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MARCH-APRIL 1986

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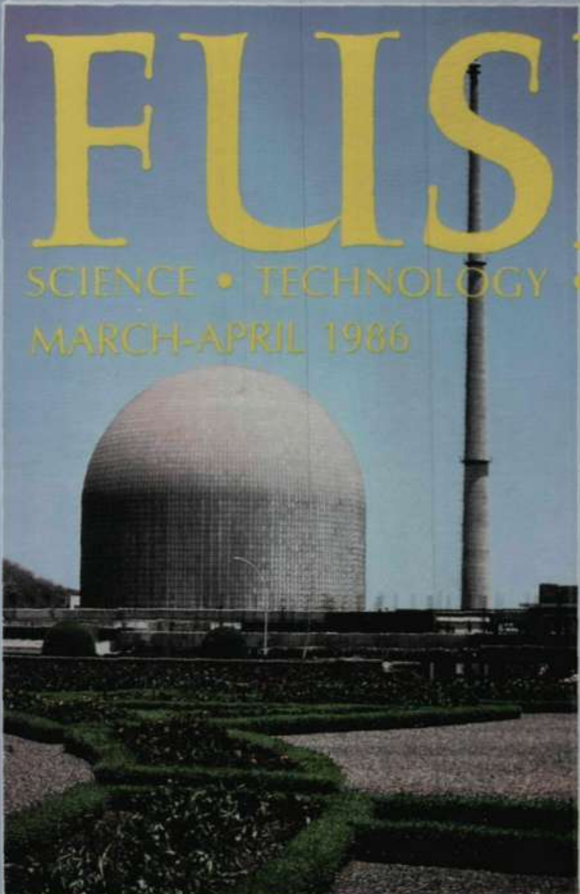

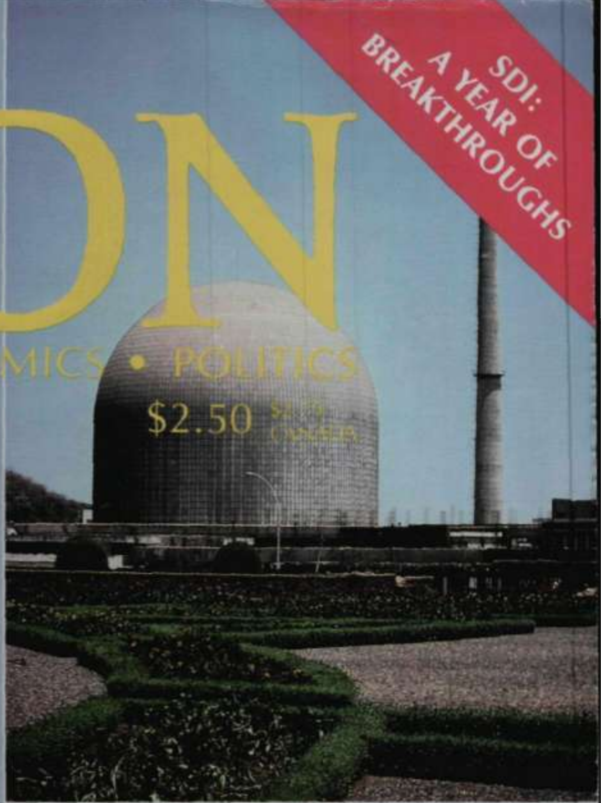

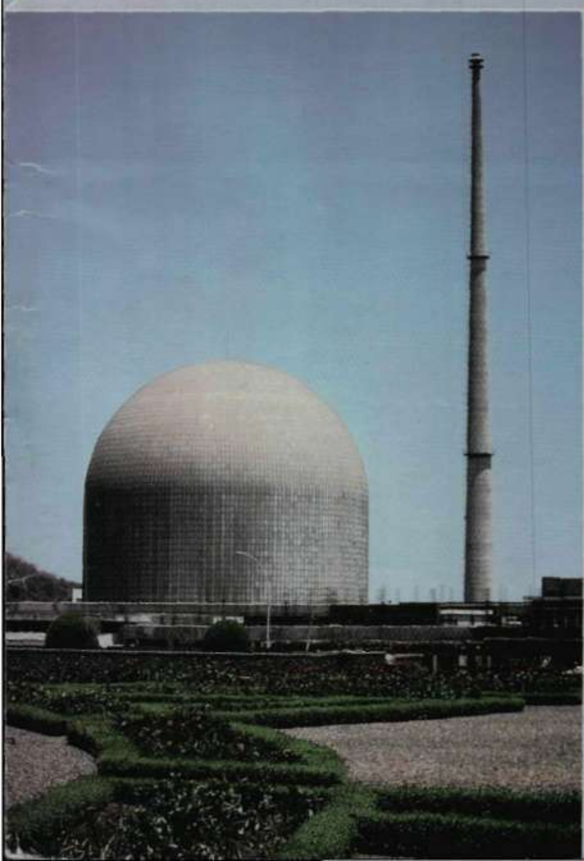

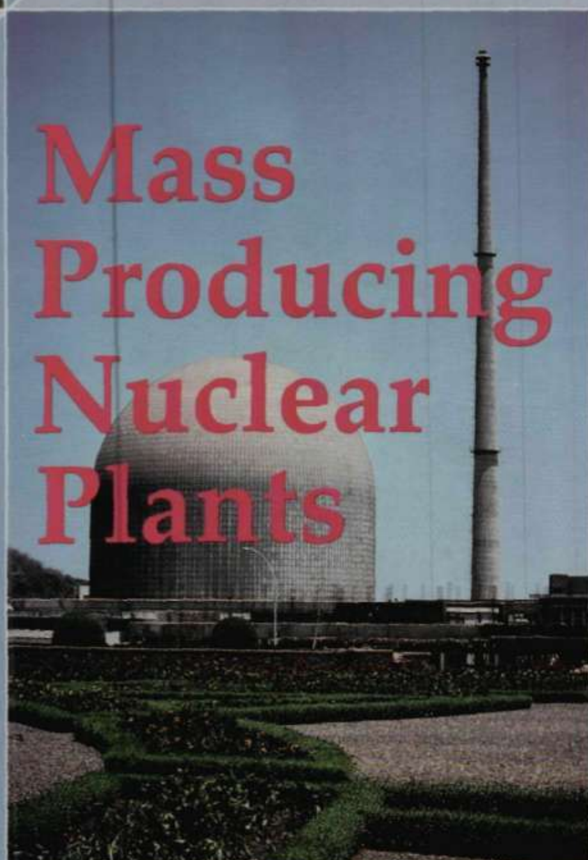

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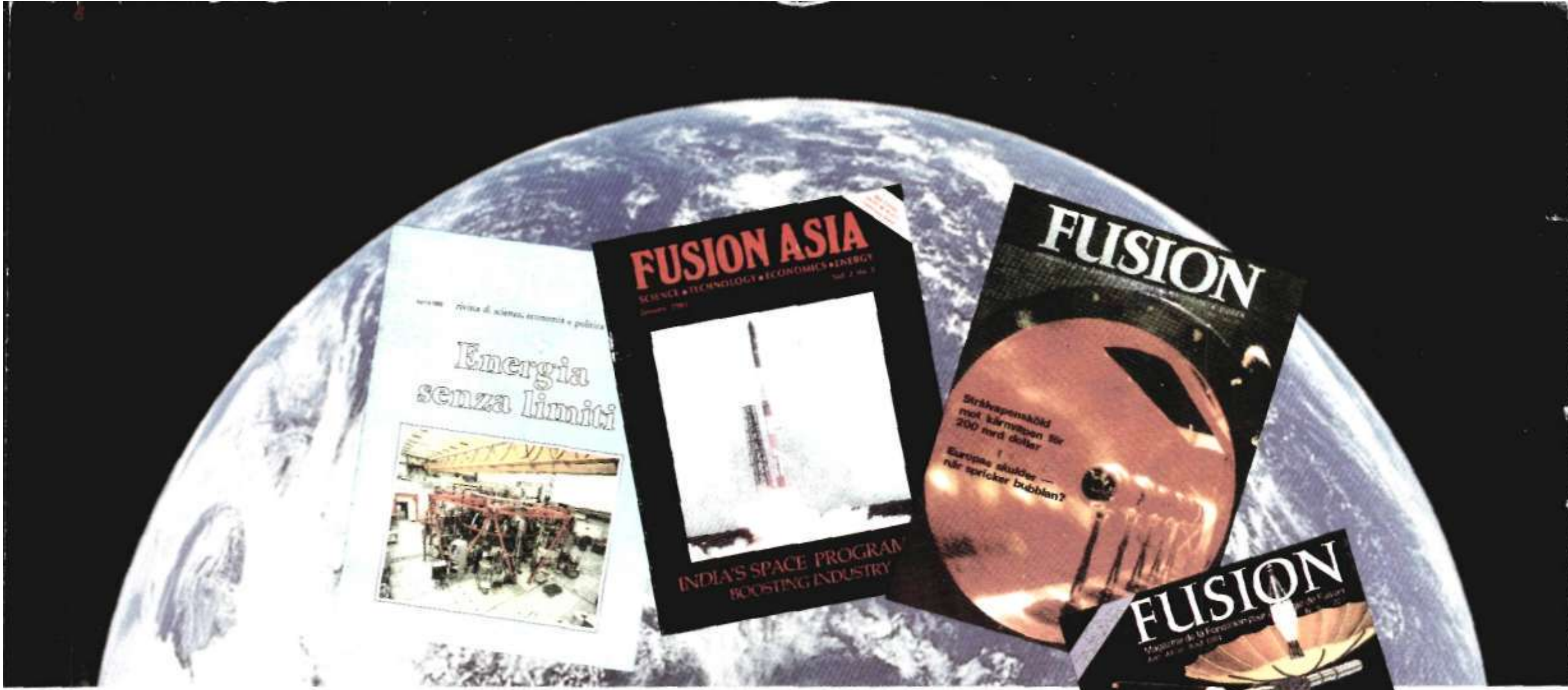

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Features

News

Departments

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On the cover: Photograph of India's Cirus nuclear reactor by Jehangir Gazdar, Woodfin Camp & Associates. Cover design by Virginia Baier.

The Leonardo Project

We were happy to report to the annual Fusion Energy Foundation membership meeting in December on the status of publications and associated work. As FEF members know, and our readers may suspect from the expansion of the number and quality of authors represented in these pages, our activities as a foundation have a far broader compass than merely publication. We are, in fact, bringing together an international network of scientists of the first rank, with the aim of reviving the method *of* Bernhard Riemann.

Key in this effort has been the revival on an expanded basis of the *Intemationl Journal of Fusion Energy* or IJFE, now edited by Dr. Robert J. Moon. In the May-June 1984 issue of *Fusion,* we published an editorial laying out a perspective for renewed publication of the journal. Our purpose was to revive it as a quarterly, to be fashioned after the influential 19th century *Crelle's Journal.*

We wished to provide a medium for scientists to publish important work, otherwise not featured in leading scientific journals because of the ideological prejudice of journal referees. Our areas of emphasis were to be plasma physics, directed energy, and optical biophysics. Our intention was to organize a series of interdisciplinary seminars to which scientists wishing to publish in the journal—and others—could bring their ideas. We would also continue the tradition of the IJFE and publish key translations of the work of Riemann and his school.

In the two years since we announced this intention, it is gratifying to report that we have succeeded in doing precisely the job we set out to do. In that time, we have hosted a series of seminars with leading scientists—many of whom have published popular articles in this magazine or had their work presented in the IJFE.

It is without doubt that the articles by nuclear pioneer Erich Bagge, fusion scientists Friedwart Winterberg and Winston Bostick, and astrophysicist Luis Carrasco are of fundamental significance in redefining an approach to physics in terms of the hydrodynamic school of Leonardo da Vinci, and more immediately of Bernhard Riemann and his school.

The publication of these articles was part of a process of bringing together representatives of the Italian and German schools educated in this tradition. One outgrowth of this seminar series was the enormously successful conference sponsored jointly by the Fusion Energy Foundation and the Schiller Institute on June 15 and 16,1985, to honor the great pioneer space scientist, Krafft A. Ehricke.

The Critical Area of Biophysics

Notwithstanding the enormous importance of continuing the direction of this work, which we began more than a decade ago, even more significant has been our success in bringing together a group of leading international biophysicists. Our contribution in this area may well prove critical in the regeneration of fundamental science.

It will also be of the utmost practical significance. As readers well know, an estimate of 50 million people already infected with the AIDS virus is conservative. More significant than the numbers of individuals currently infected with the disease, is the rate at which the disease is spreading and mutating.

Clearly we need a crash effort to defeat AIDS. Although currently available techniques of genetic engineering must be applied to the task, it is in the area of spectroscopy where the greatest gains can be made. Diagnostic tools, like the flow cytometer now being developed by Los Alamos laboratory, can allow unambiguous, virtually instantaneous detection of the disease. But far more important ultimately, may be the use of tuned radiation to destroy the virus.

It is precisely in this area that our emphasis upon the methods of optical biophysics are crucial. As we come to understand how the body actually works, we can hope to "tune in" to the resonances of cancers and viruses, in order to selectively destroy them without hurting the bodily functions. We can study how, under deteriorated living conditions and with the repeated onslaught of disease, the degeneration of the body's own DNA and RNA may contribute to the creation of viruses. Conversely, we can test our hypothesis that the body utilizes coherent radiant energy to repair itself. It is our contention that life processes are governed by a kind of higher-order lasing principle.

The interdisciplinary, international network of scientists who have come together in our seminars to discuss this question, have included several experts on AIDS per se, along with Drs. Philip Callahan, James Fraser, and Fritz-Albert Popp, whose work is discussed in this issue by Wolfgang Lillge. One question under discussion is to apply the techniques of spectroscopy to identify malfunctioning of the system, which produces disease, and similar breakdowns associated to cancer formation.

In the coming period we hope to set up laboratory facilities ourselves, where some of these theories can be tested out, as well as discussed. Another area we wish to research is that of photosynthesis. Here the techniques of spectroscopy can help us to correlate the efficiency of carbohydrate production, with changes in the frequency and density of light. We are also now funding an experiment in plasma physics, and we hope to promote other important research that would otherwise suffer from the present reduction in the level of government support to science.

Despite the grave political-economic crisis we face, most immediately over issues of the national budget, we at FEF look to this new year with great optimism, in the conviction that we are indeed working in the spirit of Leonardo to again catalyze a scientific renaissance.

Letters

Why Halley Deserves No Praise, No Comet

Editor's Note

In the September-October 1985 Fusion, *Philip Valenti told readers "Why the Credit for 'Halley's' Comet Belongs to John Flamsteed." Valenti's documentation of how Halley and Newton plagiarized Flamsteed's work was answered, not surprisingly, with an Oct. 29 article in the* New York Times *"Science Times" that effusively praised Halley. In addition, astronomer Fred Whipple gave a similarly fulsome presentation on Halley Nov. 15 to the American Philosophical Society.*

To the Editor:

To John Noble Wilford of the *New York Times,* and to Dr. Fred Whipple of the Smithsonian Institution, and to other Newtonian apologists, the great comet now returning seems to represent the restored scepter of King George III, before which all nations must bend their necks. A truthful examination of history shows on the contrary, the return of ourcomet may portend the Biblical "writing on the wall" for all British-inspired tyranny, in science as well as politics and economic policy today.

Wilford acknowledges that "Edmond Halley did not discover this particular comet. . . ."Then what *did* Halley do? Wilford answers: "He determined that comets do not travel straight lines or parabolic orbits, passing through once, never to be seen again; their orbits are elliptical, a sort of squashed circle."

Mr. Wilford, please pull off your bookshelf *The Correspondence of Isaac Newton,* published by your beloved British Royal Society for the years 1680-1685. Therein you will discover a series of letters by the Reverend John Flamsteed, Royal Astronomer at the time and bitter political enemy of Edmond Halley, in which he insists that the comet of 1680 had curved around the Sun.

Flamsteed also provided tables of data and diagrams vindicating his hypothesis, which you, out of ignorance or deceit, credit to Halley. For those five years, Newton and his protege Halley insisted that Flamsteed must be wrong, and that comets must travel in straight lines! It is fair to say that Newton and Halley *stole* Flamsteed's hypothesis in time for the publication of Newton's *Principia* in 1686.

This brings us to the political issue of Halley's personal character. Mr. Wilford quotes Philip Morrison in the November 1985 *Scientific American,* to the effect that Halley was not only "a gifted, original [sic], versatile, and productive scientist," but also an "adventuresome, generous, loving, and sweet" human being! Dr. Fred Whipple, in his recent address to Benjamin Franklin's American Philosophical Society in Philadelphia, positively gushed concerning Halley: "He is my ideal. If I were like him, I would be completely happy."

Cover-Up

In their enthusiasm to propitiate the Royal "Newtonian authority," Mr. Wilford, etal., cover up the following well-documented facts: (1) Halley and Newton, after stealing Flamsteed's hypothesis, illegally confiscated the observations of Rev. Flamsteed and then, to mask their crimes, edited his name out of the *Principia.* (2) Halley and Newton staged the infamous kangaroo court against C.W. Leibniz in 1712, in order to establish the lie of Newton's priority in the invention of the calculus, and then, again to mask the crime, edited Leibniz's name out of the *Principia.* (3) Newton, as warden of the English Mint in 1696, and Halley, as his deputy controller, ruthlessly executed the treasonous recoinage ordered by the Bank of England in that year, which finally imposed the financial dictatorship of the City of London over the English nation, paving the way for the Empire. Only remorseless proponents of the genocidal policies of the International Monetary Fund today, like the New *York Times,* could consider such a hangman as Halley "sweet."

To add insult to injury, Dr. Whipple chose the forum of the American Philosophical Society to express his schoolboyish love for Halley. I must speak out against you, Dr. Whipple, in the name of another great victim of Halley's "Newtonian methods"—Thomas Godfrey. Godfrey, a glazier by trade and a friend of Benjamin Franklin, helped to found the veryAmerican Philosophical Society whose forum Whipple has abused. Godfrey invented the mariners' quadrant in 1732. He and his mentor, James Logan, generously offered a full written description of the invention to the British Royal Society in that year. But the "sweet" liar Halley, then president of the Society, did not appreciate this intellectual "threat" from America; he larcenously claimed that British Royal Fellow John Hadley had already invented the same instrument!

Our Franklin succinctly judged this affair in his *Autobiography,* writing of "Thomas Godfrey, a self-taught mathematician, great in his way, and afterward inventor of what is now called Hadley's Quadrant."

No, this passage of our comet will not witness the revival of Imperial policies, neither in science nor politics, so wished for by the New *York Times* and others. This time, our comet will see justice done in the world. Visit the monument over Godfrey's grave in Philadelphia, and note carefully the inscription:

"Palmam qui Meruit Ferat"

Philip Valenti
Philadelphia, Pa.

Leonardo Vs. Kelvin

To the Editor:

I thought *Fusion* readers might be interested in a story that was brought to my attention by the Italian aerodynamicist Luigi Crocco. Crocco reported thatthe British scientist Kelvin, who bitterly fought against the scientific tradition of Leonardo da Vinci and Bernhard Riemann, stated flatly in 18%, "I have not the smallest molecule of faith in aerial navigation, other than ballooning."

So much for the method and insight of the British empiricist school. This alone proves the point of my article on the importance of Leonardo's method. [Jan.-Feb. 1986, p. 14].

Dino de Paoli
Washington, D.C.

Viewpoint

The Optical Computer: Reason's Chain

by Thomas M. Clarke

The lengthening and persistent shadow of John von Neumann exerts a powerful influence over the entire field of computer technology. Every aspect of computing—hardware, programs, and so forth—has a direct lineage to von Neumann's ideas. This is not to say that others did not have an effect, or made no contribution. On the contrary, much of what von Neumann used in his theories on computing was built upon the work of others, such as Babbage, Boole, and Zuse. But it was von Neumann who became the fulcrum upon which all modern and projected computer technology turns.

Part of this was because of von Neumann's philosophical ideology; part was because of the limits upon the technology *at that time.* But a large factor is simple inertia. That is, at one time, the "answer" was "explained"; since then, the question has not been reexamined. The why is, of course, a lack of vision.

Once the "answer" to the problem was already given and demonstrated, neither investment nor management support would be lent to any heretical investigation. To paraphrase the Koran, "There is no god but the computer and von Neumann is his prophet."

At the beginning *of modern computer* technology, the turn taken was not a large diversion; as time has gone by, however, the limits have been approached. Anyone familiar with the computer industry would be quite aware of the problems which are being encountered—components on chips becoming so small that their operation can be affected by molecular migration or "background" radiation (such as cosmic rays), for example.

The great technology race is now to pack more and *more* components on a single chip, and to pack more and more of these dense chips into a computer. By closely packing these chips, the conductor length is minimized to reduce signal propagation time. The computer will thus run faster; unfortunately, enormous heat is built up.

Now the optical computer is being designed on a component-by-component replacement basis for the electronic computer. In effect, all that is being done is extending the von Neumann limits a bit. It is not a new type of computer.

All of this might be a farce or slapstick comedy worthy of the Marx brothers. Indeed, if that was all this was about, the entertainment value alone would be worth it. Regrettably,

there is more to it, for what is the aim for building these densely packed, fast, hot-running machines? The goal is the so-called fifth generation computer, artificial intelligence—human artifacts that will become human masters.

I, for one, am not going to let these absurd notions pass unchallenged. I will now demonstrate the error of John von Neumann, slavishly followed unto this day, and show the proper path for building such a machine that *can* mimic the human brain.

The Error of Von Neumann

The error of von Neumann has now reached the point of folly; the human brain is now explained in terms of the computer. Our brain, and the divine mind behind it, most certainly is *not* like a von Neumann computer, or a "non-von" computer, or even a parallel computer. If one wishes to design a machine to mimic the human brain, one must first understand the workings of the brain. The artificial intelligence crowd's ploy to invert this order will notsucceed. (Butthen, reductionism never will succeed.)

If one looks at a modern computer as a fast, dumb calculating machine, one would not be inaccurate. By removing some of the mystery of computers, it becomes possible to look at the underlying problem and not be intimidated by the confusion and jumble on top.

Partly because of the limitations of the technology, but also because of von Neumann's philosophical outlook, the memory and computation functions were separated and made to operate in a sequential fashion; that is, data are entered, processed, sent to memory, returned from memory, processed further, then sent to the output.

Considering that the equipment to build these computers consisted of electromechanical relays and sem/reliable vacuum tubes, getting one to work at all was quite an achievement. The first modern computer, ENIAC, was built with von Neumann architecture ("architecture" is the design of the internal workings of a computer).

A few years later, Mauchly and Eckert built the UNIVAC I, the first electronic computer and progenitor of all computers built and sold to this day. Mainframes, minis, micros, supers—all are related to UNIVAC I.

Precisely this bifurcation of memory and processing is the cause of *our* dilemma. Perhaps most unsettling is the realization that work is being done, worldwide, on designing and building optical computers, but with the same von Neumann architecture! The opportunity for starting with the legendary "clean slate" is being spurned with loathing. And yet, the temper of the times is that the race to build an optical computer is a deadly earnest competition, with no second place.

Most amazing of all, it is the considered opinion of the computer frater-

Thomas M. Clarke is a founder of a fiber optics firm, Hologic, Inc., in California and has designed the vortex™ fiber system for his company. He is also working on an optical computer design and a radical propulsion system design.

nity that breakthroughs, like optical computers, "non-von" architecture, and submicron-chip technology, will, at long last, realize the Holy Grail of *artificial intelligence.* It is a tautology to point out that when an error has been made and compounded geometrically (2°, 2\2^{2},. . .2") no truths can be discovered. All one can do is return to where the error was made and select a different path.

A path, one hopes, that has been preselected by applying the critical faculties of the mind to determine where one wishes to arrive.

Mimicking the Human Brain

Allow me, then, to present a vision of how it would be possible to design and build a computer that will mimic the human brain.

If one desires to design and then build a device that has not been made by humans before, the best procedure, historically, has been to observe similar phenomena, usually occurring in nature, and attempt to understand—by parts, if need be—what is going on.

Observation alone is not enough; however, since one must have from the beginning a vision of the end result. If this is not present, then all the observation in the world will be at best a pleasant diversion. Once an existing example has been observed, general principles may be drawn—a book of design rules, if you like. Once this book of design rules has been drawn up, then a working prototype can be constructed according to these principles. It is then a matter of testing and refining from there, but the course has been set.

An example of exactly this process is the story of the invention of human flight. For millennia, mankind had dreams of flight—Daedelus, Leonardo da Vinci, among others. Yet, in the short span of four and a half years, Wilbur Wright, aided by his brother Orville, unlocked all the secrets of flight. Every airplane that flies does so by at least some of the principles covered in the Wright's patent. How was such a smashing success realized in less than a half a decade?

A key point was the many days Wilbur Wright spent at an area near his home where large birds flew and soared. Many pages of his notebook are filled with descriptions and speculations on how and why the birds flew. From these observations he synthesized some basic design rules, and went on from there, assisted by **Or**ville, to human flight.

In our search for a machine to mimic the human brain, we may learn a great deal from Wilbur Wright. If we design according to true principles, then we may expect our machine to have few limits, and those limits being set far back. With this in mind, we may now begin to look at our brain-mimicking machine.

The Brain As a Hologram

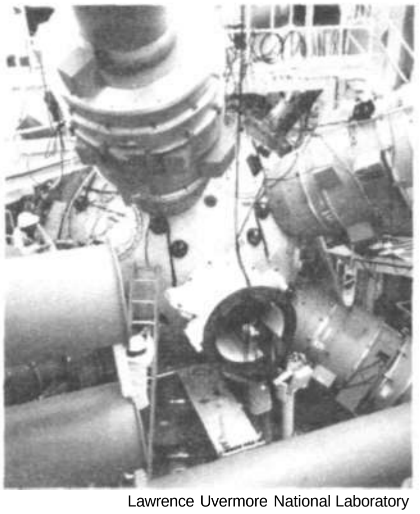
At about the same time that von Neumann was devising his architecture, another Hungarian, Denis Gabor, invented the hologram. There was the minor problem of not having a laser for coherent light, but this was because the invention of the laser was still 12 years in the future! Nonetheless, Gabor so well described the mechanism of the hologram that a working laser merely confirmed his idea: that an interference pattern could create a virtual image of the object itself.

A few years after the laser made holograms a real thing, Karl Pribram, later followed by Paul Pietsch, put forth the idea that the brain acted suspiciously like a hologram. Pietsch, a biology professor, did laboratory experiments on salamanders. He would remove some brain tissue and scramble other brain tissue. As long as some of the brain remained, the salamander knew how to be a salamander. In other words, the brain was exhibiting the same characteristics as a hologram: If any one portion of a hologram is left, it is enough to reconstruct the virtual image. (Try doing *that* with a von Neumann computer!)

If a brain acts like a hologram, where is the source of coherent radiation?

Continued on page 6f

News Briefs



Lawrence Uvermore National Laboratory

Nova's target chamber: The first experiment with fusion fuel produced 11 trillion neutrons.

LAWRENCE LIVERMORE'S NOVA LASER CREATES FIRST 'STAR'

The Nova laser at Lawrence Livermore National Laboratory, the most powerful laser in the world, created its first "star" in early 1986 when the laser imploded a tiny sphere of fusion fuel, creating 11 trillion neutrons. "This is our first successful experiment," Erik Storm, deputy director of the lab announced Jan. 13. "Its design and purpose was to produce sufficient neutrons to test some advanced diagnostic equipment. And we were delighted with the very high yield. . . . Another way to look at what we've just accomplished is that we've taken another step forward on the mile-long journey toward harnessing fusion energy."

U.S. GIVES FINAL APPROVAL TO IRRADIATION OF FRESH PORK

The Federal Register published final approval Jan. 14 on a new Food and Drug Administration regulation that permits the low-level irradiation of pork for trichina control. Processing fresh pork with gamma rays at 100 kilorads not only kills the trichina parasite, but also gives the pork a 60 percent extension of shelf life. The FDA approval was granted in response to a petition from Dr. Martin Welt, president of Radiation Technology, Inc., in New Jersey, a leader in the fight to commercialize food irradiation for the past 20 years. Consumers will be able to recognize the new product by its label "picowave treated (or irradiation treated) for control of trichina."

WORLD'S LARGEST BREEDER REACTOR COMES ON LINE

France's Superphenix, the world's largest breeder reactor, came on line Jan. 14, generating commercial electricity for the nation's electric grid. Located at Creys-Malville in southeastern France, the 1,200-megawatt Superphenix was completed in less than eight years—half the time it takes the United States to put a light water reactor on line. France has 36 nuclear plants in operation and 28 plants in construction, and by 1990, nuclear power will produce 70 percent of France's electricity.

WEST GERMAN SUPREME COURT RULES AGAINST GREEN PARTY

The West German Supreme Federal *Court* ruled Jan. 14 that the Christian Democrat and Free Democrat parties were right to deny the Green Party a seat on the Secret Service Control Commission in Parliament 15 months ago, because there "were reasons to believe the Greens would not keep state secrets." In its ruling, the court rejected a lawsuit filed by the Green Party and backed by the Social Democratic Party. As the daily Die Welt pointed out, the ruling raises the question of why the Greens are in Parliament at all if their loyalty to the state is so questionable.

WHOSE SIDE IS THE HERITAGE FOUNDATION ON?

When the supposedly conservative Heritage Foundation released its recommendations for the 1987 budget Jan. 22, it provoked the obvious question of just whose heritage the foundation is interested in protecting. The report, titled "Slashing the Deficit," would "privatize" the space program, eliminate 25 other government programs including NASA's civilian aeronautic R&D, and reduce the already scant budget for nuclear fusion and fission to "half the 1986 level." This last cut is justified, Heritage says, because "declining fuel prices have eliminated the urgency" for these energy sources. Besides, the report says, "Cutting spending for these programs in half will reflect their reduced priority."

GA Technologies

Interior of the D-lll-D vacuum chamber during the installation of armor to protect regions of high heat flux.

GA TECHNOLOGIES' DOUBLET III REFITTED FOR NEW EXPERIMENTS

GA Technologies' Doublet III tokamak in San Diego has been refitted over the past 16 months for new experiments during 1986-1987 on confinement enhancement and impurity control. The Doublet-III-D is a "D" shaped tokamak with the largest cross-sectional area and largest plasma current of any device in the United States.

TOM SAWYER, FEF FOUNDING MEMBER, DIES AT 84

R. Tom Sawyer, an internationally known power engineer who gave the gas turbine engine to 20th century power systems, died Jan. 21 at age 84 in Ho Ho Kus, N.J. "Tom Sawyer's unexpected death is a great loss," said Paul Gallagher, executive director of the Fusion Energy Foundation. "We have enjoyed the special interest, optimism, and sponsorship of Tom Sawyer for the last 10 years of his very productive life, and we will miss him."

Sawyer was the author of *The Diesel Locomotive and the Modern Gas Turbine* and a founder of the Gas Turbine Division of the American Society of Mechanical Engineers as well as a founding member of the FEF. A strong proponent of nuclear fission technologies, Sawyer was also active in the American Rocket Society.

Linda Ray

Tom Sawyer receiving an award at the fifth anniversary celebration of the FEF in November 1979.

EEC BOWS TO ENVIRONMENTALISTS, BANS SAFE ANIMAL HORMONES

The agriculture ministers of the European Community decided Dec. 19 to ban the use of hormones that make beef cattle grow larger, faster, and leaner. Their decision was admittedly a response to political pressure from environmentalists, not scientific evidence. The committee of scientists commissioned by the ministers to look at the safety question had concluded, "there are no scientific grounds for a ban on either natural or synthetic growth promoters." According *to New Scientist* Jan. 2, the extra weight gained by livestock as a result of added hormones is valued at £35 million in Britain alone. A portion of cabbage has up to 2,000 times the hormone content of a similar weight of steak from a treated steer, the magazine reports.

UNIVERSITY OF ROCHESTER LASER MEASURES FASTEST TRANSISTOR

Using a novel electrooptic sampling technique, the University of Rochester Laboratory for Laser Energetics (LLE) measured a new type of transistor that has the fastest switching speeds of any transistor yet fabricated. The gallium-arsenide permeable base transistor, developed for the Defense Department at Lincoln Laboratory, the Massachusetts Institute of Technology, has a rise time of 5 trillionths of a second at room temperature. (Rise time is a measure of how fast a transistor responds to a change in voltage.) The sampling technique uses femtosecond pulses of laser light coupled with a voltage-sensitive crystal to characterize the response of the transistor, and it allows the monitoring of individual electronic components. LLE reported Jan. 9 that it is "the only lab in the world capable at this time of measuring the performance of the new breeds of fast electronic components."

FEF SPONSORS 'LASING IN BIOPHYSICS' PANEL AT LASERS '85 CONFERENCE

An FEF panel on "Lasing in Biophysics: Implications for Beam Science and Technology" was featured at the Lasers '85 conference in Las Vegas, Nev., Dec. 5. Several of the panels featured the SDI, with speakers including Dr. Edward Teller and Dr. Gerold Yonas. The FEF session was chaired by Dr. Jonathan Tennenbaum, director of the FEF in Europe, and included presentations by Dr. F.A. Popp of the University of Kaiserslautern, Dr. James Fraser of the University of Texas Medical Center, and Dr. Philip Callahan of the U.S. Department of Agriculture in Gainesville, Fla. Popp reviewed experiments in which he measured the emission of "coherent" radiation from living cells, with results indicating that this light emission could be an essential controlling mechanism for living matter. Fraser described the general frontiers of biological spectroscopy, and Callahan discussed how "coherent lasing" of molecules is the basis for the operation of insect sensors. A version of Popp's paper appears in the *International Journal of Fusion Energy,* Vol. 3, No. 4.

LOUSEWORT LAURELS AWARD TO PAT ROBERTSON

This issue's Lousewort Laurels Award goes to Pat Robertson of the "700 Club" for his dinosaur economics. Robertson recently told United Press International, "The federal deficit is the symptom of a deeper moral problem which says, 'I want it now,' instead of deferring gratification until funds are available to pay for it."

How the Soviets and WHO Stopped a Mobilization Against AIDS in Africa

by John Grauerholz, M.D., F.C.A.P.

The International Symposium on African AIDS, held in Brussels Nov. 22-23 and attended by 700 scientists, could have been the beginning of a mobilization to stop the deadly spread of AIDS in Africa, which has now been r-eported by some doctors to have infected from 10 to 32 million people in Central Africa alone.

No mobilization occurred, however, because of a nasty operation run by the Soviets to convince African and other participants at the conference that AIDS is a result of "CIA-Pentagon biological warfare" and that to discuss the way International Monetary Fund conditions have spread AIDS in Africa is "racist."

The Soviet line was delivered in private conversations with African delegates by a group of 12 Yugoslavs and 6 Poles, working under the supervision of two officials of the Soviet Ministry of Health. This is the same Ministry from where World Health Organization assistant director-general Sergei Litvinov came to assume his present job.

The conference is a Western colonialist plot, the Soviets said, to blame AIDS on the Africans. As a result of this effort, the conference opened with rumors that it was an illegitimate conference and that the Africans would boycott it. Spreading the whisper campaign that the conference was illegitimate were World Health Organization officials and U.S. networks associated with the Centers for Disease Control and the National Institutes of Health.

This concerted effort succeeded in preventing the initiation of an emergency program to stop the spread of AIDS in Africa. It also so played on the Africans' fearof being blamed for AIDS, that the Africans as a group issued a document including the following statement: "During this symposium, papers presented did not show any conclusive evidence that AIDS originated in Africa. It is a global problem and *not* an African problem alone. Therefore, efforts directed in African association with AIDS do not contribute to future control programmes."

The end result of the Africans' statement is that the international agencies concerned will continue to suppress information necessary for a massive public health campaign to clean up the conditions of economic collapse that have led to the pandemic outbreak in Africa.

The full effect of this operation was evident at the final press conference, when Dr. Nathan Clumeck of St. Pierre University Hospital in Brussels, the chief organizer of the conference, told the press it should not print stories about AIDS in Africa because such stories might offend the Africans, while the Africans on the panel were blaming all the problems on "Western media." The final irony was the recommendation to turn the problem over to the WHO, since the major reason for convening the conference was dissatisfaction with the way WHO is handling the problem.

The Soviets ran a nasty operation to convince Africans that AIDS is "CIA biological warfare."

The Alma Ata Conference

In order to understand this situation, it is necessary to go back to the 1978 World Health Organization Conference on Primary Health Care. This conference, which took place Sept. 6-12,1978 in the Soviet city of Alma Ata, marked the formalization of a decision that no investment in major health or sanitary infrastructure would be made in the developing sector, and that capital-intensive, high-technology medical care would also be deemphasized, to the extent possible, in the West.

Instead, the emphasis was to be on "Primary Health Care" and "problem-centered, as opposed to institution-centered health care."

The coherence of this approach with the IMF and World Bank policies toward the developing sector is exemplified by the following description of "appropriate" health technology from the report of the Alma Ata conference:

"An important factor for the success of primary health *care* is the use of appropriate health technology. The word 'technology' means an association of methods, techniques and equipment which, together with the people using them, can contribute significantly to solving a health problem. 'Appropriate' means that besides being scientifically sound the technology is also acceptable to those for whom it is used. *This implies that technology should be in keeping with the local culture.* It must be capable of being adapted and further developed if necessary. In addition, it should preferably be easily understood and applied by community health workers, and in some instances even by individuals in the community; although different forms of technology are appropriate at different stages of development, their simplicity is always desirable. The most productive approach for ensuring that appropriate technology is available is to start with the problem and then to seek, or if necessary develop, a *technology which is relevant to local conditions and resources* [emphasis added].

The president of this conference, which was jointly organized and sponsored by the World Health Organization and the United Nations Childrens

Fund, was Professor B. Petrovskii, minister of health of the U.S.S.R.

The Heavy **Hand of** the **IMF**

The IMF is recognized as the major problem by the Africans, and a great deal of the anti-Americanism voiced by the Africans is directly related to United States support for the IMF and its austerity policies, which are now devastating the continent. There is tremendous receptivity among the Africans to any policy for real development, combined with a cynicism verging on despair, that any such policy will be forthcoming from the present international agencies.

It became evident at the Brussels conference that there is heavy targeting against individuals who are attempting to deal with the true seriousness of the AIDS pandemic, and that that targeting is arising from Soviet and other Malthusian networks at WHO and other agencies committed to.depopulation policies in the developing sector and deindustrialization of the West.

Despite this political operation, many of the oral presentations on the epidemiology, virology, and clinical aspects of AIDS in Africa and the various poster presentations dealing with these matters provided evidence of the seriousness of the situation.

In the opening scientific presentation, Dr. Robert Callo of the U.S. National Cancer Institute discussed therapeutic approaches to treating AIDS based on interfering with cell to cell transfer of the virus, or attacking or deceiving reverse transcriptase, the enzyme responsible for converting the virus RNA into DNA in the host cell.

