21st CENTURY SCIENCE & TECHNOLOGY

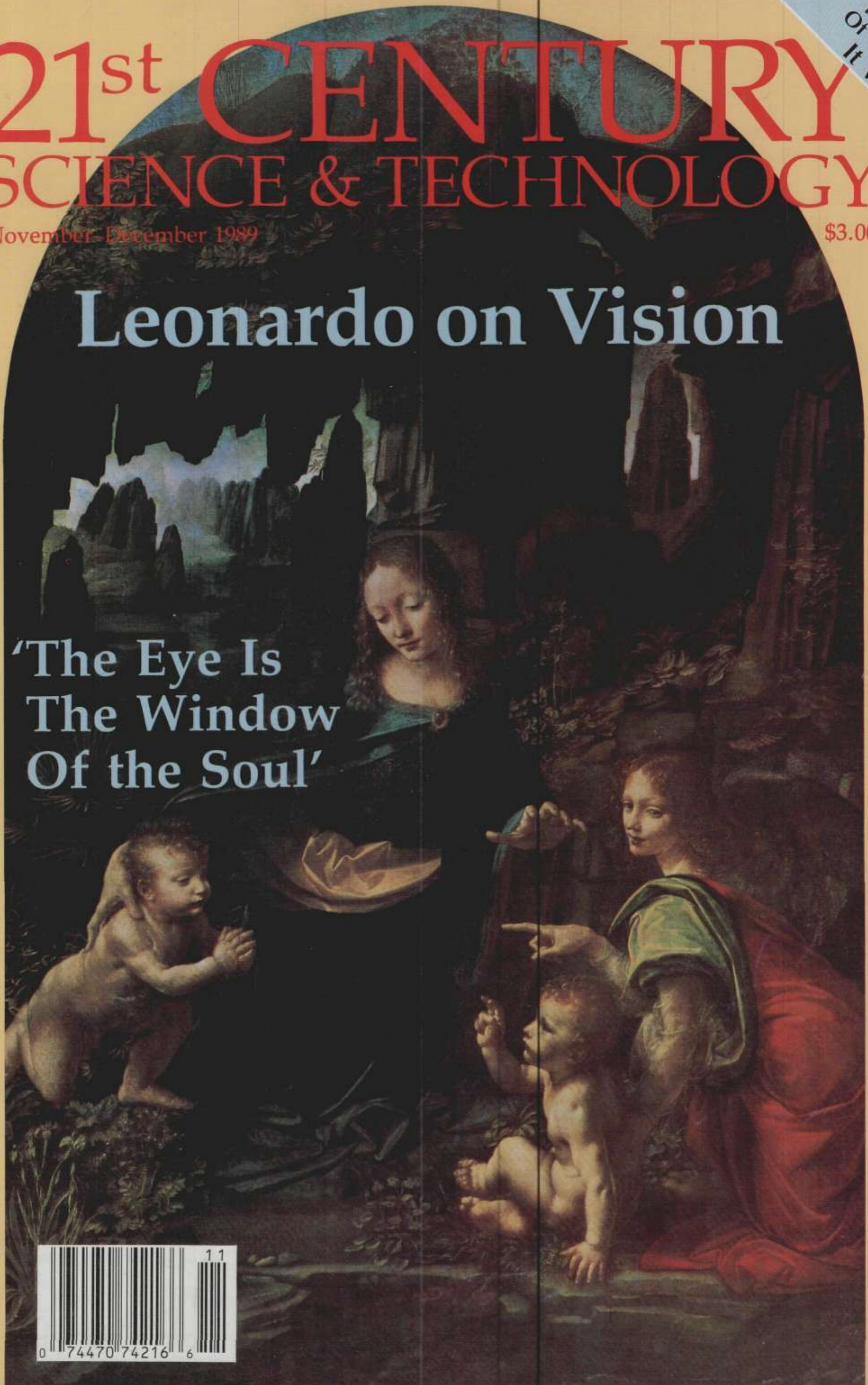
November-December 1989

$3.00

The Real Story Of Cold Fusion: It Works!

Leonardo on Vision

'The Eye Is The Window Of the Soul'



21st CENTURY SCIENCE & TECHNOLOGY

Vol. 2, No. 6 November-December 1989

Features

News

Departments

21st Century Science & Technology (ISSN 0895-6820) is published 6 times a year, every other month, by 21st Century Science Associates, P.O. Box 65473, Washington, D.C. 20035. Tel. (703) 777-7473. Dedicated to providing accurate and comprehensive information on advanced technologies and science policy, **21st Century** is committed to restoring American scientific and technological leadership. **21st Century** covers the frontiers of science, focusing on the self-developing qualities of the physical universe in such areas as plasma physics—the basis for fusion power—as well as biology and microphysics, and including ground-breaking studies of the historical development of science and technology.

Opinions expressed in articles are not necessarily those of 21st Century Science Associates or the scientific advisory board.

Subscriptions by mail are $20 for 6 issues or $38 for 12 issues in the USA and Canada. Airmail subscriptions to other countries are $40 for 6 issues. Payments must be in U.S. currency.

Address all correspondence to 21st Century, P.O. Box 65473, Washington, D.C. 20035.

POSTMASTER: Send address changes to 21st Century, P.O. Box 65473, Washington, D.C. 20035.

Printed in the USA
ISSN 0895-6820

On the cover: *The Virgin of the Grotto* by Leonardo da Vinci, courtesy of Art Resource; cover design by Virginia Baier.

The 21st Century: The Promise Exists

The next 10 years will surely be crucial to the future path of humanity for the foreseeable future. At present we are living in a period cursed by narrowness of vision and, in many instances, sheer brutality. In Africa, Asia, and now in Latin America hunger again stalks the globe—and all unnecessarily. In this next decade either we will prepare to enter a true space age, an age with an uncharted but joyously hopeful future awaiting it, or mankind will huddle here on Earth in a protracted dark age, which will make earlier such periods seem like golden ages by comparison. The choice is ours; the promise exists.

Fifty years ago the possibilities of harnessing fission energy and fusion power were still in the future. Today, we seem on the verge of new experimental discoveries about the very essence of matter. The work of Fleischmann and Pons and their associates, as well as the past years' discoveries that have expanded our notion of superconducting, pose a whole new frontier not only of physics *per se*, but also of biophysics. The human body operates on the basis of advanced catalytic principles that must be analogous to *cold* fusion and *room temperature* superconductivity, because it can deploy huge energy flux densities without raising body temperature.

Perhaps the most upsetting feature of the Fleischmann-Pons experiments to the science establishment has been their very simplicity. To repeat them obviously requires care and scientific rigor, but not megabucks. Any physics or chemistry laboratory can join the game, and many already have, in India and Latin America as well as in the United States, Europe, and Japan.

The new physics threatens to be dangerously subversive. Imagine how Leonardo da Vinci would laugh with delight as the pomposities of groups like the American Physical Society, which outlawed cold fusion out-of-hand, are punctured one after another.

The essential lesson of the new superconductors and the latest developments on the fusion front is the beautiful demonstration of the unity of physics and geometry, a unity that lay at the basis of the great discoveries of Leonardo, the father of modern science and technology.

Today, physics and mathematics have followed the same path, relinquishing the only fruitful way to discovery through the methods of constructive geometry, and replacing these methods by a dependence upon deductive logic and its sterile axiomatic foundations. From the standpoint of deductive method, creative mental processes have no valid existence in our universe; nor are major scientific breakthroughs predictable.

