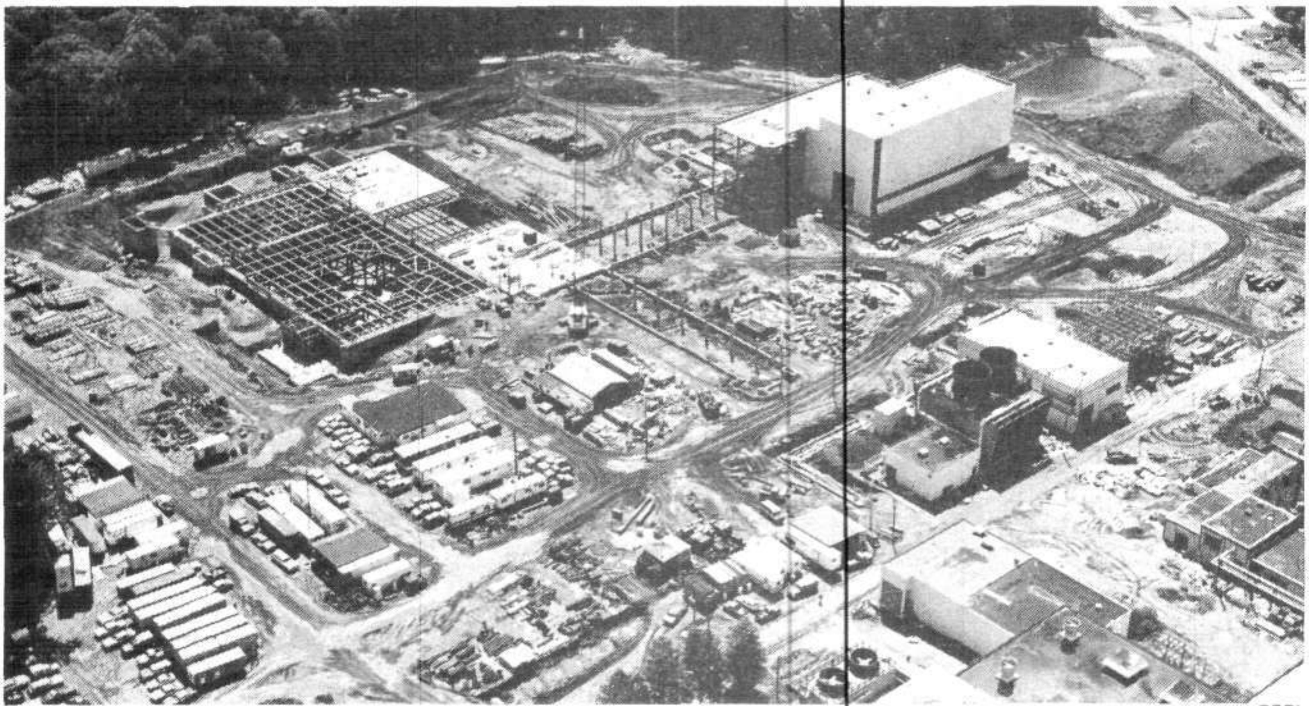
It is this benefit coupled with the immediate benefit obtained by shifts in consumption patterns of current fuels that drives the decision process in the R&D program. TFTR is a worthy undertaking if the value of the information and expectations that the project creates are greater than its cost.

The information provided by TFTR may be (simplistically) evaluated by examining its use in the tokamak R&D program shown in Figure 4. The only alternatives considered here are to continue or to terminate the program at the end of each R&D phase; thus, this analysis gives a lower bound of the value of information provided by TFTR. Without examining the details of how numerical data are generated, assume that the expected present value of a successful tokamak technology is known, $E[B]$. The net expected value of the final R&D phase, $E[\Phi_4]$, is $E[B]$ weighted by the probability of success of that R&D phase, P_4, less the present value cost of that phase, C_4.

$$E[\Phi_4] = P_4 \, E[B] - C_4$$

Then, by the process of backward induction, one obtains

$$E[\Phi_3] = P_3 \, E[\Phi_4] - C_3$$



PPPL

'An economical undertaking': Ongoing construction at the site of the Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory.

and so on until $E[\Phi_1]$, the value of TFTR, is obtained. As the results of Figure 4 show, the value of TFTR is likely to be quite high, pending validation of the model.

For people who are used to thinking in terms of benefit-cost ratios, note that in the case of a multiphase R&D program, the equivalent parameter is the ratio of the value of a particular phase to the cost of that phase. In this case, the "value-to-cost" ratio of TFTR is 188—indeed an economical undertaking.

Conclusions

The principal issue here deals with the question of parity between scientists and engineers who believe that the future of civilization rests on man's ability to develop long-range energy alternatives and economists, who, on the other hand, argue that the payback on long-range energy R&D is not adequate to justify it. We believe strongly that parity does exist and that vigorous programs of long-range energy R&D are, in fact, economically justified.

Such arguments, however, are neither simple nor easily made. First, one must deal correctly with the discount rate, properly separating the effects of inflation from those effects that are real. Correct evaluations and use of the discount rate lead to a greater recognition of future welfare compared to current welfare. Second, one must delve into the economics of nonrenewable energy resources. Here one discovers that today's prices of nonrenewable fuels are linked to ongoing energy R&D programs by the expectation of a shift in future demand for the resource brought about by R&D, and it becomes clear that benefits of long-range energy R&D can be enjoyed today by the sponsors of that R&D. Finally, long-range energy R&D must be viewed as a process of buying information—not as a process of buying a product—and evaluated accordingly.

If one insists on analyzing the economics of long-range energy R&D with relatively simple methodologies such as benefit-cost analysis, one can easily come to the conclusion that long-range energy R&D is not worth the price. But just as the research itself involves highly sophisticated concepts and theories and may require advanced forms of mathematics to analyze, so also the economics of these activities are equally complex. When one faces up to that complexity and devotes oneself to the rather substantive task of properly evaluating long-range energy R&D alternatives, one does find the parity that so intuitively one should.

Notes

1. Expected is used here to mean the mathematical expectation; that is, it is the sum of the values of every possible outcome, each weighted by its probability of occurence.

2. Hotelling, H. 1931. "The Economics of Exhaustible Resources." *Journal of Political Economy*, 38: 137-175 (April).
3. Weinstein, M. and Zechhauser, R. 1975. "The Optimal Consumption of Depletable Natural Resources." *Quarterly Journal of Economics*, 89: 371-392 (August).
4. Kalymon, B. 1975. "Economic Incentives in OPEC Oil Pricing Policy." *Journal of Development Economics*, 2: 337-362 (December).
5. Pindyck, R.S. 1978. "Gains to Producers from Cartelization of Exhaustible Resources." *Review of Economics and Statistics*, 60: 238-251 (May).
6. Hazelrigg, G. and K. Lietzke 1979. "Research and Development and the Price of Oil." *Journal of Energy*, (November-December).
7. For a discussion of this sequence of fusion R & D phases and proposed timetables, see "The 1980s: Decade for Fusion Technology," by Charles B. Stevens, *Fusion*. Feb. 1980, pp. 30-51.

Research Gap

Continued from page 24

ergy (either laser energy or subatomic particles), a beam traveling at or near the speed of light, capable of destroying an incoming missile or plane. Fired either from a satellite or from an earth-based battery, the beam weapon is the first possibility for a true defense against the ICBM.

It is clear that the Soviet Union is actively pursuing research on this weapon, and in the opinion of many experts, they are very close to deploying it as a weapon. William Perry, undersecretary for research, development, test and evaluation, summarized the Soviet approach to research on a system that could revolutionize warfare:

"The Soviets are concentrating on several unconventional technologies —high energy lasers, charged particle beams, and surface effect vehicles, for example. In particular, in the high-energy laser field, they may be beginning the development of special weapons systems. We, on the other hand, have decided to keep our high-energy laser technology in the technology base for the next few years. We believe that we understand the technical issues basic to translating high-energy laser technology into a weapons system, that our decision is correct, and that the Soviets may be moving prematurely to weapons systems."

The exact status of the Soviet program is difficult to judge. *Fusion* Magazine, EIR reports, however, provided convincing evidence in the June 1979 issue that the Soviets are in fact close to having a deployable beam weapon that may be operational as early as 1982-1983.