Gallo then asserted that the virus was spread by sex and blood, and discussed the spectrum of disorders caused by HTLV-III/LAV (the AIDS virus). In addition to AIDS and ARC (AIDS Related Complex), these include neurological (brain disease, which is becoming extremely important in the United States), congenital malformations, bleeding disorders due to destruction of platelets, and various cancers, such as Kaposi's sarcoma and lymphomas. After discussing the biology of infection by the AIDS virus, he then stated that the virus had been found in saliva, semen, tears, urine, blood, and brain and bone marrow.

CDCScience Source

HTLV-3-infected T-4 lymphocytes show AIDS virus budding from plasma membrane.

"...15 to 22 percent of AIDS cases in Central Africa are children."

Dr. Nathan Clumeck of the St. Pierre University Hospital in Brussels, the chief organizer of the conference titled his presentation "Overview of the AIDS Epidemic and Its African Connection." After reviewing the data from the United States and Europe, he concluded that AIDS did not exist in the United States before 1978, and that the same evidence exists for European cases among homosexuals, intravenous drug users, or hemophiliacs whose infection can be traced to American contacts.

He then discussed a group of cases of heterosexual Africans, living in Europe or referred to Europe for medical care, which represented 12 percent of the total European cases. These cases came from 21 different African countries, mostly Zaire, Congo, and other Central African nations. Subsequent studies, he said, revealed a high prevalence of AIDS cases and presence of antibody to AIDS virus in Uganda, Rwanda, Zambia, and Uganda, and AIDS is a leading cause of death in specific groups.

Clumeck referenced data that suggested strongly that AIDS virus, or a related virus, has been present in Africa since the early 1960s, particularly a study on serum from children in Burkina Faso, collected in 1963, which showed 2.8 percent of them to be positive by Western blot test.

After noting that 15 to 22 percent of AIDS cases in Central Africa are children, Clumeck discussed potential cofactors in African AIDS. These include environmental factors such as malaria infection, parasites, hepatitis-B, malnutrition, and poor sanitation, as well as possible genetic factors. Clumeck concluded by calling for national surveillance systems and large sero-epidemiologic studies.

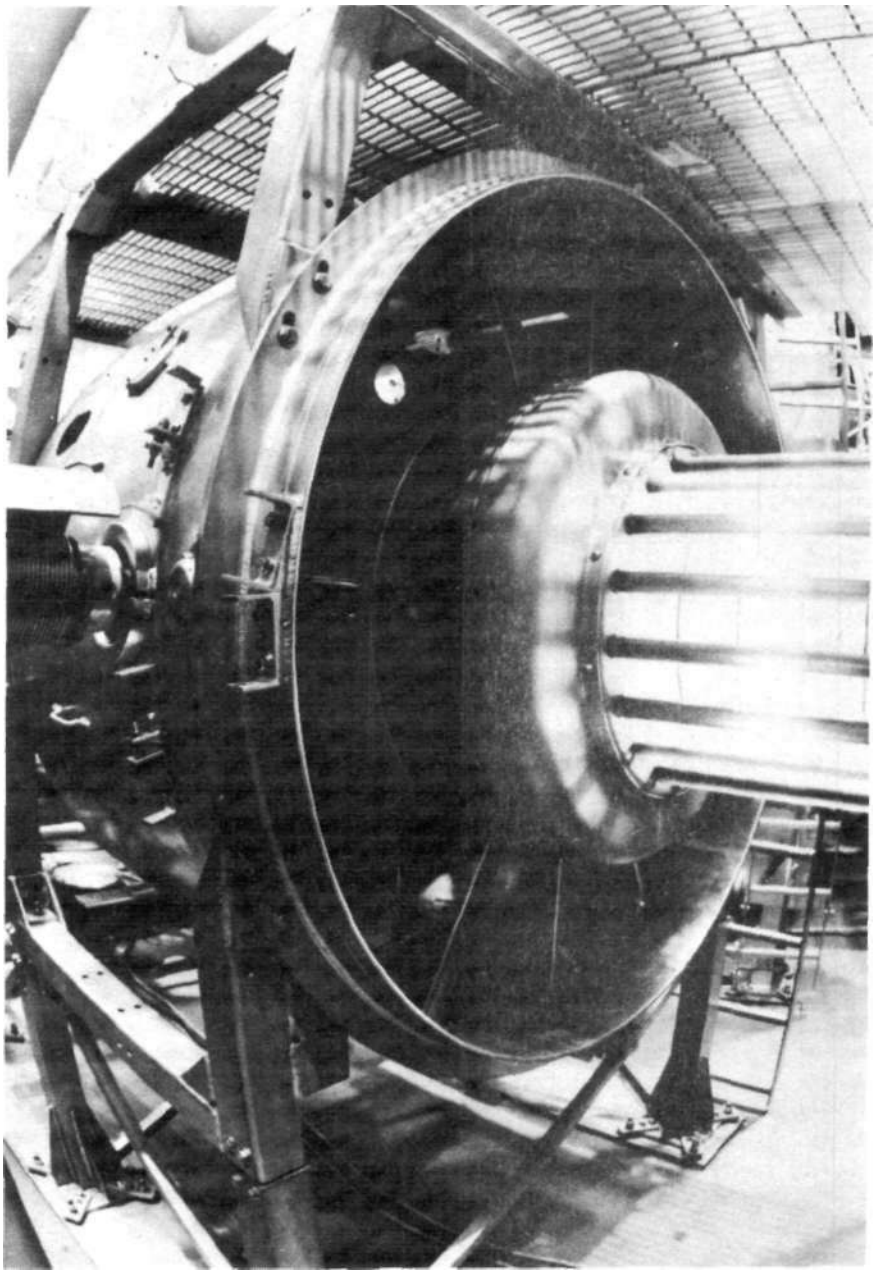
A good deal of turmoil was created by a paper entitled "HTLV-III/LAV Antigens and Detection of Possible Variants in Lymphocyte Cultures of AIDS Patients and Healthy Carriers from Central Africa and Belgium," in which it was reported that 27 percent of spouses of AIDS and ARC patients were *virus carriers, who were negative by antibody testing.* Another paper, "HTLV-III/LAV Infections of Humans and Chimpanzees," provided additional evidence for a prolonged antibody-negative virus-carrier state.

The final paper was "Simian T-Lymphotrophic Virus Type III (STLV-III AGM) in African Green Monkeys and Its Relationship to Human Retroviruses in Africa," presented by Dr. Myron Essex of the Harvard School of Public Health. Essex described a virus present in African green monkeys that shows strong serologic cross reaction with the AIDS virus. In addition, he reported studies in West Africa indicating that many people have antibodies to the monkey virus, but not to the AIDS virus.

FUSION BY 1988:

Sandia Fires World's Most Powerful Particle Beam

by Charles B. Stevens



Fusion scientists at Sandia National Laboratories in New Mexico successfully test fired the world's most powerful particle beam accelerator, the PBFA-II, or Particle Beam Fusion Accelerator, Dec. 11. The 108-foot diameter accelerator produces a 100-trillion watt light ion beam designed to achieve inertial confinement fusion. As Dr. Pace VanDevender, director of Sandia's Pulsed Power Sciences, put it after the shot, "The world now has the best light-ion accelerator for inertial confinement fusion that can be built."

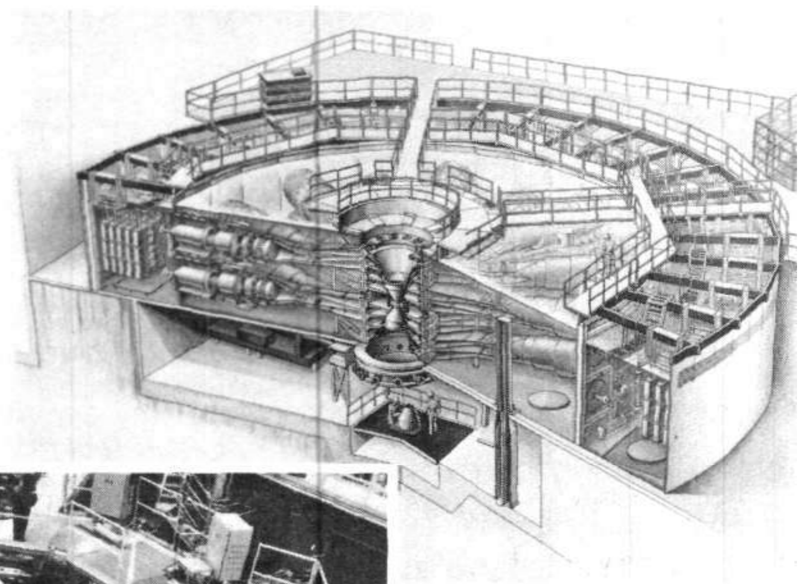
Given recent budget cutbacks in magnetic fusion research, the PBFA-II is now positioned probably to be the first facility to achieve net energy generation by igniting controlled nuclear fusion reactions in the laboratory. It will definitely be the first of the inertial confinement fusion drivers—including lasers and heavy ion beam accelerators—to demonstrate significant inertial confinement fusion gain, possibly before the end of 1988.

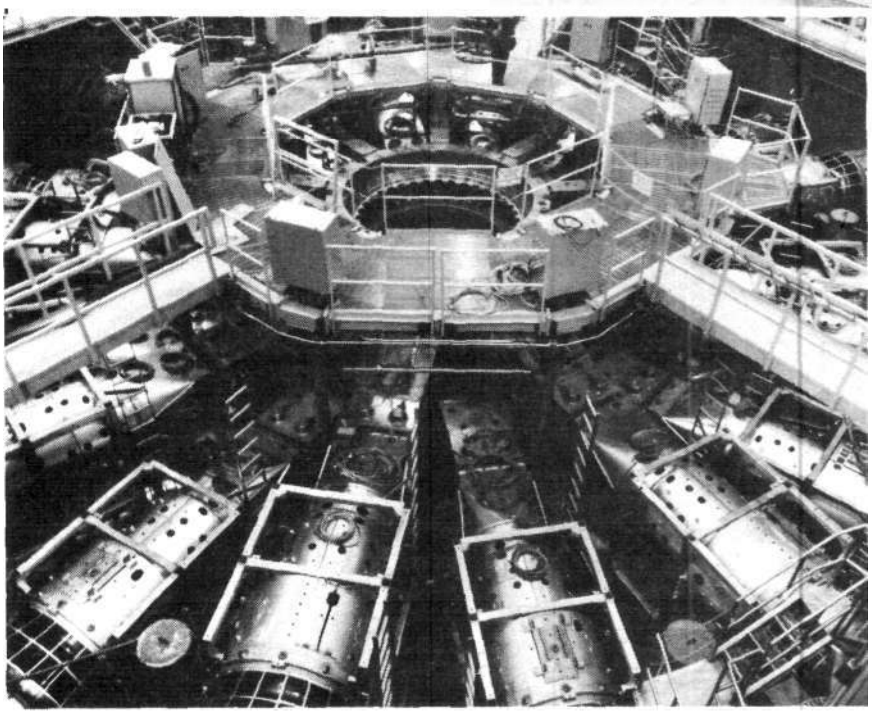
Despite the general curtailment of funding in the U.S. fusion research effort, commercial fusion reactors could still be attained by the 1990s. And while substantial technical problems remain to be resolved for commercial electrical power production, the amazing rate of progress demonstrated by light ion beam accelerator technology over the past decade makes such a development more than possible.

More generally, the successful test firing of PBFA-II on Dec. 11, seven weeks ahead of schedule and within budget, reflects a broad revolution in particle beam accelerator technology that promises shortly to produce a wide range of technological marvels beyond that of fusion energy. Already, the prototype device, PBFA-I, has been converted into an X-ray research facil-

Figure 1
WIDE-ANGLE VIEW OF
NEW GAS SWITCH
When incorporated into the PBFA-II, this experimentally demonstrated gas switch could double the beam power level to 200 trillion watts.

Figure 2
CROSS-SECTION VIEW OF PBFA-II
The outer section (right) of this 108-foot diameter "wheel" of the accelerator contains the capacitor banks and Marx generators for producing the electrical pulses for the 36 PBFA-II transmission modules. The 36 modules are stacked in four layers and immersed in water, which acts as an insulator. All converge on the central hub, which contains the applied-B diode within a vacuum chamber. Below is an overview of the transmission modules and the applied-B diode.





ity. X-ray laser experiments will also be carried out on PBFA-II.

The March to Fusion

The Sandia light ion beam program is among the youngest in the fusion field. Under the direction of Dr. Gerold Yonas, currently assistant director and chief scientist for the Pentagon's Strategic Defense Initiative Organization, Sandia scientists began exploring electron beam diode accelerator technologies as possible inertial confinement fusion drivers in the early 1970s. Previously, this technology had been developed for producing intense bursts of X-rays in order to simulate nuclear weapon effects.

Forfusion, the idea was eitherto use the electron beams directly or to use the powerful burst of X-rays they were capable of generating to compress and heat a small pellet of fusion fuel, much in the same manner as in laser pellet fusion.

To obtain significant inertial confinement pellet fusion, the driver, whether a laser, or a heavy or light ion beam accelerator, must deliver several million joules within a few tens of nanoseconds (1 nanosecond equals 1 billionth of a second) onto a fusion fuel pellet a couple of millimeters in diameter. In other words, the beam must have a power level of 100 trillion watts and a power density of several hundred watts per square centimeter.

Furthermore, the beam energy must be efficiently deposited within a thin layer of the outer skin of the pellet. In this way, most of the incident beam energy will go into driving an implosion of the fusion fuel, without heating the interior fuel, until maximum compression has been attained. This type of implosion is called isentropic compression and is essential for achieving relatively large fusion energy outputs compared to beam energy inputs—high gain inertial confinement.

Electron beam diode technology had both numerous advantages and disadvantages relative to other inertial confinement drivers. First, relativistic electron beam diode accelerators are based on the highly efficient and high energy technology of electrical pulsed power.

This means that relativistic electron beams are most capable of attaining the necessary multi-megajoule energy and 100-trillion-watt power levels needed for inertial confinement, and attaining these outputs at high system efficiency—upwards of 25 percent of the input electricity used to power the relativistic electron beam ending up in the beam, compared to less than a fraction of a percent for the case of high-power glass lasers. (High-power lasers, such as the Lawrence Livermore National Laboratory Nova, are only now approaching the 100,000-

joule energy level.)

On the other hand, it is extremely difficult to focus relativistic electron beams to high power densities. Furthermore, it is also difficult to deposit the relativistic electron beam's energy within the short distance required for isentropic compression.

In the mid-1970s, relativistic electron beam technology proved capable of also efficiently generating intense, high-current beams of light ions. (PBFA-II achieves 80 percent conversion from electron to ion beam; that is, 80 percent of the already high efficiency of the relativistic electron beam pulsed power technology is preserved.) And ions have even better pellet deposition properties than laser beams in terms of meeting the stringent conditions needed for isentropic compression; 100 percent of the incident light ions are deposited within a very thin layer of the pellet without preheating the interior fuel.

Last year PBFA-I achieved a series of major breakthroughs in terms of ion beam focusing, which totally transformed the prospects for PBFA-II. Originally designed as a facility that could at best approach fusion breakeven—production of as much fusion energy output as beam energy input—PBFA-II was planned to at least produce signficant fusion burn. The original specifications were that PBFA-II would produce multi-megajoule beams at a 100-trillion watt power level, focusable to power densities of 100 trillion watts per square centimeter.

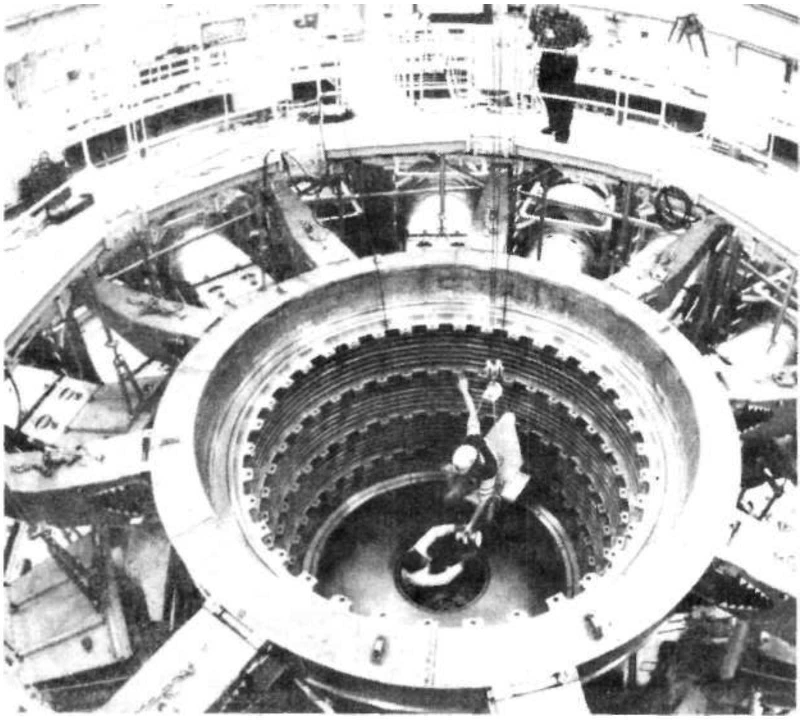


Figure 3
PBFA-II's CENTRAL HUB
The water insulator has been removed in the outer sections. The 200-trillion-watt electrical current pulse that will be directed into this central hub will contain more energy than all of the world's power plants combined, for 50 billionths of a second.

However, light ion beam focusing experiments in 1984 and 1985 on the Sandia PBFA-I and Proto-I experimentally demonstrated that much higher power densities were obtainable. PBFA-II is now projected as being capable of 3.5-million-joule energy pulses produced in 50-nanosecond bursts at a delivered power level of 100-trillion watts, but with potential power densities of 10,000-trillion watts per square centimeter. This 100-fold improvement over original projections is based on the scaling seen in beam focusing experiments on PBFA-I and Proto-I.

If this scaling is successfully demonstrated on PBFA-II, it will mean that the facility will be capable of going far beyond simple inertial confinement fusion breakeven. Conservatively, PBFA-II could shoot targets with fusion energy outputs 10 times greater than beam energy inputs. More significantly, PBFA-II could reach the high-gain inertial confinement, in the range of 20 to 100 times, needed for commercial inertial confinement fusion electric power plants.

The technical success of the Sandia light ion beam program can be judged by the fact that as little as two years ago it was thought that a facility for experimentally demonstrating high-gain inertial confinement fusion would cost on the order of $1 billion. The PBFA-II, which clearly has the potential for attaining high-gain inertial confinement fusion, has cost only $48 million—20 times less than projected.

'Fast-Tracking'

Recently, further improvements have been achieved in the PBFA-II design. "PBFA-II is a state of the art accelerator with 1985 technology, even though we've been building it for the past three years," pointed out Dr. VanDevender, who has replaced Dr. Ceroid Yonas as director of Pulsed Power Sciences. "We achieved that by fast-tracking the design at the same time we *were* constructing the accelerator. The successful first shot demonstrated that the risky fast-track process works beautifully."

VanDevender explained that "fast-tracking" means that accelerator design research continues during the construction process, making it possible *to* modify uninstalled portions of the machine without impeding the construction process.

One example of these improvements is shown in the wide-angle photograph (Figure 1) of the newly developed gas switch. This fast-opening power switch, which has just been experimentally demonstrated, may make itpossibletodoublethe PBFA-II power level to 200 trillion watts.

PBFA-II

The $48 million PBFA-II consists of 36 pulsed power modules that are arranged around a central experimental hub and deliver electric power pulses to it from all directions. These modules are arranged in four layers. Each level is arrayed like the spokes of a 108-foot-diameter wheel (Figure 2). Each module consists of a series of capacitors, switches, and transmission lines submerged in oil and water in separate sections of a 20 foot-tall tank.

During a test firing, the capacitors are charged up by Marx generators, which receive their power from ordinary electric power lines. The switches release the electrical energy of the capacitor banks in a short burst, which then travels down the water-and-oil-insulated transmission lines. The transmission lines shape and compress this initial electrical current pulse and deliver it to the central hub, toward which all of the modules converge.

The central hub consists of a vacuum chamber containing the applied-B diode (Figure 3). When the electrical pulses arrive simultaneously at the applied-B diode, intense lithium ion beams are generated and converge at the very center of the hub. It is here that the fusion fuel pellet will be placed.

1,000 Times Solid Density

These converging lithium ion beams will be utilized to compress a pellet of hydrogen fusion fuel to 1,000 times solid density—densities greater than those found in the core of the Sun—and temperatures greater than 100 million degrees Celsius. Under these conditions, the hydrogen nuclei fuse to form helium and fusion energy before the pellet disassembles. The resulting burst of fusion energy could then either be directly used to generate fuel for nuclear fission reactors or to heat liquid lithium that would then be used to produce electricity.

(The most recent Livermore reactor designs envision utilizing the liquid lithium in a magnetohydrodynamic channel to directly generate electricity at the highest efficiencies. Recent Livermore studies project that inertial confinement fusion could generate electricity in this way at less than half the cost of existing nuclear fission and coal electric power plants.)

Over the coming year, extensive pulsed power testing will be conducted on PBFA II. The first year of operation will be devoted to optimizing the accelerator. In the second year, experiments will concentrate on ion beam formation and focusing.

In spring 1985, PBFA-I delivered an 8-trillion-watt pulse of hydrogen ions onto a spot 4.0 to 4.5 millimeters in diameter. This represented a power density of 50-trillion watts per square centimeter and a 33-fold improvement in focusing over the 0.5 trillion Proto-I experiments in 1984.

This series of experiments demonstrated beam focus scaling increased beam current from 0.4 million amperes on Proto-I to 4.0 million amperes on PBFA-I. PBFA-II will demonstrate beam focusing with increased beam voltage. PBFA-II will have 30-million-volt lithium ions, compared to 2-million volt hydrogen ions on PBFA-I.

Many of these beam focusing experiments attempt to demonstrate alternative applications of the PBFA-II and new beam-focusing geometries, including ion-beam-driven X-ray lasers. Recent developments with particle beam weapons could also be included in the PBFA-II.

For example, following up research originally carried out at Sandia, Livermore scientists have recently shown that intense particle beams can be focused and transported over long distances through specially prepared plasma channels. A low-energy excimer laser pulse was utilized in these experiments to successfully produce such a plasma channel.

Beam transport through laser-produced plasma channels could provide the solution to one of the only major technical problems remaining for the light ion beam accelerator before commercialization of inertial confinement fusion power plants—accelerator stand-off. Currently, the beam generating diode is placed in close proximity to the fusion pellet. As a result the pellet implosion-explosion damages the diode and it must be replaced after each shot. By utilizing plasma channels for beam transport, the pellet could be located so that no diode damage would result—accelerator stand-off.

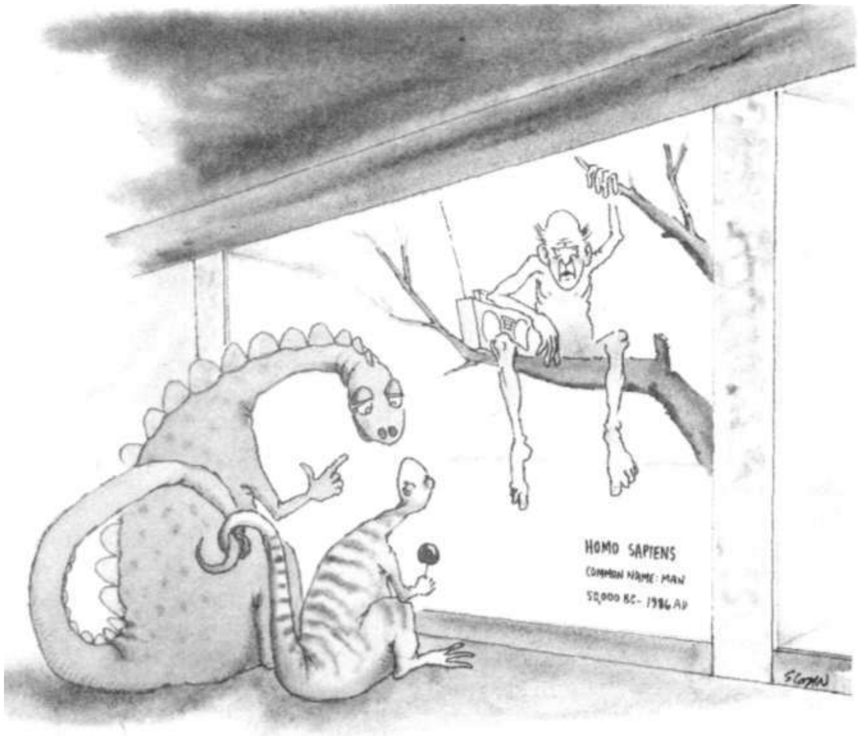
Given the current projections for PBFA-II's extraordinarily high beam power density, proposals to experimentally demonstrate beam stand-off are currently being considered by Sandia researchers.

Fusion Experiments

By 1988, PBFA-II will begin experiments with actual fusion fuel pellets, including both direct and indirect drive pellet target designs. If PBFA-II attains the power densities currently indicated by existing experiments, it will produce significant, and possibly high-gain, inertial confinement fusion. Throughout the 1970s, electrical pulsed power made tremendous strides forward, outpacing all other high-energy technologies, as PBFA-II demonstrates, and doing it on the proverbial shoestring funding. Now electrical pulsed power has become a major focus of President Reagan's Strategic Defense Initiative, and the Sandia pulsed power fusion program is just beginning to benefit from this several-orders-of-magnitude increase in research funding for pulsed power research. The prospects for light ion beam fusion, therefore, are quite bright.

Washington Report

HALL OF EXTINCTION



"Scientists thought that it was a comet that did it. ***Now*** *they know it was Gramm-Rudman."*

Will There Be Life After Gramm-Rudman?

For more than a year, both Congress and the Reagan administration have obsessively pursued "balancing" the federal budget. Across-the-board cuts have already devastated many science and technology programs—which are the engine for new technology and, therefore, any real growth of the U.S. economy.

Even as dramatic cuts have been made in the advanced nuclear and fusion energy programs, the Strategic Defense Initiative, and the civilian space program, the Gramm-Rudman balanced budget amendment, signed into law by the President, gives the Office of Management and Budget (OMB) the power to eliminate any program it deems necessary to balance the budget.

Serious trouble for science and technology programs started last year. The budget submitted by the President for fiscal year 1986, which is in force now, was inadequate, and was further cut by Congress. The fiscal year 1987 budget proposal, which the White House will present to Congress early in 1986, will be a disaster.

NASA Losing Momentum

When James Beggs came in to head the space agency in 1981, President Reagan agreed that NASA would have new program starts and a budget that would grow 1 percent above inflation each year. Later he instructed the agency to build a manned space station.

In the current fiscal year 1986 budget, $230 million has been authorized for the space station—$50 million less than NASA requested. According to Beggs, this will defer the station's initial operation from 1992, to 1993 or 1994.

This year, the agency had to renege on its commitment to the scientific community and eliminate new program starts in space science. In 1983, the Solar System Exploration Committee laid out a long-term plan for space science, which NASA accepted but which was cast aside because of "budgetary considerations" this year.

The original administration NASA request of $7,886 billion, keeping to the 1 percent real increase, has been shaved by at least $200 million by Congress. Any further back-tracking, which will be unavoidable under Gramm-Rudman, will put the space program back where it was under the Carter administration—standing still. As far back as December 1984, the Office of Management and Budget had been lobbying to cut space station funding by $1.2 billion for the fiscal year 1986-1988 period. If the timetable for operation is stretched out any further, not only will the station end up costing more, but it is questionable whether the agreements Beggs negotiated with Western Europe, Japan, and Canada to participate, will stay intact.

In October 1985, Beggs confirmed that NASA had killed plans for a rendezvous with the Wild 2 comet in 1992, citing budgetary constraints. The United States is the only space-faring nation which will not have a spacecraft to observe or intercept Halley's comet this year, though telescopes aboard Space Shuttle flights during the encounter period will observe the comet.

Just at the moment that NASA will have to fight for its life, administrator Beggs has taken a leave of absence to fight a grand jury indictment. It is doubtful that without his personal leadership NASA will have a chance against the OMB.

Fusion Program Stalemated

The picture for both the magnetic and inertial fusion programs is no more promising. Both the administration and Congress have had no remorse in killing this nation's hope for a secure, unlimited, energy future with thermonuclear fusion.

Fiscal year 1982 was the peak funding year for both parts of the fusion program. Since then, funds have declined, even without considering inflation. Plans that were made to bring next-generation large devices—such as Princeton's Tokamak Fusion Test Reactor (TFTR), the Lawrence Livermore Magnetic Fusion Mirror Facility-B, and others—on line in the mid-1980s, have gotten dimmer and dimmer.

The fiscal year 1986 Department of Energy budget for magnetic confinement fusion was given an appropriation by Congress of $382 million. This is $8 million less than requested by the administration, but, more important, a whopping *$55 million* cut from last year's budget.

The TFTR, the nation's largest tokamak, was supposed to have reached energy breakeven by now, but this milestone has now been deferred until the end of the decade. The TFTR was also to have been the first fusion device to use tritium along with deuterium for fusion fuel, as the precursor to an experimental power reactor. According to scientists at the Princeton Plasma Physics Laboratory, it is not clear whether the TFTR will ever burn tritium fuel.

The reason is that once the high-neutron-producing experiment with tritium has created radioactivity, this will prevent engineers and scientists from being able to go inside the reactor. Originally, it was presumed that a next-step engineering power reactor would come on line soon after the TFTR to provide the continued engineering test bed. But if the TFTR is going to be the last large fusion experiment for a long time, scientists want to have the flexibility to maneuver inside the reactor.

The inertial fusion program is not faring much better than magnetic confinement. The administration went after the laser, particle beam, and other inertial fusion program budgets with the budget axe last year, proposing a funding cut from $169 million to $70 million. Congress pushed the budget back up to $155 million, but in 1982 the inertial fusion budget was $209 million.

Although the question has been posed at numerous press briefings, no one in the administration has explained how the cuts in laser fusion programs could be justified given the beam weapon defense program.

Nevertheless, even these depression-level fusion program funding levels may look like prosperity when the OMB decides how it is going to cut an additional $50 billion out of next year's federal budget, in line with the guidelines of the Cramm-Rudman law.

—*Marsha Freeman*

AN SDI STATUS REPORT

Spectacular Progress, But Starved for Funds

by Carol White

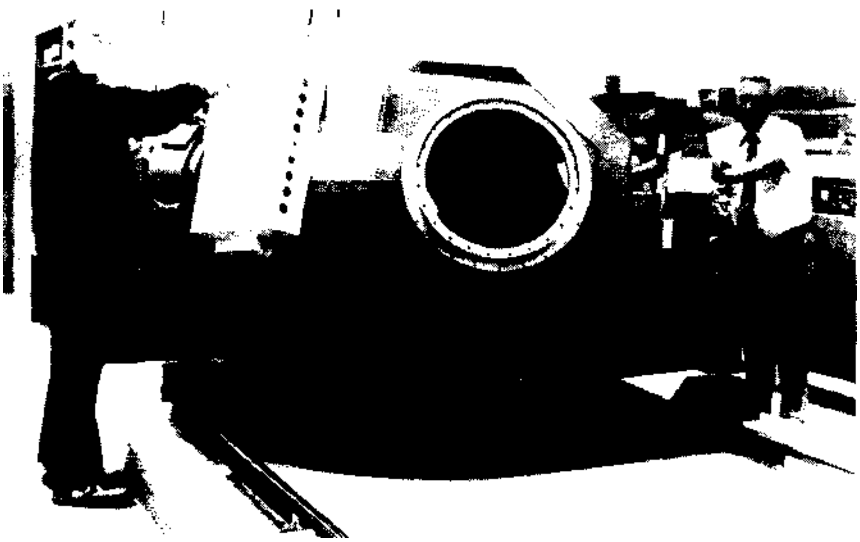
The accomplishments of the Strategic Defense Initiative over the past year have been spectacular. The program has proven more successful in its demonstrated potential than even its most sanguine supporters could have hoped—especially considering the miserable budgetary constraints to which it has been subject.

Yet, just at the point that the program is ready for takeoff, it is being starved for funds. By failing to fund the program adequately, and by restraining the program within a restrictive interpretation of the ABM treaty, the United States has handicapped its capability to have a deployable ABM capability in the immediate future, while the Soviets are rapidly moving ahead to do just that.

Nick Benton

"Are we ahead of the Soviets? I don't thinkso. " Lt.-Gen. James Abrahamson at a Washington briefing Nov. 26 *on recent developments in SDI technology.*

With passage of the Gramm-Rudman ammendment, the KGB supporters in the U.S. Congress are moving to gut the SDI budget still further; in fiscal year 1986 it was cut $1 billion below the already modest Defense Department request for $3.7 billion. This scenario of using budget-cutting as the weapon to destroy U.S. defense capabilities was, in fact, spelled out by Ceorgii Arbatov, head of the Soviets' U.S.-Canada Institute, at the time of the Reagan-Corbachov summit in November.The budget process for fiscal year 1987 looks to be even more disastrous, as Congress betrays its Constitutional mandate to ensure the nation's defense. Under the guise of abdicating its legislative function to a computer system, will it in fact be permitted to give away the SDI ?



Department of Defense

The Airborne Optical Adjunct, now under development, would identify and track warhead targets and guide ground-based interceptors to a target. A mock up oftheAOA sensor is shown here.

SDI Accomplishments in 1985

At the close of last year, Lt.-Gen. James Abrahamson, director of the SDI office, and the program's scientific advisor, Dr. Gerold Yonas, gave newsmen a roundup briefing that highlighted the extraordinary accomplishments of the program *over* the year. The kind of results they reported bore out in detail the Fusion Energy Foundation's optimism with regard to the potentialities the SDI would have—if the SDI were given the mandate to go with a crash program.

Abrahamson emphasized that the Lawrence Livermore National Laboratory's free-electron laser amplifier has made great progress over the year. Results were so good that the SDI Office, under the exigency of making forced choices, has decided to emphasize the ground-based, free-electron laser. Abrahamson defended this premature narrowing of the focus of the program as the only competent response to an inadequate budget.

He described the situation faced by SDI planners: "We didn't get the money we needed either in fiscal year '85 *or* in fiscal year '86. And we had a choice. One choice is to try to take this broad range of technology and just slow it all down evenly. I don't think that's very good management. . . j There are many different kinds of lasers which are coming ahead—excimer lasers, different chemical lasers, and the free-electron laser—and there's all kinds of ideas. We couldn't follow all those ideas. So . . . we picked as a primary one the ground-based, free-electron laser."

The intention of the SDI Office is to use these ground-based lasers for boost-phase defense. To quote Abrahamson: "For example, a ground-based laser, and you see one located there up in Alaska in this case [slides were shown in the briefing]—it might or might not be located in Alaska—going up and bouncing off a mirror in space and going forward to what we call a fighting mirror and then going down to destroy a missile in the boost phase."

Abrahamson emphasized that despite the insidious attempt now being made to redefine the SDI as merely a terminal defense program, these lasers are planned for use in boost-phase target kill. He also stressed that work is ongoing on defense against short-range missiles, which is of decisive importance in the European theater.

No U.S. Lasers in Space

The key to the present SDI R&D program is the fact that there is no provision now being made to house lasers in space. Not only does this bind the United States to the confines of the ABM treaty, which the Soviets are freely violating, but it means that those laser systems, such as chemical lasers, which mightbe readilydep/oyedinthe near future in a first-generation SDI system, are being scrapped in favor of more long-term *research* goals.

The Space Surveillance and Tracking System, scheduled to go into prototype development in January 1987 is frozen, ostensibly in order to improve the program. This system is designed to give the United States a space-based detection and tracking capability, and now the plan is simply to test its various components over the next several years.

One of the new concepts being explored is the use of a diffuse neutral particle beam to discriminate between decoys and live missiles. One particularly viable approach is to discriminate the induced gamma-ray emmissions from a missile bearing an actual warhead. These would primarily come from heavy atomic elements like uranium and plutonium, which become excited when they are hit by the high-energy protons created when the neutral beam impacts the warhead.

A great deal of ongoing work is devoted to reading the infrared signature of missiles in the boost phase. These become dispersed above the atmosphere; furthermore, the problem is to measure thousands of these booster tracks, with high resolution; and to analyze not only when they are launched and where they are launched from, but where they are going, and to do it in real time.

Another area in which Abrahamson reported significant progress was the electromagnetic rail gun program, where exceedingly small antiwarhead projectiles are accelerated using the Homing Overlay Experiment missile from the antisatellite (ASAT) weapons program. Abrahamson pointed to the Air Force's progress in reducing the size of a lethal projectile from the 2,500-pound Homing Overlay Experiment missile tested in June 1984, to less than 50 pounds in the current ASAT program. It is necessary to reduce them

SDI Productivity Spinoffs

The costs of a developing system like the SDI will be more than met by the kind of productivity spillovers into the economy that were a leading feature of the Apollo Moon-landing program. This is now being borne out by the SDI.

• One area in which major technological development has occurred has come from the need for the mass production of perhaps millions of infrared elements hardened to radiation, which will be part of a high-resolution detector system.

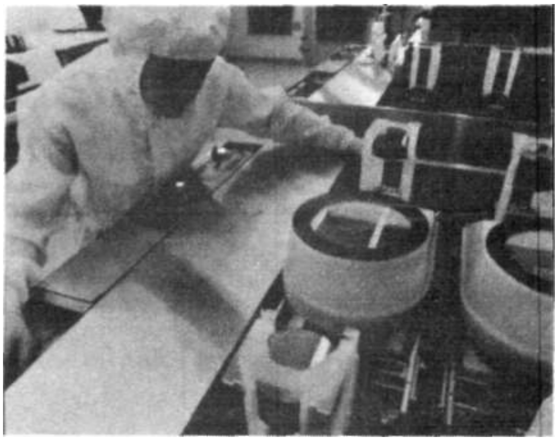
• On the materials side, a lightweight yet efficient steering method for a rocket engine has been developed, by producing a flexible rocket nozzle made of a woven carbon material.

• A miniature fiber-optic gyro that operates by circulating laser light is still in the invention stage.

• A new material has been developed that will allow a 100- to 200-fold increase in capacitor storage of electricity. This will have major implications for the ability to deploy pulsed-power in fusion energy devices, and is an advance in a technology that had been stagnant for the past 30 years. The SDI program is also looking at a flywheel device that would increase capacitance by three orders of magnitude.

• Another area under development is miniaturized cryogenic refrigerators.

• Because silicon chips are vulnerable to radiation in space, the SDI is substituting gallium arsenide and has two automated pilot production lines to reduce the currently high cost of production.