If a single, crucial physical experiment shows any strongly defended theorem of a school of mathematical physics to be wrong, its physical evidence challenges the whole deductive system and the axiomatic beliefs upon which it is based. It is true that the new high-temperature superconductors or cold fusion may be given plausible explanations, but their implications are truly revolutionary, and that is what is destabilizing the scientific establishment in the United States and Western Europe. (Interestingly, this is not the case in Japan, where the government is underwriting major experimental programs.) Indeed, the implication of the newest pattern of discoveries is the need for geometrical methods to replace axiomatics. We must look at the geometries in space and time, phase shifts over finely quantized intervals, to understand how it is that these results occur. These are not brute force experiments!

Leonardo's Method Vs. British Empiricism

Leonardo da Vinci's method can be traced backward in time to Plato, and forward through the work of Gauss, Riemann, Beltrami, and their followers. In opposition to the currently hegemonic school of British empiricism (which also dominates in the Soviet Union), Leonardo, and more recently, Bernhard Riemann, sought the geometrical determinants for phase shifts and singularities in processes. They sought physical explanations within the context of a natural law that could explain the continued perfectability of God's universe. The axiomatic method of British empiricism (and its various Kantian elaborations) can recognize the existence of discontinuities as such, but only as revealing a threatening bottomless chasm that must be bridged, with one axiomatic system attached to another to span the revealed gap.

For us, the transformation in physics and biology promised by recent discoveries is the key to the transformation that mankind must undergo in the next century. We may and we must develop unforeseen technologies that will free us from the apparent boundaries of life today, here on Earth.

Nonetheless, we cannot judge the importance of scientific discoveries in terms of immediate returns or specific applications. Indeed, the greatest benefit that we may see from the work of Fleischmann and Pons could well be in the realm of pure theory, as serious scientists are drawn to reconsider the well-springs of our culture, beginning with the scientific writings of Plato and leading from there through the great traditions of the Christian humanist scientists.

Letters

'I Want a Solar Cell'

To the Editor:

I just received with interest my first issue of your magazine. Knowing very little about any sort of science, I am nevertheless compelled to question the thoroughness of Dr. Michael Fox's report on solar energy (July-August, 1989, p. 20).

Solar energy carries a pricetag "that has already been deemed too expensive for *any* utility," he observes. No doubt; but that statement reveals a bias that plagues *most* specialists: The bucks flow from bums like me to the big boys and from the big boys to the researchers. Consequently, researchers never ask fellows like me what might interest *us.*

I want a solar cell that I can clean and point all on my own: not to charge batteries, but to make that utility company meter on the outside of the house run *backwards,* if only just a little. I know nobodies all over the country who share the desire, of which I am certain the utilities are in dread. Ask Fox about the cost-effectiveness of that—both now, and in the researchable future.

Bob Finton
Kiahsville, W.Va.

The Author Replies

My colleagues and family have found such experiments very instructional. There are many sources of information and materials. The first that come to mind are the government-subsidized solar energy failures that litter the countryside. They don't operate because the owners were left with huge maintenance and repair costs just to keep them operable. They could be acquired at minimal cost.

Be advised that their energy was typically 7 to 10 times more costly than the energy it replaced, as the General Accounting Office (GAO) reported. The owners have largely gone back to the locally available energy sources. The GAO should be able to provide the names and addresses of some of the owners.

Are the utilities in dread of citizens pumping energy back into the electrical grid from their solar devices? Not to worry. In contacting some of the utilities in the Northwest, not one solar advocate has called to be disconnected from the utility's service. In view of the booming growth of energy demand—and looming energy shortages—in much of the country, such requests would probably be welcomed.

Another source of information is the solar energy trade journals, available in most libraries. The last time I checked, it would have cost about $2,000 to provide enough electricity to power a 100-watt bulb (only on a sunny day, of course). This ignored replacement costs of the solar cells every 5 to 10 years, as well as maintenance costs, repair costs, financing costs, disposal costs, and the costs of a substantial supply of Windex and rags. The disposal costs are important because some of the candidate collector materials contain arsenic and cadmium, known carcinogens and toxins; and disposal of these materials should not be viewed as trivial.

As far as future cost-effectiveness of solar energy is concerned, the prospects are limited by physical law, not by biases or conspiracies. Solar energy flows are too low and intermittent at the surface of the Earth. These are fixed by the energy output of the Sun, the distance of the Earth from the Sun, and several other variables. Thus, the very constancy of these life-giving laws of nature limits severely the future of this energy form. In fact, we should all *hope* that these remain constant, if you catch my drift.

Cosmology Vs. Revival Tent Science

To the Editor:

David Cherry's recent article in *21st Century* concerning the cosmological implications of the redshift with respect to the origins of galaxies (May-June, p. 34) was of considerable interest. Unfortunately, there are very few genuine skeptics in this area and those there are seem quite stale and timid.

I can certainly appreciate the thrust of your argument although I must express some reservation about the creation of entire new galaxies. Quasars might well represent ejecta from galactic nuclei and might also eventually form whole new stellar aggregates. Yet the possibility that these could rival the parent galaxy in size seems remote.

I am beginning to wonder if the globular clusters surrounding the Milky Way and other spiral galaxies might not represent quasar remnants. . . . The absence of dust in them could as easily indicate youth as age.

In any event, I certainly applaud your efforts to debunk some of the sillier aspects of Big Bang creationism. The redshift in general might well be cosmological in origin, but in mechanical terms it cannot represent the sort of uniform cosmic expansion conventionally assumed. Indeed it is just this sort of naive analysis that gives science the aura of a revival tent instead of a laboratory of nature.

I am glad there is at least one outlet for serious speculative ideas in the realm of science, and I wish there were others. I have a feeling that until we can get a thorough airing of basic principles and their interplay, we will never get to the mechanical foundations of nature and theoretical physics as we know it will remain an intellectual quagmire of the first order.

Lester Zick
Los Angeles, Calif.

The Author Replies

When astronomer Halton Arp speaks of entire new galaxies being formed from the ejecta of active galactic nuclei, he is supposing that the nuclei of galaxies are the source of newly created matter. Hence there is no *a priori* constraint on the possible mass of the ejecta. The idea is developed in Arp's book *Quasars, Redshifts, and Controversies* (Berkeley, Calif.: Interstellar Media, 1987).

Concerning globular clusters, their low metallicity certainly seems to indicate that they are old.

Even conceived as a relatively local phenomenon, I think, a quasar is still too energetic to be seen as the prede-

Continued on page 5

There Is a Super Train In Our Future

Joseph Vranich

New train systems will be built in the United States before the turn of the century and they will be unlike anything most of you have seen. Some trains will operate at about 150 miles per hour, others at 300. I have no doubts about whether such systems will be built; it is now only a matter of time. We will return to the trains in record numbers.

Magnetic levitation is the world's newest mode of transportation. Maglev vehicles are lifted and propelled along and above the guideway by a wave of magnetic energy.

The German maglev, the Transrapid, has been in development and testing for 19 years. That's an example of dogged perseverance that we seem to have forgotten in the United States. A new model, the Transrapid 07, is expected to have a cruising speed of 310 miles per hour.

The Transrapid maglev is outfitted with conventional electromagnets and uses the attraction between the magnets in the guideway and those in the vehicle to lift the train about 3/8 of an inch. A high-level West German Commission has selected the Hamburg-Hanover route for the first maglev revenue service.

Japan has two types of maglev under development, both the attractive and the "repulsive" systems. In the repulsive system the magnetic field in the guideway repels the same polarity in the coils in the car's underside. This levitates the train about 6 inches above the guideway. In a test a decade ago, the Japanese successfully operated a vehicle at 300 mph.

Construction of Japan's first maglev system will begin in 1990. It will be on Hokkaido Island and will link the city of Sapporo with an airport 27 miles away.

These countries have something in common. Their central governments have made a commitment to build new super-speed train systems, or at least seriously consider them. What has happened to the spirit our federal government used to show in pioneering advances in transportation? Where is the national commitment? Unlike other countries, in the United States most of the activity has been in individual states.