Major Conclusions

In brief, the EIR study concluded the following:

(1) U.S. strategic concepts—"deterrence," "counterforce," and so on—are fundamentally at variance with Soviet strategic posture. "Soviet forces are correctly designed and trained precisely for the contingency that deterrence has failed and consequently war-fighting and war-winning, be that nuclear or nonnuclear, is their basic purpose."

(2) "In ground forces and tactical air support, the Soviets have an overwhelming superiority . . . . The Soviets have more troops in each of the five major military regions than the United States has in its entire army. And nearly every globally strategic region is within 1,000 miles of Soviet borders and internal lines of supply." Soviet reserve capability is massive, and that of the United States almost nonexistent.

(3) The U.S. all-volunteer army has been a military disaster. "Today's weapons are too complex for today's soldiers . . . . Between 10 and 30 percent of U.S. troops in Europe are on heroin or cocaine, with a much larger percentage of habitual users of hashish and marijuana; 25 percent are classed by the Army as problem drinkers. The average recruit reads at a fifth grade level, and 60 percent of recruits are rated below average in the Army's mental aptitude tests . . . . Any modern nation that is unwilling or unable to sustain a militia system is not psychologically qualified to fight through a war."

—Donald Baier

We Need 'Major R&D Effort'

General Robert Richardson of the American Security Council made these remarks on the decline of military R&D in an interview with the Executive Intelligence Review.

Question: It appears that U.S. defense capabilities have steadily declined since 1967, following cutbacks in research and development projects. Could you comment on this situation?

It started in 1961. If you turn the water off in 1961, the pipe doesn't start to reduce its flow until about five or six years later. The lead time in a system would be eight to ten years. So while a lot of systems were canceled in 1961 and 1962 for arms control and unilateral disarmament, a lot of throttling back took place. A lot of stuff on back order and purchased in the 1950s was being delivered in the early 1960s, and actually, statistically, the force grew out of sheer momentum well into the Johnson era. Then it started falling off as the impact of the shutoff occurred. You have to look at the lead time in these things.

That's why, if they go get all geared up today, you are not going to have a substantive impact before 1984-85. You need a major R&D effort. You have to get rid of these silly constraints. You have to go out and do high-risk research and development. One of the things the McNamara crew did was to kill that in 1961 and 1962 and introduce low-risk.

Low Risk Versus High Risk

When you introduce low-risk then you ordain inferiority, because low risk is the building-block approach, where the government says: look, I don't want you to build any fancy weapon system until you show me you have all the technology in hand, so we have no waste, no overruns . . . .

If you go the route we went, from everything from Polaris to Minutemen to space, and scientists say, I've never done it but I think by 1985 I can put the Rayburn Building in orbit, O.K., you fellows think you can do it, but have never done it, let's set up a program to put it in orbit; here's the money. Everybody puts their shoulder to the wheel to do it. Then, if they succeed, that's great. But since they've never done it, there's going to be a very good chance they are going to have slippage, overruns, failures, and changes.

That's high risk, but the payoff is also high results. The Soviets never had the problems of failures and overruns to cope with. Nobody blows the whistle on them when cost escalates and when somebody hits a technology problem.

Washington

Support Grows for McCormack Fusion Bill

The Fusion Energy Research, Development, and Demonstration Act of 1980 has amassed widespread support in Congress and the scientific community since its introduction into Congress Jan. 23 by Congressman Mike McCormack. The bill, HR 6308, establishes a $20 billion Apollo-style program to build a fusion reactor by the year 2000.

By mid-February, 125 congressmen had signed the McCormack bill as cosponsors, with strong support from California, New York, New Jersey, Tennessee, and Pennsylvania. (A list of the House sponsors accompanies this article.) A number of Democratic and Republican senators are now considering sponsorship of a similar bill in the Senate.

Support from the Fusion Community

Many scientists from the fusion and plasma physics community have drafted letters and telegrams to Congress in support of the bill and several have lobbied for the bill in person in Washington, D.C. An extraordinary letter of support for the bill has been signed by four of the nation's top plasma physicists who are winners of the American Physical Society's prestigious Maxwell Prize for excellence in plasma physics. Maxwell Prize recipients Dr. Richard Post (Lawrence Livermore Laboratory), Dr. Tihiro Ohkawa (General Atomic Co.), Dr. John Dawson (UCLA), and Dr. Marshall Rosenbluth (Princeton University), emphasized in their letter that the fusion bill's push to demonstrate engineering feasibility for all magnetic fusion designs is a necessary step at this time.

Telegrams of support to Congress have come from scientists and leading industrial figures from the nation's high-technology companies who served on the fusion advisory panel headed by Dr. Robert Hirsch, now of Exxon and formerly the head of the U.S. magnetic confinement program. Many telegrams were directed to Congressman Don Fuqua (D-FL), chairman of the House Science and Technology Committee, expressing congratulations that most of the committee have gotten behind the bill.

Endorsers of the bill include leaders in the labor movement such as Henry Hill, the legislative liaison of the AFL-CIO on the Central Labor Council of Cumberland County, New Jersey; and August Ebel, the president of Carpenters local 612 in New Jersey.

The bill has also received endorsement from within the utility industry, including Harold Pantis, supervising engineer of Philadelphia Electric, Bill Swiers and George Liebler from Florida Power and Light; and John W. Paul, a manager at Jersey Central Power and Light.

Dr. Joseph Dietrich, chief scientist for Combustion Engineering and Dr. Harold Agnew, the president of General Atomic Company have stated their support for the Apollo-style fusion program, as have other industry leaders such as Dennis Smith, a senior planner at Artex Fibers in Pennsylvania; Lee Brown, marketing manager at New York's McGraw-Hill Company; Joseph Corso, principal engineer at RCA in Morristown, New Jersey; Kenneth Walker Jr., the president of Walker and Walker Inc.; Anthony Santana, president of the Hispanic-American Chamber of Commerce of New Jersey; and numerous others.

On the state level, Washington State Senators Kent Pullen (R), Max Benitz (R), Ted Bottiger (D), and Bruce Wilson (D) have introduced the McCormack bill into the state senate as a memorial to the U.S. Congress. Other state legislators in contact with the Fusion Energy Foundation are considering like action.

Press Coverage Scanty

Despite the continuing front-page headlines for synfuels and solar energy, the national media for the most part have ignored the fusion bill or covered it somewhat negatively. For example, *Business Week* Feb. 18 reported the McCormack bill accurately but then painted a picture of inertial fusion researchers opposing the McCormack bill because it will take funds away from laser fusion: "Fusion re-

Rebecca Harrington

Congressman Mike McCormack (right) chatting with fusion advisory panel chairman Robert Hirsch at the panel hearings in December.

searchers working on inertial confinement, of course, strongly oppose what they see as an overemphasis on tokamak technology."

Not only was the *Business Week* emphasis gratuitous—it was wrong. The two budgets are completely separate, with magnetic confinement under the House Science and Technology Committee and inertial confinement under the Armed Services Committee.

Another peculiar formulation appeared in *Science* magazine Feb. 8. Author Arthur Robinson reported on the success of recent fusion experiments and the fact that most of the fusion community agrees that commitment to an Engineering Test Facility is appropriate now, but he ended the article with negative statements from John Holdren on the dangers from fusion's radioactive waste. Holdren's, dire predictions have been refuted time and again in the scientific community.

Some Exemplary Coverage

The best exceptions to the fusion blackout have occurred in the regional press that is less oriented to national "newsmaking" and more toward a proindustry readership. Exemplary is the *Flint Journal* in Michigan.

The *Journal*'s editorial Jan. 13 laid out the importance of the fusion program in its broadest international context:

"...If all Americans want to minimize the possibility of having to use force (in Iran) then it's absolutely essential that we undertake a crash program to break our dependence on foreign oil. The emphasis on coal, synthetic fuels, and solar power development is inadequate and widespread recognition of that in this country is long overdue.

"An energy-alternatives program that doesn't include a major commitment to nuclear power is nothing but a sham....But in the emotionalism surrounding the accident at Three Mile Island and the uproar over nuclear wastes, have we lost faith in our proven technological ability to eliminate such risks? Is overcoming the existing drawbacks to nuclear power any more impossible than achieving manned flight or reaching the moon?...

Congressional Cosponsors Of HR 6308

Listed here in alphabetical order are the 125 cosponsors of the McCormack fusion bill. Is your congressman on the list?