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This automated pilot production line is producing the first-generation of radiation-resistant solid-state computer chips made of gallium arsenide.

still further, he said, to less than 10 pounds. Eight rail-gun installations are now operating in the United States.

Abrahamson described the work being done by a U.S. "red team," which is simulating possible Soviet countermeasures to the SDI. From other sources, the FEF learned that this team has decisively put to rest the Union of Concerned Scientists' bugbear that the Soviets would be able to deploy a fast-burn booster that would be impervious to attack because of its speed. It has been shown that such a booster, if it could be built, would merely make the detection of bus-phase decoys that much simpler, since the decoys would be released in the atmosphere, rather than above it.

The X-Ray Laser Success Story

One of the great successes of 1985, not mentioned in Abrahamson's briefing, has been the X-ray laser. The continual press barrage against the X-ray laser by reporters of the ilk of *New York Times* columnist Flora Lewis is in itself convincing proof that Lawrence Livermore is doing something right. In fact, the lab has achieved lasing intensities orders of magnitude brighter than any anticipated. Indeed, these intensities have been so great that the laboratory has been unable to accurately measure them as yet. This is the basis for the KCB-cacaphony to demand that the tests be stopped!

The recent successes of the U.S. X-ray laser program were spelled out by Dr. Edward Teller at the Las Vegas Laser '85 conference. Teller also warned that, in his opinion, the Soviets might well still be in advance of the United States. As he put it, the Soviets have been working on beam weapons for the past 15 years, and the inspiration for American work *on* the X-ray laser came directly from the work the Soviets had done first.

The currently adequate funding level for the U.S. X-ray laser program is being justified by the evidence that the Soviets will be deploying their own version of the X-ray laser, perhaps in the not too distant future. Those involved in the X-ray laser program are convinced that there are no elements of the U.S. program that demand capabilities the Soviets are not known to possess.

On the same point, Abrahamson was asked whether or not the United States is in advance of the Soviets in ABM beam defense. His answer is worth quoting in detail:

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This advanced flexible rocket nozzle made of woven carbon can contain the rocket thrust and efficiently steer the rocket.

"Are we ahead of the Soviets? I don't think so. I think it goes something like this. The Soviets are going to build their system their way, if they're developing such a system based on their own techniques, and their own methods, and they have an operating system today that they have been operating for a decade and a half."

Abrahamson went on to develop his idea that the Soviets not only have a terminal defense concealed in warehouses, which he refers to as the "long pole," but other capabilities as well. He said: "And it's not the same kind of a system that we have, but the potential for that and in particular the fact that they have placed the long pole in the tent for that kind of a system and maybe for our kind of system as well, the command and control system—they've placed that out there and it's in place and it will soon be operational—means that I think they are ahead of us quite substantially."

At the same briefing, SDI scientific advisor Ceroid Yonas pointed to the following areas where considerable progress has been made in the United States: automatic atmospheric compensation, free-electron lasers, laser lethality, and midcourse discrimination technologies. Tests over the year in Hawaii have demonstrated ability to focus low-power lasers accurately through the atmosphere, by automatically compensating for distortions caused by turbulence in the atmosphere.

A Record of Successful Tests

Chemical laser tests at White Sands have demonstrated that lasers are far more effective in killing boost-phase missiles than predicted by computer models. Yonas reported that tests showed that these missiles virtually self-destructed when hit with lasers. The power necessary for the laser kill was far lower than had been expected. He attributed this to the fact that the missile shells are "very highly stressed, very thin eggshell under aerothermal loads."

It is precisely results such as these that emphasize the need for continued tests, rather than reliance upon computer simulations, which depend upon built-in, fixed assumptions. Only in this way can one learn about all of the potential nonlinear shock effects that can be expected to occur, according to the kind of theoretical considerations treated by Bernhard Riemann, and successfully applied to fusion plasmas and aerodynamics.

Political Restraints

Despite the fact that Abrahamson himself pointed to the necessity of experiments in order to guarantee the vitality of the program, political restraints have been placed upon it, so as not to offend the Soviets. In the next six months, he reported, a simulator will be built at the Martin Marietta Corporation for the purpose of "testing" pointing and tracking capabilities.

When asked about the restrictive interpretation of the ABM treaty, he replied: "At this point in time we are conducting a program within the President's policy; that was our planning and that was to do it in a strict way." The questioner had asked how much of the ABM system could be adequately tested by simulation. Abrahamson

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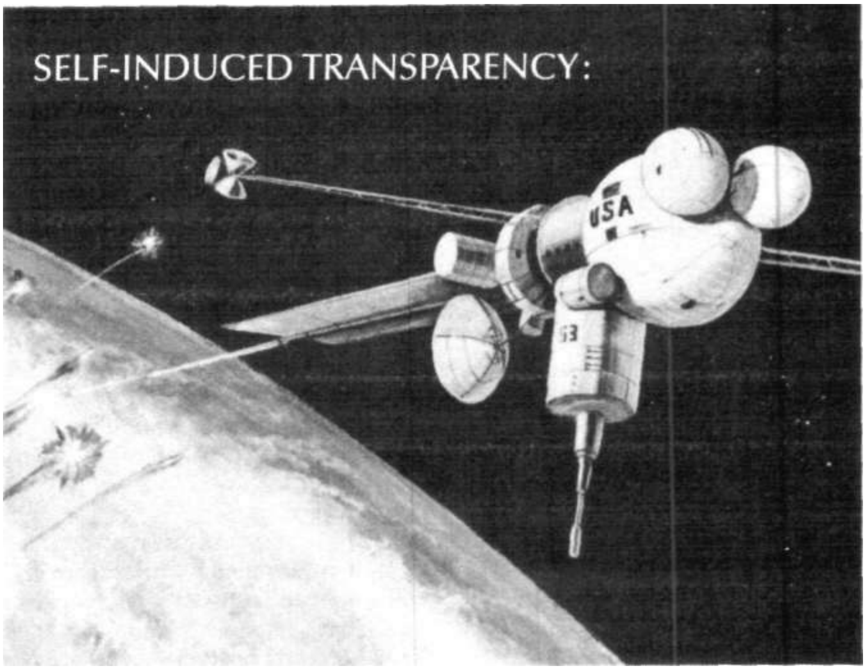


Courtesy of LTV

Artist's illustration of a space-based electromagnetic railgun intercepting and destroying nuclear-armed missiles. The hypervelocity launch technology necessary was developed in the laboratory by LTV Aerospace and Defense Company.

Key to the Success of the Tactical Defense Initiative

by Robert Gallagher

Europe and Asia require thousands of laser weapons for defense against the Warsaw Pact and its allies. These directed-energy defenses must be able to destroy or disarm nuclear-armed short-range and medium-range ballistic and cruise missiles and artillery shells armed with nuclear warheads. They must be able to shoot down Warsaw Pact aircraft of all types, from supersonic Backfire bombers to helicopter assault vehicles. The bulk of these hostile objects will travel only in the atmosphere.

Therefore, a principal task of the Tactical Defense Initiative (TDI), the name for the Strategic Defense Initiative for Europe and Asia, is to solve the remaining, strictly engineering problems of delivering kill-intensity laser energies on target, through the densest layers of the atmosphere, near the surface of the Earth where atmospheric turbulence is the greatest.[1]

The key to the solution of these engineering problems is application of the concept of "self-induced transparency," originated by Leonardo da Vinci. For high-energy laser weapons, this requires a design that takes advantage of properties of the atmosphere consistent with the transport of beams of laser light to their targets, focused, and without loss of power density. In other words, the beam must work upon the atmosphere, *not against* its own propagation, but for it.

The "optics community" sees the atmosphere only as a *barrier* to light propagation (a somewhat peculiar view given the effective action of light throughout the biosphere). Based on data generated by computer simulations of the atmosphere (known as weather modeling), the opticians rule out the possibility of a practical military solution to laser transmission through the atmosphere. These theories are the basis for the arguments of anti-SDI scientist Kosta Tsipis from the Massachusetts Institute of Technology, who is active in the Pugwash group of arms control appeasers.

Although the Strategic Defense Initiative is influenced by the optics community, the irrepressible optimism of SDI director Lt.-Cen. James Abrahamson tends to obliterate such tendencies. Nonetheless, to gain required funding, General Abrahamson, Defense Secretary Caspar Weinberger, and West German Chancellor Helmut Kohl must contend with a political opposition wielding the arguments of Tsipis and the opticians against the feasibility of the SDI and the European Defense Initiative. Here we present the scientific basis to defeat this opposition.

According to the optics community, the intensity and coherence of high-power laser beams propagating through the atmosphere is destroyed by the following phenomena:

(1) Absorption and scattering of light by the molecular constituents of the atmosphere.

(2) Thermal blooming: heating of the atmospheric path, as a result of absorption, that spreads the beam out from its origin. According to the doctrines of the optics community[2] accepted even by some contractors to the SDI,[3] thermal blooming establishes a maximum beam power that may "be transmitted through the atmosphere."

(3) Atmospheric turbulence, as observed in the "twinkling," or scintillation of starlight.

There is, in fact, an engineering problem to solve, but it is by no means as devastating as Tsipis would have it. The case of atmospheric turbulence is illustrative of this.

At the surface of the Earth, the atmosphere encounters a discontinuous boundary, characterized by irregular surface features. The smoother aerodynamic flow of upper regions of the atmosphere breaks up into vortices, upon encountering this surface. This tu rbulence is characterized by optics theory to produce spatial and temporal variations in the density of the atmosphere and, consequently, in the index of refraction, and thus the speed of any light traveling through it. As a result, according to contemporary models, portions of a beam emitted from different locations on a source, propagate at different varying speeds, with the result that the coherence and intensity of the beam is destroyed by the turbulence.

Add to this the tremendous additional turbulence that will exist over any battlefield area as a result of explosions, and variations in weather conditions, and the result is a problem that appears to require a considerable engineering deployment to solve.

Atmosphere As **Hydrodynamic** Lens

Existing optical theories, founded on statistical mechanics, rule out the possibility of a solution.[5] These models are based on physical principles inconsistent with nature, and are consequently incompetent. Equally irrelevant are any conclusions regarding the feasibility of endoatmospheric laser weapon development based on these models, such as those expressed by Tsipis in a December 1981 *Scientific American* article.[6]

It should come as no surprise that recent *experimental* results have refuted these models and have demonstrated that a solution to these engineering difficulties is feasible, at least for ranges of military interest in Western Europe and Asia.[78] However, the American optics community has yet to take notice of the significance of these results.

The properties of beam-atmospheric interaction listed by statistical optics—absorption, scattering, turbulence, and thermal blooming—over the range to a target, can be compared to a highly differentiated electromagnetic lens that changes its characteristics of action with time. At the physical dimensions of light rays and of the molecular constituents of the atmosphere, the interaction is not percussive and irreversible, as suggested by Tsipis, but electrohydrodynamic.

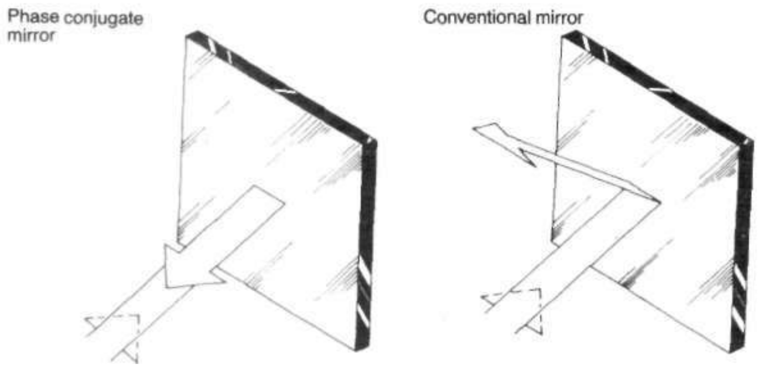


Figure 1

CONVENTIONAL VERSUS PHASE CONJUGATE MIRROR

When a conventional mirror (right) reflects a beam, the angle of reflection is the complement of the angle of incidence; a diverging beam continues to diverge after reflection. When a phase-conjugate mirror (left) reflects a beam, it sends it back in the same direction it came from, and makes a divergent beam convergent, or focused.

Turbulence, for example, changes the local electrohydrodynamic properties of the atmosphere, and it is such transformations that change the characteristics of light propagation through it.

To achieve self-induced transparency requires: (1) selection of wavelengths of laser radiation that do Dot perform work upon the molecular constituents of the atmosphere ("absorption"}; and (2) compensation for atmospheric turbulence.

Even the statistical opticians acknowledge that absorption effects are of little consequence for certain ranges of wavelengths of laser radiation. Today, the optimal laser wavelengths for both atmospheric transmission and destructive impact on target, are ultraviolet. The SDI Office agrees, and contrary to the statistical opticians' algebraic conclusion that longer wavelength infrared lasers are optimal, it has been proceeding with development of a ground-based, ultraviolet laser.

Perfect Beam Propagation Is Natural

There is a phenomenon *in nature,* known as nonlinear optical phase conjugation, that demonstrates, in principle, that beams of laser light can be preformed and directed through the lens of the atmosphere to arrive on target with near-perfect coherence and intensity. R.C. Lind and C.J. Dunning of Hughes Research Laboratories directed a coherent dye laser beam through experimentally produced, intense atmospheric turbulence into a preparation of atomic sodium pumped by counterpropagating beams of the same wavelength.[7]

"The laser was tuned near the atomic resonance of the sodium D_2 line (589.0 nanometers) to maximize the four wave mixing conjugate reflectivity," reported *Laser Focus* magazine. Upon arrival at the atomic sodium conjugator, the beam displayed severe aberrations and phase distortion from its original coherent profile, as a result of the instantaneous refractive properties of the lens of the atmosphere. The conjugator then returned the phase conjugate of the beam back through the precise path along which it had propagated from the transmitter. Along this return path, the aberrated beam reformed into an almost perfectly coherent beam. The time to conjugate the beam (10 ns) and cover the path twice was far less than the time in which the refractive properties of the atmosphere changed.

Laser Focus reported: "These data indicate near-diffraction-limited correction capability. In addition, while the aberrated beam shows severe wander and on-axis intensity nulls, the corrected beam stays locked to a particular spatial position." According to one source,[9] Hughes holds that the technique will work for beam propagation distances up to at least 50 kilometers in the atmosphere.

Optical phase conjugation is a property of a spectrum of "nonlinear" materials, from tap water to chlorophyll. One form employs Brillouin scattering, directing a beam of chosen wavelength into a liquid resonant with that wavelength, which action establishes an acoustic wave in the liquid that backscatters the conjugate of the incident beam, downshifted in frequency by the frequency of the acoustic wave so established.

The Task of Adaptive Optics

In 1984, ihe Fusion Energy Foundation proposed one use of optical phase conjugation, for a space laser system.[10] In the proposed system, a low-power laser attached to a mirror in orbit directs its beam down through the atmosphere to a station where the aberrated beam is conjugated and amplified to high power. (Figure 1 shows a schematic view of how a phase conjugated mirror works.)

The amplified beam then returns to the space mirror coherent, available for attacking ballistic missiles or high-altitude aircraft, but without the need for a high-power laser amplifier in orbit. This proposal is reportedly now under active development by the SDI.

Since optical phase conjugation requires two passes through the same atmospheric path, it is not clear how it can play the role of a "component" in a system that must directly attack targets in a single pass through the lower, densest portions of the atmosphere.[11]

The task of "adaptive optics" is thus to recreate the capabilities of the natural process of optical phase conjugation in engineering hardware that transmits a beam with a single pass through the atmosphere.

In 1984, Sandia National Laboratories demonstrated such a concept in regard to particle beams. A Sandia team led by David). Johnson ignored the prescriptions of contemporary electrodynamic theory and developed a specially shaped anode to emit an ion beam that was organized to permit a continuous flow of electrons in its path, to focus the beam on target, rather than introduce astigmatism.[12]

The requirements for a laser system for defense of Europe are more stringent. Here, the system must actively correct not just for a static, nonlinear lens action by the intervening atmosphere, but for one that changes in time, during the attack on a target, or spatially, over the course of a target's trajectory.

Thus, a principal problem of adaptive optics is to develop practical means of *sensing* the distortions, or action of the atmospheric "lens" upon an outgoing beam, so that the beam may be shaped in such a way that the action of the atmosphere, as in the case of optical phase conjugation, is to *focus* it on the target. In other words, an adaptive optics system requires some reference for the action of the atmosphere upon a beam, in order to maximize transparency, and this has to be one that holds up under battlefield conditions.

The Fallacies of Optical Theory

In arguing against the feasibility of adaptive optics systems, statistical optics dogma rests much of its argument upon an algebraic construct formulated by David L Fried in 1965, known as the "atmospheric coherence length" of light propagation.[2,5,8]

Fried holds positions of note within the optics community, and his concept influences much of the work on laser propagation in the atmosphere. Since 1968, he has been a member of the U.S. Army Science Board, and, at the same time, associate editor of the *journal of the Optical Society of America.* Thus, an objective assessment of his work is required.

"Atmospheric coherence length" is the distance r_0 perpendicular to the beam path, across which the beam is in phase ("phase correlated"; see Figure 2). Fried defined r_0 as

$$(1.09 k^2 z C_n^2 / n_0^2)^{-3/5}$$

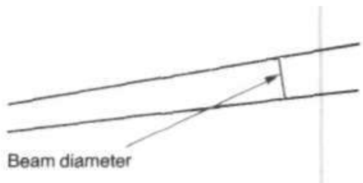


Figure 2
ATMOSPHERE COHERENCE LENGTH
The coherence length of a laser beam in a vacuum is the beam diameter.

where k is the optical wave number, z is the range to target, C_n is the "refractive index structure constant," a measure of the degree of turbulence, and n_0 is the index of refraction of the nonturbulent atmosphere."

This formulation states that a beam *must* become increasingly incoherent with distance, or with shorter wavelengths, or with increasing turbulence. It was on the basis of this algebraic construct that the Carter administration emphasized development of the deuterium-fluoride chemical infrared laser. Indeed, in 1981, a spokesman for Itek, Inc., now an SDI contractor, told *Aviation Week,* "a key parameter in assessing the effect of atmospheric turbulence is 'atmospheric phase coherence length.'"[3] The case of optical phase conjugation demonstrates that this conception is worthless.

First of all, it matters little whether the beam appears to be coherent at any point along its path of propagation. What matters is whether the beam is organized in its propagation to *arrive* coherent at the target. The work at Hughes Laboratories shows that, practically speaking, we can make the coherence length as long as we wish, as large as the size of the "collecting optics" of the phase conjugator; in other words, potentially infinite!" Lind and Dunning carried out their experiments with turbulence at the highest end of the spectrum of intensities of turbulence in the atmosphere.

Second, Luc R. Bissonnette of the Canadian Defense Research Establishment has shown that the Fried construct underestimates even the *apparent* atmospheric coherence length by a factor of at least 55.

The notion of coherence length is not the only regressive concept dominating optics in the United States and Europe. In addition, the statisticians hold that "an adaptive optics system can compensate only for phase errors that occur at some fraction of the focal plane distance,"[5] that is, relatively close to the laser transmitter. In other words, it is harder to correct for turbulence that is farther away from the controlling optics. The Hughes experiments also refute this claim: In defiance of theory, optical phase conjugation compensated for intense turbulence that occurred along the entire path of the beam.

In addition, statistical optics holds that, practically speaking, it is impossible to image real, military targets through atmospheric turbulence. It asserts that imaging targets wider than half the atmospheric coherence length is impossible. According to this theory, light from a point source wanders "randomly" by refraction through the atmosphere,[15] and under turbulence the amplitude of this wander is at least greater than % r_0 (Figure 3).

As Pearson et al. wrote: "Fried has shown that when two source elements are separated by more than one-half the atmospheric coherence length, they fall outside the isoplanatic patch; that is, they produce phase distortions at the receiver aperture that are essentially uncorrelated at any one instant. A consequence of this fact, is that if one attempts operations with information extracted from both points simultaneously, one obtains a composite phase measure that is incorrect for compensating the path to either of these points or to any other point for that matter. . . .

"At all wavelengths, the isoplanatic patch diameter, which we define as r„/2, will almost never be as large as 1 meter (with 4 km paths). . . referencing [imaging] *on* truly extended targets (greater than 1 meter) is not allowed by isoplanatic problems."

As an example, for normal (that is, nonbattlefield) atmospheric conditions near the ground, over a range of 4 km, this source estimates that ultraviolet laser light will wander within a cross-sectional area seven times the area of the isoplanatic patch of coherency of the beam. In other words, the beam will never be coherent.

Empirical refutation of these concepts for an adaptive optics system was demonstrated at about the same time as the work at Hughes, by Luc R. Bissonnette of the Canadian Defense Research Establishment. His experiments show that Fried's theory underestimates the size of the isoplanatic patch, the cross-sectional area of coherency of laser light propagating through the atmosphere, by approximately a factor of 2,000, and that the atmospheric coherence length itself is at least over an order of magnitude greater than predicted by Fried's theory.

Fried's definition of coherence length is an artificial construct that may hold in certain laboratory setups, but does not hold for nature. Light propagation through the atmosphere is always nonlinear.

In the course of his work, Bissonnette demonstrated the value, as a military system, of one proposed design for an adaptive optics system, known as the multidither outgoing wave (MDOW) system. Bissonnette's controversial work is very relevant to the development of laser weapons for the defense of Europe.

A System **That** Can Defend Europe?

An MDOW system consists of a laser, a deformable mirrorforpreshaping the beam, and a sensor. The system senses the intensity of a reflection off a target to determine the transformations required in the outgoing, attacking beam to maximize transparency through the atmosphere, and hence the energy-flux density delivered to the target. But existing optical dogma insists that such a system cannot image a target through the atmosphere without having a clearly defined area that produces a "glint" reflection of the outgoing, attacking laser beam.

According to theory, if there is no

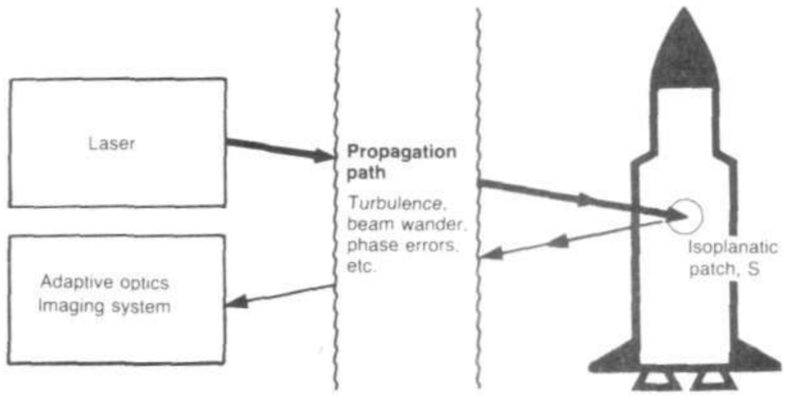


Figure 3
THE ADAPTIVE OPTICS PROBLEM

Statistical optics holds that it is impossible to image, track, and destroy a realistic military target through intense atmospheric turbulence. Shown here is the adaptive optics problem, as seen by contemporary optics, for a laser defense system attacking a target without a definite area of reflection, or "glint." The laser at left emits a beam that is distorted in its propagation to the target at right. The adaptive optics system receives the reflection of the beam from the target, through a "pinhole"at the imagingsystem below left. Based on the intensity of the point reflection, the system adjusts the profile of the outgoing beam to maximize the self-induced transparency through the atmosphere and the lethal energy delivered to the target.

According to the opticians, however, there is no lawful relationship between the intensity of a point reflection and the intensity of the beam at the target over militarily significant distances, because of random wander of the light in its course back to the imaging system. As a result, they argue, such adaptive optics systems are not feasible. In general, they state that the maximum area of coherence S *of the beam on the target is considerably less than the minimum area of "random" beam wander. Therefore, the reflection from the target could come from anywhere on it, not the chosen focal spot.*

glint, there will be no correlation between the intensity of the beam on target and the intensity measured by the sensor, so that the latter will give no indication of how the beam must be shaped for the atmosphere to focus it, or, according to jargon, for the system to "converge" to maximize beam intensity on target.

As Pearson et al. write: "Multidither systems that have been studied to date require a target highlight or bright feature (a localized region that has a higher reflectivity than surrounding regions—a "glint") for proper operation. . . . Since glint structures are known to evolve, replicate, shift and/or disappear as the target changes aspect angle, the beam may not be stable on a dynamic target [for example, an artillery shell], and with featureless targets, standard outgoing wave multidither systems cannot converge."

Obviously, such a theory has a dubious military value. We can not expect the Warsaw Pact to deploy missiles and artillery shells that maximize glint for us, upon which we can focus the impact of Western lasers.

Bissonnette wrote in *Applied Optics:* "There can be many practical instances where the target is featureless and the turbulence-spread beam spot is resolved by the transmitter aperture. This is likely to happen at short to medium ranges, where the MDOW adaptive systems are most advantageous and most suitable for applications."

Bissonnette carried out experiments to test Fried's theory of light propagation in the atmosphere as follows: To image a realistic, "featureless" military target, a target without a glint, Bissonnette measured the intensity of the light reflected off the target through a pinhole aperture, rather than collecting a broad reflection of light, in order to construct a reference whose intensity would correspond to the actual intensity of the outgoing beam at the target.

Adjustments in the deformable mirror of his system, to maximize the intensity of light through this aperture, should maximize the intensity of the attacking beam on target.

However, according to Fried's theories of coherence and isoplanaticism, the intensity of light measured through

TWO EXPERIMENTS IN LIGHT PROPAGATION THROUGH TURBULENCE THAT REFUTE THEORETICAL PREDICTIONS OF STATISTICAL OPTICS

	Experiment 1	Experiment 2
Theoretical values		
Coherence length, r_0	0.144 mm	0.101 mm
Isoplanatic patch, S	0.0651 mm^2	0.0321 mm^2
Area of beam wander, *L*	9.24 mm^2	61.4 mm^2
Ratio *L* to S	142	1913
Experimental values		
Coherence length, *r,*	1.715 mm	4.421mm
Ratio, experimental to theoretical, *rjr₀*	12	44

Two experiments carried out by Canadian scientist Luc Bissonnette demonstrated that the "coherence length" of laser light—the distance perpendicular to the beam, across which it is coherent—is at /easf -[Q to 50 times greater than that predicted by the statistical opticians.

such a pinhole would have an arbitrary relationship to the actual intensity of the beam on target, because of the wander of the light through the atmosphere. Theory requires that for a system to function, the area of wander must be less than the area of the isoplanatic patch. Fortwo experiments of Bissonnette, theory predicted the values shown in the table for coherence length r_0, area of isoplanatic patch S, and area of beam wander, L[16]

According to these theoretical values, there should be no correlation between the light through the pinhole aperture and the beam intensity at the target. However, Bissonnette demonstrated that in both cases, a positive correlation (that is, greater than 0.5) existed: in Experiment 1 with a maximum correlation of 1 .Oand a minimum correlation of 0.65; in Experiment 2 with a maximum of 0.85 and a minimum of 0.6. The table also shows the recalculated value of the coherence length on the basis of these results and compares it with that derived from optical theory. It shows that the coherence length found in the experiments is at least 44 times greater than that predicted by theory.

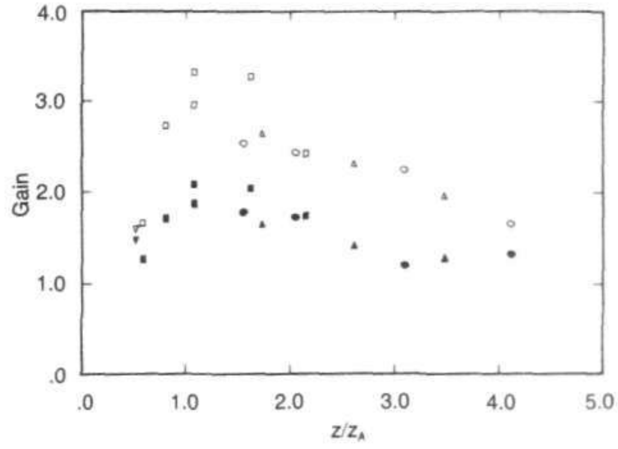
Bissonnette cast these results **in** terms of maximum effective ranges for imaging targets with his modified MDOW laser system, with reference to the opticians' notion of "amplitude fading distance" z_M the distance from a source at which the (coherent) amplitude of a beam is *Me* (37 percent) of its original amplitude. According to theory, the maximum range for imaging for Bissonnette's experimental system would be0.7z„, and that scintillation of a reflection saturates at $zlz_A = 2$.

Bissonnette's system reached its *peak performance* at a range of about 1.6 z_{Al} or more than twice the theoretical limit. He demonstrated effective ranges of up to 4.1 z_A, the distance at which the beam amplitude—according to theory—would be reduced to $1/e^{41}$ (less than 1.8 percent) of its original amplitude.

He then compared the performance of his pinhole aperture system with an MDOW system supplied with a glint. Again, contrary to theory, which states that a glint is necessary for successful operation of a multidither system, the profile of maximum intensity of the beam on target as a function of distance (measured in terms of the gain of the closed loop system) had the same shape for both systems; the amount of gain was simply lower in the case of the pinhole imaging technique. (See Figure 4, which is from one of Bissonnette's papers.[17])

Put bluntly, he showed that from the standpoint of experimental results, the theory is "off the wall." Figure 5, also from one of Bissonnette's papers, shows this most clearly in a graph of gain fading with distance, in units of the amplitude fading distance. The triangles, squares, and circles are experimental data points from Bissonnette's system; the two continuous curves are theoretical ones based on that of Fried (labeled "1") and another statistician ("2"). (Gain fading measures how the gain in intensity on target, supplied by

Figure 4
CONTRARY TO THEORY, ADAPTIVE OPTICS PRODUCE GAIN

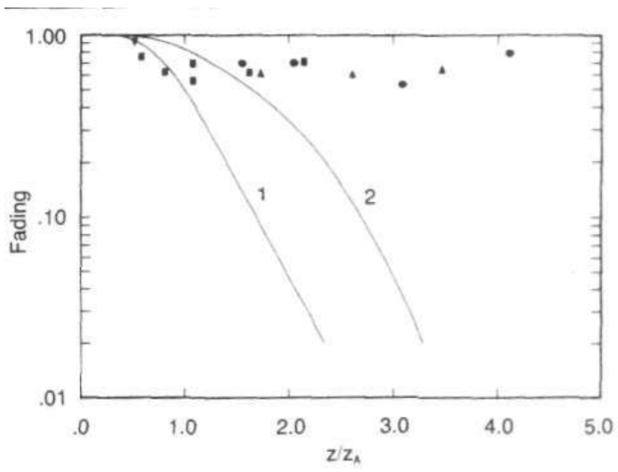


The gain of an adaptive optics system—the relative increase in laser energy flux density delivered to a target as a result of its adaptations of a beam for atmospheric propagation-varies over the range to a target and different conditions of the medium.

The open symbols are data for standard outgoing wave adaptive optics systems relying on a glint from the target for information on atmospheric conditions. The solid symbols are data from the "pinhole" imaging system tested by Luc Bissonnette.

According to theory, Bissonnette's system should producenogain. However, experiment showed that his system achieved a gain more than 2.0 and continuedto exhibit gain at a range four times the amplitude fading distance.

Range to the target is shown in units of "amplitude fading distance," Z_A, the distance over which the intensity of a beam is thought by the theoreticians to be reduced by 37 percent of its value.



an optics system, may decline with increasing range to the target.)

Pearson et al. argue that the maximum range of an MDOW system is 1.6 kilometers.[2]. Bissonnette has shown that they underestimate the maximum effective range by at least a factor of 6, resulting in a range of at least 10 kilometers. This is the difference between a system that is militarily significant and one that is not.

The Bissonnette system appears able to attack targets that rise over the horizon (only 15 km away) at ballistic velocities. Based on the physical principles discussed above, it appears certain that further extension of the feasible ranges will be demonstrated.

This writer offered some of the optical authorities whose theories are refuted by Bissonnette, a chance to publish comment on his work together with this report. All of them refused to do so. Not one disputed Bissonnette's results. Their only comments were as follows:

"I don't think the atmosphere is nonlinear at these power levels" (milliwatts).

"I always have a problem with someone who argues in simple physical terms."

"The scientific issues in propagation through atmospheric turbulence are already solved."

And finally, "This work is trash."

Notes-

1. "European Air Defense Initiative: A Crash Program for Beam Defense," *Executive Intelligence* flewew12: 46 (May 21,1985).
2. F. G. Gebhardt, "High Power Laser Propagation," *Applied Optics.* **15:**1479(June 1976).
3. An Itek, Corp. representative quoted in *Aviation Week.* **115** (8): 62 **(Aug. 24,1981).**
4. **The** notion that there is a "power density" barrier in laser propagation through the atmosphere is similar to the now refuted belief that there was a "sound barrier" to aircraft as they approached **the** speed of sound. As Uwe Parpart Henke has documented, appropriate shaping of supersonic aircraft induces transparency for their movement through the atmosphere beyond the speed of sound, and even pushes the alleged "barrier," the speed at which drag increases, from 0.7 the speed of sound to beyond Mach 2, as well as reduces the maximum amount of drag. **See** his article, "The Question of Scientific Method: How the Riemannian Approach Al-

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Optical Computers: A Decisive Edge for the SDI

by Kevin L. Zondervan

The advent of the Strategic Defense Initiative (SDI) has dramatically quickened the pace of research and development in the area of high-speed computer processors. Technologies currently under study at Air Force laboratories include very high speed integrated circuits (VHSIC), optical processing, hybrid optical/digital processing, and gallium arsenide (GaAs) semiconductor technologies.

Why the acceleration of R&D into these areas? In large part it is because experts have estimated that the processing rates for SDI battle management and sensor systems may approach 1 trillion (a million times a million) floating-point operations or flops, such as addition and multiplication, per second. For comparison, the Cray X-MP, one of the world's fastest computers, has been measured at only 33 million flops.

Typical functions performed by SDI battle management and sensor systems include sensorsignal processing, target designation and discrimination, target trajectory estimation, weapon allocation (deciding which weapons are to shoot at which targets), weapon pointing, target tracking, and weapon firing. To fulfill its mission of shooting down ballistic missiles and nuclear warheads, an SDI system must perform all of these functions simultaneously throughout the course of an engagement. However, the processing rates this entails, while allowing an SDI system to perform its primary goal, may not be sufficient also to ensure the defensibility and cost effectiveness of the system.

To achieve these additional goals, and thereby guarantee the success of SDI, the processing speeds may have to be substantially increased. This is true primarily for two reasons. First, greater processing speeds enable the system to implement more sophisticated strategies and battle management algorithms. The ability to implement a greater variety of tactics may be the decisive edge for the SDI if it is pitted against an opposing system of roughly equivalent firepower.

Courtesy ot J. Caullield

This analog device, designed by Dr. John Caulfield of the University of Alabama, uses a transparent crystal that combines light waves and sound waves.

Second, greater processing speeds also can enhance the system's relative firepower and cost exchange. For example, it has been demonstrated that if a space-based, laser boost-phase defense system can achieve the Department of Defense goal of laser firing rates of 10 shots per second or better, then the number of space-based lasers required in orbit (to meet the simultaneous launch of ballistic missiles launched from silos distributed as they currently are in the Soviet Union) varies as the square root of the number of missiles. (In other words, if 100 space-based lasers are required to shoot down 3,000 boosters, then only 141 space-based lasers are required to shoot down 6,000 boosters.)

The faster and more optimally the battle commands can be processed, the less frequently and less far each space-based laser will have to be slewed, and the more likely the 10 shots-per-second firing rate can be achieved. A square-root scaling effect essentially removes the option of proliferation from the booster force's list of countermeasures, since the space-based laser force can proliferate at a lower rate to maintain its effectiveness. Put another way, the space-based laser inevitably wins the cost exchange underthese circumstances. (If the cost of a space-based laser is equivalent to the cost of N missiles, where *N* is a constant, then under continual proliferation, a square-root scaling between assets leads to the space-based laser force eventually costing less than the missile force.)

As the laser firing rate falls below 10 shots per second, the scaling becomes a linear instead of a square root relationship, and the space-based laser loses its edge in the numbers game.

R & D **Consortia**

Because it is critical to the success of the SDI to explore every promising avenue for increasing the speed of computers, the SDI Office's Innovative Science and Technology Office has formed consortia composed of government, academia, and industry to accelerate R&D in this area.

Of particular significance was the formation of a consortium in April 1985 to investigate high-speed computing using optical signal processing.

According to the SDI Office, the optical signal processing group will conduct research leading to "major advances" in signal and image processing technology. They will focus on "high-risk research aimed at obtaining breakthroughs in the near and midterm." Two thrusts have been defined: development of innovative hybrid analog and digital optical/electronic processors and also new techniques for addressing complex nonlinear problems essential for SDI operations.

Participating in this group are the California Institute *of* Technology, Carnegie-Mellon University, Georgia Institute of Technology, University of Dayton Research Institute, University of Alabama at Huntsville, Stanford University, the U.S. Naval Ocean Systems Center, MIT-Lincoln Laboratories, and Battelle Columbus Laboratories. Dr. Keith Bromley of the Naval Ocean Systems Center is the government program manager and Dr. John Caulfield of the University of Alabama is the technical director.

The designated consortium associates are AerodyneCorp., BDM Corp., Harvard University, Houston Associates, MIT, Probe Inc., SAI Corp., the University of California at Irvine, and the University of Southern California. The budget for this work is $9 million over the next three years, with fiscal year 1985 funding being $1 million.

Over the last 20 years there has been considerable research in the general area of information processing by optical techniques, or to use the more recent terminology, optical computing. Generally speaking, this work involves the idea of using light beams or photons, instead of electrical current, to perform numerical computations.

The reasons for using light instead of electrical currentare many. Because light is at the upper end of the electromagnetic spectrum, a light signal can be encoded with much more information than lower-frequency forms of radiation. This property can be exploited to increase the density of independent channels in a computing system. Optical signals can also propagate through each other in separate channels with essentially no interaction, and can propagate in parallel channels without interference. Optical signals have also been demonstrated to interact with certain materials on a subpicosecond (a picosecond is **a** trillionth of a second) time scale, offering the potential for high throughput.

The research into the application of these properties of light for computers has followed two general paths: analog processing and digital processing. Analog computers work by measuring physical properties—numbers might be expressed as voltage levels or degrees of brightness in a laser beam, for example. Digital devices, on the other hand, work by measuring different "states," for example ON versus OFF or HIGH versus LOW. These states are then used to perform binary arithmetic, that is, arithmetic based on ones and zeros.

Since analog computers represent quantities of interest with physical properties that can be altered at speeds approaching the speed of light, the result to a complex computation can be achieved almost instantaneously. In a digital computer, these same quantities are represented as binary numbers. A complex computation typically requires manipulating these binary numbers billions of times. Consequently, analog computers can be substantially faster than digital computers.