Florida Is First

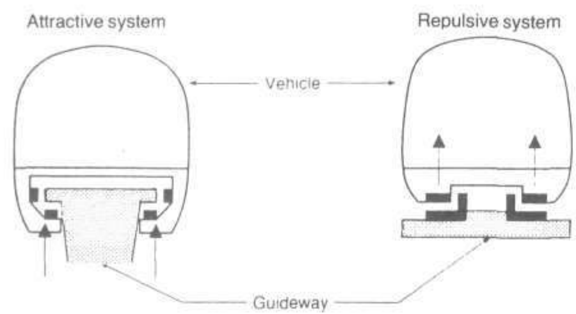
If any place needs a good train system, whether rail or maglev, it's Florida. It is one of the fastest growing states in America with a population that is expected to double over the next 15 years to 21 million.

The first super-speed maglev line to be built in this country will be by Maglev Transit Inc., a German-Japanese Consortium, using Transrapid technology. The train will link the Orlando Airport with Disneyworld Epcot Center 20 miles away, in about 7 minutes and will operate at 200 mph. It is expected to carry 8.5 million passengers annually, starting in October 1994.

The California-Nevada Super Speed Ground Transportation Commission has announced that it wants to break ground in 1993 for the Southern California/Las Vegas line and begin carrying passengers five years later. Either a Transrapid maglev or French TGV high-speed rail system will be selected in a competition. Studies have projected that 3.5 million passengers would use the train in its first year. Construction is estimated at $2.5 billion, which would be financed by a private consortium.

In June, Texas Governor Bill Clements signed legislation to create the Texas High Speed Rail Authority. This action followed a study that concluded high-speed rail is the way to accommodate future travel demands between cities including Dallas/Fort Worth, Houston, San Antonio, and Austin.

In September, Pennsylvania released a study of maglev and rail proposals that would link Philadelphia with Pittsburgh in as little as two hours.



SCHEMATIC OF A MAGLEV SYSTEM

The attractive system of magnetic levitation typically supports the magnets with a spacing of about 3/8 inch below the ferromagnetic rail, while the repulsive system has the vehicle suspended 4 to 6 inches above the guideway. The clearance between the guideway and the vehicle determines the designs of the guideway, the propulsion systems, and the secondary suspension systems.

Source: Argonne National Laboratory

Other states are also making plans to build high-speed rail systems, which have many advantages over both airplanes and automobiles.

For example, about 928,000 people were killed in automobile accidents in the United States between 1971 and 1985. The Japanese Bullet train has been operating for 25 years and has carried more than 2.5 billion passengers without a single accident or passenger fatality. It is the best safety record for any transport system ever in the history of the world.

Two months ago the Argonne National Laboratory in Illinois recommended replacing short-haul jets that travel from major U.S. airports with a 2,000-mile network of 300-mph maglev trains. At a cost of about $30 billion, that lab said, it would be a bargain, eliminating the need to build many costly new airports. Argonne used Chicago as an example, saying that more than half of the flights arriving or departing O'Hare cover distances of less than 500 miles. Maglev can take the shorter-haul aircraft off the runways, allowing an expansion of longer-range domestic and international service.

Super-speed rail will help reduce America's reliance on foreign oil. As the trains run on electricity, they produce no pollution.

I am reminded of what Daniel Burnham, the architect who designed Washington Union Station, once said. "Make no little plans. They have no magic to stir men's blood." These plans for super-speed ground transportation are not little, and I see evidence that Americans have been stirred.

Joseph Vranich, a public affairs consultant in Washington, D.C., specializes in transport issues. His experience in high-speed ground transportation dates back to 1969, when his first paper on the subject was published.

Letters

Continued from page 3

cessor of anything so tame as a globular cluster—a mere 10^6 stars, typically, with no energetic, morphologically distinct nucleus—without some compelling evidence of an intermediate form. Hence quasars are thought of as early galactic nuclei or, in Arp's approach, as ejections from galactic nuclei that evolve into entire galaxies.

How About More on Canada's Candu?

To the Editor:

I have greatly enjoyed the wide variety of material you publish, especially the pieces debunking media frauds such as cholesterol and cyclamates. The quality is vastly superior to material in the other media, even when they *are not lying*. . . .

This Canadian is somewhat amazed at a caption in the March-April issue (page 18) stating that Atomic Energy of Canada is ready to mass produce a 300-MW Candu power reactor. What do you say to the idea that several small nuclear plants may be better than one large plant. This is presumably where the 300-MW Candu fits in, but Canada has severely cut AECL's research budget as part of the privatization policy. I would like to see a little Candu and the 10-MW Slowpoke on an assembly line. . . .

How about a piece on the Candu program and its products, which have made *Ontario Hydro third in the world* in nuclear generating capacity?

Alex Crone
Vancouver, B.C., Canada

The Editor Replies

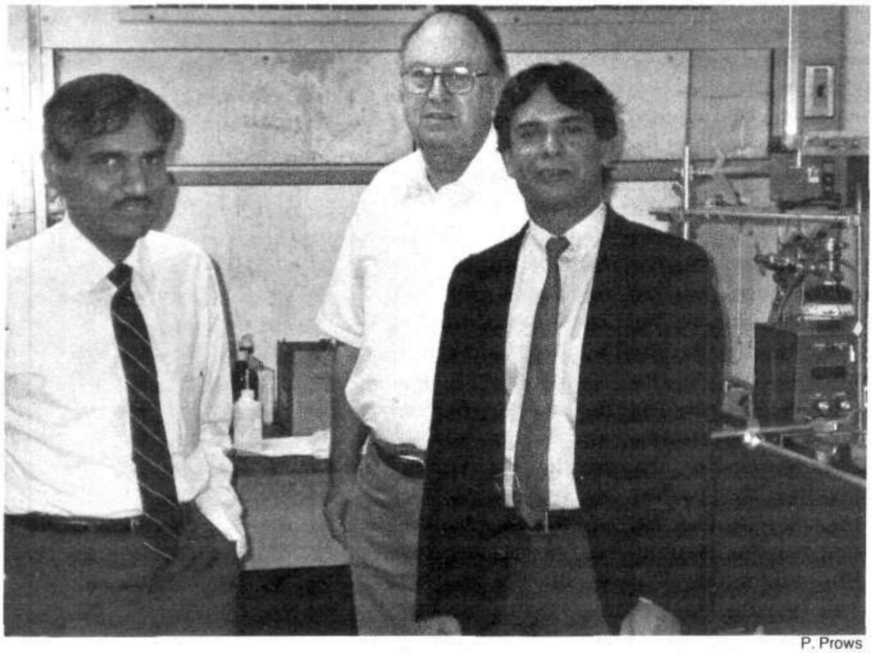
We have supported the idea of mass-produced, smaller (300 to 350 MW) nuclear plants as the fastest and most economical way to provide power for reindustrializing the developed sector and industrializing the rest of the world. Unlike the United States, which has largely dismantled its nuclear plant production facilities, Canada could (when we last checked) turn out at least 6 of the 300-MW Candu's in a year. *An article on the Candu is on our* agenda.

Cold Fusion: New Findings Overpower Stale Lies

by Ramtanu Maitra

The author, a nuclear engineer, is an associate editor of 21st Century *and editor-in-chief of* Fusion Asia *magazine of New Delhi, India. He toured cold fusion laboratories in Utah and Texas in August to provide first-hand information for this report. Coverage will continue in the next issue.*

* * *



P. Prows

The University of Utah Department of Metallurgy Laboratory, which has recorded heat from palladium electrodes at various levels of purity. This lab has raised the important issue of the role of materials in promoting cold fusion. From right, the author; Dr. Milton Wadsworth, Dean of the College of Mines and Earth Sciences; and Dr. Sivaraman Guruswamy.