A
Bill Alexander (D–AK)
Jerome Ambro (D–NY)
Beryl Anthony (D–AK)
Thomas Ashley(D–OH)

B
Robert Badham (R–CA)
James Blanchard (D-MI)
Lindy Boggs (D–LA)
Marilyn Lloyd Bouquard (D–TN)
John Breaux (D–LA)
Clarence Brown (R–OH)
George E. Brown, Jr. (D–CA)
James Broyhill (R–NC)
Clair Burgener (R–CA)

C
William Carney (R–NY)
Bill Chappell (D–FL)
Don Clausen (R–CA)
James Cleveland (R–NH)
Tony Coelho (D–CA)
Tom Corcoran (R–IL)
William Cotter (D–CT)

D
George Danielson (D–CA)
William Dannemeyer (R–CA)
Robert Davis (R–MI)
Edward Derwinski (R–IL)
Norman Dicks (D–WA)
Robert Dornan (R–CA)
Charles Dougherty (R–PA)
Robert Drinan (D–MA)
John Duncan (R–TN)
Robert Duncan (D–OR)

E
Arlen Erdahl (R–MN)
Allen Ertel (D–PA)

F
Dante Fascell (D–FL)
Hamilton Fish, Jr. (R–NY)
Ronnie Flippo (D–AL)
Thomas Foley (D–WA)
Edwin Forsythe (R–NJ)
Don Fuqua (D–FL)

G
Sam Gibbons (D–FL)
Ben Gilman (R–NY)
Dan Glickman (D–KS)
Barry Goldwater, Jr. (R–CA)
Albert Gore, Jr. (D–TN)
Phil Gramm (D–TX)

H
Kent Hance (D–TX)
Augustus Hawkins (D–CA)
Cecil Heftel (D–HW)
Harold Hollenbeck (R–NJ)
William Hughes (D–NJ)

J
James Jones (D–OK)

K
Robert Kastenmeier (D–WI)
Thomas Kindness (R–OH)
Ken Kramer (R–CO)

L
Claude Leach (D–LA)
Jim Lloyd (D–CA)
Michael Lowry (D–WA)
Manuel Lujan, Jr. (R–NM)
Stanley Lundine (D–NY)

M
Edward Madigan (R–IL)
Nicholas Mavroules (D–MA)
Romano Mazzoli (D–KY)
Paul McCloskey (R–CA)
Joseph McDade (R–PA)
Gunn McKay (D–UT)
Robert Michel (R–IL)
Clarence Miller (R–OH)
George Miller (D–CA)
Norman Mineta (D–CA)
Joseph Minish (D–NJ)
Carlos Moorhead (R–CA)
John Murtha (D–PA)
John Myers (R–IN)

N
Stephen Neal (D–NC)

P
Edward Patten (D–NJ)
Donald Pease (D–OH)
Claude Pepper (D–FL)
J.J. Pickle (D–TX)
Melvin Price (D–IL)
Joel Pritchard (R–WA)
Carl Pursell (R–MI)

R
John Rhodes (D–AZ)
Fred Richmond (D–NY)
Don Ritter (R–PA)
Robert Roe (D–NJ)
Dan Rostenkowski (D–IL)
Toby Roth (R–WI)
John Rousselot (R–CA)

S
James Scheuer (D–NY)
John Seiberling (D–OH)
Neal Smith (D–IO)
Arlan Stangeland (R–MN)
Fortney (Pete) Stark (D–CA)
Al Swift (D–WA)
Steven Symms (R–ID)

U
Al Ullman (D–OR)

V
Harold Volkmer (D–MO)

W
Douglas Walgren (D–PA)
Robert Walker (R–PA)
Wes Watkins (D–OK)
Richard White (D–TX)
William Whitehurst (R–VA)
Charles Wilson (D–TX)
Larry Winn, Jr. (R–KS)
Jim Wright (D–TX)
John Wydler (R–NY)
Chalmers Wylie (R–OH)

Y
Don Young (R–AK)
Robert Young (D–MO)

"In recent years, significant progress has been made toward creating a much more sophisticated reactor model, called the fusion reactor....The Department of Energy has a 40-year research and development plan for fusion power. A growing number of scientists and others say that because of recent achievements in fusion research that timetable can now be cut in half.

"Characteristically, the DOE is not about to take the lead in pushing this potential energy source. But there are some people in Washington who are....

"What is needed to really push fusion power into the forefront of energy-alternatives development is a national Apollo-like program in the 1980s. McCormack has been trying to persuade President Carter on the necessity of such an effort....

"It's time that the president and the nation climb aboard the fusion power bandwagon...."

—Marsha Freeman

Buchsbaum Ctte. Begins Fusion Review

The Buchsbaum Committee, commissioned by Dr. Edward Frieman, the new director of the DOE Office of Energy Research, met in Washington Feb. 13 to begin its review of the U.S. magnetic fusion program.

The committee is named for its chairman, Sol Buchsbaum of Bell Laboratories, and includes: John Foster (TRW), Eugene Fubini (Fubini Consultants, Ltd.), Marshall Rosenbluth (Princeton University), Marvin Goldberger (Cal Tech), James Fletcher (University of Pittsburgh), Wolfgang Panofsky (Stanford Linear Accelerator Center), Robert Conn (UCLA), and Roy Gould (Cal Tech).

The purpose of the committee, according to its charter, is to "review and evaluate the progress, status, and prospects for magnetic fusion" by June 1980. The "rapid technological development in fusion research since the last review [1978] suggests a new evaluation of the promise of this program is in order," the charter continues. "The dominant concern should be the judicious choice of the next major steps to be taken in proceeding in the next generation of experimental devices to lead to a demonstration of economical fusion power production. A concomitant concern, is the soundness of the overall strategy for magnetic fusion including its pace, scope, and funding profiles."

Fusion Sources Optimistic

After the last review of the fusion program commissioned by the DOE in 1978, the Foster Committee review, then energy secretary James Schlesinger proposed to cut the fusion budget by $100 million. This time, sources in the fusion community are optimistic that the Buchsbaum committee and Frieman will support the efforts by scientific and congressional leaders to accelerate the current DOE fusion timetable and budget.

At its first meeting, the committee heard presentations from DOE Fusion Office director Edwin Kintner and deputy director John Clarke summarizing the physics and status of the scientific development. Frank Coffman, the director of the development and technology division of the Fusion Office discussed fusion technology, and Mike Roberts, director of the planning and projects division, discussed the planning strategies of the program.

The ETF Question

The major program decision to be made now is whether to commit to design and construction the next-step Engineering Test Facility (ETF) this year or to wait either for results from the Princeton Tokamak Fusion Test Reactor to start coming in over the next couple of years or until other magnetic fusion concepts catch up to the mainline tokamak program.

The current DOE timetable waits for *both* these events to take place, thus setting the entire magnetic confinement program back at least a decade. The DOE Fusion Office, Congressman Mike McCormack, and other fusion scientists who favor accelerating the timetable have proposed an Engineering Test Facility that generically tests and demonstrates the fusion technology required for virtually any magnetic fusion design and geometry.

Transferable Technology

The purpose of this generic ETF design is to develop engineering confidence in fusion; the type of driver the fusion device has is a secondary question. The ETF would not depend on its particular design becoming commercial, but would provide transferable technology that could be used with various driver designs.

The fusion scientists in the DOE program report that there is a good working relationship between the fusion community and the members of the Buchsbaum Committee. The committee will hold meetings with fusion program directors at the Princeton and Livermore laboratories (and possibly other labs), and it will get other first-hand briefings on the status of the research efforts. It is expected that the committee may complete its review by late March.

The Buchsbaum findings will be presented to the DOE's Energy Reseach Advisory Board for use by DOE administrators. Sources report that here the committee's report may meet a hostile response. There are two antinuclear activists on the advisory board —Tom Cochran from the Natural Resources Defense Council and Dennis Hayes, the organizer of "Sun Day" in 1978. Both were appointed by Undersecretary John Deutch.

—Marsha Freeman

DOE Restricts U.S. Role at Hydrogen Conference

U.S. scientific participation in the Third World Hydrogen Energy Conference, to take place June 23-26 in Tokyo, looks dim, according to DOE sources. Nearly 40 U.S. researchers had planned to attend, present papers, and chair program sessions. The latest estimates are that perhaps 10 will receive DOE travel money to attend the conference. As one source put it, "This makes the United States, the richest country in the world, look quite foolish, since the Japanese have always been active participants in the world meetings.