Analog Devices

An analog system is one in which the inputs and outputs can take on a continuum of values. Typically, in optical systems, these inputs and outputs are intensities or brightness. In order to utilize the parallel processing capabilities of optics, intensity profiles in two or three dimensions can be utilized, as is done in optical image processing.

Operations of the analog variety have been widely developed over the last 20 years. There is a fairly well-defined repertoire of operations that can be performed, including such important operations as addition, subtraction, multiplication of images, Fourier transformation (representing a signal with a finite number of sinusoids), correlation (comparing two quantities), convolution (multiplying two functions) and other operations that can be derived from these. The last three are especially significant as they are useful for solving differential equations.

Historically, there has always been a problem maintaining the accuracy of analog processors because of component stability, approximation error, and noise (unwanted signal) propagation.

The first drawback stems from the fact that analog devices represent numbers by physical conditions such as voltage levels or brightness. If the components generating the physical condition change in some fashion over time, the calibration of the analog device can be altered. This, in turn, can effect the computational accuracy of the device.

The second problem, approximation error, is due to the fact that physical phenomena are being used to model mathematical operations, which is the converse of the usual situation. Thus, because mathematics only approximates reality, the mathematical calculations performed by analog devices are necessarily approximations. In addition, these approximations usually hold only over a limited operating range.

Finally, the operating principles underlying analog devices generally result in unwanted signals being propagated and amplified throughout the entire sequence of their mathematical operations. Depending on the amplitude of these signals, the computational accuracy of the analog device can be substantially degraded.

Optical Analog Devices

In large part, because digital computers did not suffer from the above operational problems, computer users preferred them over electronic analog devices for their computational needs. However, current progress suggests that optical analog devices will not suffer the same fate.

Exemplary of the progress made in analog devices is the 1981 design of a vector-matrix processor, a device that performs highly repetitive mathematical operations on large amounts of similar data, by Dr. John Caulfield of the University of Alabama. Caulfield used Bragg cells—a transparent crystal that combines light waves and sound waves in such a way that the path of the light beam is dependent on the amplitude and frequency of the sound wave—to construct his device. A key feature of the implementation was the use of feedback (the routing of the output back to the input) to improve the accuracy of the device.

Harper Whitehouse of the Naval Ocean Systems Center in San Diego subsequently showed how the use of a convolution technique could improve the accuracy of Caulfield's device even further. Following this, Peter Guilfoyle, head of CuilTech Research in California's Silicon Valley, combined Caulfield and Whitehouse's ideas into an optical processor that apparently possesses both analog speed and digital accuracy. Exactly how the device works Guilfoyle will not reveal.

Both Caulfield and Guilfoyle see the initial use of their processors as add-on devices for existing digital computers. The resulting hybrid computer is expected to perform faster than the digital computers alone and still maintain digital computer accuracies.

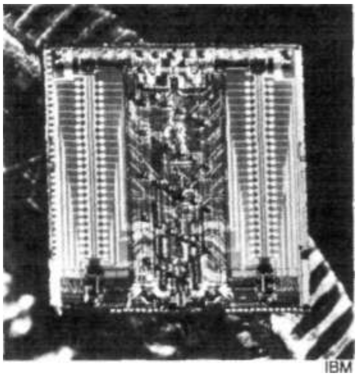
Digital Devices

Optical techniques not only have potential for transforming the design and construction of analog devices, but also hold tremendous promise for revolutionizing digital devices.

When computers were first developed, the hardware for gates (typically a logic circuit) and for gate interconnections was expensive. Thus a computer design evolved that minimized the hardware requirements. These requirements have led to the classical von Neumann computing system architecture shown in Figure 1. In a von Neumann machine, all of the processing logic is contained in the central processing unit and the memory is located almost entirely in a separate unit.

Input-output is generally performed by the central processing unit or by a system closely coupled to the central processing unit. The central processing unit accesses the memory through a binary addressing unit, and memory contents are returned to the central processing unit through a single or small number of lines.

Although the serial addressing and multiplexing scheme of Figure 1 re-



Electronic circuit technology-the IBM memory chip.

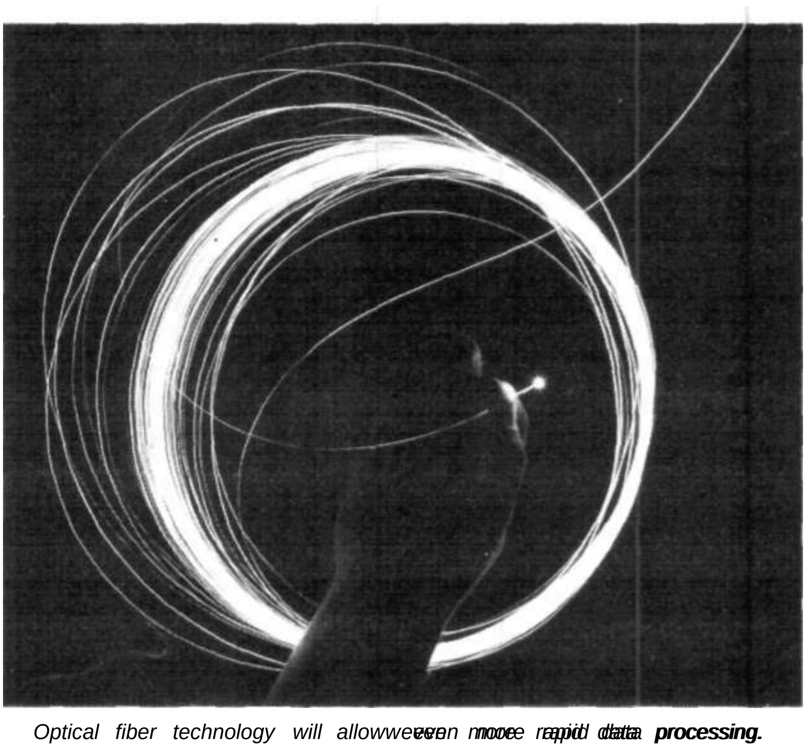
Optical Circuits Increase Throughput of Computers

The introduction of light as a medium of communication in computers will increase the number of mathematical operations that may be performed per second. The most obvious reason for this is that an optical circuit has zero resistance to flow, whereas an electronic circuit, like the one shown here (left), always presents some inertia that must be overcome for current to flow and calculations to be carried out.

As a result, the speed of data transmission in an electronic computer is, inherently, considerably slower than the speed of light; consequently the speed of mathematical transformations that it carries out is necessarily slower than an equivalent optical circuit.

This difference can be looked at by comparing the nature of the waveguides required in electronic and optical circuits. The low frequency of the electromagnetic radiation known as electric current requires a conducting substance for its ordered transmission, as indicated even in the microcircuit shown above. (For comparison, the edge of a U.S. coin is shown in the background.) Furthermore, electromagnetic interference phenomena require that the waveguides be sufficiently distant from each other, or insulated.

On the other hand, coherent light in the optical range does not require a waveguide for linear transmission, and distinct signals may intersect each other with no practical interference. Optical waveguides—for example, the optical fiber shown at left—are required only for turning the direction of a signal or for preventing its dissipation over long distances.


Optical fiber technology will allow even more rapid data processing.

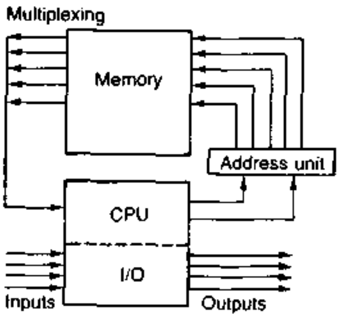


Figure 1
CLASSICAL VON NEUMANN COMPUTING SYSTEM ARCHITECTURE
A computer design that minimized the hardware and created the von Neumann bottleneck.

duces interconnection and communication requirements and minimizes the number of lines, it has the disadvantage of limiting the time it takes to transfer information between memory and the central processing unit. The eventual limitation of this tradeoff on computing speed is known as the von Neumann bottleneck.

Other Limitations on Processing Speed

This is only one of several fundamental problems constraining the processing speed of today's and future electronic computer systems. The most important of these other problems are interconnection bandwidth, clock skew, electromagnetic interference (EMI), and crosstalk.

Bandwidth. As system cycle time and pulsewidths shrink for the purpose of increasing processing speeds, the bandwidth (the range of frequencies that a circuit *can carry* above a specified percentage of its maximum power level) needed to preserve the squarewave shape of these signals increases. (Recall that a square wave pulse is the sum of many different frequency sinusoids.) This forces the need for bulky and expensive terminated coaxial interconnections. Thus, the amount and speed of information transfer is restricted. Furthermore, the terminating resistors on the ends of the cables reduce system energy efficency.

Clock skew. The problem of clock skew occurs when signals from different parts of a circuit arrive at a gate at different times. If this skewing is severe, the gate can generate an erroneous output. As computational cycle times become shorter, the amount of clock skew that can be tolerated diminishes. To keep clock skew within acceptable limits, all interconnection lengths between gates must be kept constant. If this is not possible, shorter lengths must be padded with gate delays to make the propagation time equivalent to that of the maximum interconnection length.

The problem of clock skew also makes it difficult to exploit the performance advantage *of* extremely fast logic gates in traditional electronic circuits. Inputs to a logic gate must be allowed to settle before the output of the gate can be considered reliable. The input settling time is dependent on the time it takes to fully charge a connection. In most circuits this settlingtime is longerthan typical transistor switching times. Clearly, gates with switching times less than the interconnection settling times are of little benefit under these circumstances. Very large scale integration, VLSI, provides no solution to this problem because the scaling down of circuits does not change the settling time properties of interconnections.

Electromagnetic interference and crosstalk. The problems of EMI and crosstalk stem from the fact that electrical signals affect each other over a distance. Consequently, adequate shielding and separation between signal paths to maintain the integrity of each signal necessarily limits the number of channels that can be supported per given volume. This, in turn, imposes a minimum separation distance, and therefore a minimum signal propagation time, between gates, ultimately restricting computing speed.

All the above problems are interrelated. While increasing cycle times (that is, diminishing both separation between pulses and pulse widths) circumvents the von Neumann bottleneck, it aggravates the bandwidth, clock skew, and electromagnetic interference problems. Since the root cause of these problems stems from the inherent properties of the electromagnetic radiation used to perform the task, solutions ultimately lie in developing techniques to perform the task using a "higher quality" form of radiation. Thus, we are naturally led to consider the binary computing problem from the standpoint of light and optics.

The Advantage of Optics

What do light and optics have to offer? First, optics is capable of communicating many high-bandwidth channels in parallel. Lenses, prisms, and mirrors can convey images consisting of millions of resolvable spots. Each spot is capable of supporting a very large bandwidth channel. In addition, optical beams do not interferwith each other and can cross each other without interaction.

Although these attributes have been exploited in analog optical devices, they have not yet been fully applied to digital systems. The main reason for this has been the lack of suitable optical logic and memory devices, but this situation has recently changed.

Transphasors. The fundamental components of any digital logic or memory device are switches capable of two different states of transmission. A dominant factor in the speed of the component is the time required for a switch to change states. Currently, computers use transistors to perform the switching function. The fastest these devices can be made to change states is about a nanosecond, or a billionth of a second.

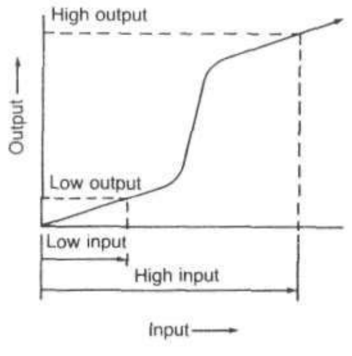


Figure 2
CHARACTERISTIC CURVE OF BINARY SWITCH
The curve's nonlinearity is the key attribute that permits the implementation of logical functions.

Researchers at several laboratories (for example, Bell Labs in the United States and Heriot-Watt University in Scotland), however, have developed an experimental optical device analogous to the transistor. This is called a transphasor and it can achieve switching times on the order of a few picoseconds (a picosecond is a thousandth of a nanosecond).

Like any switch, the transphasor is based on a physical phenomenon whose input-output relationship takes the general form of the characteristic curve shown in Figure 2. The curve's nonlinearity is the key attribute that produces a binary (that is, high versus low) output based on a binary input and permits the implementation of logical functions.

For example, if we desire a device that outputs a high signal only if its two inputs are simultaneously high (the classic AND function), we can scale the inputs such that only when they are both high will the total input signal exceed the kink in the curve of Figure 2 and produce a high output.

Similarly, if we desire a high output when either one of the two inputs is high (the OR function), we can scale the inputs such that a single high input exceeds the kink in the characteristic curve and produces a high output. Given the AND and OR functions, all of the logical functions required of binary digital computers can be constructed.

Most transphasors are constructed using a Fabry-Perot interferometer and a material with a nonlinear refractive index in the interferometer cavity. In its simplest form, the Fabry-Perot interferometer consists of two plane, partially reflecting mirrors placed parallel to each other and separated by a cavity or space. If a coherent beam of light is input through one of the mirrors, the intensity of the beam output from the other mirror is dependent on the interference pattern set up in the cavity by the incident and reflected beams.

At full destructive interference the intensity in the cavity is almost zero and transmission through the output mirror is negligible. However, at full constructive interference the intensity of the cavity can be as much as 10 times the intensity of the incident beam. Because of the losses through the output mirror, the intensity of the output beam is roughly equal to the incident beam intensity for this situation. By placing a material in the cavity whose refractive index (ratio of speed of light in a vacuum to its speed in the material) is dependent on the intensity of the light passing through it, the conditions under which constructive or destructive interference take place can be made dependent on the intensity of the incident beam.

For example, suppose at low incident beam intensities, destructive interference prevails in the cavity. The intensity of the output beam is therefore negligible. As the intensity of the incident beam is increased, it causes the material in the cavity to achieve a refractive index that results in constructive interference, and the intensity of the output beam increases dramatically. The resulting input-output relationship looks generally like that shown in Figure 2.

By altering the length of the interferometer, the wavelength of the incident beam, or the material in the cavity, a hysteresis loop can be created, as shown in Figure 3. In simplified form, the occurrence of a hysteresis can be explained as follows: As the intensity of the incident beam is reduced, enough light remains in the cavity to keep the refractive index near the value corresponding to constructive interference. Thus the "decreasing incident intensity" curve is to the left of the "increasing incident intensity" curve.

An optical device that exhibits this behavior is said to be optically bistable because it has two stable regions where the transmitted intensity changes very little with variations in the incident intensity. Either the high state or low state can be maintained indefinitely with an incident beam of intermediate intensity. The obvious application of such a device is as a binary memory element.

The transphasor described above is known as an intrinsic system because its performance is based on the intrinsic refractive properties of the material in the interferometer cavity.

Hybrid systems. Work is also being done on so-called hybrid systems, which typically employ a crystal whose refractive index depends on an applied voltage rather than incident light. The voltage is generated by a light detector that detects a portion of the output beam of the interferometer via a beamsplitter. The resulting feedback loop causes the electro-optic crystal to behave in the same manner as a crystal with an intrinsic nonlinear refractive index. Depending on the tuning of the feedback loop, a characteristic curve of the form shown in Figures 2 or 3 can be produced.

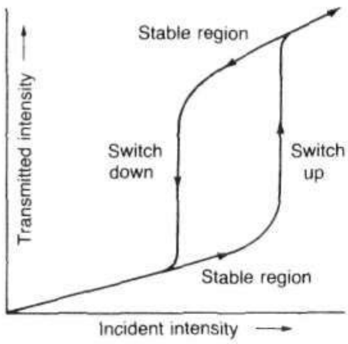


Figure 3
CHARACTERISTIC CURVE WITH HYSTERESIS, OR BISTABILITY
The decreasing incident intensity curve is at left; the increasing incident intensity curve at right.

Transphasors have also been constructed without the use of Fabry-Perot interferometers. Most of these hybrid devices are based on liquid crystal light valves. This device is a small wafer sandwich composed of essentially two different materials positioned back-to-back—a photoconductor crystal and liquid crystal material much like that found in watches and calculators.

An electrical current applied to the device is modulated by the intensity of an incident beam directed on the photoconductor crystal. The modulated current, in turn, effects the optical polarization properties of the liquid crystal material. When a secondary beam, or a reflected portion of the input beam, is reflected off the liquid crystal it becomes polarized. By passing the output beam through a polarized lens, its intensity can be made dependent on the current applied to the liquid crystal, and ultimately dependent on the intensity of the incident beam.

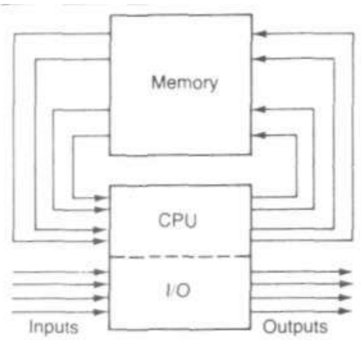


Figure 4
NON-VON-NEUMANN COMPUTING SYSTEM ARCHITECTURE

The ability to update all memory elements in parallel eliminates the need for a memory addressing unit (see Figure V and, therefore, obviates the von Neumann bottleneck.

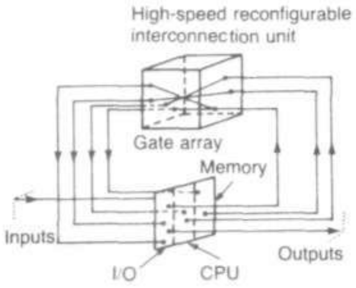


Figure 5
NON-VON-NEUMANN OPTICAL COMPUTER SCHEMATIC

This computer uses a single integrated optical gate array or "chip." The communication among transphasor arrays comprising the chip and the three functional chip units fully exploits the properties of light.

The input-output relationship of the device has the general form of the curve shown in Figure 2. Use of an optical feedback loop can create the curve shown in Figure 3. The utility of liquid crystal light valves is being investigated primarily at the University of Southern California, University of California at San Diego, and Ohio State University.

Optical Arrays and Computer Architectures

In principle, two-dimensional arrays of transphasors can be made from either intrinsic or hybrid devices. The reason for doing so is to permit parallel operation of a large number of transphasors. Even if the switching speed of each element is relatively slow, the large number of parallel operations can produce very high total data rates and processing speeds.

The availability of optical logic and memory arrays, plus the freedom to make arbitrary interconnections, makes possible totally new computer architectures. For example, the ability to update all memory elements in parallel eliminates the need for a memory addressing unit (see Figure 1) and therefore obviates the problem of the von Neumann bottleneck. An illustration of such an architecture is given in Figure 4.

Theoretically, it is possible to implement such an architecture using a single integrated optical gate array **or** "chip." This array would combine many transphasor arrays to create an input/output unit, central processing unit, and a memory unit on a single chip. The communication among transphasor arrays comprising the chip and the three functional chip units would fully exploit the properties of light.

A schematic *of* this implementation provided by researchers at the University of Southern California is given in Figure 5. A key feature of this implementation is the ability to redirect communication paths during computer operation. Reconfigurable holograms under computer control is one method available for doing this.

Multilevel Logic

Perhaps even morepromisingforincreasing the utility and speed of corn-

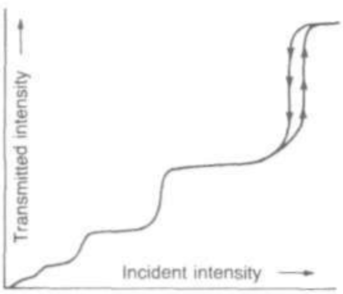


Figure 6
MULTILEVEL CHARACTERISTIC CURVE WITH SINGLE HYSTERESIS

puters than the list of innovations available for binary logic computers is the development of computers with multilevel, or multidiscrete, logic. This becomes possible if switching and memory devices with more than two states can be developed.

Intrinsic transphasors such as the Fabry-Perot have been designed to produce characteristic curves like that in Figure 6. Note that only a single region of bistability exists, limiting the use of the device to a multilevel switch. Several multilevel regionsof bistability must exist before a multilevel memory is possible. Of course, multilevel switches and memories can always be developed by combining several binary devices of differing operational input levels. When this is done using today's electronic devices, the interconnection complexities that result make implementation of electronic multilevel devices impractical. However, as reported above, this problem can be circumvented with light and optical devices.

Another obstacle that now affects multilevel computing is the lack of a well-developed theory for its implementation. Most of the work in this area *concerns* the theory of residue arithmetic, which still has several difficulties: Division of two numbers, sign testing, and relative magnitude comparisons are not easily and conveniently handled. Suffice it to say that much work remains to be done. However, if this work is brought to a successful conclusion, the payoff could be significant. Several experimental residue processors have been built and tested and have performed many times faster than binary devices performing the same computations.

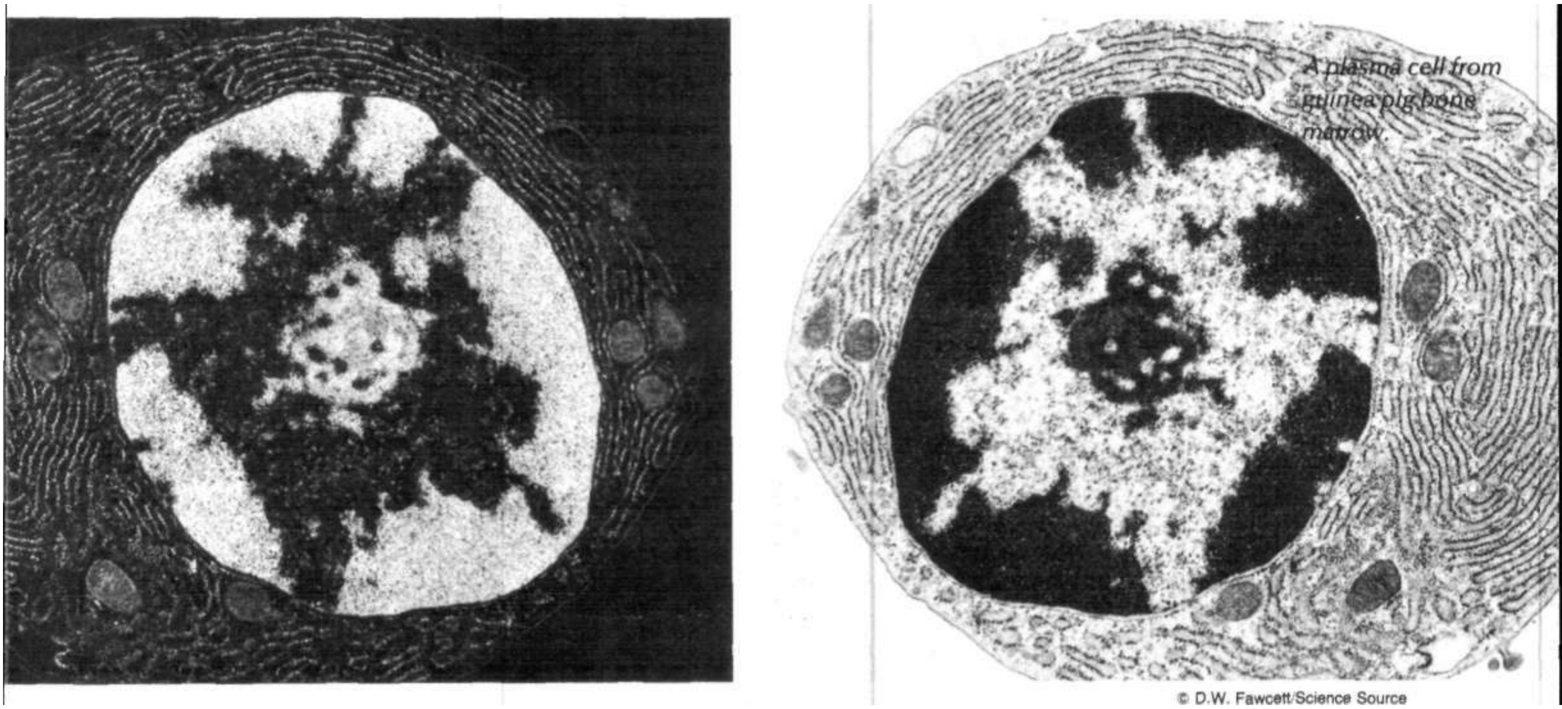
The Future

Current R&D in the area of information processing and computing is examining virtually every premise underlying the design of today's computers. This return to fundamentals has come on the heels of major advances in the field of lasers and optics. Results to date make it clear that only time and money stand in the way of major breakthroughs in all areas of information processing.

Without question, the new generation of optical computers will far sur-

Continued on page 64

Recent advances in optical biophysics may aid in uncovering the secret of what is life and the prevention of deadly diseases like cancer.



A plasma cell from guinea pig bone marrow.

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'Optical Biophysics': The Science of Light and Life

by Wolfgang Lillge, M.D.

Only very recently have scientists again started to attack a problem that has the most fundamental implications for mankind: What is life, and what are the controlling forces behind biological processes? An answer to this question could easily lead to a scientific and technological revolution on a scale unparalleled in history.

Research into the life sciences has in the past produced some of the greatest contributions to human knowledge and human mastery over nature, from Plato's insights into the geometric ordering of the universe, to Leonardo da Vinci's intensive studies of the human body. The basic law discovered by Leonardo was that all living matter in its geometry is governed by the golden mean proportion, and that this applies to all processes in the universe, from the macrocosm of the stars to the microcosm of the individual cell.

Scientists in Leonardo's tradition knew that the evolution of life on our planet must have followed the same lawfulness as the creation of the universe itself, so that the existence of rigorous geometric laws in nature reflects a higher ordering principle that must also be true for any other aspect of the universe. From this standpoint, it appears evident that light coming from the Sun is of particular interest when we ask what are the key forces controlling life.

When we speak of "light," however, we do not mean only visible light, but the electromagnetic spectrum as a whole, which includes radiation of very long to very short wavelengths. Light that man can perceive with his eyes is actually only a tiny fraction of all electromagnetic action existing in the universe, and may not even be the most important one. When we divide the spectrum according to octaves of the musical scale (Figure 1), we see that the visible part of the spectrum corresponds to only one octave, while the infrared region includes seventeen octaves and the ultraviolet, six.

These proportions make clear that "light," in whatever form and intensity, has *an* almost unlimited potential to perform work in the universe. Of course, light or radiation in the upper part (short wavelength) of the spectrum, like X-rays or gamma rays, has a much higher energy content than light of longer wavelength, and in higher doses even has lethal effects for life. As far as is known today, the light that controls life processes is mainly in the microwave, infrared, or ultraviolet range. In effect, this light is coherent—such as laser light, which at low intensities easily penetrates a much higher "background radiation."

The second basic law of nature, which goes back to the work of Gottfried Wilhelm Leibniz, is the principle of least action, which requires all processes in nature to run with highest effectiveness and least loss of energy. Life is characterized by this principle, and radiation (light) of low intensities is the medium through which nature performs work of greatest efficiency.

Popp's Biology of Light

Researchers internationally have assembled an impressive amount of evidence for the effects of low-level radiation in nature. Dr. Fritz-Albert Popp, a biological physicist working at the University of Kaiserslautern in West Germany, is *one of* the leaders in this area of biology.[1] In a book published in 1984, *Biology of Light: The Basis for Ultra-Weak Cell Radiation,* Popp presented an overview of the last 60 years' experiments and concepts on the role of coherent radiation in life processes, and reported on his own pioneering work in measuring very-low-intensity photon emissions from living matter.

As Popp describes, one of the first experiments that gave rise to the hypothesis of specific light emissions by plants was conducted by the Russian biophysicist Alexander G. Gurvich in 1922. Gurvich brought the tip of an onion root into close proximity to the shaft of a second onion root and observed an increase of cell divisions at the side of the shaft pointing to the root tip. To exclude any "chemical" influence, Gurvich separated the two onion roots by glass containers. The experiment worked only when quartz glass was used. That it did not work with normal window glass, which almost totally absorbs any ultraviolet radiation, suggests that ultraviolet light was responsible for the growth effect (Figure 2).

The basic problem in directly "proving" the existence of light emissions from living matter was, and is, that the electromagnetic action involved is of a very low level. Only after World War II, when technology was available to directly measure the low-level photon emissions, did a variety of new experiments become possible. In the 1960s and 1970s, Soviet science writers reported regularly on new findings in "ultraweak luminescence." Popp quoted a description of one of these experiments (Figure 3):

> In two containers of quartz glass cells live in a nutritive solution. The sides of the containers directly touch each other. One of the cell cultures is being infected with a virus: Almost at the same time, the neighboring colonies also get sick. . . . Only when, instead of quartz glass, normal glass was used, did neighboring colonies not suffer the same fate as the former. . . .

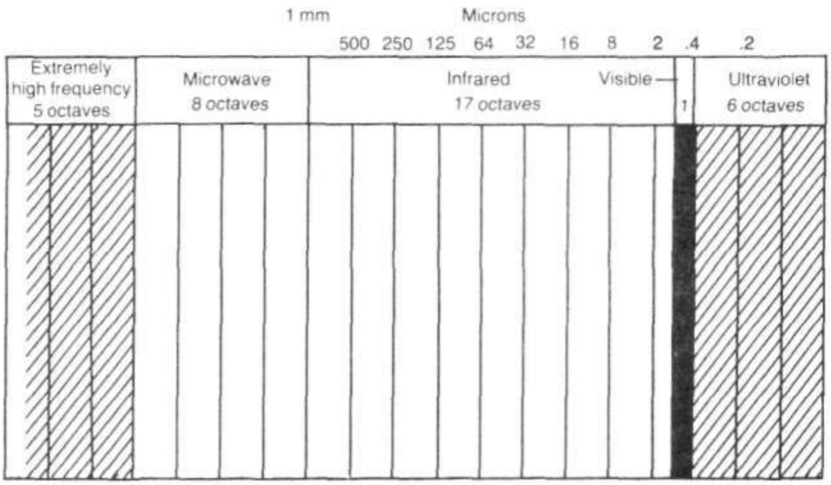


Figure 1
THE ELECTROMAGNETIC SPECTRUM

There are 37 octaves of radiation between the extremes of radio waves and X-rays in the electromagnetic spectrum. The black bar represents the one octave of visible light, while the huge range of infrared, microwave, and ultraviolet is mostly unexplored electromagnetic action—action that is key for controlling life processes.

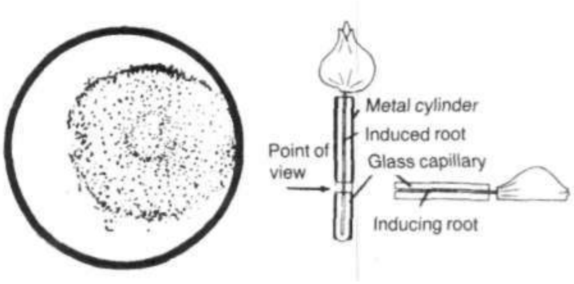


Figure 2
CURVICH'S BASIC EXPERIMENT
Gurvich's basic experiment demonstrated that photon emissions from cells have an influence on life processes. When he brought the tip of an onion root near the shaft of another onion root, he observed increased cell divisions at the point of influence. At left is a microphotograph of the root cross section showing more mature cell nuclei in the half directed toward the other onion root tip.

Source: Fritz-Albert Popp, *Biology of Light,* p. 34.

With a photon multiplier the radiation of cells was measured. Normal cells emitacontinuous flow of photons. This flow abruptly changes when a virus enters the cell: explosion of radiation; silence; another explosion; slow decrease of emission in several waves, until the death of the cell. . . .

These phenomena can be explained from the standpoint of the least-action principle: Considering the huge amount of cellular interactions at any given point that are all mediated through coherent action of light, we are dealing with a fantastic efficiency of cellular work, and only a very small amount of energy (light photons) is lost during the process. No man-made machine has ever reached such astounding efficiency. However, when this process is interfered with—when a virus enters the cell or life is stopped by poison—the highly ordered life process becomes disrupted and inefficient, leading to a much higher rate of photon emissions.

Another field of intense Russian research was the effect of low-intensity coherent microwaves on biological material. Specific frequencies in the millimeter band were found to increase cell divisions in cell cultures by an order of magnitude, if a specific threshold of intensity was reached. Characteristically, the low-intensity radiation did not heat up the cells, and further increases in intensity beyond the effective level did not result in a still higher yield.

One hypothesis to explain this is based on the idea that microwaves of specific frequencies are able to resonate structures in the cell, like membranes, which themselves are vibrating very fast, in the order of 10" and 10^{12} hertz, because of the relatively high electrical charge over the cell membrane. This vibrating frequency corresponds exactly either to the microwave frequency or to some harmonic frequency—in a way comparable to playing a specific tone on a piano and hearing the vibration not only of the string with the same pitch, but also all the overtones of this tone.

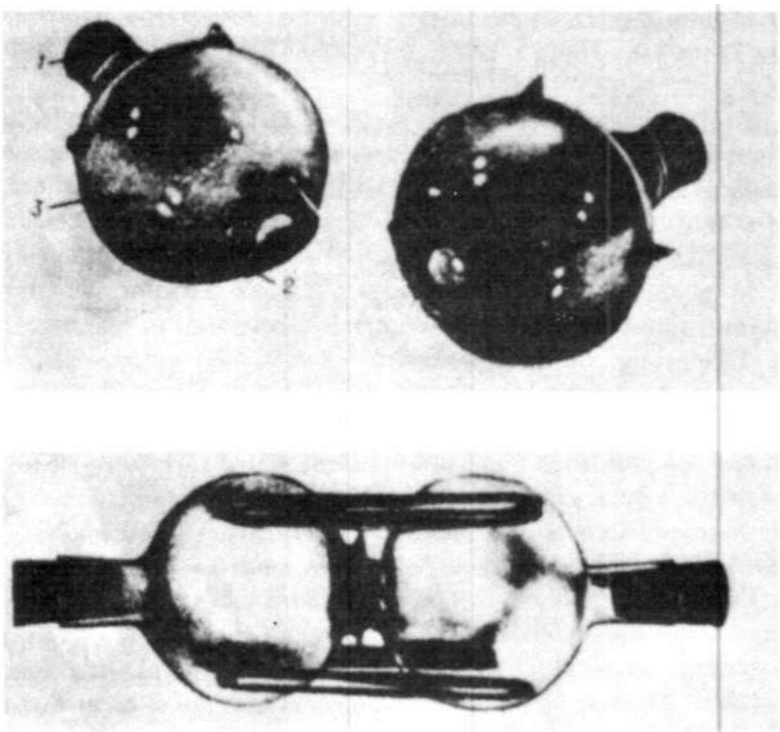


Figure 3
TRANSMISSION OF VIRUS SYMPTOMS VIA LIGHT
The Russian experiments conducted by Kaznacheev et al. at Novosibirsk and published in 1981 took identical cell cultures in two glass bottles and infected one of the cultures (top left) with a virus. After a certain time, the second culture showed symptoms of disease, although there was no virus present-

Source: Fritz-Albert Popp, *Biology of Light,* p. 39.

The electromagnetic energy added by this process would stimulate enzyme activities in the cell through what is thought to be long-range electromagnetic coupling, and lead to an increased cell metabolism and reproductive rate.

New Insights into Cancer

This same concept of light in biological processes motivated Popp to take a closer look at the causes of cancer and the so-called carcinogens, substances that are thought to trigger malignant growth in the body. Actually, the known carcinogens are substances of such divergent chemical nature and properties that there is no way to explain their carcinogenic effect in terms of a common molecular reaction process. Nevertheless, current cancer theory tries to do just that, diverting itself into a never-ending hunt for more carcinogens, which must then be reconciled again with the different chemical properties of the substances discovered before.

Popp took a totally different approach to finding a "common denominator" for the various substances. He investigated the spectroscopic qualities of carcinogens; that is, at which part of the spectrum these molecules absorb and emit light of specific frequencies. He found that most of these chemically very different substances were absorbing in a small area of the ultraviolet spectrum, suggesting a common electromagnetic action.

The most striking case Popp studied is one of the best known carcinogens, 3,4-benzopyrene (3,4-BP), a molecule that supposedly destroys the genetic code in the cell by means of a highly reactive epoxide. However, there is also 1,2-benzopyrene (1,2-BP), which is structurally and chemically very similiar to 3,4-BP, but does not have any carcinogenic effect whatsoever. Popp and his group have demonstrated that this close proximity of harmfulness and harmlessness has its basis in different spectroscopic qualities; that is, in the absorption and emission of ultraviolet light. Taken together with the empirical phenomenon that very weak ultraviolet light makes it possible to repair genetic damage [probably by activating specific enzymes (photoreactivation)], it is quite feasible that carcinogenic substances in the cell absorb the ultraviolet light that is usually used for repair activation of genetic damage, and this then gives rise to malignant growth. It should be noted that genetic damage, "mutations," occur "normally" in each cell at a relatively high rate.

DNA As a Laser

In order to verify the older Russian experiments, Popp and his group designed a highly sensitive machine to measure extremely weak radiation from cells, a photon multiplier, which in fact could detect light emissions of a firefly over a distance of 7 miles.

With this machine Popp was able to verify low-level light emissions from plant cells, which also continue when the cell is kept in a dark container for several hours. In addition, using different types of experiments, he opened the door to understanding the origins of low-level luminescence. Before measuring light emissions from cucumber seedlings, for example, Popp irradiated the seedlings with weak monochromatic light of varying frequencies—626, 695, 550 nanometers (nm).[2] Popp found that this light was absorbed and stored very efficiently in the cell, because increased emissions from the cells after irradiation lasted for almost two hours. In fact, the curve of decrease in photon intensity has a form whose half-time increases constantly.