I came here from New Delhi knowing that the optimism about cold fusion in India and in Japan was not shared by establishment scientists in the United States, but that many researchers were reporting good results—finding excess heat, neutron bursts, and tritium—and were excited about cold fusion's prospects.

It was a pleasure to be able to talk with some of these scientists about what they are doing and thinking, and where their experiments are headed. It convinced me that cold fusion is alive and well not only in Asia, but also in the United States, and I am happy to share this information with *21st Century* readers.

Only five months ago, cold fusion seemed like the greatest scientific happening since the fission of uranium atoms. Yet the initial enthusiasm was buried by the skeptics and naysayers and their friends in the press. Those who base their information on the established media might think that cold fusion is yet another comet with a blazing tail that petered out, leaving a faint memory behind. However, as I discovered, cold fusion is far from dead and may, in fact, prove to be a pathfinder to a new understanding of microphysics, among other things.

The startling announcement of Professors Martin Fleischmann and B. Stanley Pons at the University of Utah in March 1989, claiming that they had produced a fusion reaction in a simple electrochemical cell, shocked the world.

Their apparatus consisted of palladium and platinum electrodes placed in a glass tube with heavy water. According to Pons and Fleischmann, a voltage applied across the electrodes splits the water into oxygen and deuterium (D)—a heavy isotope of hydrogen with one proton and one neutron in the nucleus—and the deuterium released is absorbed by the palladium lattice.

So far, this is acceptable to all scientists. But when the two electrochemists reported that the deuterium atoms inside the palladium crystal lattice undergo fusion, all hell broke loose within the "established scientific community." The Utah team offered as proof their measurements of heat generated by the cell as well as the observation of a few neutrons, which are essential by-products of the fusion process. Nevertheless, the Fleischmann-Pons results came under heavy and often vitriolic criticism from some established scientists, and the professors were accused of sloppy, imprecise work.

Despite the criticism, the Fleischmann-Pons findings inspired many experimentalists all around the globe. Results from similar experiments came pouring in from distant places—India, China, Japan, Hungary, the Soviet Union, Brazil, and Mexico. Inside the United States, a few researchers duplicated the experiment and announced positive results, while others labeled cold fusion a hoax.

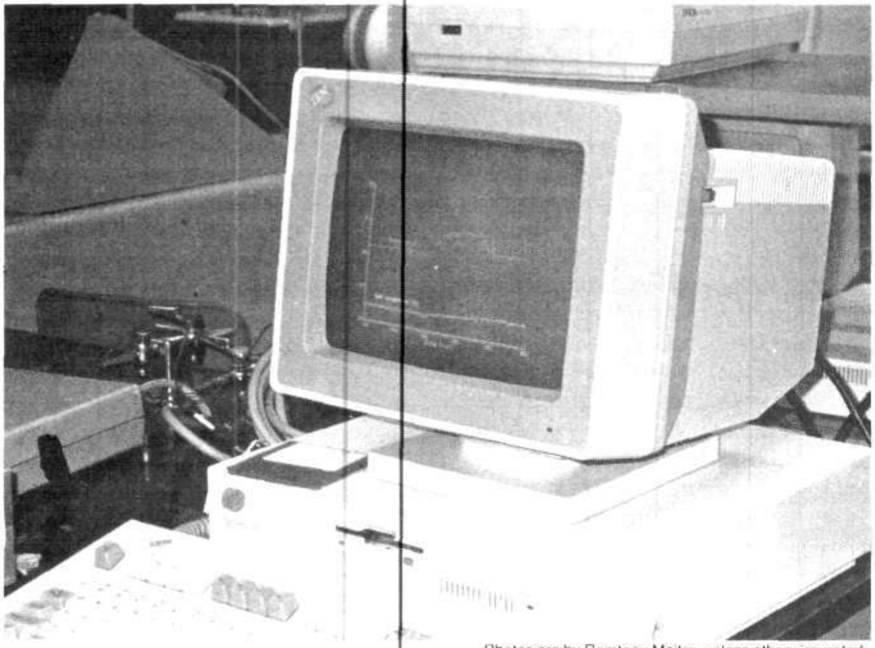
Believers Vs. Nonbelievers

The battle lines in the scientific community were quickly drawn between "believers" and "nonbelievers." The believers insisted that something unknown was going on inside the palladium electrode; the nonbelievers, weighed down with the established laws of physics and afraid of the unknown, said, "If it's real, prove it."

Besides demanding the proof, the nonbelievers—that is, scientists belonging to the large, prestige laboratories—began pooh-poohing the various reported experimental findings as mere figments of imagination. They also demanded proofs to be presented quickly.

The charge was led by scientists from the Massachusetts Institute of Technology, Yale University, Caltech, and some of the national laboratories, where renowned experimentalists using top-notch diagnostic equipment failed to duplicate what Fleischmann and Pons had done in their modest laboratory at the University of Utah. These scientists reported failure to observe a significant amount of heat or generation of neutrons at a level that could justify the fusion process.

Although there are ample reasons that the experiment cannot be easily duplicated—and Prof. Robert Huggins, an electrochemist at Stanford University has said so publicly—the science establishment has been more interested in trying to knock down whatever experimental results have been validated by the different groups working on cold fusion.



Photos are by Ramtanu Maitra, unless otherwise noted.

A computer graph at the Metallurgy lab, which shows a heat burst from a palladium electrode almost three weeks after the cell was activated. The peak of the burst contains about 1 million joules of energy.

Irrational Criticism

This process unleashed a series of irrational statements from many prominent scientists. Some, like Dr. Moshe Gai of Yale University, took recourse to suppressing facts to justify their abrupt conclusions. Gai, whose experiment (under his name and that of many colleagues) was published in *Nature* magazine July 6, 1989, stated categorically, "no statistically significant deviation from the background was observed in either gamma-ray or neutron detectors." Yet, at least one scientist who knew what was going on with Gai's experiment has reported that Gai did observe neutron bursts but chose to suppress this fact in his article.

Whether Moshe Gai was acting instinctively as an "establishment scientist" or was merely trying to publish a paper in a journal that does not want to publish anything positive about cold fusion experiments is a moot question. It is clear, however, that *Nature* magazine, which defines itself as setting the trends in science, is unhappy about cold fusion. Editor John Maddox editorialized in the same issue in which Gai's article appeared that "The end of cold fusion is in sight."

Citing various experiments including Gai's, Maddox concluded, "it seems the time has come to dismiss cold fusion as an illusion." The Yale group, Maddox stated, "has done its best to replicate the conditions of the original experiments, but has failed to replicate their results." The whole thing, Maddox declared, seems to have been "a brave leap of the imagination."

Why Such Acrimony?

In order to explain why there is such acrimony concerning cold fusion, one has to look historically at other groundbreaking researches over the years. Establishment scientists, having made themselves acceptable by wearing blinders that allow them to look only at what are considered "accepted theories," will obstinately and arrogantly refuse to look at new findings.

According to Dr. A. John Appleby and Dr. Supramaniam Srinivasan of Texas A&M, the problem is that the cold fusion results emerged from the "Third World universities in the United States." In other words, the initial findings were not made at the "developed-sector Ivy League"—the universities and research centers where the high priests of American science reside and from which citadels they make their pronouncements.

There is no doubt that the Texas team is partially right, but, there is more to it. Most important is the fact that the findings emerging from cold fusion experiments have begun seriously to question the validity of many existing nuclear physics theories. The well-established quantum mechanics, which deals with the micro-universe, could very well also become a casualty.

Such an upheaval within the scientific establishment is nerve-wracking to most established scientists. It means getting involved in new work, shedding the old beliefs, and renouncing theories from whose mastery many had won fame and authority. It is anyone's guess at this point how many former Nobel prize win-

Continued on page 10

What the Experiments Have Produced

Here are highlights of some of the experiments carried out around the world to explore the Fleischmann-Pons findings.