Inside DOE

The DOE Budget: Less Energy For More Money

"Conservation" is featured as an energy resource in the fiscal year 1981 budget posture statement that Energy Secretary Charles Duncan presented to the House Science and Technology Committee Jan. 31. "The most readily available, economic source of additional energy is conservation," Duncan told the committee, which has authorization repsonsibility over the major part of the DOE budget.

As Duncan presented it, the DOE budget states flatly that the nation has reduced its commitment to nuclear technology and is putting any energy development money into solar energy and synthetic fuels—both proven to be costly and inefficient methods of producing energy. The DOE has termed this process of less energy for more money *diversification*. "The DOE sees its mission as assuring the nation's orderly transition from an economy dependent upon oil to an economy relying upon diversified energy sources," Duncan said.

"Energy consumption will be held near current levels over the next five years. A resumption in economic growth will not increase end-use energy consumption as much as in the past because it will occur in the context of higher prices...." Primary energy consumption may grow, however, even as end-use consumption remains constant, Duncan stated, because consumers will be paying for high conversion losses (less delivered energy per unit of fuel) in the synthetic fuel programs!

To carry out a program of conservation to reduce demand, Duncan asked Congress to authorize a $1.067 *billion* effort, which includes $50 million for an "energy information campaign," $298 million for "research and development" in energy-saving gadgets, and $569 million for state and local programs.

Duncan also outlined three other initiatives for forced demand reduction; phased decontrol of oil prices, import limitations on oil that are punishable by import fees, and contingency plans that include mandatory rationing of "scarce energy supplies."

Budget authority for research, development, and applications for the DOE totals $4.092 billion for fiscal year 1981, as requested in the administration bill. This includes $868 million for solar and other "soft path" renewables. If the cost of $355 million for solar tax credits and $53 million for geothermal tax credits is added in, more than $1 billion is projected out of the tax fund for primarily economically unfeasible and noncompetitive technologies.

The fossil energy budget request of $1.165 billion is a $200 million increase over the 1980 budget, with half of the money going into costly synthetic coal conversion schemes. This synfuel program, which is entirely separate from the $88 billion Carter has requested for a 10-year commercial synfuel industry, will produce energy at a cost outside the possible range of most consumers—at least at $42 per barrel of oil equivalent.

Advanced Technology 'Not Needed'

The nuclear fission budget has been cut from $1.186 billion in 1980 to $925 million in fiscal year 1981 in keeping with the administration's commitment to discontinue the fast breeder program at Clinch River and to drag out indefinitely the rest of the advanced nuclear program. Magnetic fusion is slated for a 12 percent increase to $404 million—barely enough to keep up with inflation. The DOE figure is based on Duncan's stated policy of keeping fusion on a go-slow program timetable.

Duncan justified the reduction in the budget for advanced nuclear technology as follows:

"Our estimate of the future growth in the nuclear-generated share of electricity was reduced in the aftermath of the accident at Three Mile Island. This continues the trend of reduced forecasts that began in the early 1970s.... Funding for the Liquid Metal Fast Breeder Reactor has been reduced in light of current projections that breeder reactors will not be needed until after 2020."

—*Marsha Freeman*

National

The U.S. Nuclear Industry:
Going...Going...Gone?

The largest cancellation in the history of the U.S. nuclear industry occurred in early February when the Central Area Power Coordinating Group, a consortium of northern Ohio utilities, announced that it was abandoning four major nuclear plants in the area. The consortium cited "intensified political and regulatory uncertainties" after last year's incident at Three Mile Island.

A week before the $7.4 billion cancellation in Ohio, New York state refused approval to Rochester Gas & Electric to build the 1,157-megawatt Sterling nuclear plant. The New York State Board on Electric Generation Siting and the Environment also denied plans to build a nuclear reactor on Lake Ontario and two nuclear units slated for Jamesport, Long Island. The Long Island Lighting Company, which planned to build the Jamesport installation, will thus remain 100 percent dependent upon imported oil.

That the New York decision was made on the basis of antinuclear politics instead of energy needs is clear. The head of the New York State Public Service Commission cited the "considerable regulatory uncertainty surrounding nuclear plants since Three Mile Island . . . ." A spokesman for the utility called it a "political decision" and "a grave error."

According to U.S. nuclear industry sources, this brings to 13 the total number of nuclear plants already underway that have been canceled since Three Mile Island.

The phrase "grave error" is an understatement, given the fact that one nuclear plant generates the equivalent of 10 million barrels of oil in a year and that one such plant provides electricity to power a city of more than 600,000.

The bill of materials for such projects requires tens of thousands of tons of specialty steels, concrete, sophisticated electronics, and engineering products plus the skilled labor to produce that bill of materials and construct the plant. The death of this technological capability would represent an incalculable loss to the United States and the world.

Only four years ago the United States was leading in nuclear energy development and supplying the French and West German nuclear industries. Now, one of the two major U.S. nuclear suppliers, General Electric, is on the verge of shutting down its nuclear division. "We don't see any realistic prospects for a new order this year," said a GE official. General Electric's last order predates the Carter administration.

Three Mile Island builder Babcock & Wilcox is also all but out of business, along with numerous smaller nuclear suppliers and vendors.

—*William Engdahl*

A special report on the status of the U.S. nuclear industry appeared in the February issue of Fusion.

The Rogovin Report
A Schizoid View of TMI

The final report of the Nuclear Regulatory Commission's Special Inquiry Group on Three Mile Island, released Jan. 24, is especially interesting because it presents the distinctly different viewpoints of two groups of people: engineers and scientists on the one hand and antinuclear lawyers on the other. In fact, the report is almost schizophrenic in nature, in that portions of the conclusions and recommendations bear no resemblance to the actual technical evidence presented in the report.

The Special Inquiry Group was hired as an independent investigative body by the NRC, which chose the Washington, D.C. law firm of Rogovin, Stern & Huge to conduct the inquiry, with Mitchell Rogovin, a senior partner in the firm, as study director. The key to the report's schizophrenia is Rogovin and his career as an environmentalist and antinuclear advocate (see box).

The Special Inquiry Group itself was a mixture of technical specialists and lawyers. Most of the technical people and technical support staff appear to have been of high quality, and some of the technical consultants are well-known names in the nuclear industry. The report gives the distinct impression, however, that these technical people carried out investigations and evaluations, wrote up the results, and turned them over to the lawyers—Rogovin and staff—who then wrote the conclusions and recommendations without any regard for the technical report. It looks like the summary of the technical evidence presented in volume 1 of the report was also written by the lawyers.

Competent Technical Analysis

The report's technical presentation of what happened during the first week after the March 28 incident is probably the best summary that has been made by any of the investigative groups of what actually happened.

This part of the report makes it absolutely clear that the incident that began at 4:00 AM March 28, 1979 *was over* at 7:50 PM that same evening, less than 16 hours later. The events that occurred after that, especially during the next four days, were either contrived or completely misinterpreted by the news media, the NRC, or other government agencies as a result of ignorance, poor judgment, or incorrect information due to poor communications.

For example, the report states: "At 7:50 PM after a successful bump [running the pumps for a few seconds] the operators put the 1A coolant pump into normal operation. This puts the reactor into the forced-cooling mode, at high pressures, *and terminates the major phase of the accident*. For the first time since a few minutes after 4:00 AM that morning, the plant has

Mitchell Rogovin Dennis Brack/Black Star

Who Is Mitchell Rogovin?

Here are the credentials of Mitchell Rogovin, the attorney whom the Nuclear Regulatory Commission selected to head its independent investigation of Three Mile Island.

- He is a fellow of and general counsel to the Institute for Policy Studies, a group that is on public record as involved in the funding, training, and deploying of environmental-terrorist groups, including the Baader Meinhof, the Weathermen, and Black September.
- He is a member of the New York Council on Foreign Relations, whose stated policy in its *1980s Project* is the "controlled disintegration" of the world economy.
- His law firm, Rogovin, Stern, & Huge has been taking the lead in environmentalist cases in California, including the "water case," which seeks to establish that federal waters will not be available to persons who own more than 160 acres.
- He has been vice chairman of the Center for Law and Social Policy, an avowedly antinuclear group that, among other things, has filed three suits to prevent the export of nuclear fuel to the prodevelopment government of Indira Gandhi.
- He has been general counsel to Common Cause, one of the most antiindustrial, zero growth operations on the U.S. political scene.

been returned *to* a relatively stable condition. The reactor will now remain in this forced-cooling high-pressure mode for several weeks, gradually cooling down" [emphasis added].