In the same way, Popp also detected a significant difference between the behavior of normal cells and cancer cells. Tumor tissue not only exhibited a much faster decrease of photon emissions than normal tissue over time, but also lost the ability to respond to a second input of light of the

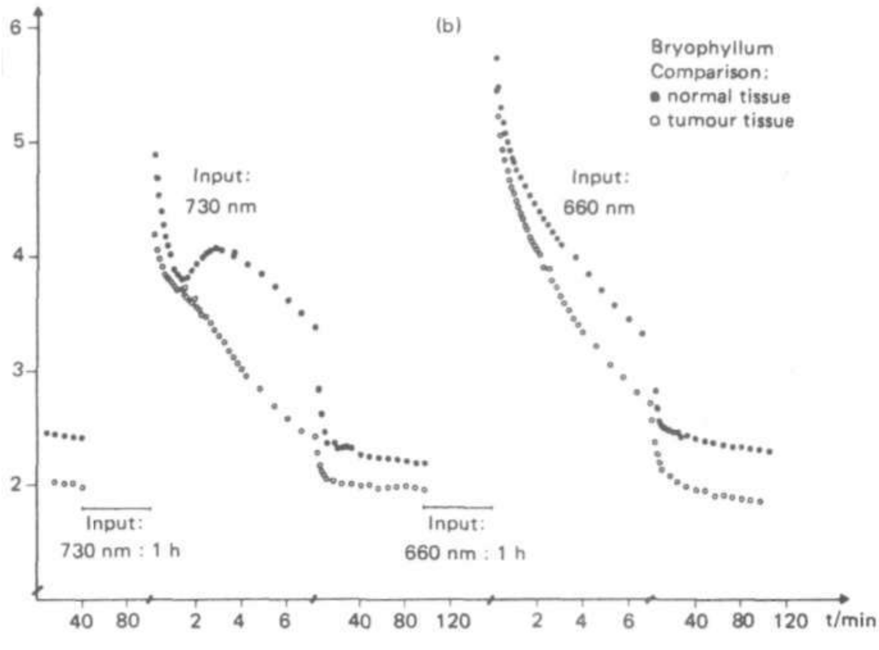


Figure 4
LIGHT EMISSION FROM NORMAL AND TUMOR TISSUE
The light emission of cells shows significantly different behavior in normal and tumor tissue. After excitation with monochromatic light, tumor tissue cannot store this light as efficiently as normal cells, but emits "loose" photons at a faster rate. Furthermore, tumor cells lose the ability to increase the intensity of emission after a second input of monochromatic light.

Source: Fritz-Albert Popp, *Biology of Light,* p. 74.

same wavelength with a resurgence of emissions, as normal tissue is able to do (see Figure 4).

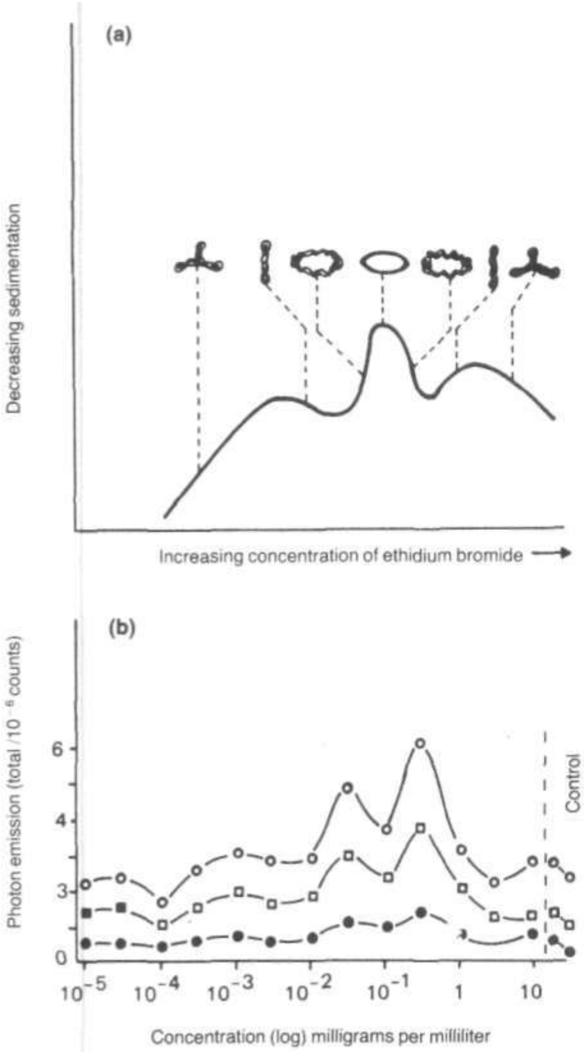
All these experiments point to the fact that structures must exist inside the cell that are capable of storing photons in a way unmatched by any technical device man has built so far. A man-made machine most comparable to the light-storage capacities of the cell would be a Hohlraum resonator system, which, at present technology, has a storage capacity of at best milliseconds. When a simple cucumber seedling is able to store light in the range of several hours, we are dealing here, it seems, with a phenomenon several billion times superior to the best machines man has invented. But we can observe even more astonishing capabilities in cells.

Popp observed during his experiments that cucumber seedlings emit light of a shorter wavelength than the light used during the irradiation; that is, the emitted light has a higher energy content. At no point has such a phenomenon been reported in the context of physical resonator systems. In fact, we have to consider such a frequency upshift as an expression of the life process, a negentropic effect that signifies that living matter has performed work in the universe. Interestingly, as shown by Popp, tumor tissue has lost these basic abilities that are characteristic of life.

In this context, it should be said that comparisons of life processes with models taken from the physics of "dead-bodies" can at best give only a very rough image of the real characteristics of life. The example of the resonator system cited above demonstrates that we are dealing here with a different geometry, a phase shift in the quality of the process. The same warning should be kept in mind when we speak about cells or DNA working like a laser—emitting coherent electromagnetic light, even if only of very low intensity. Although a laser is a very fascinating device, and can be used to protect us from incoming Russian missiles, it is still a quite ineffective instrument, operating with only 5 percent efficiency in respect to the energy input. Nature would never operate in such a wasteful way. In nature, everything has its purpose. If that were not the case, all the wasted light would have to be dumped by the cell, resulting in a much higher photon emission rate to be measured with Popp's photon multiplier. Or, we might see every plant or tree in nature illuminated like a Christmas tree, getting rid of its wasted energy.

The 'Antenna' Principle in Nature

There is every reason to assume that the key structure responsible for efficient photon storage in the cell is the DNA molecule, which is a natural object of interest in uncovering the secret of life because of its tremendous properties and geometries. It is known from antenna technology that structures like helical systems are ideally suited to work as waveguides, which "attract" electromagnetic waves by their geometric form and physical properties. Just as entomologist Philip S. Callahan was struck by the morphology of insect sensillae (antennae) and found that, in fact, insect navigation follows the principles of radar technology,[3] we might consider the DNA molecule to be an antenna/waveguide operating on a shorter wavelength, according to its size, in the ultraviolet range of the spectrum.



10 1 10
Concentration (log) milligrams per milliliter

Figure 5

DNA AND ULTRAWEAK CELL EMISSION

As the concentration of ethidium bromide (EB) solution is increased, more and more EB molecules are intercalated between the DNA base pairs (a). This intercalation leads to the unwinding of the helical DNA superstructures. Experimentally this can be established by DNA sedimentation. After the complete unwinding of DNA, a continuing intercalation does not lead to further dissolution of the DNA polymer, but to a renewed rewinding of the DNA helix structure; however, the rewound structure has opposite spin.

The total amount of ultraweak emitted photons observed after cells are treated with EB (b) shows after one hour (bottom curve) indications of the same concentration dependency as *in (a). This typical profile becomes even clearer after a longer registration time, three (middle curve) and five hours (top curve), an indication that ultraweak cell emission depends on DNA conformation.*

Source: Fritz-Alberi Popp. *Biology of Light,* p. 89.

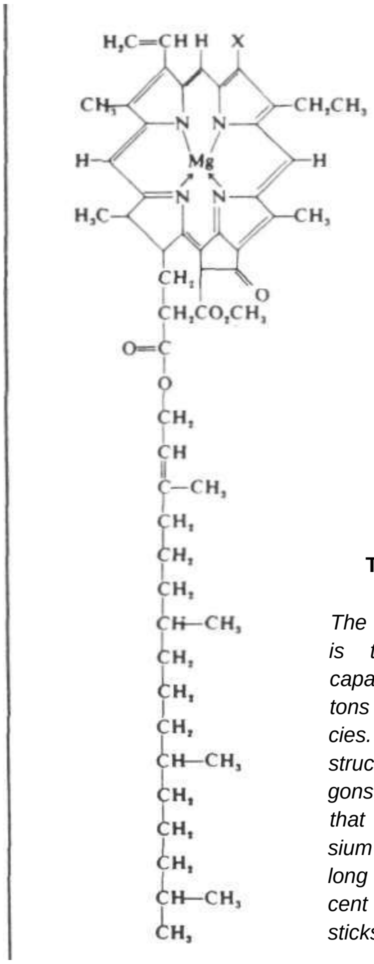


Figure 6
THE GEOMETRY OF CHLOROPHYLL

The chlorophyll molecule is the primary substance capable of capturing photons of specific frequencies. The geometry of its structure has four pentagons linked in a ring form that encloses a magnesium atom at the center. A long side chain, reminiscent of a rod antenna, sticks out from the ring.

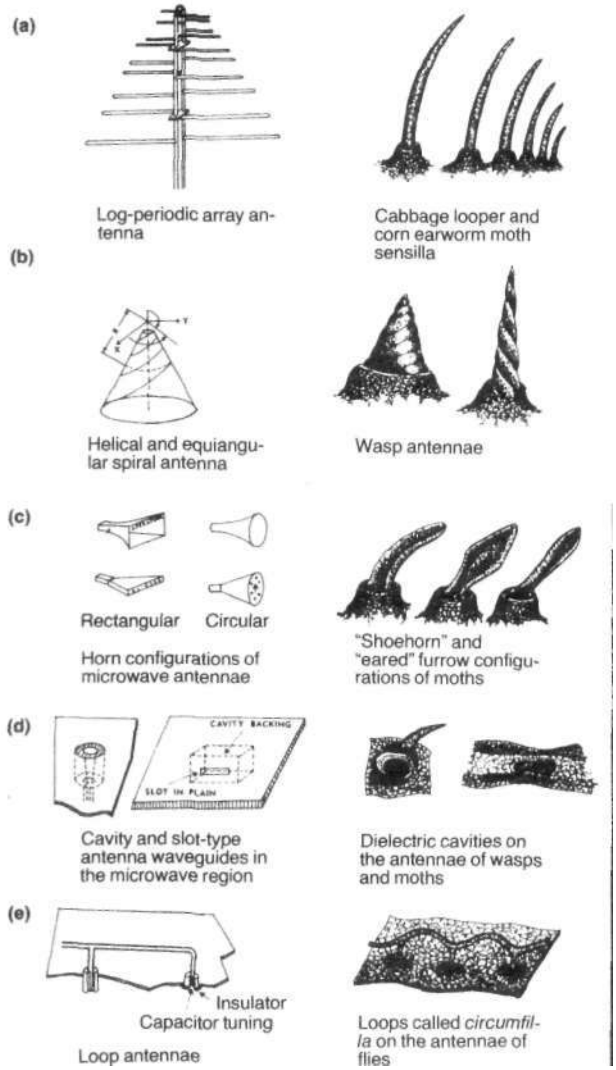


Figure 7
MAN-MADE ELECTROMAGNETIC ANTENNA AND INSECT COUNTERPARTS

Here are just a few of the types of electromagnetic antenna radiation collectors (left) and their insect dielectric counterparts.

Source: Philip S. Callahan, *Tuning in to Nature,* (Old Greenwich, Conn.: The Devin-Adair Company, 1975) p. 101.

In a simple experiment Popp succeeded in demonstrating that DNA, in fact, is the primary structure functioning as a "photon trap." Before measuring emissions from cucumber seedlings, Popp treated the cells with ethidium bromide, a red dye that penetrates the nucleus and selectively intercalates into DNA, unwinding the superstructures of this huge molecule. However, as researchers have discovered, the unwinding of the DNA molecule depends on the concentration of ethidium bromide, with the additional feature that at a certain point of concentration the unwinding comes to an end and suddenly, when the concentration is increased even more, turns into a rewinding (with opposite spin!).

Results of photon measurements of cells at different levels of dye concentration show an exact correlation of photon emission and the degree of DNA rewinding and unwinding (see Figure 5).

There are several conceptions about how DNA is capable of capturing, storing, and emitting photons, all of them still in the form of hypotheses. The situation is complicated, because electromagnetic action at the cell level is of such low intensity that it is hardly accessible with current technology. And, when we go down to the level of molecular interaction, we are at the subquantum range, that is, in a smaller space than that required to generate the smallest quantum of light action, a photon. Nevertheless, each molecule has an electric charge that identifies it like a fingerprint and may account for the highly specific functions in which each molecule is engaged.

Popp provides several indications that the DNA molecule might be a mini-antenna. First, calculations suggest that sunlight hitting the Earth, which is normally incoherent light, might turn into coherent light when it reaches very small surfaces. This surface area is in the range of 10 * square centimeters, which roughly corresponds to the size of a cell. Popp demonstrated this effect with his photon multiplier when he left a tiny slit in the measurement chamber corresponding to the size of a cell. The scattering light in

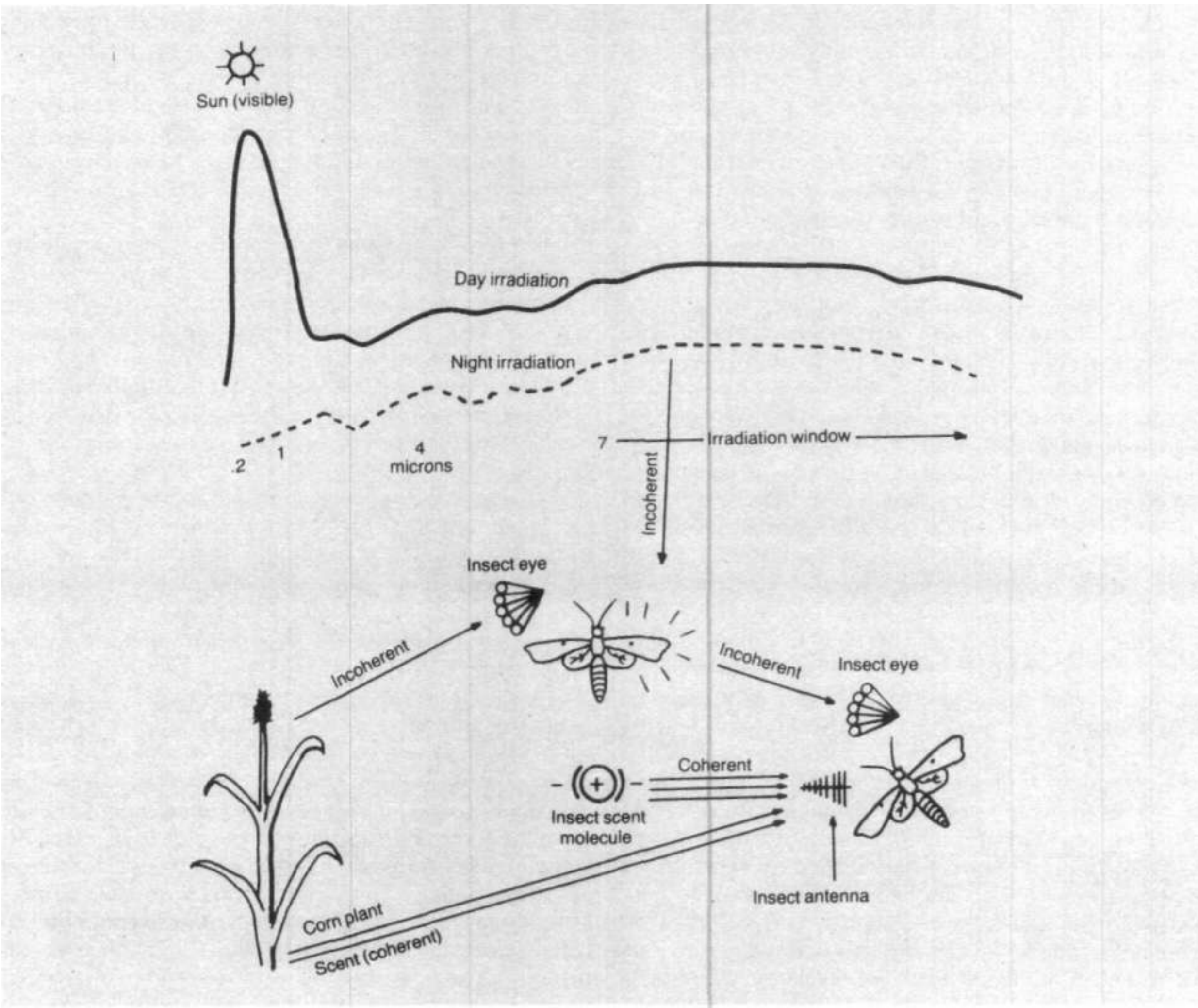


Figure 8
COMMUNICATION SYSTEM OF A NIGHT-FLYING INSECT
Philip Callahan's schematic of the infrared environment and communication system of a night-flying insect.

the chamber proved to be almost of the same coherence as the light emitted by living cells.

Also, the double helical form of DNA is known from technical designs to be an ideal form of an antenna, which can capture coherent radiation and even adjust itself to varying frequencies of incoming light. Furthermore, Popp found that the distance between two base pairs in the DNA molecule is 0.4 nm, which corresponds to the "resolution power" of the incident sunlight—the distance necessary for a photon to be generated or captured.

Nature knows a broad variety of antenna applications, all tuned to a specific frequency band and fulfilling specific functions.

(1) Probably the most well-known example of how light is used to generate life processes is photosynthesis, the ability of plants and some bacteria to produce carbohydrates from water, carbon dioxide, and sunlight. The chlorophyll molecule, also known as an "antenna pigment," is the primary substance capable of capturing photons of specific frequencies. Its structure (Figure 6) has a very interesting geometry: four pentagons tied together in a ring form, enclosing in its center a magnesium atom, with a long side chain sticking out—very reminiscent of a rod antenna of a radio receiver. Experiment has shown that small variations in the configuration of this side chain, which have no effect on the "chemical" properties of the molecule, significantly alter its absorption characteristic, shifting the frequency to longer or shorter wavelengths.

(2) The eyes of insects include crystalline cones that are effective infrared detectors. There are also indications that the rods and cones in the human retina are tuned antennae.

(3) Entomologist Philip Callahan has demonstrated that all aspects of insect life involving navigation are controlled by antenna functions, working specifically in the infrared region of the spectrum. Callahan wrote: "The moth antennae resembles in every way the shape of the antennae used

by the Royal Air Force to fool the Luftwaffe. The moth antenna, in fact, looks very much like a TV antenna—long bars (spines) at the base for long waves, and short bars (spines) at the tip for shorter waves."[4]

As Callahan has explained, his insight into the secrets of insect life was very much a product of the Allied war mobilization, where his task was to run a radar station in Ireland that beamed the navigation signals for the bombers to direct them to their targets. Without Callahan's insight, we would not know anything today about these obscure structures that sometimes make insects look like horror-film creatures. Callahan was convinced from the beginning that all these horns, sensillae, and antennae of short, straight, curved, or bent forms (see Figure 7) must have a purpose. Otherwise they would not have developed in that form.

Callahan also knew that if the "classic" molecular theory of smell and orientation of insects were true—that is, that scent molecules for different "smells" must stick on a "receptor" and trigger a chemical reaction leading to a nerve impulse—then all these mysterious and wonderful insect structures would be totally unnecessary and superfluous. Taking them as radar or radio antennae tuned to different wavelengths, the whole insect and its behavior suddenly make much more sense. A few measurements and calculations allowed Callahan to predict that the frequency to which insect antennae were tuned must be in the infrared. And in fact, in looking for an appropriate emitter of coherent infrared radiation, he found in spectroscopic analysis maser-like emissions from pheromone molecules (sex attractants) in exactly the bandwidth fitting the insect antenna.

The entire concept of insect communication, which Callahan has termed "insect molecular bioelectronics," is shown in very simple form in Figure 8. At the top is the infrared curve for visible daylight, and below the infrared curve for the nighttime environment. Radiation from such an environment takes three incoherent forms: (1) infrared light from the sky, which could possibly reflect from the moth's wings and enter into identification between moths as it does with butterflies in the daytime light in the visible region; (2) incoherent radiation from plants, radiated by moonlight; and (3) choppy, incoherent blackbody infrared of a vibrating moth. Coherent radiation could originate in the maser-like action of scents. Entering into such a communication system would be the incoherent receptors—the eyes and ocelli of the moths—and the coherent receptors—the dielectric polytubular antennae arrays of the insect.

With one crucial experiment Callahan proved that, for insects, infrared radiation alone is sufficient to allow orientation in space. He took the sex-scent of a female moth, put it into a bottle, closed it tight, and shined ultraviolet light on it, in order to amplify the emissions of the scent molecules. A male moth brought into the vicinity of the bottle reacted exactly as if the scent of a female moth had been right there. Yet there was no scent; there were only infrared emissions of the pheromone, and when the amplification of the scent was interrupted, the male moth went back to normal!

Science in this form is not only exciting, because we are discovering something real, but is precisely in the tradition *of* Leonardo's scientific method—trying to understand phenomenain naturebyaskingtheirpurpose. Itisthesame method Bernhard Riemann applied when he studied the functioning of the ear and was stunned by the tremendous sensitivity of its mechanical apparatus. In an 1866 essay on "The Mechanism of the Ear," Riemann said:[5]

> In order to account for what the organ actually accomplishes, we look to its construction. In our search for this explanation, we must first of all analyze the organ's task, the problem it must solve. This will result in a series of secondary tasks or problems, and only after we have become convinced that these must be solved, do we then look to the organ's construction in order to infer the manner, in which they are solved.

This was also Callahan's approach to the problem of insect antennae: starting with an appropriate hypothesis about the necessary function and continuing to ask the right questions, instead of resorting to the accepted textbook theory of molecular action—that is, systems analysis.

The work of Callahan and Popp is of tremendous practical importance. With Popp's insights into cellular life processes, we might be able to open a new chapter in areas like genetic engineering, cancer research, or laser technology, while Callahan's research simply demands application in insect control. As soon as we can build cheap, small lasers to imitate infrared emission of insect pheromones, we could attract any bug or mosquito to any place we want. If we could tune into the right frequency for the malaria mosquito, for example, and find some means to destroy the insects as they approach the light source, malaria could be eradicated worldwide in a short period of time. This laser insecticide is extremely versatile, and able to target any insect much more selectively than a chemical pesticide can.

Unfortunately, scientists like Popp and Callahan are condemned by their systems-analysis and molecular-oriented colleagues to work in virtual isolation. To find new answers to the question of what life is all about, we have to revive the science tradition of Leonardo da Vinci and Riemann on a broad scale.

Wolfgang Lillge, M.D. is on the staff of the Fusion Energy Foundation. He recently participated in a series of FEF seminars on optical biophysics.

Notes

1. Fritz-Albert Popp's book, *Biology of Light: The Basis for Ultra-Weak Cell Radiation,* was published in German by Paul Parey in 1984. The author's technical review of Popp's work appears in the *International Journal of Fusion Energy.* April 1985, p. 58. An article in English by Popp, "Principles of Quantum Biology As Demonstrated by Ultra-Weak Photon Emission from Living Cells," appears in the *International Journal of Fusion Energy,* Oct. 1985.
2. A nanometer is one-billionth of a meter, the frequency of light in the visible spectrum.
3. An article by Callahan for the layman, "Insects and the Battle of the Beams," describing his work appears in the Sept.-Oct. 1985 issue of *Fusion,* p. 27.
4. "Insects and the Battle of the Beams," p. 34.
5. The first English translation of Riemann's 1866 essay, "The Mechanism of the Ear," appears in the Sept.-Oct. 1984 issue of *Fusion,* p. 31.

An inside look at rocket development, from the A-4/V-2 work in prewar Peenemunde in northern Germany to the U.S. Space Shuttle, highlighting the role of one of the key German scientists, Dr. Krafft A. Ehricke.

From the First Large Guided Missile To the Space Shuttle

A PICTORIAL HISTORY

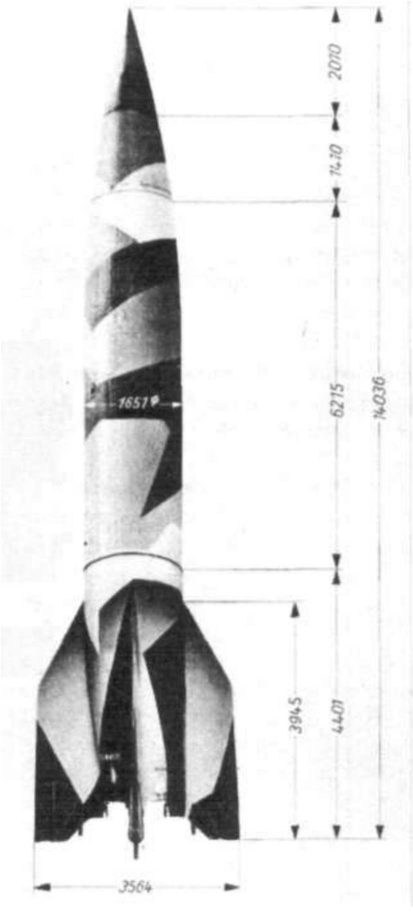


Figure 1
THE V-2 **ROCKET**
This was an important milestone in the history of rockets, marking the change from solid to liquid propellants.

Illustrations are courtesy of Konrad Dannenberg. the Alabama Space and Rocket Center, and NASA.

by Konrad Dannenberg

The design and development of the world's first large guided missile, the V-2, or the A-4 as it was named by its developers, was greatly influenced by the studies of Professor Hermann Oberth and his 1923 book *Methods to Space Travel* (Wege zur Raumschiffahrt), in which he laid out all key principles of rockets. Krafft Ehricke as well as Wernher von Braun were ardent scholars of Professor Oberth's writings.

Why was the V-2, shown in Figure 1, such an important milestone in the history of rockets and space vehicles? After all, rockets had been built and used before and certainly presented no drastically new idea in regard to the principle of their operation. In fact, rockets had been used for warfare purposes for hundreds of years. The Chinese had been doing it, as documented, since 1232, and the British and Danish artillery battalions had used rockets. Therefore, what really was the big step taken with the V-2?

After the Cerman army began to put money into projects to build big rockets in 1932, von Braun decided to use liquid propellants not only for performance reasons, but also for necessary controllability as well as for safety considerations. Most of the mishaps at that time were related to the use of solid propellants. Solids are very difficult to control, particularly in regard to their cut-off accuracy. Of course, von Braun also knew from Professor Oberth's book that liquid hydrogen and oxygen were theoretically the best propellant combination

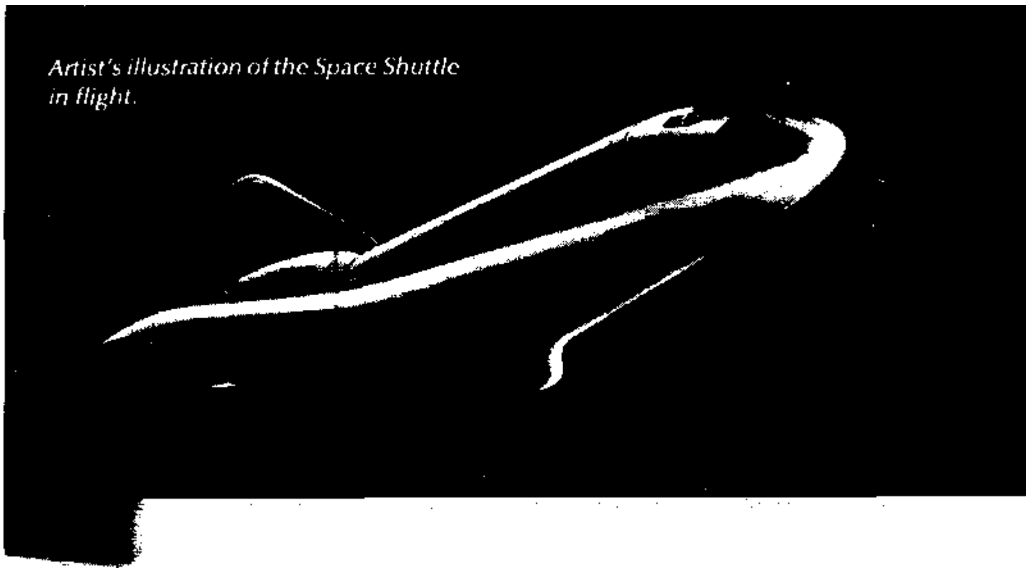

Artist's illustration of the Space Shuttle in flight.

Figure 2
ROBERT GODDARD AND HIS ROCKET LAUNCH STRUCTURE
Coddard's launch structure was typical of rocket activities all over Europe at that time.

Figure 3
AERIAL VIEW OF ALABAMA SPACE AND ROCKET CENTER
The history of modern rocketry includes the smallest, the V-2, standing in front of the largest, Saturn I.

Figure 4
FIELD PREPARATION FOR A V-2 ROCKET
The V-2 was built as an easily deployed military weapon.

available. This is still true today; we can still build better liquid rockets than we can build solid propellant rockets.

At the time when Dr. von Braun started the A-4/V-2 development, rocket activities in the United States were typified by the work of Professor Robert Coddard. His rocket launch structure, Figure 2, was typical of the type being built all over Europe at that time. Like Professor Goddard, many people had drawn the conclusion that the best way to go was to use liquids. Coddard did not want to build artillery shells that could fly over very large distances; he only wanted to reach higher altitudes for his research rockets. Yet he also decided that just to obtain the desired altitudes, he needed to use liquid propellants.

In the photograph, the rocket chamber is at the top of his configuration; the combustion chamber is in front of the nozzle.Atthetime, Professor Goddard puthistanks behind the rocket motor, since he did not develop a working guidance and control system until later. Below in the photo are the tanks where Goddard stored his propellants. The pressure generated by heating propellants from the exhaust in the tanks fed through the tubes in the side, then into the rocket engine. This was, of course, a very primitive method that Goddard employed to avoid a heavy pressurization system or a complicated turbopump. The main shortcoming of this method was that it did not always create a sufficient thrust to lift his rockets off the launch pad.

Goddard's greatest problem, however—unfortunately, for this country—was that he did not get federal support. I am sure if he had had the funds that were made available in Peenemiinde for the development and the production of the V-2, Goddard probably would have arrived at very similar solutions to those of von Braun.

Von Braun's advantage was that the military was willing to invest in a major way in rocketry. Military representatives watched the early rocket tests often and became convinced of the benefits of rockets. The Treaty of Versailles after World War I had forbidden Germany to have heavy artillery, so there was a strong incentive to come up with a replacement, and this led ultimately, to enabling von Braun to develop and build the V-2.

In the aerial view of the Alabama Space and Rocket Center, Figure 3, the V-2 rocket is the little one standing in front of the tallest rocket in the photo, a Saturn I. Krafft Ehricke, together with Pratt and Whitney Aircraft Corporation, developed the engine for the second stage of Saturn I. Next to the V-2 are two or three Redstones; they are the slender ones and the fat one is a Jupiter. In the foreground, lying on the ground, is a Saturn V. Thus in one picture we have an overview of rocket history.

The basic method of deployment of the V-2, which was built as a military weapon, is shown in Figure 4. It could be prepared for launch in the little shed in the back, pulled to the launch site either on a relatively simple road transporter, or, as is shown here, on two dollies running on small-gauge railroad tracks and pulled by a locomotive. At the site, it could be erected on a launch table, fueled, and launched. The V-2 was empty until it was erected; the tanks were filled only after it was in its launch position.

In Figure 5, we see a V-2 being prepared for launch in 1941. The guidance and control system had to be placed on top of the vehicle, and quite a bit of servicing also had to be performed down at the power plant.

Peenemiinde

PeenemiJnde, the German rocket center, was located in the northern part of Germany, in the state of Mecklenburg. Figure 6 is a map of northern Germany at that time; now Poland extends over two-thirds of this area. Peenemiinde is very advantageously located on the island of Usedom; you can see the potential trajectory emanating from the area. Peenemunde's location had several unique advan-

Figure 5
PREPARATION FOR LAUNCH
The guidance and control system was placed on top of the vehicle, as shown in this 1941 photo of a V-2 being prepared for launch.

Figure 6
LOCATION OF PEENEMUNDE
The *German rocket center was located in northern Germany near the Baltic Sea coast.*

Figure 7
MORE DETAILED MAP OF PEENEMUNDE
At the top of the map is the test stand shown in Figure 5. A short distance to the south were the assembly facilities.

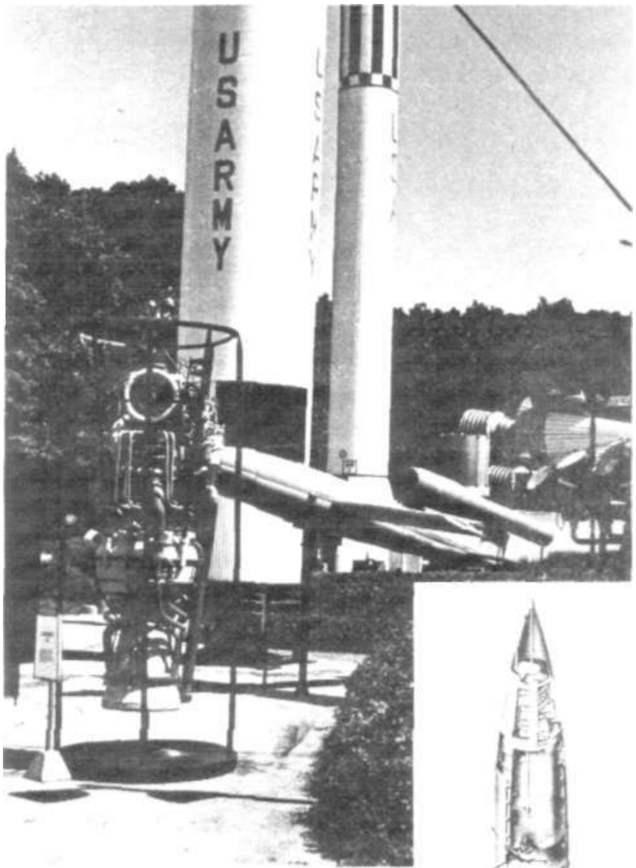


Figure 8
THE V-1 **PULSE JET**
The gray body in the foreground is the V-1, an automatically operated and controlled airplane with a pulse jet as its power plant.

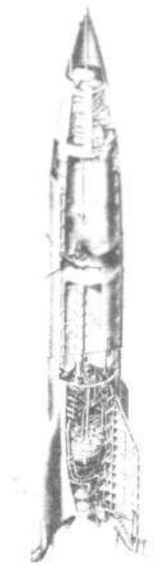


Figure 9
CUTAWAY VIEW OF **THE A-4**
This was later renamed the "V-2" rocket by propaganda minister Joseph Coebbels.

tages. First, the area was sparsely populated, so the land was cheap and people were not endangered by the launching of these vehicles. Second, the vehicles could be launched along the coast of Germany at that time with a range of about 200 to 300 kilometers, so that the impact could be observed.

A relatively small river called the Peene flows through Mecklenburg, then empties into the Baltic Sea, and at the mouth of that river you find Peenemunde. On the other side, now Polish, is Swinemunde with a similar, smaller river, the Swine. The island of Usedom is between these two rivers.

A more detailed picture of Peenemunde itself, in Figure 7, shows the test stand from which the missiles were fired. The test stand shown in Figure 5, called the *Prufstand* No. 7, is at the top of the map. A little bit farther south was one of the first test stands, accordingly called *Prufstand* No. 1. Still a little bit farther south were the assembly facilities. It was a relatively short distance from the assembly facility to the test stand area. A little farther west of the test site was an Air Force test station, with its own air field. The black spot you see almost all the way on top is a launch site for a V-1 .The V-1 was not a rocket and should not be confused with the V-2 rocket, as you can see in the photograph in Figure 8, taken at the Space Center at Huntsville. The gray body in the foreground is a V-1, which was basically an automatically operated and controlled airplane. It had a pulse jet as power plant, which is the tube on top of the airplane-type structure. Since it sucked in air from the outside, it was not a rocket, which always carries its own oxygen supply. A V-2 power plant is in front, while behind are some U.S. Army missiles; the front one is a Jupiter, with a Redstone behind it.

Figure9isadetailedpictureoftheA-4, which propaganda minister Joseph Coebbels later named the "V-2," for *Vergeltungswaffe* or vengeance weapon. It was a follow-on to

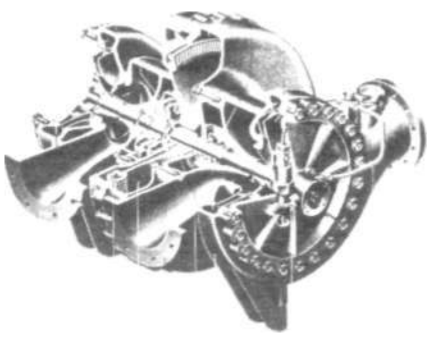


Figure **10**
CUTAWAY VIEW OF TURBOPUMP
The turbopump was needed to build a rocket light enough to be launched vertically.

Figure **11**
THRUST CHAMBER OF THE V-2
The propellants were fed in at the top under high pressure and operated at about 20 atmospheres of pressure.

the V-1. The technical people and al existing documents, however, used the term "A-4," *Aggregat 4.* There was also an A-1, A-2, and A-3; in fact, before the A-4 was developed, a half-scale version, the A-5, was used for early research.

Krafft Ehricke, who was a major contributor later to the U.S. rocket program, came to Peenemunde in early 1942. He was assigned to Dr. Walter Thiel, who was in charge of all propulsion developments. Thiel had decided to cluster the individual combustion elements into a basic combustion chamber. He conceived the "steamplant" to drive the turbopump, as well as many other propulsion features that are typical of the V-2. Unfortunately, he was killed in August 1943, during the first major air raid on Peenemunde.

I also worked for Dr. Thiel and was selected to tell Ehricke about all these unique features. We discussed such items as the turbopump shown in Figure 10, which was needed to build a rocket light enough to be launched vertically.

Most of the early rocket pioneers could not launch their rockets straight up because the technology did not yet exist to generate more thrust than the weight of the rocket. The concept of a turbopump overcomes this problem. The oxidizer pump is in front, a fuel pump is on the far side, and a turbine is in the middle. By driving the turbine at a pretty good speed, both propellants, the liquid oxygen and the fuel—in this case 75 percent ethyl alcohol—can be put under high pressure and injected into the rocket engine. This must be done to get a high thrust level, while the pressure in the two propellant tanks can remain low to minimize the rocket weight.