* * *

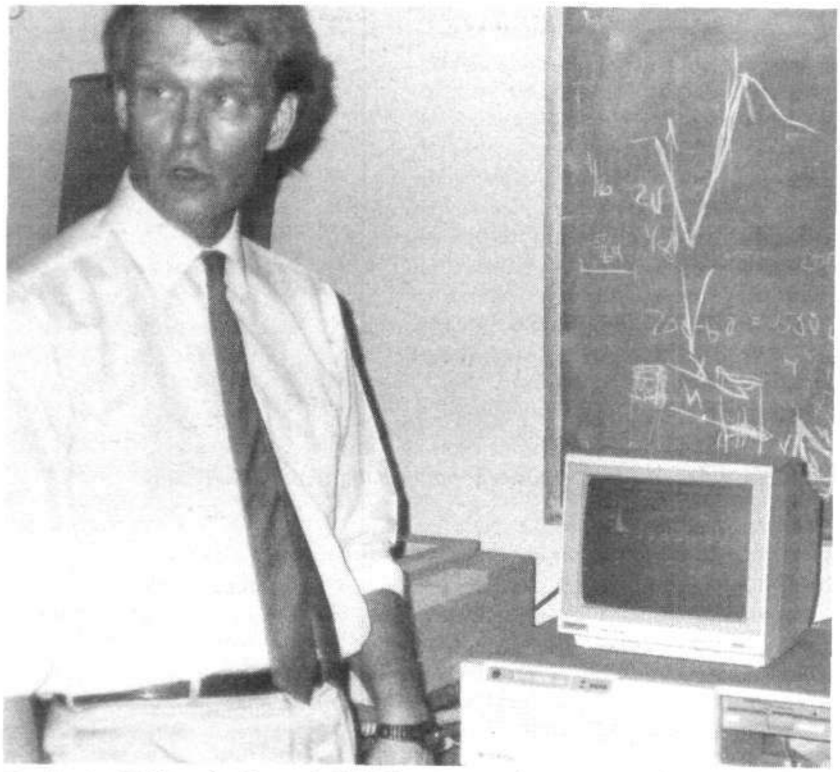
Neutron Detection

Brigham Young University. In a paper dated March 23, 1989, Steven Jones and associates at Brigham Young University's Department of Physics and Chemistry and J. Rafelski from the Department of Physics at the University of Arizona reported the observation of cold nuclear fusion in condensed matter (*Nature*, April 27, p. 737). Using a sensitive neutron spectrometer, the researchers detected neutrons of approximately 2.5 MeV energy. The experiment consisted of a palladium electrode dipped in heavy water plus various metal salts (ferrous sulfate, nickel chloride, lithium sulfate, sodium sulfate, and so on).

The neutron spectrometer developed at Brigham Young consists of a liquid organic scintillator contained in a glass cylinder 12.5 cm. in diameter, in which are embedded three glass scintillator plates doped with lithium-6. Neutrons generated during the experiment deposit energy in the liquid scintillator via collisions, and the resulting light yields energy information.

These neutrons are then captured by lithium-6 nuclei embedded in glass plates forming tritium and helium-4. The experimenters, who observed a low-level neutron generation, considered that "the discovery of cold nuclear fusion in condensed matter opens the possibility of a new path to fusion energy."

Bhabha Atomic Research Center, India. The Fleischmann-Pons experiment was confirmed at the Bhabha Atomic Research Center in Trombay, one of the largest nuclear research centers in the world. Dr. R. Chidambaram's physics group, equipped with a laboratory and scientists as good as the best in the world, observed neutron generation.



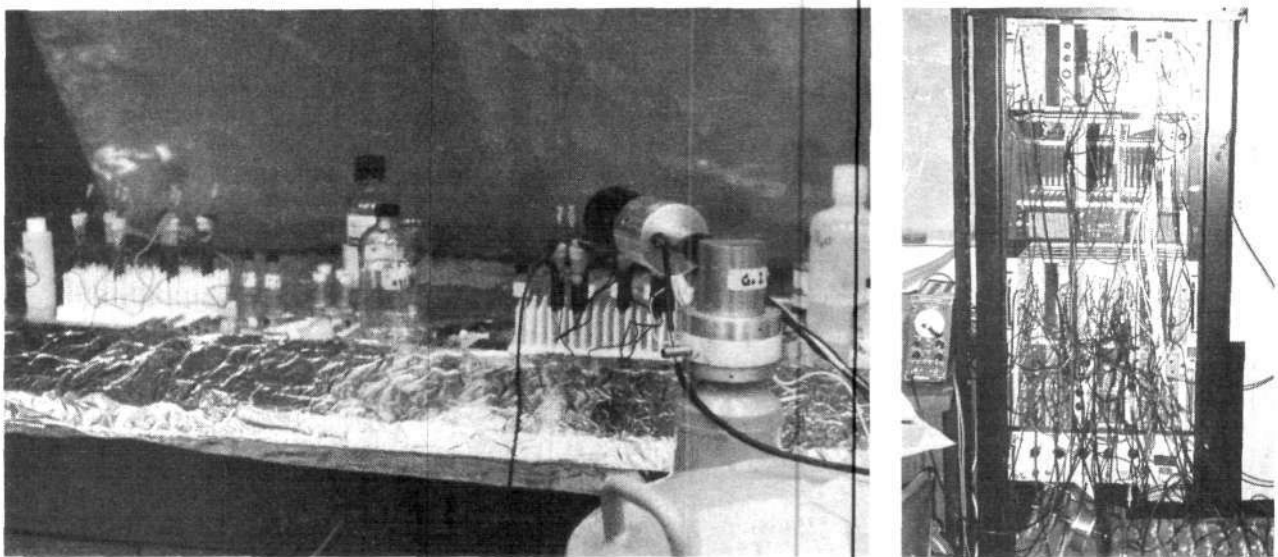
Dr. Kevin Wolf at the Texas A&M Chemistry Laboratory, explaining the high levels of tritium found in eight electrolytic cells. These findings are expected to make the "nonbelievers" squirm.

"We surely have seen neutrons here and some cold fusion is certainly going on," said Chidambaram. "The process seems to depend on so many poorly understood parameters—it is not a straightforward experiment. . . . If the process was simple and straightforward, we should have struck gold by now. We haven't. On the contrary, we are still trying to find out the basic parameters of the experiment. . . . But like ceramic superconductors, we may be onto something that may be a long way from practical use."

University of Hokkaido, Japan. Experiments evaluating neutrons from an annealed palladium cathode in a LiOD-D_2O solution, carried out by students of Dr. John Bockris of Texas A&M, indicate generation of neutrons that "correspond to the energy of neutrons evolved from the deuterium-deuterium nuclear fusion reaction."

The experiment was conducted in an underground room, about 5 meters below the ground level and surrounded by thick concrete walls, to shield some of the background neutrons. The neutron detector was shielded by lead bricks (2 inches thick) and borated polyethylene bricks (4 inches thick). In addition, the front of the neutron detector was covered with a 1.0 cm cap of metallic lead.

The University of Hokkaido team used a palladium rod of 99.9 percent purity, 0.3 cm in diameter and 10 cm long. The electrolyte used was 0.5 molar LiOD with D_2O.



The experimental setup at the Chemistry Laboratory at Texas A&M. The "tritium factory" found here indicates that a significant amount of neutrons is generated in the palladium cells.

Excess Heat Production

The National Cold Fusion Institute at the University of Utah. Researchers in engineering and metallurgy have recorded at least nine heat surges in their electrochemical cells. These range from one in which a cell produced seven times as much energy as that put into the cell to a more recent event in which the energy output was about 100 percent higher than energy input.