As for the events that took place in the next few days—the radioactive fission gas release scare, the evacuation hysteria, and the hydrogen bubble fraud—the technical summary states the facts:

"The accident at Three Mile Island did not result in radioactive release levels that posed any threat to public health, even in the long run. Public alarm over radioactivity fueled by the governor's evacuation advisory to pregnant women and preschool children two days after the accident, and the fear caused by reports the next day and afterwards of a possible hydrogen bubble explosion, turn out to have been vastly exaggerated by the NRC's disorganized response to the emergency."

Bedtime Story

The report continues to point out how badly these next few days were handled:

"Wednesday it was a reactor out of control; Thursday everything was fine; Friday morning, there is a radioactive release scare and an evacuation false alarm; and the bedtime story Friday night is a possible meltdown. Now NRC Chairman Hendrie is working on an interpretation that will eclipse them all before the day is out.... To this day, months after the TMI-2 accident, no one seems quite sure what started Joe Hendrie worrying about a hydrogen explosion inside the Unit 2 reactor vessel; only that it seemed to hit him Friday night...."

Finally, the report concludes, "Hendrie's fears will prove groundless, as he will be the first to admit. The hydrogen never explodes in the reactor vessel; it blows up instead, in the media."

The technical report vindicates Metropolitan Edison, the operator of TMI that was made the scapegoat for most everything that went wrong during those days. Even though mistakes were made during the early hours of this incident, the report says, the TMI engineers and operators performed their job quite well and, on the whole, did what they should have done. Most of the "mistakes" made are attributed to the government agencies, the NRC, the Pennsylvania Emergency Management Agency, and the Federal Emergency Management Agency.

As for Met Ed being told to quit making public statements the report says: "On balance, the quality of Met Ed's information has not been that bad—overall at least as accurate, if not more so, than the NRC over the course of the accident....NRC's continuing refusal to collaborate with the utility on plant status briefings is consistent with the agency's original fixation on avoiding the appearance of conflict of interest. The NRC has been inordinately touchy about appearing in any way to assume joint responsibility for plant operations with Met Ed during the accident. Be all that as it may, just now seems an unfortunate time for Met Ed to lose its voice, since at the moment the utility is accurate in its evaluation of the plant status, is making the right moves to bring it to cold shutdown, and seems inclined to give more details. After a sorry start, Met Ed has regained its composure."

The Bubble Story

On Met Ed's response and handling of the hydrogen bubble, the report relates:

"The Met Ed, GPU (General Public Utilities), and B & W (Babcock & Wilcox) people who are controlling the plant do not follow Hendrie's new line of reasoning for a minute—they are convinced that the excess hydrogen in the system prevents the freeing of oxygen. Nevertheless, such is the state of their image with the media that they are not eager to make the matter public."

However, Met Ed overcomes this hesitation: "Herbein [Met Ed vice president] has some news; the hydrogen bubble has been reduced to two-thirds its Friday dimensions, and the crisis at TMI 2 is over. Herbein, it will turn out, is correct; but who is paying attention to Herbein these days?"

"An hour later, Denton [Harold Denton, the NRC's on-site man in charge] says the crisis is not over, gladdening the hearts of a nation of Sunday headline-writers with a perfect balance of stories; 'It's Over'—'It's Not Over.'

Denton also takes issue with Met Ed's figures on the bubble size. Four days later, on Tuesday, April 3, Denton finally announces in a press conference to the world 'the bubble has been eliminated, for all practical purposes.' "

The report continues: "Asked why the bubble had gone away, Denton replied: 'I think it was a little bit because of our actions and maybe a little bit of serendipity.' Although probably not intending to do so, Denton seemed to have given credit to the NRC for removing the bubble. To the contrary, as NRC inspector Charles Gallina, who had been at the site from the beginning of the accident, observed, 'The hydrogen bubble did not miraculously disappear, it was systematically and professionally eliminated by Met Ed operators.' In fact, studies performed for the Special Inquiry Group show that the bubble was probably all gone some two days before Denton made it official."

Finally, the report concludes: "In an investigation like this, the very purpose of which is to focus on what went wrong and what needs changing, it is inevitable that less attention than is deserved will be given to what 'went right'—the strong points in the system. Chief among these is the fact that the 'defense in depth' concept worked to protect public health and safety. In spite of multiple equipment malfunctions, human failures, and the creation of conditions in the reactor and auxiliary buildings that were never contemplated in the design of the plant's safety systems, the utility and its engineering support staff were able to bring the system to a stable condition without releases of radioactive materials to the atmosphere that could have resulted in significant health effects to those living near the plant."

Technical Report Junked

Given all these conclusions, it is hard to see the connection of the report's technical assessment of the TMI incident to the report's overall conclusions—except that the technical assessment was completely ignored by the Rogovin team.

For example, the report proposes that some private or public consortium take over Met Ed's and presumably all of GPU's reactors, as well as reactors from many of the other utility companies. It recommends: "The chartering of an operating consortium with the capability to operate the plants of a number of utilities on either a contract or 'receivership' basis." This is nothing less than a complete takeover of the utility industry by the government.

The Rogovin report then makes two crucial recommendations sure to set the U.S. nuclear industry back even further—if not kill it completely. The first is a recommendation to "establish an Office of Public Counsel; and agency funding of intervenors who make material, substantive contributions to licensing and rule making procedures."

This will simply provide full government funding for groups like the Union of Concerned Scientists, the Natural Resources Defense Council, various Ralph Naders, Barry Commoners, and Common Cause John Gardners to do more of what they are already doing—shutting down the nuclear industry. This recommendation may satisfy attorney Rogovin and his various environmental clients, but it certainly does not follow from the technical conclusions of the report.

Finally, although the report does

Carter Decides Not to Decide on Nuclear Waste

In a message to Congress Feb. 12, President Carter proposed a "15-year national program" to develop a safe method of permanently storing the radioactive wastes created in the manufacture of nuclear weapons and in the generation of electricity by atomic power reactors. The Carter plan delays until 1985 the decision on a burial site for high-level wastes, citing lack of technical data. Under the program, the date for putting a permanent depository into operation will be 1995.

Carter's proposal ignores all competent scientific advice, including the report of the Interagency Review Group on Nuclear Waste he commissioned in 1977. That report said a burial site could be chosen now and be in operation by 1988. This study was severely criticized by the nuclear industry because it accepted Carter's ban on nuclear fuel reprocessing and left the final decisions on waste disposal up to state and local authorities. However, it had the good sense not to claim that after 40 years of dealing with nuclear waste, the nation does not know how and where to bury it.

As the distinguished nuclear scientist Dr. Edward Teller recently put it, "It is said that we have no method of waste disposal. A committee of the prestigious American Physical Society found unanimously that a good method of disposal exists. The report was published in the January 1978 issue of the *Review of Modern Physics*. Apparently no one in Washington has read it yet."

The Reprocessing Question

Carter's real decision on the waste question was announced three years ago, shortly after his inauguration. In April 1977, he decided to stop all government funding for the 75 percent complete, Barnwell, S.C. fuel reprocessing facility—a move that halted all construction on this plant and killed all commercial reactor fuel reprocessing in the United States. This plant not only was to take all spent fuel from U.S. reactors and reprocess it back into new fuel, but also was going to separate out the small portion of material—less than 4 percent—that is considered nuclear waste. This waste was then to be concentrated as a liquid and stored in tanks at Barnwell for a maximum of 10 years, after which time it would be solidified in a stable, vitreous form and shipped to a permanent depository for burial.

Instead, during the next five years, Carter's program proposes continued research on various burial sites and types of geological formations in order to determine which is the best for burial. The question of in what form the not propose a moratorium on nuclear plants (even though the *New York Times* claimed that an earlier draft version of the report did), it recommends the next nearest thing:

"For existing reactors; the promulgation by the NRC of specific criteria for determining the minimum evacuation planning zone around each plant; the conditioning of operating licenses on such plans being approved and workable; and the closing down of existing plants that cannot meet these new criteria."