The thrust chamber is shown in Figure 11. The combustion chamber (at the top) is fed with propellants under high pressure and operated at about 20 atmospheres of pressure on the inside. The combustion temperature is also very high, so the chamber walls have to be cooled. The A-4 uses the fuel as a coolant. It enters at the bottom of the combustion chamber, flows through the double wall of the corn-

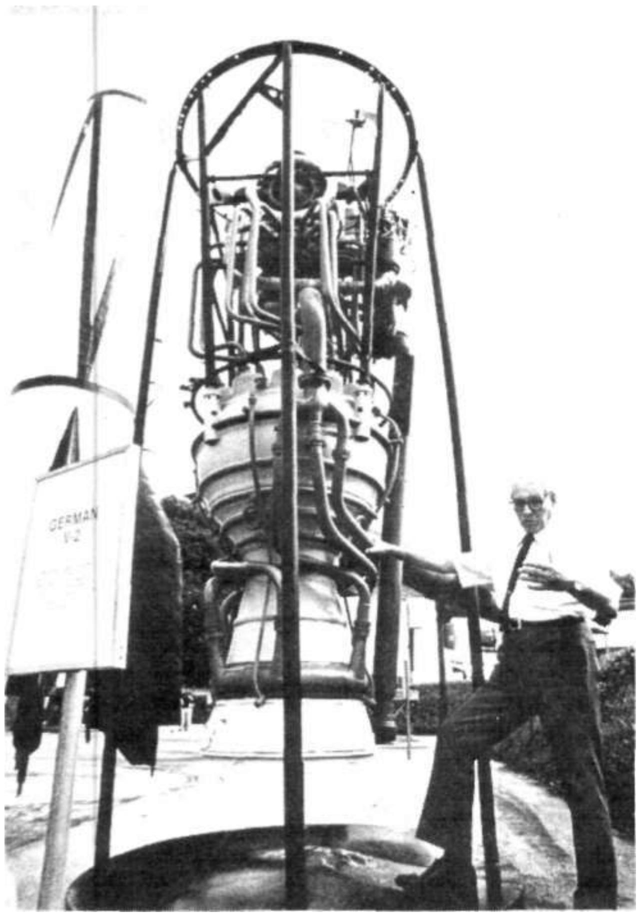


Figure 12
THE V-2 ENGINE
The author is shown with the V-2 model at the Alabama Space and Rocket Center.

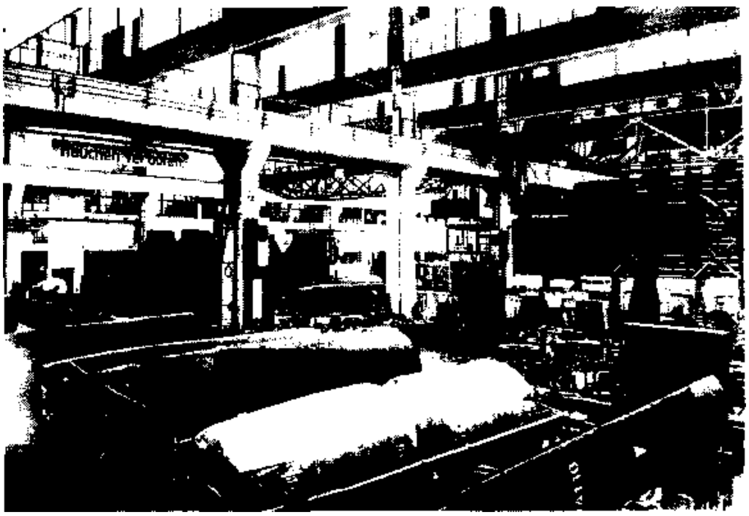


Figure 13
ASSEMBLY OF V-2 CENTER SECTION
The center section included a fuel tank (left) and a liquid oxygen tank (right).

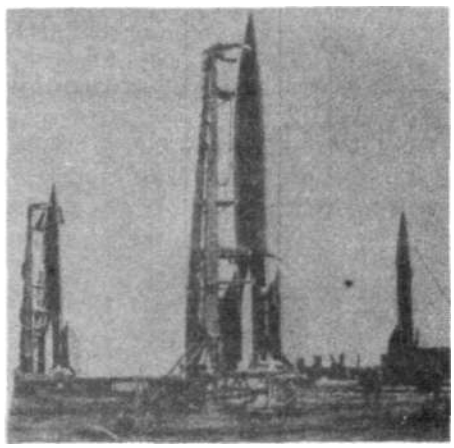


Figure 14
THREE V-2s AND THEIR ERECTION EQUIPMENT
Trained soldiers of a rocket battery were expected to launch all three V-2s within a two-hour period.

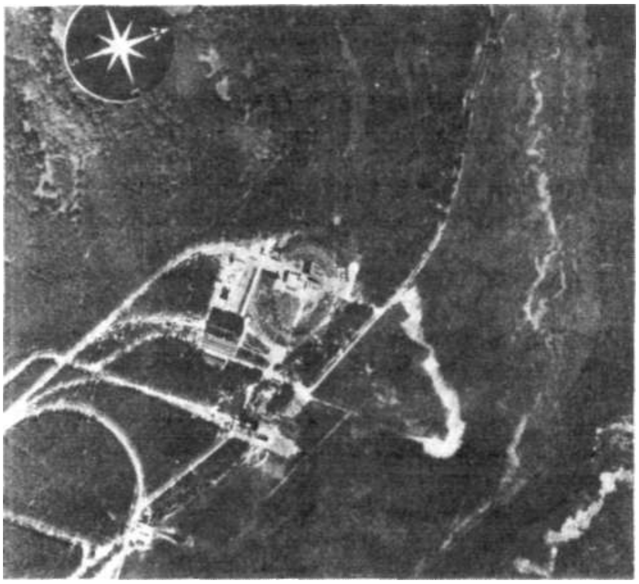


Figure 15
BRITISH INTELLIGENCE AERIAL VIEW OF PEENEMUNDE
This photo was taken less than a month before the first air raid on Peenemunde.

Figure 16
GENERAL J. BRUCE MEDARIS AND THE REDSTONE
Major-Ceneral John Bruce Medaris took the V-2 development experience and applied it to U.S. Army programs.

bustion chamber, and then finally enters into the individual combustion elements of the rocket engine.

My very first job when I came to Peenemunde was to design and develop these individual combustion elements, which had an individual thrust rating of 1,400 kilograms. Eighteen of them were "clustered" in order to generate the 25 tons of thrust needed to lift off with a 12-ton A-4 completely fueled. At the top of Figure 12 is the turbopump, and a little farther to the right is the equipment needed to drive the turbine. To provide power to the turbine, Dr. Thiel decided to use hydrogen peroxide from a relatively small pressurized container that pushes the hydrogen-peroxide through a catalyst bed. There it is decomposed into superheated water steam with some oxygen in it; these gases drive the turbine.

The assembly of the A-4 center section is shown in Figure 13. The two tanks are in front; the left one is a fuel tank, the somewhat smaller one the liquid oxygen tank. The fuel tank is conical in front. Both tanks were assembled inside of two half-shells, which make up the center section, a separate building element. The tanks were not "integral" as they are today for more modern launch vehicles.

Ehricke was given an overview of these systems and his assignment was to write the first complete handbook on the A-4, the A-4 *Fibel* or primer. He documented exactly how the A-4 worked technically, describing it in simple grade-school language, so that any German soldier—who very often was not too well-educated—could understand and eventually operate and launch the A-4 without any mistake. Ehricke also had to see to it that the trained soldiers of one rocket battery could eventually handle their complement of three A-4s, and launch all three of them within a two-hour period. Three A-4s with the erection equipment, which was attached to a transporter vehicle, a *Meiler-Wagen*, are shown in Figure 14.

Ehricke's instructions told the soldiers exactly what had

Figure 17
THE V-2 IMPACT AREA
London, the main target for the V-2, is toward the middle of the map. The other circled area showing off-target impacts is Norwich.

to be done and what support equipment was needed to launch all three within the allotted time period. This included pulling them to the launch site, erecting them, and filling the various tanks with the two main propellants, the hydrogen-peroxide and the liquid catalyst. The guidance systems had to be adjusted and aligned, which required knowing exactly in what direction the vehicle was to be launched in order to hit the invisible target. Missile range was determined by cutting the engine off at the exactly right time. The soldiers used target tables *(Schluss-Tafeln)* to get the proper alignment. The engine cutoff *(Brennshluss)* was given by the first automated computer, which was on board the A-4. Unless they were stopped by air raids, all trained rocket batteries could fulfill these tasks.

This aerial photo of Peenemunde in Figure 15 was taken by British Intelligence less than a month before the first air raid took place. The test stands were not destroyed during the raid, since they were designed and built to withstand explosions of rocket engines. The buildings where the A-4s were assembled, the office buildings, and maintenance shops, however, were destroyed. Therefore, the entire operation was dispersed over the entire island of Usedom and a portion of the organization moved to the mainland.

The U.S. Army Rocket Program

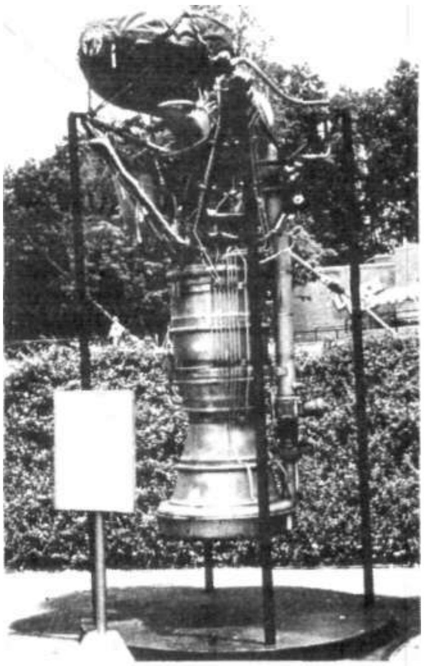
Let me jump ahead about 10 years and talk about missile and launch vehicle developments in this country. Col. Holger N. Toftoy (later Major General) was instrumental in bringing the "von Braun Team" to Ft. Bliss, Tex., where more than 50 A-4s were launched by the group from the White Sands Proving Ground in New Mexico. In 1950, the "team" transferred to Huntsville, Ala., where there were more permanent facilities.

One of the key figures in the early Army days was Major-General John Bruce Medaris, Figure 16, who had recognized the advantages of guided missiles and rockets and had very ambitious plans for the role of the U.S Army. General Medaris was instrumental in taking the A-4/V-2 development experience and applying it to Army programs. That is why he is shown here with a Redstone missile, an IRBM-Jupiter, and also a Jupiter C, which is an improved Redstone, modified for scientific purposes and little more powerful than the military model.

Even while still in Peenemunde, the von Braun team had already recognized the shortcomings of the A-4. This is illustrated in Figure 17, a British Intelligence photograph that shows the large area of A-4 impacts. In the center of the map is London; a little bit farther up is the city of Norwich. Of course, the intent was to hit downtown London with all the V-2s, but you see what actually happened! The V-2 was not completely ready for military use; in fact, the technical people were opposed to its deployment at that time; nonetheless, a political decision was made. The Nazi leadership decided that the V-2 must be used regardless of its development status, and these are the results of that decision.

Many of the misfirings were caused by the ineffectiveness of the stabilization fins after the rockets returned from above the atmosphere. Many V-2s, therefore, came down "broadside" and broke up, missing the target. Others had development problems and never obtained the desired trajectory. The U.S. Army decided, therefore, to develop an advanced version of the A-4 for the Redstone missile, which would eliminate many of the trouble spots. Figure 18 shows the Redstone. The warhead can be separated from the rocket. This did not make it a two-stage vehicle, because the warhead was not propelled, just accurately controlled. This however, was sufficient to overcome the problem of reentry, when the rocket would break up and be lost. Now the guided warhead reentered under proper control and hit the target. This cleared the way for all missiles in use today.

Because the Redstone was the first large missile in the



•^ **Figure 18**
THE REDSTONE MISSILE POWER PLANT
This is an advanced version of the V-2 engine.

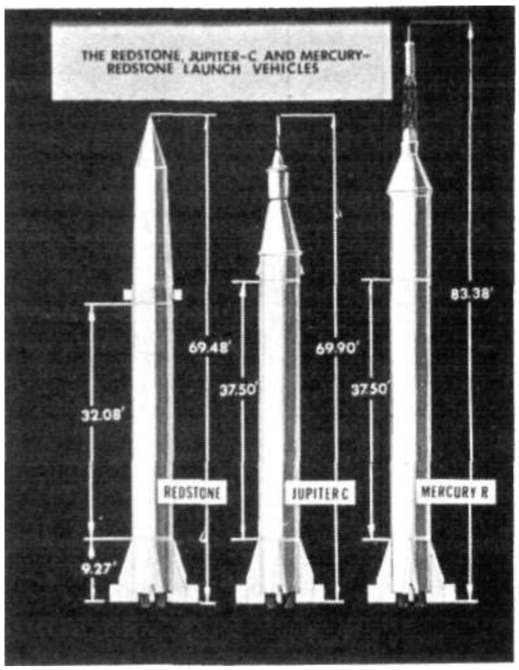


Figure 19 •
THE REDSTONE WITH VEHICLE CONFIGURATION
Shown from left to right are configurations depicting the varied uses of the Redstone: military ballistic missile, multistage Explorer satellite launcher, and Mercury version for manned launches.

Figure 20
THE FIRST U.S. SATELLITE LAUNCH
The *launch of this Explorer satellite was to catch up with Russian space accomplishments in the framework of the International Geophysical Year—1957-1958.*

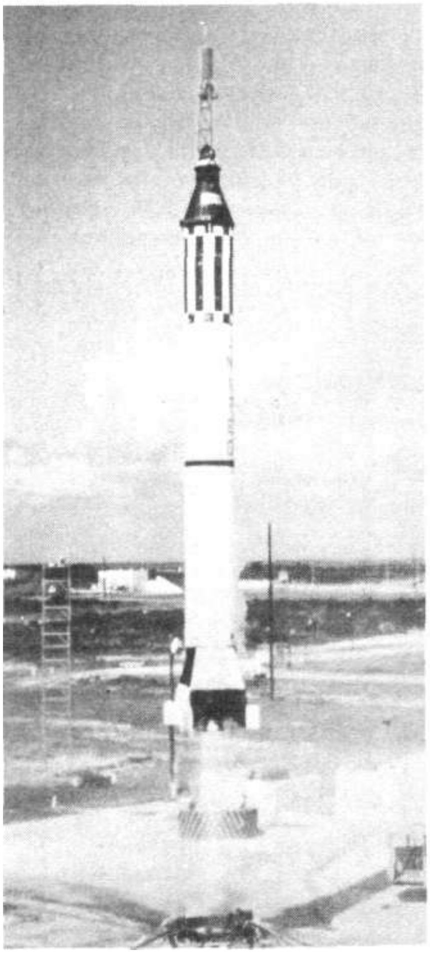


Figure 21
A MERCURY LAUNCH
Mercury was used to put the first two American astronauts into space.

U.S. arsenal and turned out to be extremely reliable, it was also used as a launcher for scientific missions and the first two manned U.S. flights. The three basic versions of the Redstone are shown in Figure 19: on the left is the military ballistic missile; in the center, the multistage Explorer satellite launcher; and at right, the Redstone Mercury version for manned launches.

An early follow-on project of the Army was to replace the warhead of the Redstone missile by a supersonic ramjet vehicle, (sometimes referred to as an "aethodid"), which could carry the military payload over a range of about a thousand miles. Ehricke was asked to design, develop, and test the air intake of this supersonic projectile, since he had an outstanding mathematical knowledge and among the German scientists was the one with the best backround for this type of novel studies. He made excellent progress with his investigations, but the Army decided that such a vehicle, flying at the rather slow speed of Mach 3, was too prone to enemy countermeasures, and the project was dropped.

It was at this time that Ehricke decided to leave the von Braun team, since he felt that the group was too conservative, applying essentially the old conventional A-4 technologies. He was convinced that Professor Hermann Oberth's approach of using liquid hydrogen as fuel for advanced missions, would eventually be necessary for more ambitious missions to the Moon, the planets, and deep space. He joined the Bell Aircraft Company in Buffalo, N.Y., but left there fairly soon to go to the Convair Division of the General Dynamics Corporation in San Diego. There he was soon appointed manager of the Centaur Project, the development of an upper stage for the first U.S. ICBM, the Atlas, which had also been developed by Convair and already been deployed.

In the meantime, the U.S. Army adapted a Redstone missile to the satellite configuration. The launch of this Explorer satellite, shown in Figure 20, was an effort to catch up

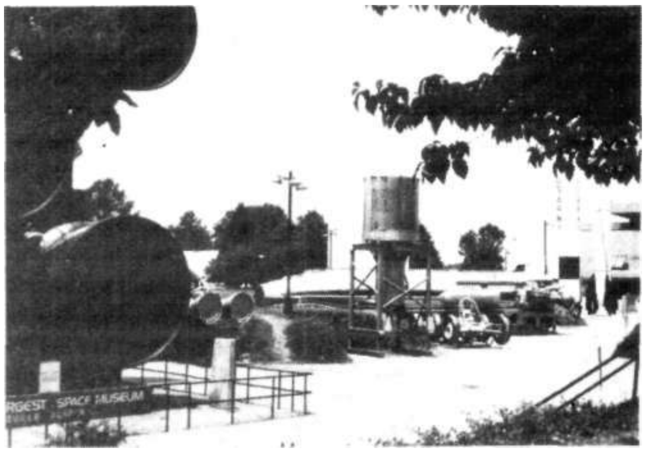


Figure 22
THE ATLAS MISSILE (IN BACKGROUND)
Forthe orbital flights, John Glenn and three other astronauts used the Atlas as a launch vehicle.

with Russian space accomplishments in the *framework* of the 1957-58 International Geophysical Year. The entire assembly at top of the Redstone had to be spun at about 50 revolutions per minute to keep the satellite stabilized after its separation from the booster.

A little later, the Redstone, adapted to the Mercury configuration, was used for the first two American suborbital flights, which put the first two American astronauts into space on top of what was called "Old Reliable." One of these launches is shown in Figure 21. The orbital flights with John Glenn and three other astronauts used an Atlas launch vehicle. The Atlas ICBM is shown in Figure 22, somewhat hidden behind a nuclear engine and a test vehicle to study some typical design features of a lunar rover.

While these events put the von Braun team in the limelight *of* national attention, Ehricke was working on the Centaur upper stage for the Atlas launch vehicle. This combination, which would be propelled by two RL-10 liquid hydrogen engines, is No. 6 in the series of U.S. launch vehicles in Figure 23.

The Centaur upper stage provides the Atlas-Centaur combination with outstanding performances for space missions, especially for planetary flights. The Huntsville Space Center has an ICBM-type Atlas missile on display, but no Centaur combination. However, here is an excellent cutaway model of an RL-10 engine (Figure 24), which the Space Camp uses to instruct youngsters. This is the first liquid-hydrogen-propelled engine ever built and flown. Krafft Ehricke was instrumental in its concept and development, together with Pratt and Whitney, the builder and manufacturer of this most successful engine. The double wall of the A-4 and the Redstone engine were replaced by a system of individual, small stainless steel tubes, properly preshaped and soldered together to make up the combustion chamber. A lot of weight can be saved this way, and the cooling characteristics are much better than with the earlier de-

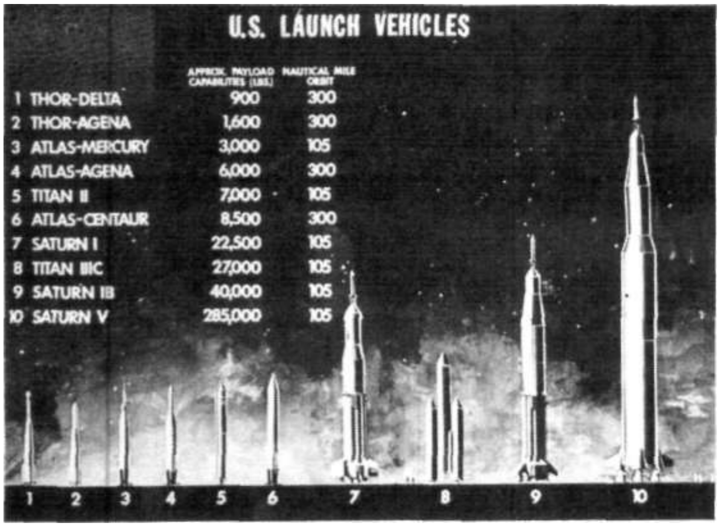


Figure 23
U.S. **LAUNCH VEHICLES**
The Centaur upper stage, designed by Krafft Ehricke, is No. 6, shown in combination with an Atlas launch vehicle.

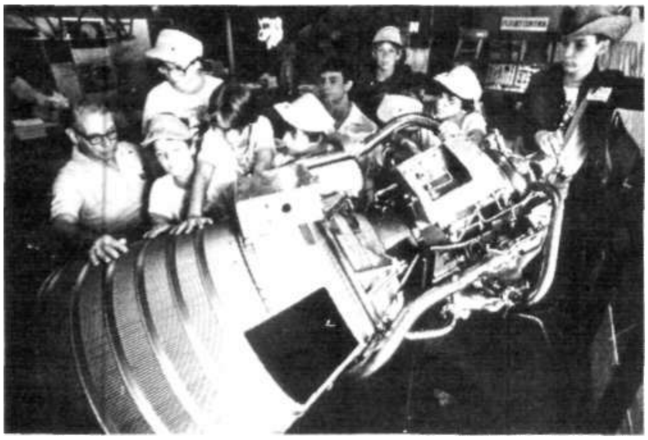


Figure **24**
THE RL-10 ENGINE
This cutaway model of the RL-10 is on display at the Huntsville Center.

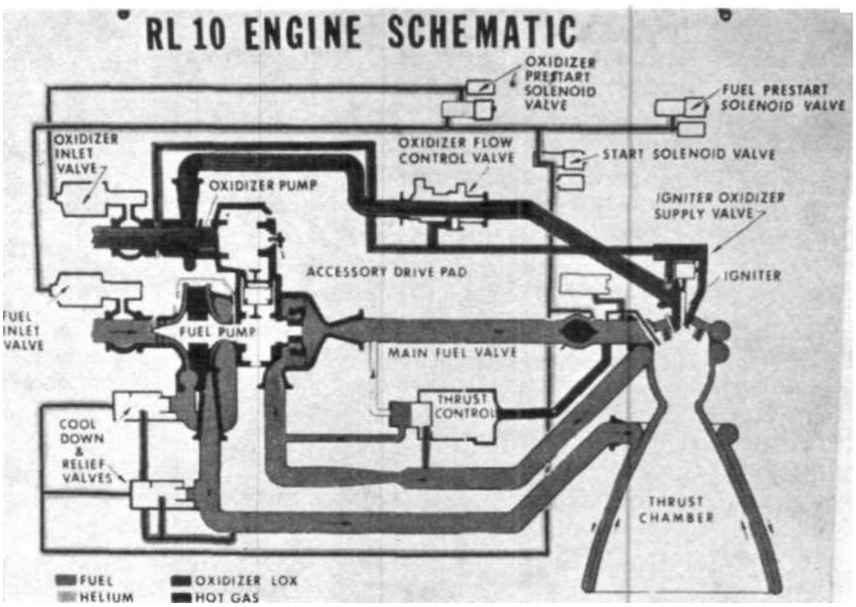
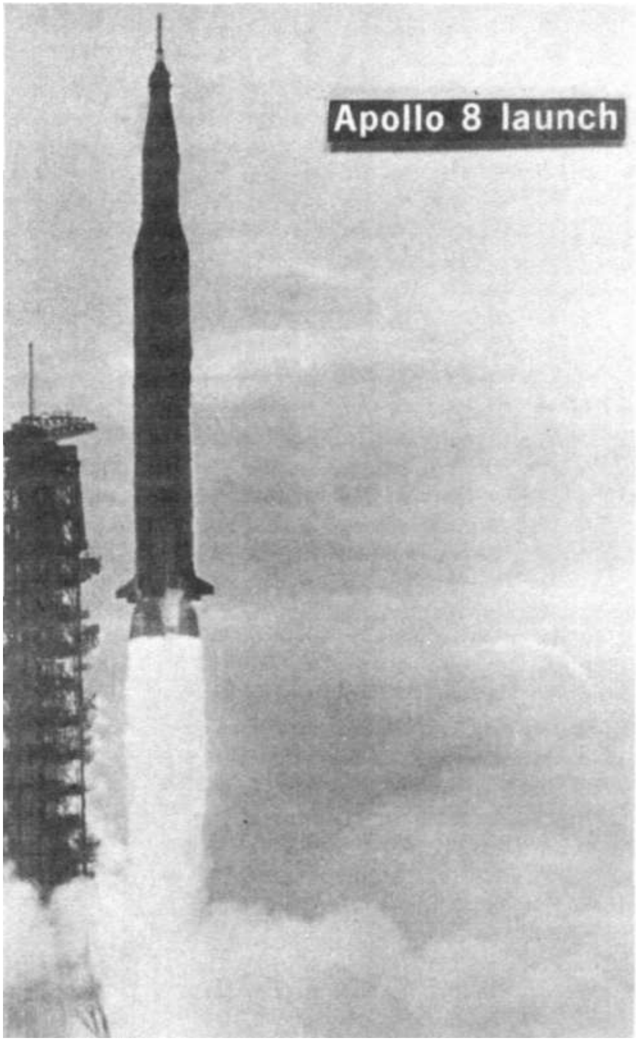


Figure 25
RL-10 **ENGINE SCHEMATIC**
This was the first engine to use liquid hydrogen as fuel for the propulsion system.



signs. This permits higher combustion temperatures, higher pressures inside of the chamber, and, therefore, higher performance.

The RL-10 engine schematic shows, in Figure 25, other typical features of this novel engine. Liquid oxygen enters the engine at the inlet valve (top left). This valve starts and cuts off the oxidizer flow by opening and closing. The oxygen pump will pressurize the liquid oxygen and feed it through a control valve directly into the combustion chamber, where it will react with the liquid hydrogen to generate the combustion gases for propulsion.

The liquid hydrogen has to go through a more treacherous flow path: Another inlet valve controls the hydrogen flow. The fuel pump pressurizes the hydrogen to a much higher pressure than the one on the oxygen side, since the hydrogen will pass through the large number of thin stainless steel tubes at very high flow rates. This process cools the combustion chamber; it also heats up the hydrogen fuel to such a degree that the hot fuel can now be used to drive the turbine of the propulsion system. This is a very unique feature of the RL-10 engine. After the hot fuel has passed quite a bit of its energy to the blades of the RL-10 turbine, it finally enters the combustion chamber, where it reacts with the liquid oxygen and generates the propulsive force of the rocket engine.

Since the RL-10 engine in the Centaur upper stage had a number of successful flights, it was also used in a cluster of six engines to propel the second stage of the Saturn I launch vehicles. The six engines, which generate a total thrust of 90,000 pounds, propelled three Pegasus satellites into Earth orbit for micrometeoroid studies in the early phases of the manned space program. Ehricke's pioneering work with liquid hydrogen propulsion systems contributed essentially to all these accomplishments—to the later designs of the J-2 engine for the upper stages of the Saturn IB and the Saturn V launch vehicles, as well as the main engine of the Space Shuttle.

Figure 26
APOLLO 8, FIRST MANNED FLIGHT AROUND THE MOON
This mission demonstrated that all of the technical requirements for a lunar landing were met by the Apollo design.

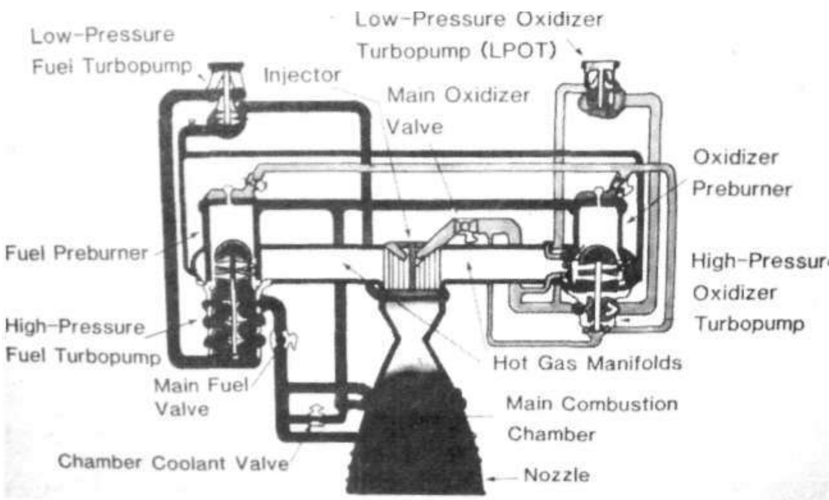


Figure 27
SPACE SHUTTLE MAIN ENGINE CHARACTERISTICS
The groundwork for this design was laid by the earlier efforts of Krafft Ehricke, as well as the German team of rocket scientists and engineers, who had always dreamt about space stations in Earth orbit.

The Age of Space Exploration

The results of these early endeavors were summarized in the flight of Apollo 8 around the Moon, Figure 26. Although commander Frank Borman and his crewdid not land on the Moon, the mission demonstrated that all the technical requirements for a lunar landing had been met by the Apollo design. For the first time, man had left Earth orbit and was getting ready to set foot on another body on the solar system. The age of space exploration was now really opening its doors to mankind.

The Space Shuttle is, of course, the next major step. Here in Figure 27 is a schematic of the Shuttle's main engine, which uses two turbopumps to assure a quicker engine start for liftoff than is obtainable with the RL-10. The groundwork for this design was laid by the earlier efforts of Ehricke, and the German team of rocket scientists and engineers, who had always dreamt about space flight as a follow-on to military rockets.

An early concept of a space station, shown in Figure 28, is similar to the id eas of Hermann Oberth and Von Braun. Many people believed in earlier times that man needed simulated gravity in order to function and to survive in the weightlessness of orbital flight. Therefore, it was proposed to generate such simulated weightlessness by rotating the entire station around its axis. In modern designs this assumption is no longer made; for reasons of simplicity and cost savings, today's versions are rather simple configurations, like the one proposed by NASA's Marshall Space Flight Center in Figure 29. Here a Space Shuttle is approaching the station, at which a large radio antenna is under construction, using a manipulator arm and an astronaut to aid in its assembly.

Looking toward our future, Figure 30 shows a group of young future astronauts at the Alabama Space and Rocket Center. They are at Space Camp for a week, learning about space and spaceflight. They are taught that they will even-

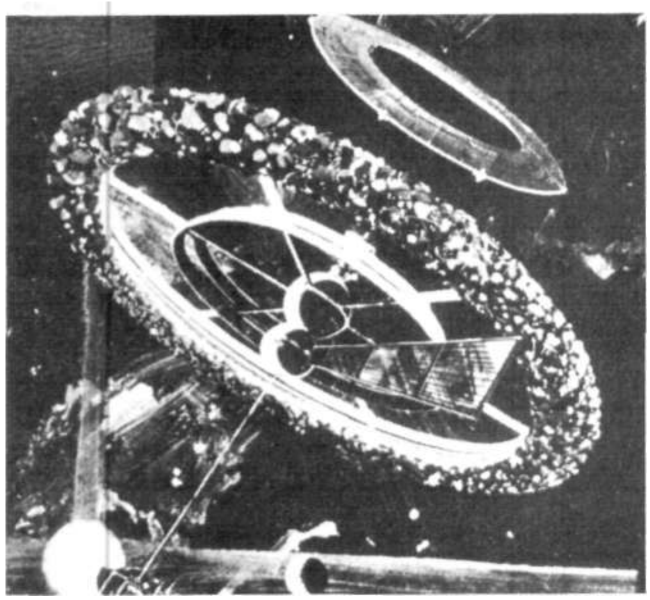


Figure 28
EARLY SPACE STATION CONFIGURATION
To *simulate gravity, the entire station rotated around its axis.*

Figure 29
CURRENT NASA SPACE STATION CONFIGURATION
Simplicity and cost savings, rather than simulated gravity, are considerations in modern space station configurations.

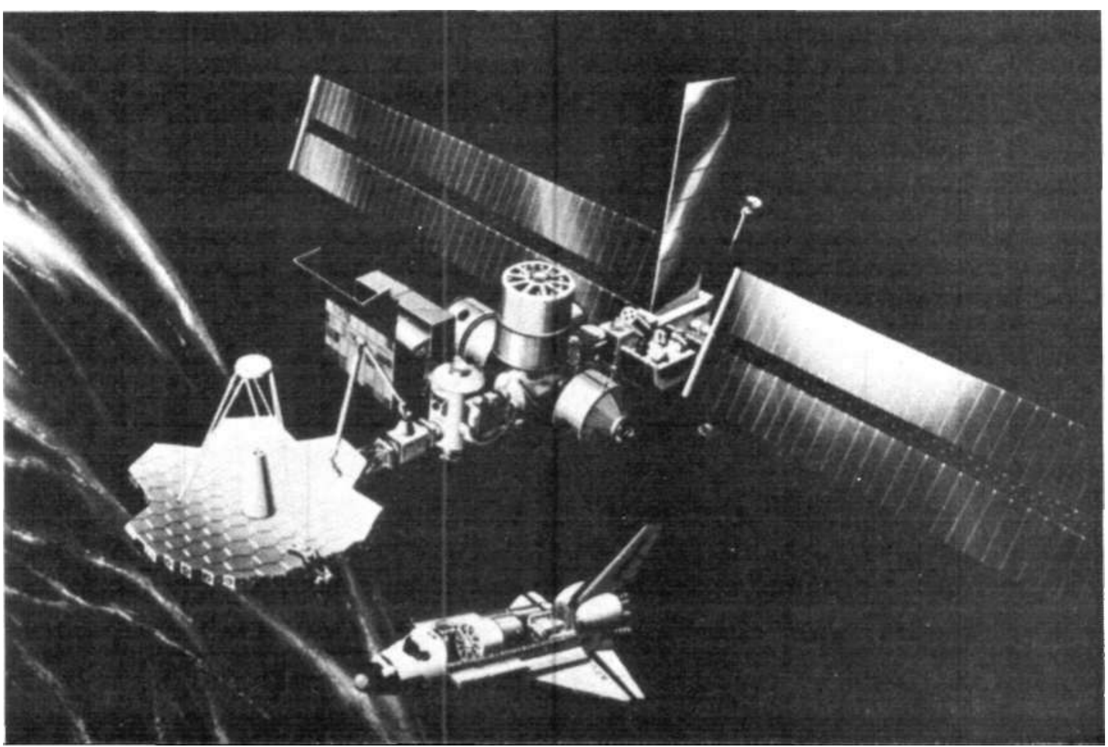


Figure 30
SIMULATED SPACE SHUTTLE FLIGHT
Future astronauts, at Space Camp for a week, learn about space and spaceflight.

tually be able to do all these things in reality, not just as a simulation exercise. They can fly up to a space station and do meaningful work there. A space station simulator facilitates training for long-term space visits. A highlight at Space Camp is a simulated flight inside a cargo bay of a future Shuttle equipped to carry personnel. With such simulations we can conduct about six flights in a day, while NASA still needs about a month between missions.

And finally, in Figure 31, we have a historic panorama of rockets. The small vehicle in back is the A-4. In front of it is the Mercury-Redstone with the Mercury capsule on top. Behind it is the huge Saturn, whose second stage is powered by the Centaur engine cluster of six RL-10s, developed by Krafft Ehricke. This created the granddaddy of all Saturns for early progress in the Apollo program and the use of liquid hydrogen as a fuel. This high-energy propellant was needed to generate the necessary power to carry men to the Moon. As you know, six of our Apollo teams visited the Moon, and twelve people walked on the Moon and used three "Moon buggies" for transportation.

I hope that this is not the end of space ventures, and that the Space Shuttle has only opened the door to further explorations and even to the permanent habitation of the universe on a scale not envisioned at this time. Our children and their children will thus encounter a future with unimaginable possibilities!

Konrad Dannenberg is a consultant at the Alabama Space and Rocket Center in Huntsville. He was director of rocket motor development at Peenemunde, director of Redstone and Jupiter-ICBM production, deputy program manager of the Saturn booster project that put the first men on the Moon, and space station program manager at NASA's Marshall Space Flight Center in Huntsville, Ala. His article was written in memory of space scientist Krafft A. Ehricke, who died Dec. 11, 1984.

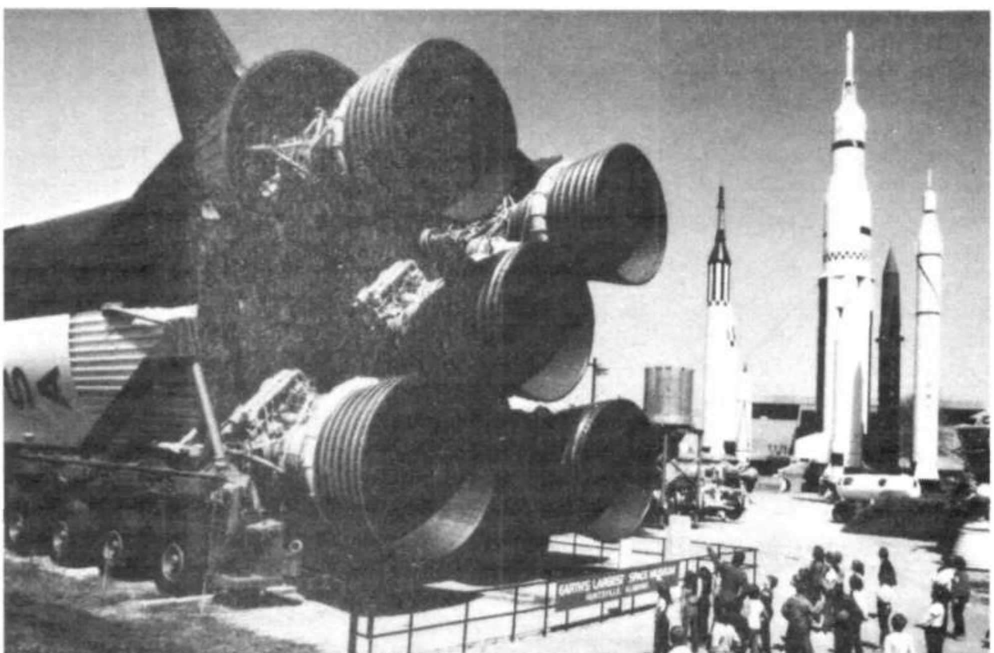
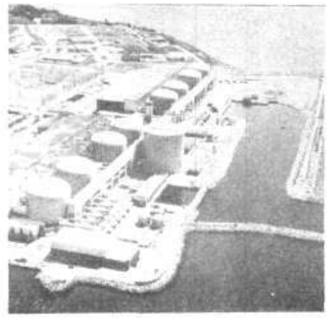


Figure 31
PANORAMA OF ROCKET HISTORY
The small vehicle in back is the V-2. In front of it is the Mercury Redstone with the Mercury capsule on top. Behind it is the huge Saturn, whose second stage is powered by the Centaur engine cluster of six RL-10s developed by Krafft Ehricke.