Tata Institute of Fundamental Research, India. The Tata Institute in Bombay recorded a phenomenal temperature rise of 1 degree Celsius per minute with their Fleischmann-Pons type of apparatus. According to Dr. K.S.V. Santhanam, head of the Chemical-Physics Department, "We detected the presence of neutrons and gamma-rays at a level above that of normal background radiation. I estimated about 2 in every 50,000 deuterium atoms were fusing."

Tritium Production

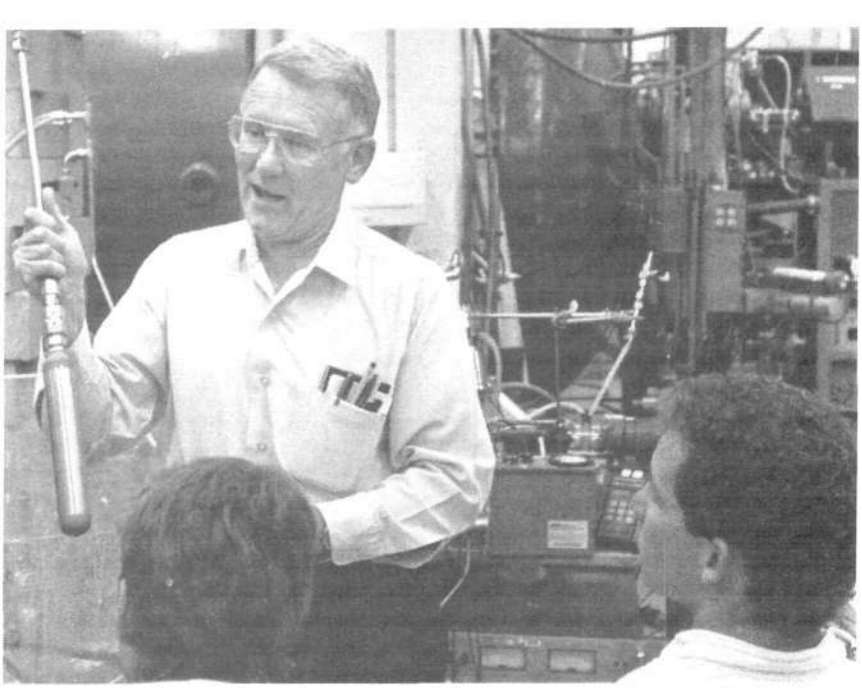
Texas A&M. The Department of Chemistry and the Cyclotron Center reported production of tritium from D_2O electrolysis at a palladium cathode. The experiment consists of palladium cathodes of diameters 1 to 6 mm dipped in a D_2O-0.1 Li-OD electrolyte. Samples of liquid electrolyte were measured using liquid scintillation counting.

In all 11 cells undergoing electrolysis, measurements were made of the activity of tritium in solution, and in one cell the gases evolved were recombined external to the cell using 0.5 percent platinum on alumina catalytic beads. The resulting liquid was analyzed in the same way as the electolyte samples. The palladium cathodes used were of 99.9 percent purity and 99.9 percent pure nickel wire was used for the anodes, spot welded to palladium wires.

The maximum tritium count observed in one cell was 4.9×10^6 disintegrations per minute per milliliter (dpmml^{-1}) of sample. The samples sent to various other laboratories showed the tritium count of 2.13×10^6 dpmml^{-1}, one week after the high current density treatment. The tritium count was 1,157 before the high current density treatment. The density of current was varied during the experiment period, and at low current density no tritium production was observed.

Theoretical Results

University of California at Santa Barbara. S.E. Koonin and M. Nauenberg report that theoretical calculation of cold fusion rates indicates that the rate for D-D fusion is 3×10^{-64} per second. The theoreticians also found that the rate for proton-deuterium fusion is faster. Both results are reported in their paper "Cold Fusion in Isotopic Hydrogen Molecules."



Dr. E. Paul Palmer: "Something is surely happening." Palmer worked with Dr. Steven Jones at the Department of Physics, Brigham Young University, where they recorded a low-level production of neutrons using the setup shown here. He is now working on the physics of what's going on inside the electrode.

Continued from page 7

ners' work in these areas may turn out to be mere "also-rans" in the search for physical laws.

Then there is also the nagging issue of Malthusianism. During discussions with Dr. Hugo Rossi, Dean of Science at the University of Utah and recently appointed director of the university's new Cold Fusion Research Center, he pointed to what he called the "sinister" statement of Jeremy Rifkin. Rifkin, a hard-core Malthusian masquerading as an environmentalist, told the *Los Angeles Times* that if cold fusion becomes a reality, the resulting abundance of inexpensive energy would cause a population explosion on Mother Earth. If Rifkin or his friends in the scientific community have their way, it would be safe to presume that they would try their best to shut down the development of such a potential energy source.

Another reason that cold fusion has been scorned is the perceived threat felt by those scientists who have dedicated their careers to generating hot fusion—fusion energy created in the laboratory by heating up hydrogen to high temperatures and high density. Some of these scientists are so obsessed with their own work that they have ridiculed cold fusion experiments. Many such reactions are prompted by the fear, albeit not unrealistic, that in the wake of the cold fusion excitement, the already meager funds for the magnetic and inertial confinement fusion experiments will be further cut back.

Whatever the primary or secondary reasons are behind the irrational attitude of the science establishment, it is nonetheless clear that the believers are not yet ready to throw in the proverbial towel.

The New Findings

At the University of Utah in Salt Lake City, optimism runs high. In spite of a negative draft interim report of the U.S. Department of Energy's Energy Research Advisory Board on cold fusion, the state of Utah has allocated $5 million in seed money to set up a cold fusion research center at the university's Research Park in Salt Lake City. (The advisory board report, which many think was premature, stated that the evidence of cold fusion is unconvincing and therefore "no special programs to establish cold fusion research centers or to support new efforts to find cold fusion are justified at the present time.")

The work of the new center, according to its director, Hugo Rossi, is to replicate and validate the Fleischmann-Pons experiment and to work on the theoretical physics in order to explain the phenomenon (see interview, p. 18). Rossi clearly stated that after these present objectives are achieved, new tasks will follow.

At the university's Metallurgical Laboratory, Dr. Milton Wadsworth and Dr. Sivaraman Guruswamy were perplexed by the assertive negativism of the establishment scientists. This team has observed a significant amount of heat energy generation from palladium cells bathed in deuterium hydroxide. In certain cells they have witnessed energy bursts in the form of sharp spikes, generating at least 1 million joules of energy at peak (see photo, page 10).

Yet, the process of energy generation is not steady and the heat bursts were noticed only once over a seven- or eight-week period in these cells. More intriguing perhaps is the finding of the Wadsworth-Guruswamy team that 99.295 percent pure palladium rods function as better heat generators than the 99.5 percent pure palladium ones. It is this materials part that both Wadsworth and Guruswamy are investigating, and right now they find it excruciatingly puzzling. Nonetheless, there is no question that the team has witnessed generation of surplus heat energy from the Fleischmann-Pons set-up.

At Brigham Young

At Brigham Young University (BYU) in Provo, Utah, Dr. E. Paul Palmer, who worked with Dr. Steven E. Jones on the low-level generation of neutrons using a Fleischmann-Pons set-up, is convinced "something is surely happening" that physics must explain. Palmer, not yet a "believer," does not expect that the cold fusion process will be able to heat water for commercial purposes within a decade or so, but he is aware that careful experimentalists have already reported findings that the present understanding of physics cannot explain.

As Steven Jones points out, however, on the basis of the conception of fusion as developed to date by nuclear physics, it would be inaccurate to call the Fleischmann-Pons experiments "fusion." Jones is not ready to close the door on cold fusion; like Palmer, he agrees that it is time to take a fresh look at the physics. Jones also points out that in order to do this, however, we need to do some very careful experiments and use the findings to set parameters on which the new understanding of physics has to be based (see interview, p. 15).