As the antinuclear groups have emphasized, New York, Chicago, and other large metropolitan areas cannot easily be evacuated, even in the event of a nuclear war. As a minimum, then, what this recommendation really means is that plants like New York's Indian Points 2 & 3, Chicago's Zion plants, and many more, must close down. Again, since the report's technical conclusions make it very clear that all the evacuation nonsense around the TMI events was exaggerated and unnecessary, why is evacuation getting such a big push in the overall recommendations?

Again, the answer lies with Mitchell Rogovin and his career as an antinuclear environmentalist attorney.

—*Jon Gilbertson*

---

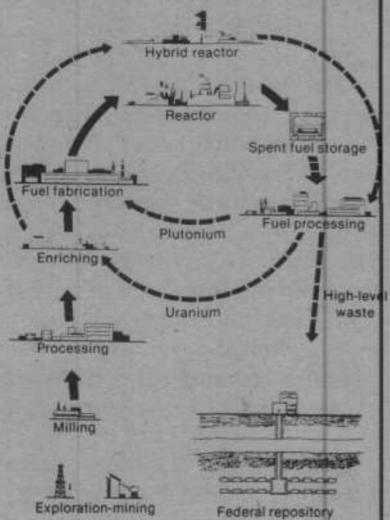
waste should be buried was also left up in the air.

Carter himself favors treating *all* spent fuel material as waste and therefore permanently burying whole spent fuel assemblies. The U.S. nuclear industry and the rest of the world's nuclear-reactor-producing countries, France, West Germany, the Soviet Union, Great Britain, and Japan, prefer and are committed to the much more economical fuel reprocessing route where only the very small portion of actual waste material is buried.

During the five-year delay, Carter's program encourages state and local governments to get actively involved in the decision-making process. To do this, he has already set up, by executive order, a 19-member State Planning council made up of governors and other elected officials, headed by Gov. Richard W. Riley of South Carolina, a state whose Savannah River facility is one of the major storage areas for high-level wastes generated by the military. This will guarantee further delays since no decision can possibly be made by a democratic vote on such an issue. This is a federal matter concerning national security, and should be located on federal land if necessary.

If one takes away all the verbiage, all Carter has decided to do is simply not to make a decision. He has chosen to play politics, continuing to propitiate the antinuclear environmentalists, rather than act for the good of the nation.

—*Jon Gilbertson*



CLOSING THE NUCLEAR FUEL CYCLE
The internationally preferred way of processing spent reactor fuel and the relatively small quantities of high-level wastes is to reprocess spent fuel for separation and recovery of nearly 96 percent of the material that is reusable. The 4 percent of actual nuclear waste material can then be disposed of. President Carter's proposed program without reprocessing means more waste and no place to put it.

France, India Sign Development Accords

Pana-India

Giscard and Gandhi in New Delhi

After a four-day visit to India at the end of January—the first such visit ever by a French head of state—Valery Giscard d'Estaing reported that he and Prime Minister Indira Gandhi had achieved "identity of views" on the strategic situation and that this was inseparable from the agreed-upon high-technology development program.

The fact that detente and nonalignment depend on economic development was underscored by the hefty bilateral package signed by both participants. Seven protocols concerning wide-ranging economic cooperation were termed by President Giscard as "vast and exciting" in scope. The joint communiqué described it as the "deepening of economic cooperation corresponding to the priorities of India's economic development where French industry with its technological capabilities can make a sizable contribution."

In addition to a bauxite-aluminum industry project, coal mining, agricultural development, petrochemicals, and industrial and commercial cooperation, the accords also agree in principle to joint projects for the development of third countries.

It had been expected that Giscard and Gandhi would sign an expanded nuclear accord. Sources report that one such accord already exists, and that it was decided that a high-level Indian team will go to Paris for detailed dis~ussions on fast-breeder reactor deveıopment in the near future. Indian Atomic Energy chairman Homi Sethma was directly involved in the talks.

During his visit, Giscard referenced the great advances made in Indo-French collaboration in the field of applied mathematics, data processing. solid state physics, microelectronics, biophysics, and electrical engineering. India has the third largest pool of scientists and engineers in the world.

Financial Ingredient

The major new ingredient in the package was financial. France made an exception to its usual policy, and extending an initial credit of 1 billion francs to finance some of the projects Giscard also made available, for the first time ever, treasury loans and guaranteed commercial credits, some to be repaid through buy-back provisions.

The French economic package had been carefully drafted over the several months time and was very detailed. For example, the aluminium plant that became the highlight of the package was the outcome of a two-year feasibility study by the French company Aluminium Pechiney. The project will invest $1.2 billion in setting up a bauxite-aluminium industry in Orissa, that will output nearly 8 million tons a year. The French assistance will help establish the necessary infrastructure, including a 600-megawatt power plant, railway lines, and port installations.

The French-assisted aluminum project will be adjacent to the aluminum project that the Soviet Union is currently aiding. The toal effort will establish a major industrial complex in the resource rich but underdeverloped eastern region.

The May issue of Fusion *will feature India's development program and the history of the Indian nuclear program.*

Giscard on Nuclear Power

" . . . Why nuclear electricity? At the present time there is no other readily available technology. There won't be for 20 or 30 years. Moreover, it is an investment that pays off highly since the higher oil price means that 1 kilowatt-hour produced in a nuclear plant will cost about 13 or 14 centimes whereas the kilowatt-hour produced from oil will cost on the order of 24 to 25 centimes . . . .

"nuclear electricity enables France to be more independent from the energy viewpoint; that is, so nobody can tell us what to do."

—Valery Giscard d'Estaing in a Europe No. 1 radio interview, Jan. 18, 1980

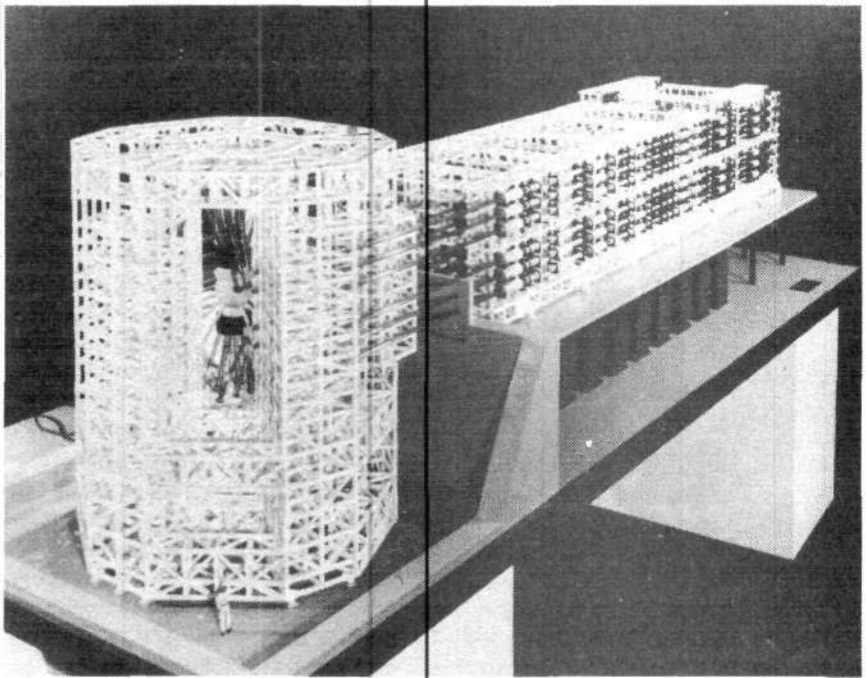
EBT-P Begins Bidding Process

The proposed Elmo Bumpy Torus proof-of-principle (EBT-P) test device is just beginning the process of bidding, final design, and construction. The Oak Ridge National Laboratory completed the reference design in January for the device, the next step for its Elmo Bumpy Torus toroidal mirror experiment.

The question of whether action on the Oak Ridge design would have to wait until the Buchsbaum Committee completes its review of the magnetic fusion program came up at the first committee meeting Feb. 13. Edward Frieman, director of the DOE Office of Energy Research, who commissioned the Buchsbaum Committee review of fusion, asked chairman Sol Buchsbaum if there was any reason to wait on the EBT-P. Buchsbaum said no, and so Oak Ridge is now putting the request-for-proposal out for private industrial consortia or individual companies to bid on the contract to build the EBT-P.