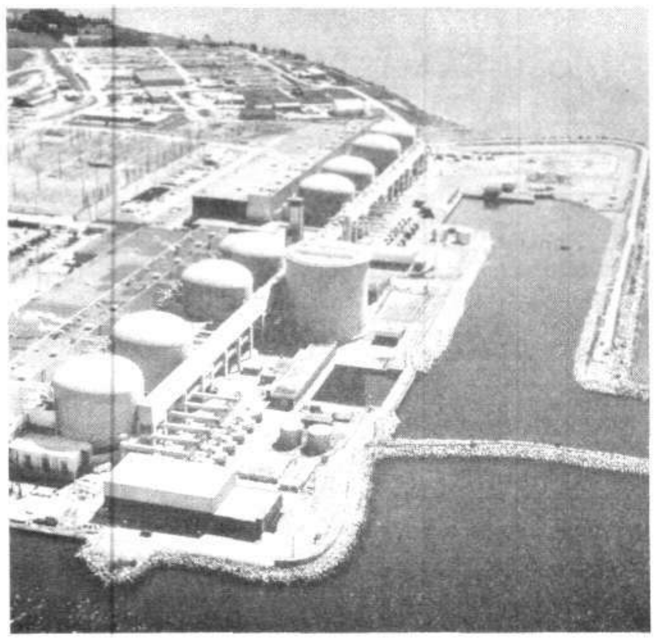
The United States could soon begin to produce 300 modular, smaller nuclear plants a year, with a three-year start-to-finish construction time for each plant. The first step is to overthrow the environmentalist tyranny that has turned nuclear plant construction from a seven-year routine to a fifteen-year nightmare.

Mass Producing Nuclear Plants

The United States Can Do It!



by Marjorie Mazel Hecht



No one who keeps his house at an uncomfortably cold temperature in the winter to save on electric power costs has to be convinced that the United States needs more and cheaper electricity. And if the current trends continue, the situation can only get worse, as there is less power, more demand, and higher costs. Some utility analysts are predicting brownouts and blackouts in parts of the country as early as the end of this decade.

Even at the very minimal growth rate of 2 percent, electricity demand in the United States will outstrip installed generating capacity by the year 1994, according to the Edison Electric Institute.[1] At a 2.5 percent growth rate, the crunch would come two years earlier, in 1992, and at a 4 percent growth rate, the shortfall would be felt by 1988 (Figure 1). The quite conservative estimate of the U.S. Department of Energy forecasts that U.S. power generation would have to increase current capacity by 50 percent by the year 2000, adding approximately 300 gigawatts (GW) to meet the increasing demands of a modest 3 percent annual growth rate in electricity use.[2] Actually, a recent study by the Fusion Energy Foundation has shown that if there is to be any *real* economic recovery, the United States would require at minimum double this amount—approximately 650 gigawatts of additional power. And if the urgent needs of the developing sector are added in, the required number of additional gigawatts would at least double again.[3]

Eight 514-MWe Candu reactors are lined up at Canada's Pickering station. Atomic Energy of Canada Ltd. is ready now to turn out five to six 300-MWe Candus per year.

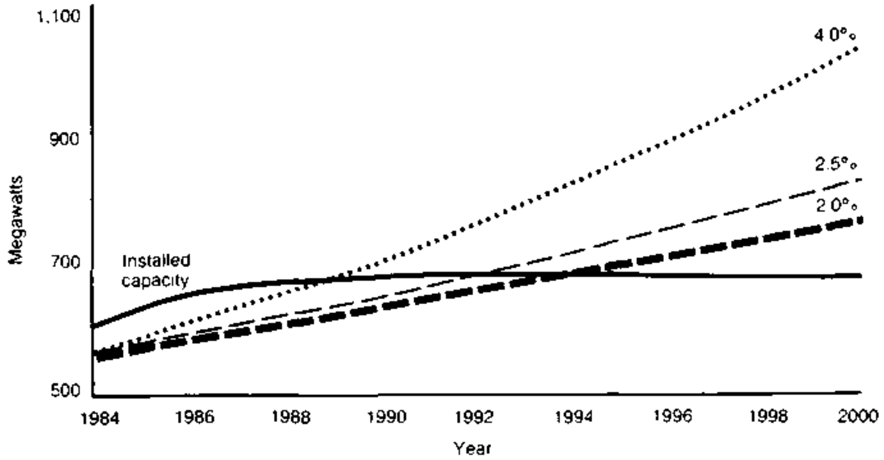


Figure 1
U.S. ELECTRICITY SUPPLY AND DEMAND
Whether the U.S. demand for electricity grows at a slow 2 percent rate or a more optimistic 4 percent, demand would outstrip current installed capacity by 7992.

Source: Edison Electric Institute

Can we meet this world demand of 1,300 gigawatts new capacity, and can we do it rapidly? The answer is yes—if we usher in the next generation of nuclear plants. The concept here is a simple and familiar one, similar to Ford's plan to produce Model T's: mass produce modular nuclear plants using standardized parts and assembly-line shop fabrication. Transport these plants by rail, barge, or truck and install them in sites that are built to increase capacity as needed by adding more of the modular reactors.

In order to reap the benefits of shop fabrication, these nuclear plants have to be smaller in capacity than the typical 1,000-megawatt (MW) plant of today, but as shown below, the loss of economy-of-scale is compensated for by other factors. In addition to the cost savings of assembly-line production, there will be savings from the sharing of some facilities, such as turbines and control centers and auxiliary systems, as well as savings from not having to license each plant site individually after the basic design is licensed. There will be further savings from making use of the latest in nuclear technology, like the high temperature gas reactor, which will vastly increase industrial productivity. There are also indications that these smaller plants may prove more reliable, saving costs by being on line more of the time than larger plants. And with smaller plants it is possible to build in so-called passive safety systems for a "walk-away" reactor that will cool itself down without any outside intervention if a problem arises.

The main advantage of these smaller plants is that many of them could come on line quickly. How rapidly could such modular plants be turned out? In general, after a three-year startup period to prepare the factory assembly sites and gear up the now languishing heavy industries, U.S. nuclear suppliers could mass produce plants from start to finish in about three years, by their own conservative estimates. An FEF survey indicated that with a crash program approach, once the required parts were "on the shelf," this process could be reduced to two years.

Despite the fact that the U.S. nuclear industry is stuck in a mire of overregulation, financial warfare, and antinuclear politics, every U.S. nuclear supplier, looking toward the needs of the future, has on the drawing board designs for smaller, modular plants—from modular light water reactors, to modular high temperature gas reactors (HTCRs), to modular breeder reactors that breed enough fuel to supply themselves. These range in size from the 10-MVV Triga reactor of CA Technologies to the 135-MW Prism breeder designed by General Electric, to the CANDU-300, a 300 MW heavy water reactor designed by Atomic Energy of Canada, Ltd. The modular HTGR and breeder are the optimal choices for mass production because of their increased efficiency and versatility, but initially all of the modular reactor concepts will be needed to meet the urgent need worldwide.

Small Reactors—The Precedent

Small-reactors are not a new concept. They have an important historical predecessor—the submarine, ship, and barge reactors pioneered by the U.S. Nuclear Navy beginning in 1954. The U.S. and German nuclear ship construction programs have produced significant numbers of small-sized nuclear reactors for submarines and surface ships, reaching production times as short as four years for multiple units at the same shipyard, at Bridgeport, Conn., for example, and elsewhere. Production in a Navy Yard facility proved to be extremely efficient in terms of manpower, for construction and for regulation and inspection. Atthepeak of submarine reactor construction programs, yards with multiple reactors under construction have typically employed 70-75 inspectors, compared to the 700-1,000 inspectors overseeing a beleaguered large-scale nuclear construction site today. The Navy reactors, and a few similar floating reactors built by the U.S. Army for mobile use (for example, in the Panama Canal Zone) have been extremely reliable throughout—and in some cases, beyond—their planned lifetimes.

Reactor designers experienced in the marine reactor programs have suggested two reasons for this increased reliability. First, they point to the lower pressure under which smaller reactors operate (typically 25-30 percent lower pressures than those in units of 1,000 MWe or more) as extremely important to their superior reliability. The Navy reactors and other prototype small reactors now being developed give the small reactor itself somewhat more elbow-room within its containment structure, which is reduced in size but not by quite as much as the reactor is reduced. This lowers the operating pressures on reactor and containment walls, allowing simpler layouts of steam, water, and other subsystems around the reactor, which can thus be more easily maintained.

Second, the small reactor designs remove the traditional sharp pressure barrier between the primary cooling water, which is pressurized to drive it far above its boiling temperature, and the secondary system, which drives steam through the generator. In place of this sharp pressure gradient, the small reactor designs use large temperature gradients that drive the steam through *internal* steam turbines by natural convection, still remaining within the maximum parameter of operating temperature for the reactor. This removes what many experienced reactor engineers call the most important factor in cooling system and related failures that shut down reactors—high pressure operation of the water and steam systems.

Today, 40 percent (140 plants) of the world's 344 nuclear plants are 600 MW or less. In 1983, the International Atomic Energy Agency (IAEA) began a study of small and medium power reactors (SMPRs), sending out questionnaires to suppliers and potential buyers worldwide. An initial IAEA report, issued in July 1985, is motivated by the statement that "to assist primarily developing Member States to introduce nuclear power earlier, the IAEA has since more than 20 years tried to promote the industrial production of nuclear power plants smaller (100 to 500 MWe range) than were generally available on the international market.""This IAEA effort has been unsuccessful, the report says, but because of the "uncertain home" market, now some of the industrial nations are "compelled" to take a new look at the potential export market.

Among the advantages noted by the IAEA for SMPRs are lower absolute capital cost with smaller financial burden, distribution of economic risk through several smaller plants, better controlled construction schedule due to the less onsite work and smaller size components, earlier introduction of nuclear power that will give environmental protection compared to fossil-fired units, lower absolute heat rejection that permits better adaptation to cooling capacity and extends the number and location of possible sites, better fit to smaller and weaker grids (the rule of thumb is that no one plant should be more than 10 percent of the grid), fit to low load growth rate situations, better past performance records than larger plants, high degree of shop fabrication and potential for series production, and earlier introduction of nuclear power with potential for longer-term technology transfer if the introduction does not come too early.

Also mentioned in the report are some of the special uses for smaller plants—cogeneration, district heating, process heat, and desalination. In particular, the electricity-intensive aluminum and magnesium production processes are noted as candidates for cogeneration. Some of these applications require less sophisticated designs than electricity-producing plants.

The trends the IAEA points out among the23 various small and medium power reactor designs that were submitted in response to the agency's 1984 questionnaire are: reduced construction schedule, use of systems already proven in commercial operation, simplification of safety systems using inherent small reactor characteristics (natural circulation), a high level of prefab and shop fabrication (maximized in Navy Yard or barge-mounted designs), high seismic design and ability to function with relatively high cooling-water temperatures (in tropical countries), meeting criteria for smaller and weaker power grids.

The Developing Sector Market

In the entire underdeveloped world, whose nations account for three-quarters of the human population, there are today fewer than 25 nuclear reactors, located in only a dozen nations. In response to its questionnaire, the IAEA received 23 design concepts from suppliers (12 of which were for 300-MW reactors) and interest expressed by 17 potential buyers, mostly developing nations: Argentina, Chile, China, Colombia, Equador, Finland, Indonesia, Malaysia, Mexico, Morocco, Nigeria, the Philippines, Sri Lanka, Thailand, Tunisia, Turkey, and Uruguay.

Developing nations' requests for small-reactor construction go back *to* the 1960s' IAEA conferences on atomic energy, but these requests were bypassed by the nuclear suppliers of the industrialized countries until the last few years, which have seen calls for new, "inherently safe" small reactor designs and a demand for small nuclear reactors to produce power for space systems.

Most important for an underdeveloped nation, with an inadequate power grid full of "holes," is the relatively rapid, continuous addition of high-quality electric power increments to meet the needs of industrial and agricultural development. Particularly for nations without plentiful, easily tapped hydropower sources, this can be accomplished only with nuclear reactors. The civil engineering work involved in installing reactors of this type will be minimized. The plants can be barged to locations anywhere along river or coastal waterways, requiring a relatively shallow draft, unlike the very large floating nuclear reactors Westinghouse had planned to mass produce at its now-closed Jacksonville, Fla., facility. They can also be transported short distances by truck to final locations. The powering of the Panama Canal Zone for 13 years (1949-1962) by a U.S. Navy floating barge nuclear reactor of 30 MWe, is a good example of the high-quality, readily available electricity that small nuclear reactors can provide for developing nations.

Argentina has now developed a new prototype project for the mass factory-production of small light water pressurized nuclear reactor modules, capable *of* being quickly taken by truck or barge to virtually any region of the continent. This is important because it demonstrates an indigenous Ibero-American capability to supply the area and because of the intrinsic merit of its design. The Argentine prototype, scheduled for completion by the end of this year, is known as "Proyecto Carem" (Carem Project). It is designed and engineered by an experienced nuclear firm, INVAP, S.A., of Barriloche, Argentina, which is linked to the Argentine Nuclear Energy Commission. The Carem prototype will demonstrate nuclear reactor modules in the power range of only 15-30 MWe, which can be serial-produced by factory methods and then either used individually or combined into clusters of up to 200 MWe total power.[5]

The Carem Project design study states, "Our proposal . . .consists in using power plants made from small reactors (modules), small enough to enable a serial production . . . for electricity in isolated or remote places, or for being interconnected with small networks. It can also be used for bigger power plants, adding more reactor modules for the production of industrial steam, urban heating, or for desalination." In other words, this is a small-sized version of the "nuplex" concept for agroindustrial development.

Similar to the Argentine Project Carem prototype for mass production and developing-sector use, but also probably intended for potential use in space, is the "Power Triga" of CA Technologies, Inc. Modeled on the widely used Triga research reactor (60 Triga reactors now operate in 23 countries), the Power Triga would cost approximately $40 million each, designed for an output of 10 MWe.

The Power Triga will be built in five modules and can be preassembled or shipped and then reassembled. GA expects to sell them in clusters for reliability, where the servicing and maintenance would be shared in order to save costs. One of the primary uses of the Power Triga will be the provision of district heating; that is, the use of excess reactor heat at appropriate temperatures to heat industrial and residential buildings in the area of installation.

Doubling Electricity Capacity in 10 Years

A recent survey of the world's nuclear power industries by the Fusion Energy Foundation has shown that the Argentine concept—small nuclear reactor modules for mass production—is now shared by most major nuclear technology firms in North America, Europe, and Japan. Ten firms, including the nuclear giants like General Electric, are preparing a capability to factory-produce reactors ranging from 10 MWe to 335 MWe, although most of these plans are in the conceptual design phase. It should be noted that the gen-

The High Temperature Gas-Cooled Reactor

The HTGR, which uses helium gas as a coolant, is an important advance over current water-cooled nuclear plants, because it can operate at much higher temperatures, producing high-temperature steam and process heat appropriate for many processing industries. Making use of advanced fuel assemblies and materials, the HTGR is also safer, more economical, and more flexible than its predecessor light water reactors.

The latest designs forthe HTGRwill produce process heat or steam at about 550 degrees Celsius, compared to the limit of about 330 degrees for water-cooled reactors. For the production of electricity using steam turbines, this means a greater heat-to-electricity conversion efficiency—40 percent compared to 32 percent for light water reactors—since that efficiency is a function of the difference between the inlet and outlet temperature.

The uniqueness of the HTGR lies in the fact that at the same time that the reactor is designed to produce electricity, it can also have some or even all of its nuclear energy diverted to produce process heat and steam for industry, as required. Today, more than 70 percent of the energy used in U.S. industry is nonelectric, in the form of heat or steam. At 550 degrees, the reactor can provide at least half of the steam and process heat to U.S. industry that is now supplied by the burning of finite fossil fuels. In 1981, U.S. industry used approximately 20 quadrillion BTUs of primary energy for heat. Of that, 15 quads were at temperatures of 550 degrees or lower, and about 9 quads were in the form of steam. The current HTGR design could supply all of this.

Advanced ceramics and carbon-carbon composites now under development for energy applications, such as high-temperature magnetohydrodynamic direct conversion, would allow the HTGR to go up to more than 950 degrees. This would be the basis for economical production of hydrogen, and in addition would make it possible to use gas turbines, thus eliminating the need forthe century-old steam turbine production of electricity.

Safety Advantages

The major safety breakthroughs made in developing the HTGR were a product of the research and development work done in the 1960s in nuclear reactors designed for space.

If a chemically inert gas like helium is circulated though the reactor core as the coolant, there is no possibility of corrosion in the piping or other metal reactor parts because the helium does not react with other materials. Helium is also a gas in every phase of its use in the HTGR. In a light water reactor, the original water coolant becomes steam in its gaseous phase during cooling. This phase change makes it more difficult to accurately measure the pressure and other parameters of the coolant, which is not difficult in the helium-cooled reactor. In addition, the gaseous helium makes it possible to visually inspect the inside of the reactor during all phases of operation, which is not possible if the operator has to try to see through water.

Unlike water, helium is also virtually radioactively inert. The gas has a low neutron absorption cross section, which means that even if the coolant were bombarded by neutrons from the fissioning fuel (which is extremely unlikely) it would not become radioactive.

Another feature that came out of the NASA program is the design of fuel pellets that can withstand high temperatures and that are thermally insulated to keep the fuel intact. The Fort St. Vrain HTGR in operation today in Colorado and the HTGRs in operation in West Germany make use of these pebble designs. The pebbles consist of a particle of either fissile uranium or nonfissionable but fertile thorium, eral preference is toward the upper end of the range, particularly for use in the advanced sector.

On the basis of these plans alone, it should be possible, by constructing 100 nuclear-plant-producing factories, to turn out 300 or more small and medium reactors per year by 1990 (allowing three years for the construction of the initial nuclear-plant producing factories). This would double the total available nuclear power in the developing sector each year. Of course, this does not begin to meet the needs of the advanced sector under conditions of a real recovery. However, once such a recovery were under way, particularly with the stimulus of the large-scale development of advanced technologies, the scale of production of nuclear plants could be vastly expanded. Moreover, construction of larger plants in the United States, Europe, and Japan could be resumed on an increasingly standardized basis, as has been demonstrated most successfully in France, and also by approximating mass production in a "floating plant" marine construction environment where possible.

Merely by rationalizing regulatory requirements, by ending the political tyranny now exercised by the antinuclear political lobby, the situation will be considerably improved. More than 20 gigawatts of nuclear capacity, now stalled in construction, can immediately be brought on-line in the United States.

In the decade of the 1960s, the United States had a 6.5 percent rate of growth of electrical energy; a 7 percent growth rate would mean doubling the electricity supply every 10 years. Since the industry has been subjected to enforced stagnation, particularly in its nuclear component, the addition of a four-year gearup to double capacity by the year 2000 is within the parameters of growth of which the nation was capable in the 1960s.

The present depression reflects the structural imbalance of the U.S. economy. In order to return the economy to a healthy condition, the number of operatives presently employed in the United States must at least double. In fact, merely to provide a doubled productive workforce with the

the size of a grain of sand, which is coated with a graphite and silicon carbide shell.

The Modular HTCR

The modular HTGR now being designed by GA Technologies will produce 350 MW of thermal energy, which can be converted to about 140 MWe. A factory-produced, modular reactor would have an upper limit on size of about double that amount.

The factory mass production method can reduce the time it takes to build a plant to less than three years. The reactor will be inspected at the factory and certified before it leaves the plant. Then it can be shipped, in one piece, to the site by truck, ship, or rail and simply dropped into place when it arrives. One promising configuration is to place the HTGR module, along with its attached steam generator, underground in a silo. Rather than using prestressed reinforced concrete for containment, the reactor would be inside a pressure vessel, simFlar to today's nuclear plants, surrounded by a concrete-lined silo.

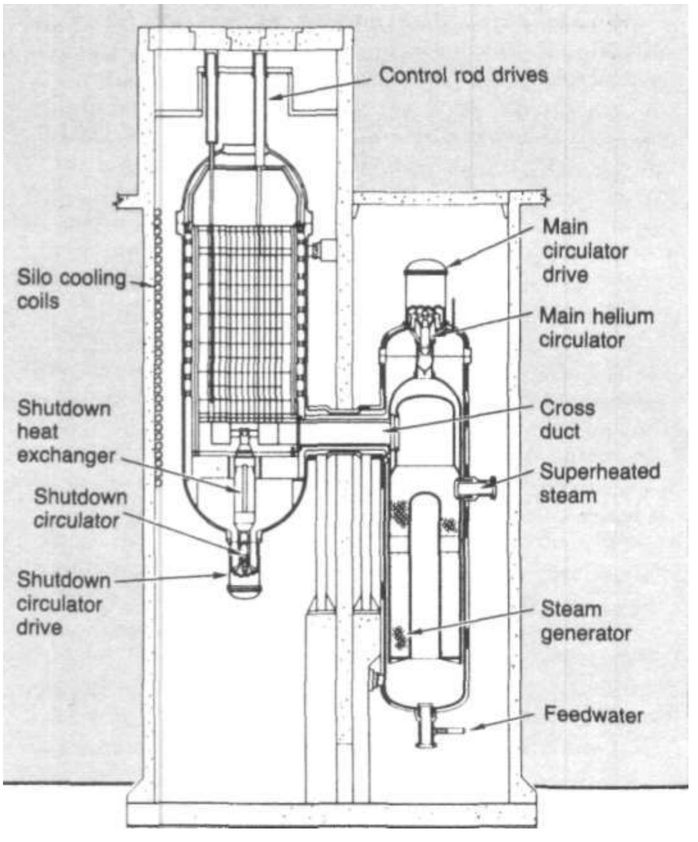
The preparation of the silo and the nonnuclear balance of plant above ground would be proceeding at the same time that the factory was producing the module. When the module was then "plugged in" at the site, the entire plant would be ready for operation. In this way, the plant could be on-line in about 33 months.

The target cost for the modular reactor is about $2,200/kW of installed capacity. GA Technologies has estimated that if the units were sited in pairs, two dual-unit pairs would bring the cost of delivered electric power down below the cost of power from an advanced pulverized coal plant and below the cost for a single, comparably sized light water reactor.

-Marsha Freeman

MODULAR HTGR IN A CONCRETE SILO

The most promising basing mode for the modular HTCR is to place it in a concrete-lined silo underground. This design by GA Technologies places the steam generator on the side of the nuclear reactor. The helium coolant flows through the cross duct to the steam generator. Cooler feedwater is provided from the bottom. The superheated steam, which has absorbed heat from the hot helium is removed from the generator at right. The reactor is refueled from the top, where the fuel assemblies, composed of pellets, are removed about once every four years.



electrical power needed for production at present levels of technology would necessitate increasing the existing capacity of approximately 650 CW only by one fourth. However, to reverse the deepening depression, technology must be massively upgraded everywhere, particularly in the United States, which has increasingly obsolete infrastructure. We need to increase energy densities at the point of production and energy throughput per operative.

The FEF program has taken this increased energy density into consideration in posing the need to double the energy grid. For the United States, the goal must be to increase infrastructure for the production of nuclear power plants, to provide added capacity, including export, of at least 1,300 gigawatts by the end of the century.

In the United States, the situation is worsened by the aging of plants. By the year 1994, 100,000 MW of electric

GE's PRISM—Power Reactor Inherently Safe Module

General Electric was awarded the Department of Energy contract in October 1984 for the design of an innovative modular liquid metal breeder reactor to be the focus of the government's breeder program after the cancellation of the Clinch River plant. The 135-MWe PRISM, or the Power Reactor Inherently Safe Module, is designed for factory assembly and transportation to the site on a railroad car. Any number of modules can be grouped at a site, depending on the needs of the buyer.

PRISM incorporates all the advantages of smaller, factory-assembled reactors with their passive safety systems, plus it breeds enough fuel to refuel itself. PRISM is pool-type reactor, liquid-metal-cooled with a low-pressure, high-boiling point coolant (sodium). Its nuclear envelope or nuclear island is self-contained and the parts are designed to be shop-fabricated, assembled, and shipped to the plant for rapid installation. The GE design calls for embedding each reactor unit in a silo underground with the steam generator by its side in another silo. The rest of the plant is conventional in design.

GE aimed to cut the demonstration costs from billions of dollars (the Clinch River project) to hundreds of millions for this project, anticipating that the higher productivity of factory production would offset any loss of economy-of-scale. GE expects to construct a test module to prove PRISM'S self-protecting features in order to get an operating license from the Nuclear Regulatory Commission. This will set the precedent for the total plant, leading to prelicensing of the standardized modules. Having the safety features confined to the reactor module itself and prelicensing these modules are expected to be a tremendous cost saving.

Commercial PRISM plants would have three segments or power blocks (see figure), each with three PRISM modules. The segments would be functionally independent; that is, each would have its own intermediate heat transfer system and steam supply, but the various reactors would have a common tie at the steam drum. Low-pressure liquid sodium is circulated through the core by four cartridge-type electromagnetic pumps. Heat is transferred from the hot primary sodium to sodium in a fully isolated intermediate system by means of four heat exchangers. These intermediate heat exchangers are connected to a common header that leads to a separate steam generator.

The containment vessel is 19 feet in diameter and 64 feet high, and the whole assembly (without fuel) weighs 950 tons and is shippable by rail, barge, or road. There are 48 fuel assemblies in the core, and the breeder blanket has 66 uranium oxide assemblies. The design will also accommodate the new fuel assembly proposed and tested by Argonne National Laboratory, which avoids many of the problems of an oxide fuel. PRISM would have to be refueled once a year; it breeds this fuel at a slightly faster rate, which takes into account any losses during the reprocessing and fuel fabrication.

The reactor has a double containment system, with the second vessel to keep the sodium from leaking if there is an accident and thus make sure that the core would always be covered. The first containment is the reactor vessel itself, which operates under a pressure of 1 atmosphere. There is a 7-foot concrete shield around the unit.

A new design feature of PRISM is its passive decay heat removal system, called RVACS for radiant vessel auxiliary cooling system. RVACS removes the reactor's heat if there is a loss of off-site power, or if the feedwateror circulating water systems fail, or if there is any incident that causes a loss of the normal energy conversion systems in the non-nuclear part of the plant. No mechanical devices—dampers, valves, pumps, fans, and so on—are involved, and there is no piping to fail. The shut-down heat path consists of radiant heat transfer from the reactor vessel to the containment vessel, where the heat is removed by the natural circulation of air between the containment vessel and the concrete wall. There is also a series of electrical vaults around the base of the reactor to provide emergency power and automatic controls to shut down the reactor if there is operator failure or equipment malfunction.

If the intermediate heat transport system is lost, the sodium temperature increases to a peak of 1,105 degrees F., which is less than the "upset" temperature of the sodium (1,200 degrees). Thus, the reactor core can be adequately cooled. Even in the unlikely event of a blockage of the air flow over the containment vessel, a safe sodium temperature will be maintained by radiant heat transfer from the containment vessel to the concrete shield. As is the case in the smaller reactor designs, thermal radiation, "a basic law of nature," is thus used to assure safe shutdown "under all foreseeable conditions."

Passive **Safety Systems**

PRISM is "exceedingly tolerant of operator errors and major accident conditions," according to GE. For example, the reactor almost immediately begins to shut itself down producing capacity will be 30 years old and due for replacement. Peak demand is expected to rise from the present 465 GW to 566 GW. Even with the currently planned increase of capacity to 704 GW, a reduction from the 175 GW scheduled to be added to the grid a mere two years ago, the reserve margins for demonstrated capacity will fall below 21 percent. Such a reduction in excess capacity places the whole national grid in jeopardy.

The Cost of Environmentalism

Only with the rapid expansion of nuclear power plants is there a hope of meeting sucha demand. Immediately, 20 GW of nuclear electric power, which have been stalled by the political intervention of antinuclear forces, can be brought on-line in the United States alone. The first step toward meeting this demand is to end the tyranny of the environmentalists, who have acted as an arm of the Malthu-

in an accident. This occurs because of a "flowering" of the reactor core, which produces a fissioning loss. In other words, the core opens up on top, like a blossom, allowing fast neutrons to escape. The core heats up and the control rods begin to expand because of the increased temperature, shutting down the reactor. The combination of these two things reduces net reactivity to zero after 10 minutes.

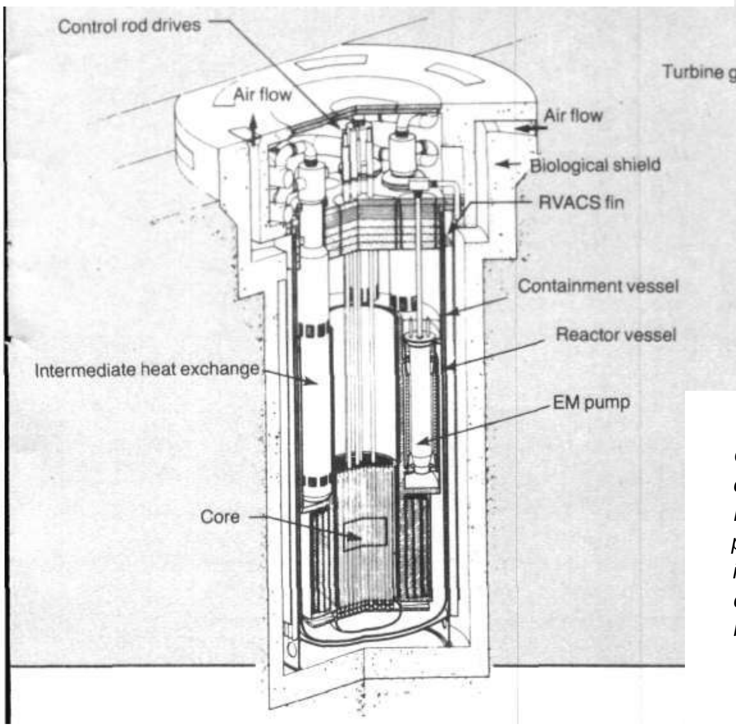
GE comments on the safety question: "Some have claimed a new technical approach is needed to provide an increased level of safety; however, General Electric does not believe it is necessary to increase the safety level over current light water reactor (LWR) designs. Rather, GE has directed effort toward simplifying and reducing the number of safety systems with no loss of safety."

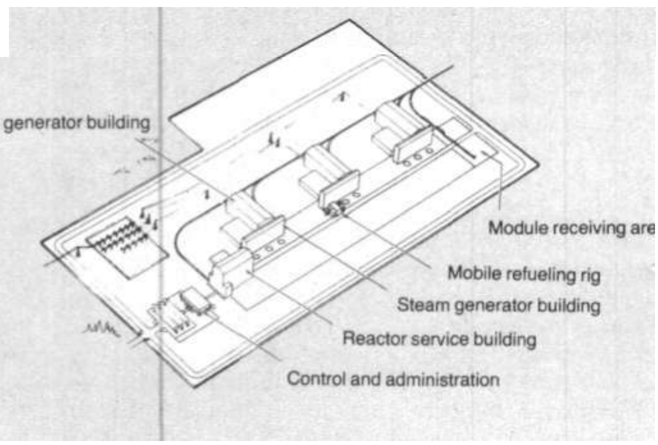
PRISM is installed using an overhead crane, enabling the reactor to be moved for resiting or for replacement and decommissioning. Thus the site itself can be reused simply by inserting a new reactor module into the old silo. For each three groups of three modules, there will be one reactor service building, one control/administration building, and one mobile refueling rig. The present reference design would construct each site in segments of about 400 MWe, with the final result a 1,200 MWe plant.

PRISM's operating costs are expected to be quite low because of its high capacity factor (80 percent compared with 65 percent of a typical LWR). This is the result of the reduction in the redundancy of safety systems; the small size of components and simplicity of the reactor, which should reduce maintenance time; and the modular setup, which means that while one module is being refueled or maintained, partial power continues from the other units.

Starting from scratch, GE estimates that it would take at least12 months and possibly as much as 18 months to build the factory to produce the modules, and the company is now looking for appropriate sites. In those 12 months, GE would also accumulate the materials necessary for the factory to begin production. It would then take an additional 36 months to begin to turn out modules. Once everything was geared up, GE estimates that it could turn out one module every 3.5 months.

The construction on site would take 34 months. Of course, with assured financing, this could overlap with the production cycle. Once the factory was set up and the materials were in the pipeline, GE estimates a 34-month schedule for each power block of 3 modules. A 1,200 MW total station would take approximately 49 months to complete, and GE is working on a design whereby one module would be put on line at a time, thus supplying power right away at some level. If there were an aggressive market, GE expects they could have completed modules on the shelf, ready to ship them as fast as the orders came in.





GE's PRISM breeder reactor is designed for siting in a concrete-lined, underground well. In a typical nine-module PRISM plant (inset), three modules of 135 MWe each comprise an assembly, and plant capacity would be increased in approximately 400 MWe increments. The initial assembly can begin generating electricity for revenue while the remaining assemblies are still under construction.

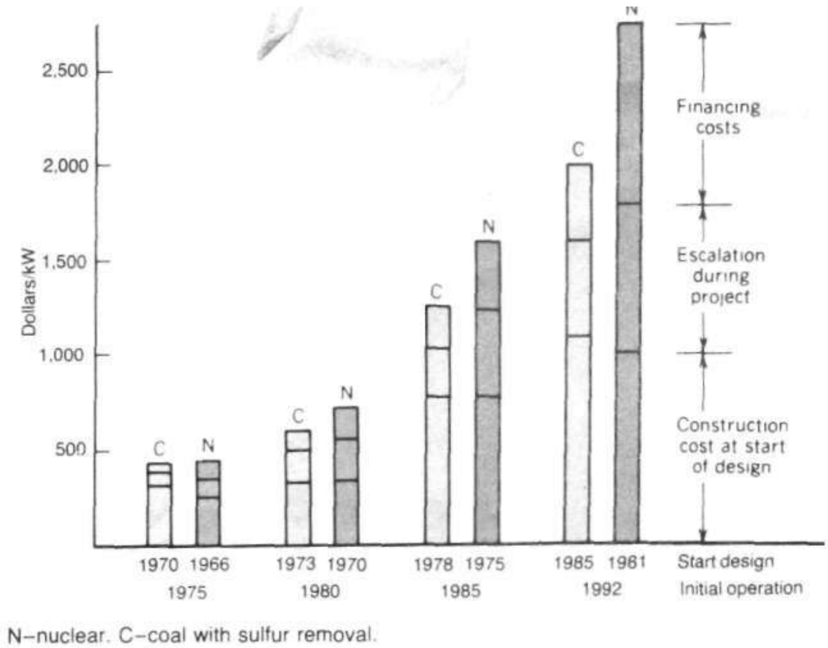


Figure 2
CAPITAL COST COMPONENTS OF TYPICAL U.S. GENERATING PLANTS

The zooming cost of financing nuclear plants (N), the cost of environmentalist delays, and the increase in construction materials are vividly shown here, along with the rising costs for comparable coal-fired plants (C) with sulfur removal.

Source: Electric Power Research Institute

sian International Monetary Fund, systematically destroying the economies of the Western nations and developing sector. Over the past decade, the average lead time for construction of a U.S. nuclear plant has doubled, from 60 months to 120 months, as regulation requirements and environmental obstructions have delayed the process of putting power plants on-line. The 1985 Department of Energy Nuclear Energy Cost Data Base puts the lead time for seven plants due for completion in 1984 at 165 months, with a construction time of 130 months.[6]

At the same time, the capital cost per plant has soared, rising faster than the rate of inflation. Today, the total capital cost of a nuclear plant of 1 GW capacity ranges from $2 billion to $5 billion, most of which is related to increased costs from time delays and changes required by additional Nuclear Regulatory Commission regulations. If the present trend continues, one source estimates, "by 1988, more than 50 percent of total plant cost will be time charges, and the nuclear island [the actual reactor] will cost only 10 percent of the total investment."

According to the Congressional Office of Technology Assessment's 1984 report,[7] in the early 1970s, nuclear power plants were completed for a total cost of about $150 to $300 per kilowatt (kW) capacity, while in 1983, seven nuclear power plants ready to come on-line cost from $1,000 to $3,000 per kW—a 550 to 900 percent increase. General inflation alone would account only for an increase of 115 percent from 1971 to 1983, while inflation on components—labor and materials—would account for a further increase of about 20 percent, according to the Office of Technology Assessment. The Department of Energy Nuclear Energy Cost Data Base report shows the total costs of a typical 1,000 MW nuclear plant in January 1984 dollars to be $5,220 per kilowatt based on average experience and $2,985 per kilowatt based on the best experience.

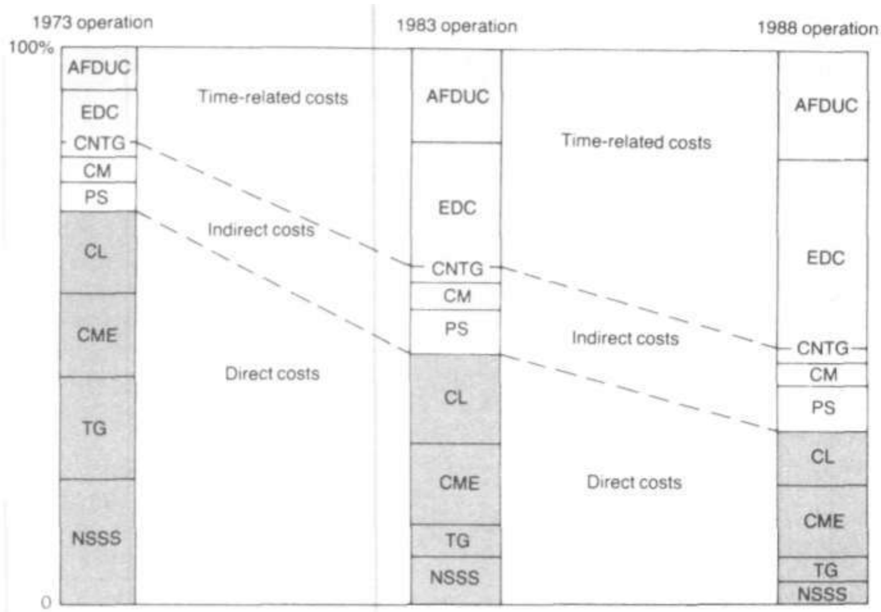
Another recent study published by the Electric Power Research Institute (EPRI) says:

> The major cause of nuclear construction delays is the regulatory ratcheting phenomenon, which results in plant redesign, rework, and backfitting. Direct increases in labor and materials requirements, or deliberate delays by the owner utilities, have each contributed 20 percent or less to the total measured lead time delay. It is thus estimated that the combination of various regulatory ratcheting measures, and the utility's ability to respond to the required changes, are the major causes of the increasing plant lead times and capital costs.[8]

A look at the breakdown of current costs in Figures 2 and 3 gives a vivid idea of how the increased cost of a nuclear plant is *not* directly related to the nuclear island. Material costs have increased as a result of Nuclear Regulatory Commission (NRC) regulations. For example, in 1971, an average plant needed 2,000 feet of cable per MW; now, 5,000 feet per MW are required. Similarly, in the late 1970s, the NRC revised seismic regulations, which increased the demands on the piping systems so that pipe supports that cost several hundred dollars have been replaced with very sophisticated restraints called "snubbers" with shock-absorbers, costing many thousands of dollars. Also, structural steel supports now cost between two and three times the cost of the same quality steel supports used for general construction, and those that were used on nuclear plants until 1975.