The Texas Stunner

The experimental findings at Texas A&M—College Station are expected to put a lot of pressure on the skeptics. The earlier work in this university by its Center for Electrochemical Systems and Hydrogen Research and the Department of Chemistry, presented at the Workshop on Cold Fusion Phenomena at Santa Fe, N.M., just two months after Fleischmann and Pons had announced their shocking findings, indicated observation of excess heat generation. Even more startling, the electrolyte, a D_2O-LiOD solution, later showed presence of tritium (see interview, p. 12).

The findings, although significant to those who were working in this area, failed to make much impact on those who refused to believe.

Later, a team at Texas A&M's Department of Chemistry and the Cyclotron Center carried out an experiment using a palladium electrode bathed in D_2O-0.1 LiOD. The objective was to generate tritium—the heaviest known isotope of hydrogen, which contains two neutrons and one proton in its nucleus. Tritium does not exist in nature; it is formed when the lithium present in the LiOD captures a free neutron released through nuclear reactions.

The result turned out to be a stunner. The tritium produced during the experiments in 11 electrolysis cells was 100 to 100,000 times more than that expected from the normal isotopic enrichment from electrolysis. The Texas researchers have sent their samples to established laboratories such as Battelle, Argonne, Los Alamos, and General Motors for analysis, and the tritium count of these noted labs was no different from that the Texas-researchers have themselves counted.

Palmer also obtained a low-level production of neutrons while experimenting with setting concrete under pressure. The pennies are used as insulation.

The Floodgate Ahead

What do all these findings mean?

It is too early to predict because so little is known about a whole gamut of physics associated with the experiment. The tritium work, under Dr. Kevin Wolf, Nigel Packham, et al. at Texas A&M will be hard to ignore or dismiss as irrelevant. The work is thorough, and preventive measures were undertaken to protect the experiment from any probable contamination—tritium coming from background sources.

Still, it would be naive to believe that the discovery of these tritium factories will change the basic belief-structure of the science establishment. There are rumors that the "tritium contamination" accusation was leveled against the Texas A&M people as a ploy to discredit their findings.

The Texas A&M work will open up a floodgate. Already the word is out—right now private communication between scientists remains the most efficient way to pass information—that Glen Schoessow at the University of Florida in Gainesville has done closed calorimetry and lit a glow lamp using the Fleischmann-Pons type of arrangement. At the Santa Fe Research Center in Columbia, Tenn., Joe Champion has observed 40 to 600 percent surplus heat from a large single cell. At the University of Minnesota, Dr. Richard Oriani in the Chemical Engineering and Metallurgical Group has also observed a significant amount of surplus heat generation. And one of the first to successfully reproduce the Fleischmann-Pons experiment is Dr. Robert Huggins, an electrochemist at Stanford University, who has observed surplus heat in his experiments.

The list is growing longer every week, although it does not get publicized by the national media or even the science media.

Outside of the United States, positive results have been reported from India, Japan, China, Italy, and elsewhere. In India, the scientists working on cold fusion are reportedly in the process of scaling up their experiment significantly.

In Japan, 80 scientists are working under a newly formed umbrella organization, the Institute of Fusion Science, to detect neutrons in detail from cold fusion experiments, to find the most appropriate conditions in deuterium electrolytes, and to study the theoretical physics that could explain the cold fusion phenomenon.

AN INTERVIEW WITH TEXAS A&M RESEARCHERS

How We Discovered We Had Tritium

Ramtanu Maitra had a wide-ranging discussion with the Texas A&M cold fusion group, Dr. A. John Appleby, Mr. Nigel Packham, and Dr. Supramaniam Srinivasan, about their experiments. Here we excerpt only a small part of their discussion, the remarks of Nigel Packham on how the Texas group discovered that some of their cells were "tritium factories." The next issue will cover more of this discussion.

* * *

Fleischmann and Pons's first statement that their experiment can be done on a kitchen table was quite misleading and very wrong. Certainly the electrochemistry is quite involved. If you don't know what you are doing, there is no way you will get any results.

We concentrated . . . in [John] Bockris's lab on trying to get the heat and any radioactive particles we could measure. At that time Kevin Wolf was not connected with us. He now does a lot of work with us.

The easiest possible radioactive particle you can look at is tritium. It's a very quick, very easy, some would say very foolproof, method of determination. Now, I say foolproof, but then when you go a little bit further down the line, that has come back to haunt us, with the word chemiluminescence attached to it. . . .

We have a paper purely on the production of tritium. It has now been accepted by the *Journal of Electroanalytical Chemistry and Interfacial Electrochemistry*. We did submit it to *Nature* and it was rejected at the time, probably for very good reasons, because the blanks weren't there. Now, of course, I don't think *Nature* is going to publish anything positive. . . .

I think [editor John] Maddox's piece did influence a lot of people, in fact there won't be any positive papers published there, I'm sure.

Getting back to tritium, we had a couple of dead cells. We had set up 24 electrochemical cells and we decided—this was after the first big push—that as we were a very fundamental electrochemistry group, we should treat it like any other electrochemical problem that we have. And that would be a rigorous treatment of the surface, of the electrolyte, and so on. And so we did that.

Texas A&M

Nigel Packham: "The big question is, where are the neutrons? You have to imagine a mechanism where you don't produce neutrons, or very, very small amounts of neutrons, which the physicists obviously cannot accept."

We treated the surface. Well, we left one like Pons and Fleischmann who didn't do anything to the surface. So we said OK, let's take it as it is and put it into the cell.

We annealed some for 8 hours at 800 degrees at 10^{-6} torr, which should clear anything out of there. We acid dipped—etched—some electrodes. We did some electrochemical cleaning of the surface. The electrolyte we used was lithium deuteroxide. We decided to use a 0.1 molar [moles per liter] solution of lithium deuteroxide solution and also one with an additive of 0.1 millimolar of sodium cyanide.

Bulk Process or Surface Process?

Sodium cyanide is a good poison for hydrogen evolution, so it would tend to drive deuterium into the electrode. At that time, and maybe even now, it was thought that it's a bulk process, not a surface reaction. So we set up the 24 cells, 8 of which were 1-mm diameter palladium, 8 of which were 3-mm palladium, and 8 of which were 6.3-mm palladium, and put them on a charging current density which we deemed to be 50 milliamps per square centimeter (this is what Pons and Fleischmann told us).

After about 16 days at this current density, we put the 1-mm electrodes up to high current density, which was 500 milliamps per square centimeter for periods of up to about 12 hours. We wanted to see if there was anything being given off.

In the first place, we were looking for neutrons. So we took a cell over to the Cyclotron Center and put it in front of the neutron counter. We didn't see anything after 12 hours, and naively we said, OK, there is nothing there.

The neutron background, right now, is down to about 0.6 neutrons per minute. So anything above that is significant. I mean we are seeing—the maximum we ever saw was 4 to 5 times above background, which is statistically informative, and certainly is there, and we do r-squared tests, where we take the cell away from the counter [to a distance of r], and the count goes down by r^2, so we know it's coming from the cell.

After doing the neutron count on this cell and not finding anything, the anode connection to our nickel anode broke off—we use nickel anodes in all cases—so we said, OK, what can we do with this cell? We decided to test the electrolyte, and see what there was in it.

One of the easiest ways of doing that *is to look with a liquid scintillation* counter. So we called around campus to find out who had a liquid scintillator. The people running it said, certainly, bring some samples over. We had no idea at all that there was going to be any tritium.

I took the samples over there on a Friday evening, and picked them up on Monday morning, and the person who actually ran the tests on the samples came up to me and said, "what kind of sources did you put in this thing?"