The EBT-P will be a proof-of-principle test device, similar in experimental scope to the Princeton Large Torus in the tokamak field. It will lay the scientific basis for a later power breakeven demonstration, parallel to the Tokamak Fusion Test Reactor now under construction at Princeton, and eventually for a fusion reactor based on the physics and special properties of the EBT.

Information for the Oak Ridge study was derived from reports submitted by EBASCO Services, Inc.; Grumman Aerospace, Inc.; McDonnell-Douglas Astronautics Company; and Westinghouse Electric Corporation—all of which are interested in the contract to build the new EBT device.



The Shiva laser: A flagship experiment

LLL

House Armed Services Committee To Restore Shiva Laser Cuts

Sources in the House Armed Services Committee report that Congress will reverse the cutback in the laser fusion program proposed in the Carter adminstration's fiscal year 1981 DOE budget request. Acting over the objections of the Office of Management and Budget, the administration had removed the $60 million funding for the Nova laser fusion experiment at Lawrence Livermore Laboratory, leaving the program with only monies unspent in the 1980 authorization.

"The committee will reverse the administration on the Nova cutback, and if that doesn't work, we'll go to court," a committee source told *Fusion*.

The 300-trillion-watt Nova laser is a flagship experiment that could demonstrate the scientific feasibility of laser fusion in the mid-1980s—if the program is not unnecessarily stretched out. The Carter cutbacks threatened the entire laser fusion program, because current experiments on Livermore's Shiva laser, a 20-trillion watt facility, and later work planned on the Nova would also provide key scientific and technical data on major defense systems.

When asked what he thought the Soviets would think about the Carter budget move, one source on the House Armed Services Committee commented: "Carter is like a worm in the sun, and the Soviets are enjoying watching him wiggle."

Mirror Experiment Upgrade Ok'd

An internal DOE Office of Fusion review committee and the DOE's Fusion Power Coordinating Committee have approved the upgrade of the Mirror Fusion Test Facility (MFTF) now under construction at Lawrence Livermore Laboratory in California. The upgrade, known as MFTF-B, would add a second mirror plasma chamber to convert the design into a more efficient tandem mirror experiment.

Although the MFTF-B would not operate with actual fusion fuel, it would demonstrate the scientific characteristics required for a mirror fusion reactor and would be the next step toward a full-scale mirror power plant—a physics ignition test reactor.

The Fusion Power Coordinating Committee, which is composed of DOE fusion scientists, fusion program managers, and consultants, did not recommend an immediate increase in the mirror budget but a reprogramming of the money now being spent on the MFTF to redirect the tandem mirror design. It will require substantial amounts of money to change the design, and this means reauthorization from Congress to spend the money already authorized toward a new program goal.

The tandem design will double the cost of the MFTF from $100 to about $200 million, but the result will more closely resemble a practical mirror fusion system.

NAS Eliminates Fusion Energy As a 'Dark Horse'

The recently completed National Academy of Sciences study, *Energy in Transition: 1985–2010*, includes a supporting paper on "Controlled Nuclear Fusion, Current Research and Potential" that advocates a strong U.S. fusion program and says that scientific feasibility is near. However, the overall National Academy study ignores its own fusion report and concludes that fusion can't even be a "dark horse" in the energy resource race.

The reason for this discrepancy can be seen just by looking at the personnel responsible for each document.

The fusion report was produced for the National Academy by a Fusion Assessment Resource Group that consisted of knowledgeable and prestigious fusion scientists, including Marshall Rosenbluth, William Gough, Gerald Kulcinski, Don Steiner, and others. The National Academy group responsible for the entire study, its Committee on Nuclear and Alternative Energy Systems (CONAES), involved a number of antinuclear scientists, including John Holdren.

Apparently, the CONAES group nearly came to blows on many issues because members had such opposite outlooks.

The CONAES study was originally commissioned by Dr. Robert Seamans of the Energy Research and Development Administration, which preceded the Department of Energy. Interestingly, the ERDA request said nothing about "alternative energy systems"; the National Academy decided to add them in on its own.

Fusion Report Sound

The ignored fusion report was completed before much of the past year's encouraging results were available, and, therefore, it is more cautious than most of the fusion community would be today in terms of accelerating fusion development. Nevertheless, the group states: "because of its reliance on virtually unlimited and cheap fuel and its relative safety, a strong program of fusion power development deserves the full support of the federal government."

The report also notes that "the near-term objectives [of the program] are in a state of transition. Although scientific feasibility has yet to be demonstrated by any of the approaches now under construction, there is a growing conviction that this will be achieved relatively soon. No fundamental conceptual difficulties seem to be evident that would indefinitely delay the demonstration of scientific feasibility."

Somewhere between the fusion group's report and the CONAES final study, fusion became a technology that "has not reached a stage of development at which it can be counted on even as a 'dark horse' in meeting future energy requirements."

"Despite many hundreds of millions of dollars spent on research in its basic science and technology", the CONAES study says, "fusion has yet to be demonstrated as technically feasible.... Until a scientific demonstration is made within the next five years, little can be said about the engineering or economic feasibility of fusion as a source of power...."

The CONAES study made the same basic assumptions about the future energy supply and economic situation as the Carter administration. It is not surprising, therefore, that its recommendations parallel current DOE policy, with conservation proposed as the major source of energy in the near-term and coal synthetics and other cost boondoggles for the period after the 1980s.

—*Marsha Freeman*

MIT Researchers Expect Breakeven On Alcator

Fusion scientists working at the Massachusetts Institute of Technology expect that they will demonstrate energy-producing confinement conditions on the Alcator C tokamak, although not with the requisite ignition temperatures.

The Alcator is a small tokamak—100 times smaller than the Princeton Large Torus —but it has achieved the highest Lawson product ever attained in magnetic confinement: 30 trillion nuclei per cubic centimeter per second. (The Lawson product measures the time the fusion product is confined times the density of the fusion product.)

Since the rebirth of the U.S. fusion effort in the early 1970s, the chief scientific goal has been to demonstrate experimentally the quality of confinement of hot fusion plasma needed for energy production. As understood since the 1950s, achieving this even without simultaneously attaining the temperatures needed for fusion reaction ignition was the most crucial problem of fusion development.

Obtaining high temperature plasmas, above those needed for fusion ignition, had been accomplished routinely since the early 1960s. But these high temperature experiments failed to stably confine the plasma at a sufficient density for a long enough period to demonstrate net energy-producing conditions. From a scientific standpoint, therefore, the key to fusion success was producing systems in which the plasma is stably confined for significant periods of time and sufficient densities. Larger and more complex experiments could then scale up the system to fusion ignition temperatures.

Poisoned Prose

A New Look at Two Antinuclear Scientists

Poisoned Power: The Case Against Nuclear Power Plants
Before and After Three Mile Island
John W. Gofman and Arthur R. Tamplin
Emmaus, Pa.: Rodale Press, 1979
353 pp., $9.95

With some revulsion, this writer has reviewed the newly issued book *Poisoned Power, The Case Against Nuclear Power Plants Before and After Three Mile Island*. Actually, this is an old book, first issued in 1971 by two scientists, John Gofman, Ph.D., M.D. and Arthur Tamplin, Ph.D., after they were fired for incompetence from the Lawrence Livermore Laboratory in California. The book's reissue at this time, as the title indicates, is a propaganda effort oriented to make the most of the antinuclear hysteria after the Harrisburg affair. It boasts a new preface, tacked onto a 10-year old set of emotionally charged accusations, warnings, and just plain lies about the nature of nuclear power.

The kindest thing to be said of the book is that it is not intended for a well-informed readership and, therefore, does not allow scientific fact to interfere with the flow of emotional language.

The book's central theme is that "with heavy foot and arrogant hand," the nuclear industry is "continuing to foist . . . totally unnecessary, unacceptable technology upon the world" that is already producing "destructive radiation" in sufficient quantity to destroy mankind. The kind of so-called facts marshaled are typified by the fraudulent statistical argument that, if everyone in the United States were to receive the amount of radiation currently allowed, there would be 32,000 more cancer and leukemia deaths per year than under the zero allowable level the authors recommend.

No Science, No Nukes

Within a short time of its original publication, every argument the book presented had been thoroughly refuted by the Atomic Energy Commission and the nuclear industry. I reiterate some of the case here because the antinuclear groups still present the book's lies and distortions as fact, crowing that the authors represent the "scientific" view of nuclear danger.