The EPRI study shows how there has been a doubling and

Figure 3
SHIFTS IN DISTRIBUTION OF NUCLEAR POWER PLANT CAPITAL COSTS
The nuclear component of the power plant has become an increasingly smaller part of the capital cost of a plant since 1973. By 1988, one source estimates, the nuclear island will be only 10 percent of the total investment.



Key: NSSS-nuclear steam supply system. TG-turbine generator. CME-construction material and equipment. CL-craft labor. PS-professional services. CM-construction tools and material. CNTG-contingency. EDC-escalation during construction. AFUDC-interest during construction.

Source: Electric Power Research Institute

tripling of the amount of electrical and other commodities required per plant—concrete increased 64 percent from the late 1960s to the 1970s, pipe increased 72 percent, and wire increased 100 percent. The unit prices of these commodities have also increased from four to eight times in this period. Many of the increased costs are the result of extensive modifications the plants had to undergo when they were partially completed, because the regulations were revised in midstream.

With the increase in regulations, came an increase in manpower needs. Whereas in 1967 a nuclear plant came on-line with an average of 3.5 construction manhours/kW of power, in 1982-1985, 21.6 manhours/kW were required. Nonmanual field and engineering labor increased from 1.3 manhours/kW in 1967 to 9.2 manhours/kW in 1980. The EPRI study points out, "The fastest increasing component of total costs in the last three years has been the cost of noncraft labor, which includes all engineering and supervisory manhours. The cost of engineering services for a nuclear plant completed by 1990 will be higher than the total capital cost of a plant completed in 1970, even when measured in constant dollars."

An interesting comparison is France, where total manhours required per kilowatt are half those of the United States. Unlike the United States, which has four nuclear reactor suppliers, several architect-engineering firms, and plant designs that depend on the particular specifications of the utility, France has standardized two types of reactors—925 MW and 1,300 MW. Also, in terms of time, the French put the Superphenix on-line in eight years. This is the first commercial-size liquid metal fast breeder, an enormous construction effort, built in half the time it takes the United States to put an ordinary light water reactor on-line.

There is also a great deal of variation in plant costs for the same size plant, depending on the utility that built the plant. For example, Long Island Lighting Company's Shoreham plant is four times higher in cost per kilowatt, in 1982 dollars $3,500/kW, than Duke Power's McGuire 1 and 2 at $4,840/kW. A study by Charles Komanoff for the Office of Technology Assessment found that plant cost decreases by 8 percent to 10 percent for each previous plant site built by the same utility, and that plant cost varies by manufacturer as much as 15 percent for plants in the Northeastern region (mainly because of higher labor cost and shorter construction seasons).

Also, Komanoff says, costs decrease about 15 percent for every doubling of the number of megawatts at a particular site. This latter estimate is the conventional wisdom of the utilities companies, which have always estimated that the upscaling of power is cost efficient. Today, however, a number of experts in the field have concluded that there is much to be said for reversing the trend toward larger and larger power capacity per nuclear plant. Rather than continuing to upscale capacity to more than 1 gigawatt, the thinking now is to move in the opposite direction and produce nuclear complexes in which each individual unit might be as small as 300 MW.

Economies of Scale

The environmentalist attack on nuclear power, especially since Three Mile Island, has meant that the economy of scale has not proven true over the last decade. The nightmare of environmental regulations placed increasingly complex and contradictory demands on the same nuclear plant subsystems, sharply reducing both reliability *and* safety, as every competent power engineer now agrees. In addition, many experts now argue that as reactors were scaled up from 500, to 1,000, and then to 1,100-1,300 MW, with higher and higher operating pressures and pressure differentials within the steam generator and cooling systems, the application of the same light-water and pressurized-water designs that worked reliably at smaller sizes, produced increasing and costly "down-time" for repairs of leaks, generator problems, and so on.

The result—50 percent and even higher down-times—robbed the expected economies of scale even when reactors did, miraculously, get operating approval. The only exception has been the French nuclear industry, unquestionably now the world's leader, which has come as close as large reactor sizes allow to standardized, mass-production of a single reactor design on a reasonable time scale.

Small-sized reactors, by contrast, allow for greater flexibility of design, and their standardization allows for simplified training of operatives who will run them. At the same time, their production can be automated with far greater ease than that of the larger plant. They can be produced in factories using prestressed concrete or steel containments and standardized subsystems, allowing a breakthrough to much higher rates of production and, with the new designs now being pioneered, greater reliability of operation. The present hand-tailored method of construction in the United States to individual specifications not only is uneconomical, but also means that safety requirements have to be reviewed on site. With *one* basic design guiding the mass production of plants, most regulatory questions can be solved at the point of production.

In the advanced sector, small nuclear plants would obviously be desirable in remote areas. However, there is a strong argument that introducing them in configurations of three, in place of the single 1-gigawatt plant, can also be advantageous in areas where there is a high concentration of population or industry. For example, the reduction in the construction time might save $200/kW electric. The reduction *of* capital costs is another important feature. One U.S. study by General Electric showed that the total carrying costs of three 400-MW electric plants in a station may be equivalent to or lower than those for one 1,200-MW pressurized water reactor. A Finnish study cited by the IAEA, indicated that the carrying costs *were* lower for two 500-MW nuclear plants than either a 1,000-MW nuclear plant or two 500-MW coal plants.

While larger plants, above 900 MW, are generally competitive with oil- and coal-fired plants, the situation is less clear for small-sized nuclear power reactors. An Indian study, cited by the IAEA, compared the Madras Atomic Power Station Unit I (235 MWe) with the Singrauli Super Thermal Power Station (3 units of 200 MWe). Both plants were commissioned in 1982. The nuclear plant was found to be competitive, with a cost of 30.9 paisa per kilowatt-hour for the nuclear plant, compared to the higher 33.14 paisa for the coal-fired plant, located at the pithead. When costs for transporting coal had to be included, the differential was considerably greater.

Developing nations have such extreme electricity shortages for housing and agriculture—not to speak of industrialization—that they cannot tolerate the typical *minimum* of seven years construction and licensing for a nuclear power reactor to come on-line. The large size of the final addition to the grid does not compensate for this. Not only that, but the smaller size of the power-plant components is a positive advantage in the case of a country that is just beginning to electrify on a large scale. In its most recent world power surveys, the IAEA emphasizes that no single unit in a national electricity grid should account for more than 10 percent of its total capacity, "if the dynamic stability of the system is to be ensured." It is difficult and degrades reliability to connect a big power plant to a weak grid, and is far more useful to distribute several smaller plants near the high consumption centers of the grid.

The most persuasive argument for producing plants in the small and medium power range is in the far greater ease of mass-producing such plants and doing it quickly. Argentina already has its modular Carem Project under construction and estimates the cost per Carem module (15-25 MW) to be $30 million, a comparable cost per kilowatt of capacity to that of today's large reactors, aside from their massive environmentalism-added "delay costs." The company plans a factory facility able to construct three modules at *one* time, completing the modules in 36 months, but adding new "starts" each year, so that the output of the factory would be three units per year from approximately 1988-1989 onward. Obviously, a network of serial-production factories could be constructed by cooperative agreements *among* Ibero-American nations and with nuclear production firms in North America.

And in the United States, according to industry spokesmen, there is no objective reason that the first factory-produced modules could not start rolling off an assembly-line at the beginning of the 1990s.

Marjorie Mazel Hecht is the managing editor of Fusion. *This article is based on the work of an FEF research team, including Marsha Freeman, Paul Gallagher, and Carol White, that prepared a detailed report on the state of nuclear power for the* Executive Intelligence Review Quarterly Economic Report, *Oct. 15, 1985.*

Notes

1. Edison Electric Institute, cited in "The Electricity Industry's Dilemma," *Science,* (July 19,1985), p. 248.
2. "Strategic Plan for the Civilian Reactor Development Program," U.S. Department of Energy, Oct. 25,1985 (Draft preliminary document).
3. A detailed report on the FEF study appears in the Quarterly *Economic Report* of the *Executive Intelligence Review,* Oct. 15,1985.
4. "Small and Medium Power Reactors: Project Initiation Study, Phase I," A report prepared by the IAEA and the OECD Nuclear Energy Agency (Vienna: IAEA, 1985) IAEA-TecDoc-347.
5. An article by Paul Gallagher, "The Argentine Plan to Mass Produce Small Reactors," appeared in the Sept.-Oct. 1985 *Fusion,* p. 13.
6. "Nuclear Energy Cost Data Base," Washington, D C : U.S. Department of Energy, June 1985) DOE/NE-0044/3.
7. "Nuclear Power in an Age of Uncertainty," (Washington, D.C.: U.S. Congress, Office of Technology Assessment, Feb. 1984)OTA-E-216.
8. *A Guide to Nuclear Power Technology,* written by Frank J. Rahn, Achilles G. Adamantiades, John E. Kenton, and Chaim Braun of the Electric Power Research Institute staff, was published by John Wiley & Sons in New York in 1984. This is an excellent source book for those concerned with nuclear power.

The Optical Computer: Reason's Chain

Continued from page 5

Even Cabor needed, ultimately, a laser to turn his hologram from theory into reality. It now turns out that the very process of life is closely allied with coherent radiation. Fritz A. Popp recently brought to our attention the work that has been going on for some time in optical biophysics. The cells, in particular the DNA molecules, absorb infrared radiation [>800 nanometer (nm)|, store this radiation while shifting the frequency to ultraviolet (<400 nm), and, as needed, emit coherent ultraviolet radiation.

The amazing part of all this is that it seems to be a central function of life. However, it was not until Theodore Maiman invented the laser in 1960 that it was even possible to speculate on this.

Work has been done on holographic storage of data. Lynn Boatner, among others, has done research into ferroelectric crystals. Much work remains in this area, of course. Advances in materials science to discover better and purer storage crystals are a necessity. The theoretical possibilities are astounding. According to the formula for three-dimensional storage:

$$D = (nVA^3)(V/mm^3)(eff/100).$$

If we take a crystal 1 centimeter (cm) on a side (approximately that of an ordinary sugar cube), 660 nm coherent light (bright red), and an index of refraction of 1.5 (air = 1.0), at an efficiency of 1 percent, then our sugar cube-sized crystal would store =1.5 x W terabytes ("tera" is a million million) that is 15,000,000,000,000,000,000 bytes of data. (The U.S. Library of Congress contains about 16 terabytes or 16,000,000,000,000,000,000 bytes of data.)

Such is the potential of optical holographic data storage. This also carries implications of the vast potential of the human brain.

The parts are all there: What is lacking is an architecture to tie it all together and make it work. I am certain that the computer community, with its lack of vision and slavish devotion to von Neumann, would be most willing to use these principles to achieve more of the same. But I sincerely doubt that computer scientists can do it, for this is something that is unworkable von-Neumann-style.

What is required is an architecture that can function as a whole, not bit-by-bit; that can interpret, compare, and alter some virtual image or virtual data as a unit; one that can put this into memory, manipulate or process it, and send it to output *simultaneously.* This is impossible to do with a von Neumann computer. However, an optical holographic computer demands this.

Professor Thomas Gaylord has suggested such an architecture. The architecture he proposed can write into memory, read from memory, and process data or images simultaneously. Further, the processing step may be done in such a way as to alter the data continuously. If the answer arrived at is not the desired answer, the polarizing beam is turned off, and all the data resume their previous state; should the answer be acceptable, a higher-powered pulse alters the data so that they remain that way. This process, of course, is not limited; it may be repeated many, many times.

Think Like Wright

If one observes an intelligent, thinking human brain, and, like Wilbur Wright, attempts to understand what is happening, then mysteries fade away and the hidden truths become plain. What has been described is an outline for what would be required to design and build a device to mimic the human brain. If a successful joining is made, of all of these various concepts, then a series of devices, the likes of which have never been seen before on Earth, will come into being, aiding in the transformation of the universe, as well as the uplifting of mankind.

How, you ask? The computer as we now know it is not going to do any great and wonderful things for humanity. It cannot, because of its inherent flaws. But an optical holographic computer, because of its immense memory and processing power and similarity to the human brain, could become "almost intelligent." Because it would lack emotion and passion, it would not be able to become an initiator. It would, though, be a powerful and willing servant.

Think of the possibilities! In size, such a device would not be very large, nor consume much power. The cost to the end user would not be very much more than an advanced personal computer, say in the range of $10,000-$20,000 per unit. Put in an ambulatory robot, it would become a servant, bodyguard, companion, tutor. Put on board automobiles, trucks, aircraft, ships, it would be an error-free pilot. Placed in factories, it would cause productivity to rise dramatically, freeing human labor for higher tasks.

The increase in material wealth and human longevity from this is incalculable. Tie it into other advances—the fusion torch, for example—and the increases multiply vastly.

How long will all of this take? Perhaps as little as five years, perhaps as long as twenty. I'm an optimist; I lean toward the former figure. If there are those of you reading this willing to share the vision and work toward its realization, then please write to me in care of *Fusion* magazine. With the other advanced technologies already under way, this can become a part of the greater whole.

Friends, our future awaits us!

Books Received

Fusion Energy, by Robert A. Gross. Wiley-Interscience.

Free-Electron Lasers, by Thomas C. Marshall. Macmillan, 1985. Hardcover, 191 pp.

How To Make Nuclear Weapons Obsolete, by Robert Jastrow. Little, Brown, 1985. Hardcover, $15.95, 175 pp.

Star Warriors, by William J. Broad. Simon and Shuster, 1985. Hardcover, 245 pp.

A Guide to Nuclear Power Technology—A Resource for Decision Making, by Frank J. Rahn and others. Wiley-Interscience. Hardcover, 950 pp.

One Hundred Billion Suns—The Birth, Life and Death of the Stars, by Rudolf Kippenhahn. Basic Books, 1983. Hardcover, 264 pp.

Principles of Stellar Evolution and Nucleosynthesis, by Donald D. Clayton. Reprint edition. University of Chicago Press, 1983. Paperback, 612 **pp.,** $17.

How to Use an Astronomical Telescope—A Beginner's Guide to Observing the Cosmos, by James Muirden. Linden Press, 1985. Hardcover, $21.95.

Exploring **the Moon through Binoculars and Small Telescopes,** by Ernest H. Cherrington, Jr. Enlarged edition. Dover, 1984. Paperback, 229 pp., $10.95.

The Young Scientist

Could Water Mean There's Life on Mars?

by Marsha Freeman

Ever since the Italian astronomer Giovanni Schiaparelli pointed his telescope at Mars in 1877 and described what he saw there as "canali" (by which he meant "channels"), man has wondered whether there is water, and possibly life, on the red phnet.

Schiaperelli's "canali" was mistranslated as "canals," which started decades of speculation as to whether these "canals" had been constructed by intelligent beings. The 1971 Mariner 9 orbiter and the mid-1970s pair of Viking landers found no intelligent beings, but they also did not close the book on whether or not there is any life on Mars.

It does seem that the channels were formed by flowing water, and an ongoing careful reexamination of the Mariner and Viking photographs has led scientists to believe that there is more water on Mars than they originally thought.

That discovery makes the possibility of life on Mars more likely, and the Mars Observer Mission scheduled for launch in 1990 will increase our understanding of how Mars functions today and what it might have been like in the past.

The answer to the question, "Is there life on Mars?" will probably not be answered until we send people there to find out for themselves.

The Only Other Planet Like Earth

Of all the planets in the solar system, only Mars has the qualities that would make it possible for life to exist there already. Even if there is no life on Mars now, it is the planet that could be "terraformed" or, made like the Earth.

Although our Moon is much closer—about a quarter of a million miles away, compared to at least 35 million for Mars—it has no water, and is not massive enough to hold down an atmosphere. The exhaust from the Apollo space ships that landed on the Moon six times, for example, did not start an atmosphere; it just floated away.

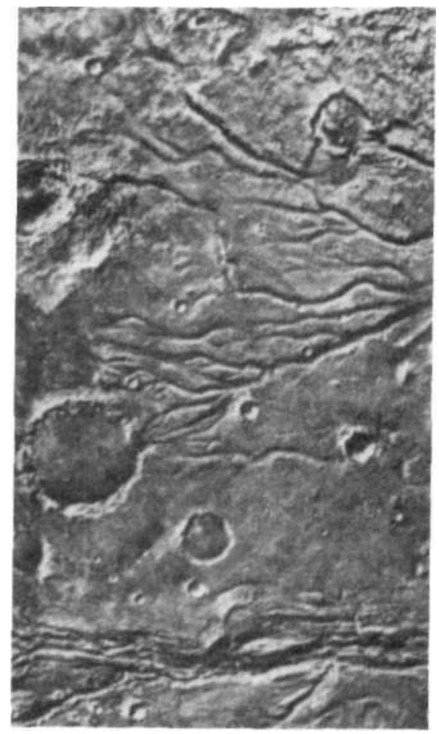
Venus, the neighbor of the Earth that is closer to the Sun, is hot enough to melt lead and could not provide a livable environment. Mars is a solid body, with an atmosphere, water, and periods of relatively moderate temperature during its different seasons.

It is the only planet in addition to Earth that has a tilted axis of rotation, which creates the seasons (as the angle of the Sun's rays hitting the planet varies). If there is sunlight, water, and a carbon dioxide atmosphere on Mars, there might be at least a primitive form of life.

The polar caps of Mars are visible with a ground-based telescope, and astronomers can watch them grow smaller in the summer and larger in the winter. Because the Mars atmosphere is 95 percent carbon dioxide, scientists thought at one time that these frozen solar caps might be just solid carbon dioxide (dry ice).

However, scientists now are convinced that there is water ice in the polar caps, and that there may also be either flowing or frozen water still beneath the surface. They can observe the water ice in at least the northern polar cap in the summer, when the overlying dry ice vaporizes.

On Oct. 8,1985, a panel of scientists who have been studying this

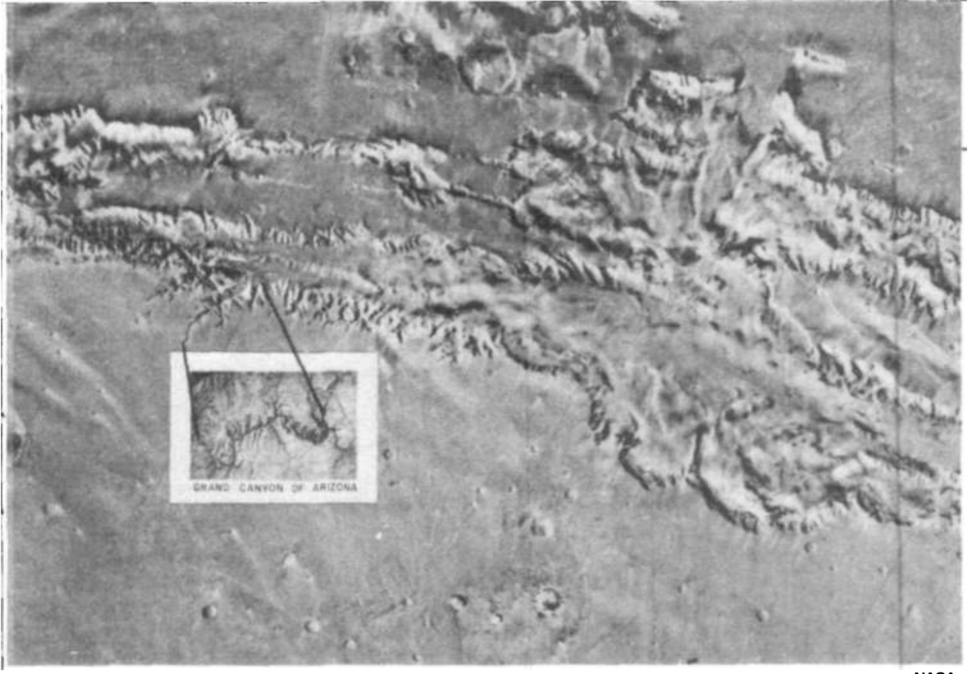


Were these channels on Mars formed by flowing water? The aerial photo is from the Viking 2 mission in 1976.

question presented new findings at the Ames Research Centerof the National Aeronautics and Space Administration (NASA) in California.

The water ice in the Martian polar caps does not melt, because temperatures rarely climb above freezing, according to NASA. The water sublimes directly into the atmosphere; that is, it turns from a solid directly to a gas. This evaporated water forms wispy clouds that can be seen in the Martian sky.

Scientists are now trying to figure out how the channels on Mars, which



NASA

The great canyon system on Mars, Valles Marineris, is more than 5,000 kilometers long. Compare this to the "tiny" size of the Grand Canyon in Arizona, which is superimposed on the Mars view in the upper left. The intricate system of canyons extending back from the rim may have been developed during melting and evaporation of subsurface ice. The photo was taken in 1975 by Mariner 9.

indicate water flow, were created; why the water disappeared, or where it might have gone; and if there is any remaining water, in any form, in addition to that at the poles.

They hope to learn how the water on Mars could have shaped the planet's surface and climate.

The Water on Mars

How did the channels on Mars, photographed by Mariner 9, develop? This is what scientist Gary Clow from the U.S. Geological Survey tried to envision.

The channels resemble dry riverbeds on Earth. At one time, when the poles of Mars were tilted more directly toward the Sun, ice may have sublimed into the atmosphere and been deposited in the regions of the equator as snow. Clow thinks that this equatorial "snowpack" could have trapped sunlight, causing some of the snow underneath to melt and flow out, etching out the channels.

Mars has been too cold for eons, however, to have any flowing water on the surface. What changed the Martian climate? One theory, put foward by James Pollack of NASA's Ames Research Center, is that the Martian climate was warmer and wetter than today because the atmosphere was much thicker.

This earlier, thicker atmosphere would have captured more of the Sun's warmth. Pollack suggested that perhaps the presence of liquid water accelerated the weathering of rocks on Mars, which enhanced the chemical reactions that pulled carbon dioxide out of the atmosphere and into minerals.

As the atmosphere thinned, less heat was retained, locking up water on Mars as ice while the planet cooled, according to Pollack. Other planetary scientists have suggested that some cataclysmic impact may have changed the climate on Mars.

But where did the water go? Robert Haberle of the Ames Research Center has been studying water distribution on Mars, and reports that the water lost by the north pole during the summer is not fully recovered in the winter.

According to Steven Squyres of Ames and Michael Carr of the Geological Survey, there is ice present in the ground in regions above 30 degrees latitude on Mars. They make this judgment based on the Viking data that showed evidence of "terrain softening" or the rounding off of features of smaller, more recent craters.

Like the permanently frozen tundra of Alaska, this frozen ground never thaws. According to Carr, the presence of ice in these regions outside of the poles would indicate the presence of liquid water deep within the planet.

Carr postulates that perhaps a half mile beneath the surface, water in the rocks of Mars is liquid, because it is heated by the higher temperatures present closer to the core of the planet. We will only know for sure when we can go there and do the necessary on the spot geological studies.

Viking also returned photographs of Mars that showed canyon systems in the immense Valles Marineris (see photo). The floor of these canyons, Steven Squyres says, reveals thin, flat-lying layers of sediments, which could have been laid down by standing bodies of water.

Perhaps, long ago, Mars had huge ice-covered lakes, flowing rivers, and snow storms. If that is true, the climate would have surely been moderate enough for at least the most hearty life forms. It would also mean that the Martian gravity, though only 38 percent that of the Earth, was great enough to hold down a thicker atmosphere than now exists. This thicker atmosphere would be required for higher forms of life.

Making Mars Habitable

During the 1990s, the United States will send the Mars Observer around the planet for one Martian year (approximately double an Earth year) to study the geochemical makeup and climate of Mars. In the first decades of the 21st century, it will be possible—and necessary—to begin to send manned expeditions to visit, explore, and colonize Mars. That is when we will finally know if there is any life existing there already.

Whether there is life on Mars or not, the purpose of these Mars missions will be to create an Earth-like home for man. Warming the planet is a top priority and changing the composition of the atmosphere could be done by increasing the amount of sunlight reaching Mars, through a set of orbiting mirrors. These mirrors would relay the Sun's energy to the surface. The albedo of the planet (the amount of light it reflects back to space rather than absorbs) could be decreased by darkening the surface of Mars.

The dark material needed to decrease Mar's albedo could come from the two Martian moons, according to a proposal by scientist James Oberg in his book *Mission to Mars.*

As the mean temperature of the planet increased, even just in local targeted regions, waterwould be released from ice, and evaporation would take place, thickening the atmosphere. Polar ice and perhaps even the trapped ice below the surface would be available for use. The thicker atmosphere would absorb more of the Sun's energy, and a climate and weather system not that different from that of the Earth would develop.

Although we don't know now whether there is some primitive form *of* life on Mars that has managed to live in its cold climate with a whisper-thin carbon dioxide atmosphere, we do know that we will bring human life to Mars some time in the future. These studies and speculations mentioned here on how to terraform Mars are just the beginning of engineering the planet Mars to make it habitable for man.

Optical Computers

Continued from page 30

pass the capabilities of the computers available today. These new computers not only will fulfill the needs of strategic defense systems, but also will provide many other benefits.

It is no coincidence that the electromagnetic phenomena that can be used to satisfy the computational needs of a successful SDI system also provide its required kill mechanism. Advances in tools such as computers and lasers (or anything else that does useful work) are ultimately dependent upon advances in our understanding of ever more highly organized forms of electromagnetic action. Tools do not create action, they simply redirect it.

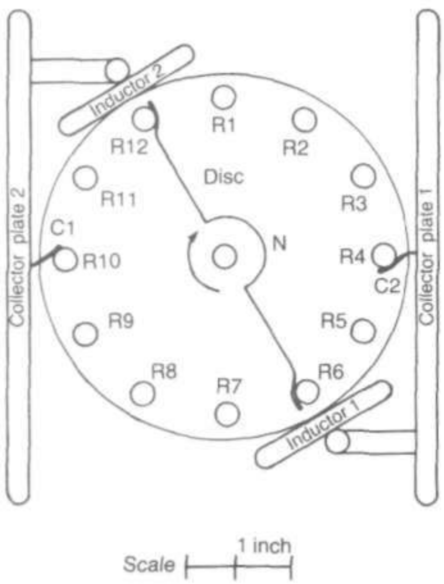
The progress being made in optical computing is but one example of the true promise of the SDI—not merely as a defense against ballistic missiles, but as the spawning of a new industrial revolution.

SDI Status Report

Continued from page 18

said that they were still limiting themselves to the phase of understanding elements of the system, rather than testing the deployment of the system.

He continued: "It's very different to take a large laser and to fire the laser and have it bounce off a mirror and go thousands of miles away and destroy a booster. That is a difficult problem. . . . It's really a matter of understanding . . .at least at this point. Now at some point in time we may find that it is very very important, but we are conducting a program in accordance with the President's policy.



Attention Young Scientists

This is a corrected front view of Dirod 2 showing the distribution of charges. The illustration that appeared in the January-February issue, page 59, in the article on "How to Build an Electrostatic Generator" was mislabled. In addition, the figures referred to *on* page 59 as 3 and 4 were actually shown as Figures 2(a) and 2(b). We apologize for any confusion that was caused.

Self-Induced Transparency

Continued from page 24

lowed the Development of Supersonic Flight," in *Fusion,* Jan.-Feb. 1986, p. 39.

5. James E. Pearson, R. H. Freeman, and H. C. Reynolds, "Adaptive Optical Techniques for Wave Front Correction," in *Applied Optics & Optical Engineering,* Vol. 7. R. Shannon and J. Wyant, eds. (New York: Academic Press, 1979), p. 245.
6. K. Tsipis, "Laser Weapons," *Scientific American* **245** (6): 51 (Dec. 1981).
7. "Real-time Compensation of Atmospheric Turbulence by Nonlinear Phase Conjugation Demonstrated," *Laser Focus* 19 (9): 14 (Sept. 1983).
8. L. R. Bissonnette, "Adaptive Optical System Referencing in the Case of Resolved Targets Illuminated Through Turbulence," *Applied Optics* **21**: 3998 (Nov. 15,1982). Also, "Outgoing-wave Adaptive Optics Systems: Error Sensing Method in the Case of Extended Targets in Turbulence," *Proceedings,* Society of Photo-optical Instrumentation Engineers **365:**32 (1982).
9. "Adaptive Optics," *Science Digest* 92 (5): (May 1984).
10. "At the Forefront of Laser Technology: Optical Phase Conjugation," *Executive Intelligence* Review **11:**12 (June 19,1984).
11. One possibility might be to irradiate atarget and then conjugate and amplify a coherent reflection. However, it is questionable whether the power levels of such a reflection from an arbitrary target would be large enough, and whether it would be possible to isolate that portion of the reflected beam that was coherent at the target.
12. D. J. Johnson et al., "Electron and Ion Kinetics and Anode Plasma Formation in Two Applied B Field Ion Diodes," *J. Appl. Phys.,* 57 (3): 794 (Feb. 1, 1985); and "Time-resolved Proton Focus of a High-power Ion Diode," *J. Appl. Phys.,* **58(1):** 12 (July 1985).
13. Or in the language of Pearson et al., "the atmospheric coherence length [isj the distance perpendicular to the beam path over which [refractive] index fluctuations are phase correlated."
14. For the turbulence level and the wavelength of the laser light in the Hughes experiment, statistical optics estimates r_0 at less than 1 cm! See Note 2.
15. J. Strohbehn (ed), *Laser Propagation Through the Atmosphere.* (New York: Springer-Verlag, 1978), p. 71. "The phase fluctuations arise directly from the fact that the refractive index is a random function of space and time, which from the simple relation $v = c/n$ [where c is the velocity of light and n is the refractive index of the atmosphere] produces a random velocity in the propagating wave."
16. Bissonnette, personal communication.

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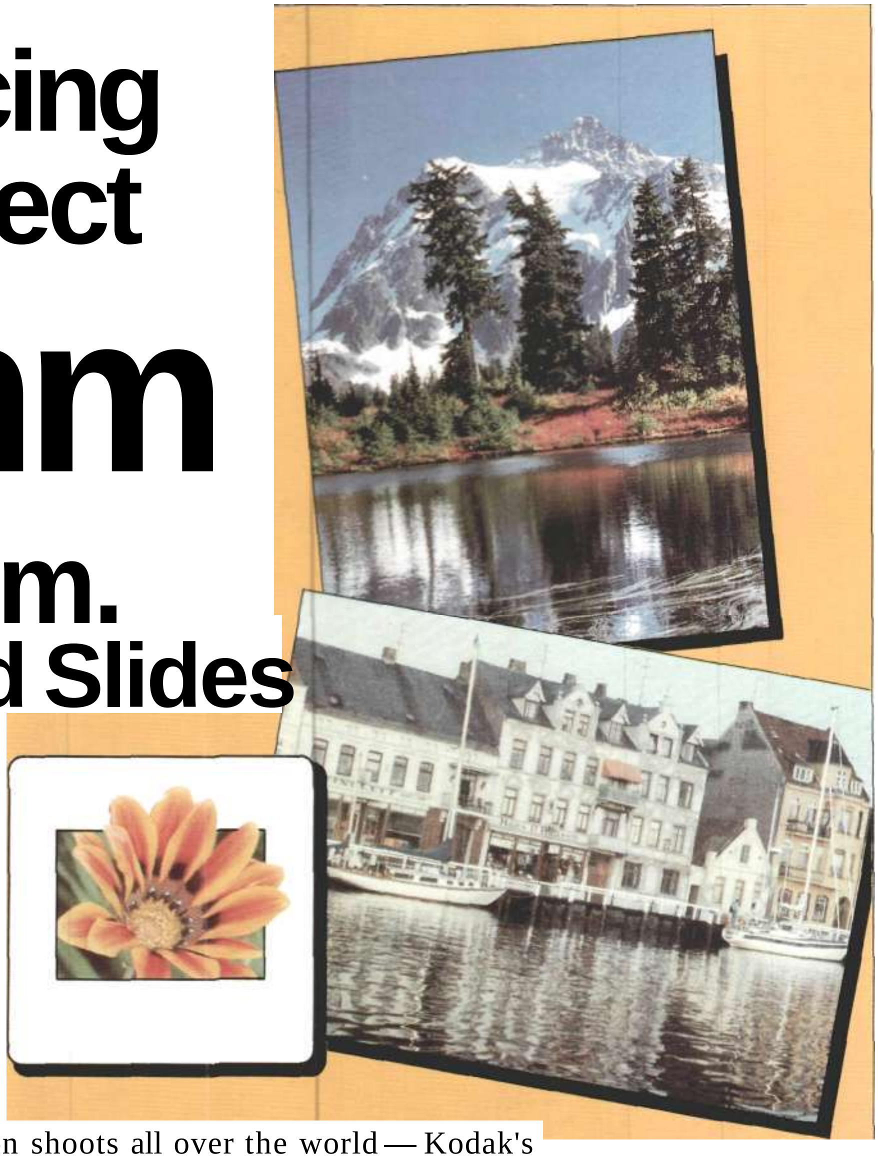

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In This Issue

MAKING THE WORLD GO NUCLEAR—QUICKLY

How fast can we put nuclear power plants on line? Within three years—if the plants **are** factory-fabricated, standardized, and small to medium in size. As our cover story demonstrates, mass-producing smaller nuclear plants would go a long way toward industrializing the developing sector and putting the U.S. economy back on its feet.

FUSION BY 1988?

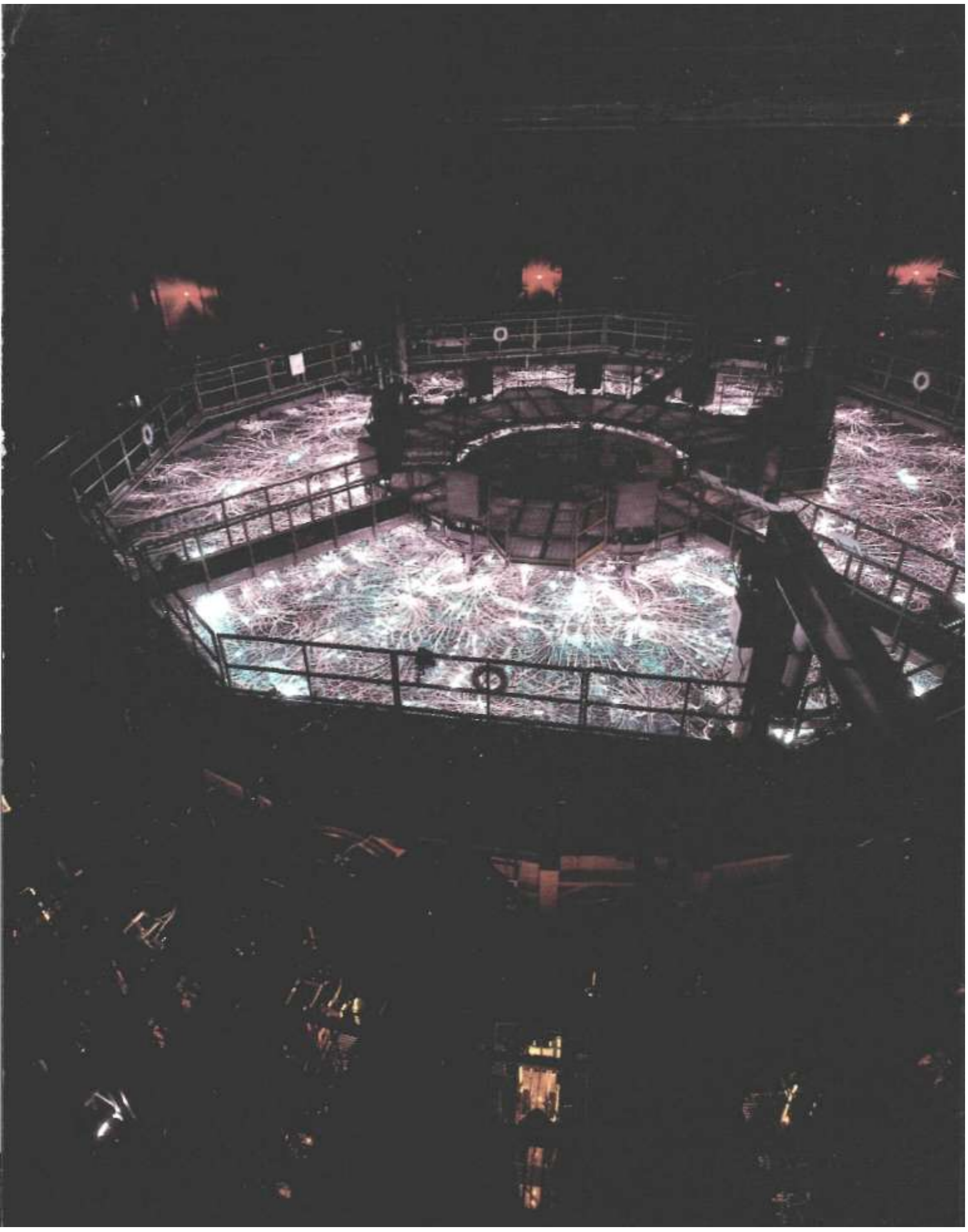
Sandia National Laboratories' PBFA **II,** the most powerful particle beam fusion accelerator in the world, is the first machine with the potential of igniting a controlled laboratory fusion reaction. Fusion technology editor Charles B. Stevens tells how the **PBFA II** could achieve fusion as early as 1988.

THE SCIENCE OF LIGHT AND LIFE

What are the controlling forces behind biological processes? Wolfgang Lillge, M.D., gives a fascinating account of the latest research on the role of very-low intensity photon emission in living matter. Research into optical biophysics, he says, could be the key to understanding—and curing—diseases like cancer and **AIDS.**

Electrical discharges illuminate the pulse-forming section of Sandia's PBFA II during its first shot, Dec. 11, 1985.

Sandia National Laboratories

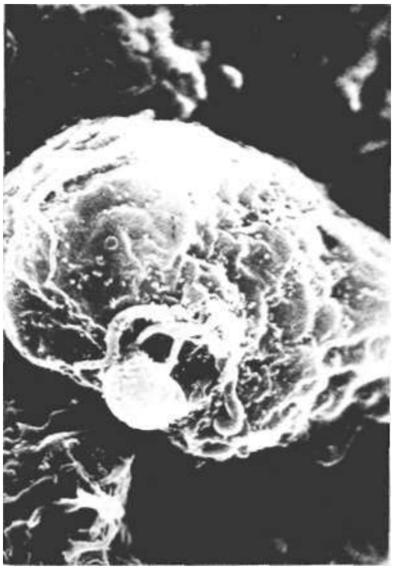


Courtesy of Konrad Dannenberg

Author Dannenberg with a model of the V-2 engine at the Huntsville Space and Rocket Center in Huntsville, Ala.

ROCKET DEVELOPMENT—
FROM THE V-2 TO THE SHUTTLE

Rocket scientist Konrad Dannenberg presents a pictorial history of the development of rocket and space flight, from the early work at Peenemünde in Germany to the Space Shuttle, highlighting the role of space scientist Krafft A. Ehricke.



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