First, as the *Journal of Nuclear Energy*'s 1973 review by P. R. Smith reported, "The now famous Gofman and Tamplin estimate that an average permissible annual exposure of 0.17 rad applied to the whole U.S. population would result in an increase of 32,000 fatalities from cancer or leukemia each year . . . is based upon the theory of linearity of radiation effects at low doses, which is not generally accepted since the experimental evidence is inconclusive."

This is the mildest way of putting it. In fact, Gofman and Tamplin's linear approach is the equivalent of arguing that, because any person who drinks a glass of fluoride will die, small amounts of fluoride in the general water supply will kill a certain percentage of people. In fact, all evidence demonstrates that although high dosages of radioactivity can kill, low dosages are either not harmful at all or are biologically *repaired* like any small injury.

Continued on page 72

Moving?

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

Books Received

Scientists Must Write: A Guide to Better Writing for Scientists, Engineers, and Students, Robert Barass, New York: Halstead Press, 1978, 176 pp., $8.95.

Proliferation, Plutonium and Policy/Institutional and Technological Impediments to Nuclear Weapons Propagation, Alexander De Volpi, New York: Pergamon Policy Studies, 1979, 361 pp., $25.

Obstacles to Mineral Development: A Pragmatic View, John S. Carman, New York: Pergamon Press, 1979, 200 pp., $17.50.

***Chemistry: A Study of Matter*,** W. T. Lippincott, et al. New York: John Wiley and Sons, 1977, 761 pp., $19.95.

An Introductory Approach to Operations Research. Robert J. Thierauf, New York: John Wiley and Sons, 1978, 366 pp. $20.50.

The Future With Microelectronics, Ian Barron and Ray Curnow, New York: Nichols Publishing Company, 1979, 234 pp., $17.50.

Sociobiology, Edward O. Wilson, Cambridge, Mass.: Harvard University Press, 1980, 301 pp., $9.95.

Construction Materials, Caleb Hornbastel, New York: John Wiley and Sons, 1978, 856 pp., $35.

Internal Combustion Engines, Rowland S. Benson and N. D. Whitehouse, vol. 1 and 2, New York: Pergamon Press, 1979, $14.75 each.

Processing Equipment for Agricultural Products, Carl Hall and Denny Davis, AVI Publishing Company, 1979, 294 pp., $18.

Energy Crisis, Lester A. Sobel, ed., vol. 1-3, New York: Facts on File, 1979, $45 per set.

Continued from page 71

After reviewing the book's similarly distorted treatment of other issues, the cited 1973 review concludes: "The growing environmental lobby in this country will become increasing insistent that such issues be discussed openly and freely; nuclear engineers should welcome such discussion as a greatly preferable alternative to the proliferation of books such as this."

The 'Greedy Bosses' Theory

Turning from Gofman and Tamplin's old bunk to the new preface, we find new proof of an old adage: Give a fellow enough rope and he'll hang himself. Whereas former editions emphasized the credentials of the authors, Gofman and Tamplin's new preface reveals their true political colors, explaining the source of their bias and their incompetence. For example:

"There can be no doubt that the promoters of nuclear power—be they engineers, politicians, or scientists—are indeed committing crimes against humanity. Americans would be justified in demanding that Nuremberg-type trials be held for these individuals . . . .

"This book . . . exposes the moral corruption of scientists, lawyers, physicians, industrialists, and government leaders in attempting to deceive the public into believing that there exists such a thing as a 'safe,' 'permissible' or 'allowable' dose of radiation which will do no harm . . . .

"This book . . . is about the lies, the cover-ups and the callousness of those who are willing to trick you into accepting nuclear power so that they (or their bosses) can make money or expand a bureaucratic empire, even though their activity kills people."

The history of human development has always been plagued by a small minority of people who try to stop the technological and economic progress of nations. For example, such people, small in numbers but financially powerful (like the backers of Gofman, Tamplin, and the environmentalist movement today) produced the Black Death of the 14th century by crushing technological development. The authors' demagogic language reveals their membership in the "left-liberal" political swamp that attempts to introduce a medieval, antitechnology outlook in the clothing of self-righteous, moral concern.

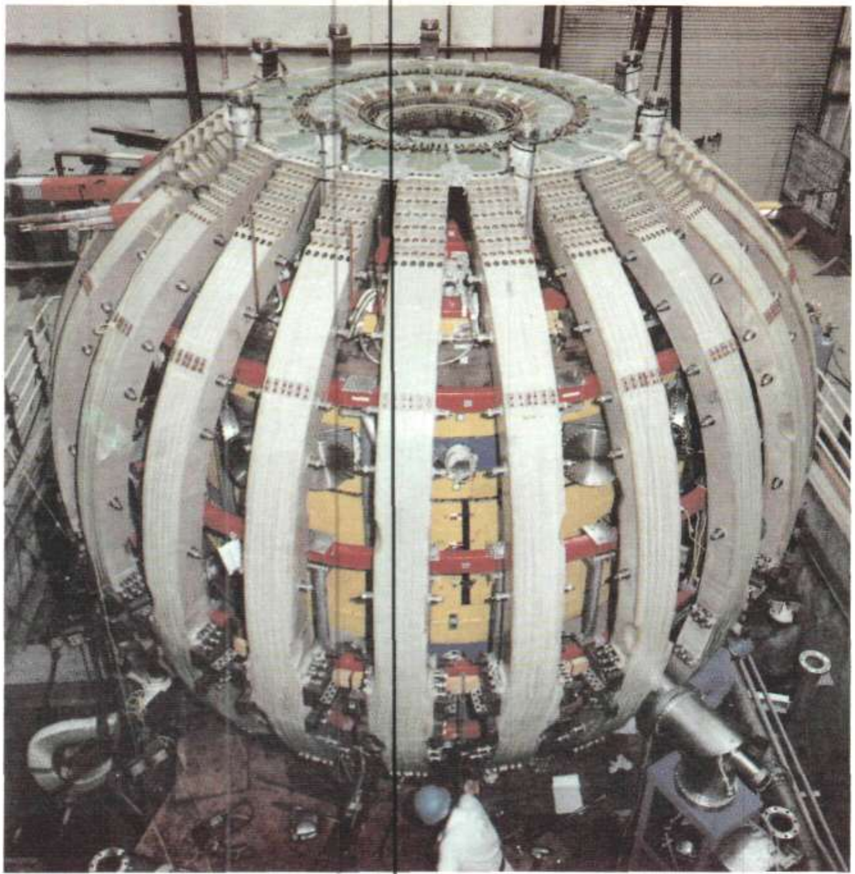
I agree with these two creatures on only two things. First, there is indeed a moral issue; second, Nuremberg is an appropriate point of reference.

The rate of increase in productive output in the advanced nations that is required to develop the Third World industry and agriculture is so great that without nuclear power several billions of persons will die in these underdeveloped nations in the two to three decades immediately ahead for lack of energy resources. Those who prevent nuclear power development by opposing it with distortions and lies are indeed candidates for Nuremberg trials for crimes against humanity.

—Jon Gilbertson

Now that you've read Fusion, join the Fusion Energy Foundation

America's strongest lobby for progress



The Doublet III tokamak fusion device, courtesy of General Atomic Co., San Diego, California

Membership

- ☐ Individual Membership $75 (includes 12 issues of *Fusion*, 4 issues of IJFE)
- ☐ Individual Membership $50 (includes 12 issues of *Fusion*)
- ☐ Sustaining Membership $250
- ☐ Corporate Membership $1,000

I would like to contribute $______ to the Fusion Energy Foundation.
Memberships and contributions are tax-deductible.
For a list of *Fusion* reprints available, send us a stamped, self-addressed envelope.

NAME ____________________

TEL. ____________________

STREET ____________________

CITY ________ STATE ________ ZIP ______

OCCUPATION ____________________

Subscriptions

- ☐ 1 year *Fusion* (12 issues) $20 ($25 Canada)
- ☐ 2 years *Fusion* (24 issues) $38 ($45 Canada)
- ☐ 1 year *Fusion* (airmail overseas) $40
- ☐ 1 year *International Journal of Fusion Energy* $35 ($40 Canada)

Total enclosed or charged ______

☐ Master Charge Card number ____________

☐ Visa Expiration date ____________

☐ Diners Signature of holder ____________

Make checks payable to Fusion Energy Foundation, Suite 2404, 888 Seventh Ave., New York, N.Y. 10019, (212) 265-3749.

Join the fight for progress now!