I said, "there is no source in there, all there was, was an electrochemical cell."

He replied, "there certainly must have been *something* in there, because you've got 1.6×10^6 counts per minute of tritium."

This was in two cells in the original case. So we then looked at the other cells that we'd had running, and we also found tritium in originally 6 out of 8 one-mm cells. The maximum we detected was 4.9×10^6 *disintegrations* per minute per milliliter of solution [dpmml^{-1}]. Now if you put it in terms of a rate, you are talking about something like 10^{10} atoms of tritium being produced per second.

Where Are the Neutrons?

The big question is, where are the neutrons? If you have 10^{10} atoms of tritium per second, you should also have 10^{10} atoms of neutrons.

We were not measuring heat at the time. In fact the 1-mm cells are so small *in palladium volume, that you* wouldn't be able to detect that heat. But we also didn't detect any neutrons, and 2.4 MeV neutrons are easy to measure. You can't make a mistake.

So, they are not there. So you have to imagine a mechanism where you don't produce neutrons, or very, very small amounts of neutrons, which the physicists obviously cannot accept.

Why should they accept anything that goes against everyday modern physics? There are some mechanisms that are being proposed to account for why *you don't see neutrons.* There may be some orientation on the electrode itself—in the electric field of the double layer, which may mean that the most obvious collision would be toward producing tritium, rather than neutrons. That may be a case.

But I think that needs to be looked at in much more detail. It's a very young science. . . .

OK. There was no doubt that we had tritium. In fact, to confirm that, we sent samples to Battelle-Columbus lab, to Argonne National Lab, and to General Motors, and I *took* a sample to Los Alamos National Lab.

There is a table in the paper which shows the results. We measured, for example, 2.1×10^6; they had 1.96×10^6, so there was no question about the presence of tritium. If Los Alamos cannot do tritium analysis, I don't know who can. Many critics said, what about tritium in your D_2O [heavy water], or in your lithium deuteroxide? Again, we check every batch of D_2O and LiOD, and they come out very, *very low. So there was no question but* that the tritium came from the electrode.

Looking for Contamination

Now, there are still a few questions. Could it have been in the palladium before you did the electrolysis? Could the palladium have been stored somewhere, where there was a huge amount of tritium? We looked at that too. We sent palladium metal to Los Alamos and said, please find out if there is any tritium in it. And there is *none*.

And likewise with the nickel anodes that we use. Now, in an electrochemical sense, even if there were tritium inside the palladium, it would stay there. Since it is cathodic, it would drive tritium inside, rather than evolve it from the inside. But in any case, there was no tritium inside the palladi-

Deuterium in Nuclear Fusion Reactions

There are two known fusion reactions of deuterium nuclei that produce the following products at the specified energies:

$$(1)\ D + D \rightarrow \underset{\text{Tritium}}{T\ (1.01\ \text{MeV})} + \underset{\text{Proton}}{H\ (3.02\ \text{MeV})}$$

$$(2)\ D + D \rightarrow \underset{\text{Helium-3}}{\text{He-3}\ (0.82\ \text{MeV})} + \underset{\text{Neutron}}{n\ (2.45\ \text{MeV})}$$

Two other fusion reactions involving deuterium have been hypothesized. One combines two deuterium nuclei to produce helium-4 and energy; the other is a reaction between deuterium and lithium-6, producing two helium-4 nuclei and energy.

So far cold fusion results indicate closer resemblance to the first two reactions. However, the heat observed in these experiments exceeds the energy levels demanded by these two reactions. The excess heat measured by various experimenters cannot be explained away by citing any known *chemical* reaction. But *no other known nuclear* reactions can explain the amount of heat generated.

It is not surprising that Fleischmann and Pons believe that reactions (1) and (2) above are "only a small part of the overall reaction scheme and that the bulk of the energy release is due to a hitherto unknown nuclear process or processes."

um or the nickel.

Could there have been tritium on the glass cell that we used? These are strange questions that we *had* to answer over the course of the past two and a half months: Was the tritium in the rubber stoppers that we had in our electrochemical cells? Was it in the cutters that we used to cut the palladium?

Again, we have another table here that shows the results of tests on dissolved shavings from the spot welder, from the vacuum chamber, from the cartons, from recombination—I'll come back to that—from the rubber stoppers. They are all zero. So there is *nothing* in our setup that could have produced tritium, apart from a nuclear reaction.

We also decided that if there is this amount of tritium in the solution of the electrolyte, then we are probably venting a very large amount of tritium into the atmosphere, and it would be interesting to see how much is going out. The easiest test is to recombine the gases external to the cell. We did that using 0.5 percent platinum on alumina beads.

We collected the off-gases, converted them back to a liquid, measured the liquid—and there is a ratio of about 100 to 1: One hundred times higher in the recombined gases than there is in the electrolyte.

Five times 10^8 is one of our counts, in fact. It then came down to 5×10^7 compared to the electrolyte at 5×10^5, so between 50 and 100 times more in the gases than in solution. That is really the extent of our tritium results.

Chemiluminescence

But then, of course, a major criticism that came up was chemiluminescence. That was a very difficult one to deal with, and it still is, even though we *know* we are not seeing chemiluminescence; neither did Los Alamos, nor Argonne, nor Battelle. But the Department of Energy's ERAB [Energy Research Advisory Board] committee that came around—one of their biggest criticisms was, "You say that you are not seeing chemiluminescence; how can you say that?"

Again, we did a test of what happens when you look at high concentrations of LiOD. At one molar there is a huge amount of chemiluminescence, and this was discovered entirely by accident, because Dr. Oliver Murphy of the Center for Electrochemical Systems and Hydrogen Research gave me a sample without telling me what it was.

I put it into the liquid scintillation counter and got 10^5, 10^6, and I went back to Oliver and said, "I think you are going to be very pleased." And he said, "No, I'm not; because all I gave you was 1 molar of lithium hydroxide and lithium deuteroxide that had never even seen a cell."

So we said, OK, that is a problem.

We did a profile and found that really below 0.3 molar, you have no problems at all. The instrument that we use has got very good chemiluminescence monitoring on it—in fact on all three instruments. If you check the chemiluminescence on each instrument, there was none during that time for which we obtained those results.

So the criticism of chemiluminescence is really invalid. But it seems to be the one that most people are hanging on to, as well as saying, OK, you are adding D_2O all the time into these cells; this D_2O has to have tritium in it. And it does—we know that.

The critics then say, so it's just going to build up and build up—which is not right. One of the best-qualified people in the world sitting over there [Dr. Srinivasan] will tell you that because of the separation factor among hydrogen, deuterium, and tritium, it *won't* build up to the levels that we obtained. In fact we found that if you have 200 dpm [disintegrations per minute] per mil D_2O to start with, you will only increase as much as the separation factor. Since the separation factor is only two or three, it will only increase two or three times, maximum. So the maximum that you could assume to get to is 400 to 600 without having any fusion occurring.

Now, if there is any fusion occurring, anything above 600 is significant. Obviously 10^6 is highly significant, but I would say even something at the level of 1,000 dpm would be significant.

AN INTERVIEW WITH DR. STEVEN JONES

'The Excess Heat Is Interesting, But Not Fusion'

Marjorie Mazel Hecht

Dr. Steven Jones: "Things have got to get to the point where they are reproducible." Jones is shown here at the April 26, 1989 congressional hearings on cold fusion. He used the little plant to make the point that fusion was in its infancy, its future growth as yet unknown.

Ramtanu Maitra interviewed Prof. Steven Jones of Brigham Young University Aug. 23. Jones pioneered research in muon-catalyzed fusion. He began work on cold fusion last year, independent of the work of Fleischmann and Pons. Based on reports of geologists that helium-3, very rare on Earth's surface, is found near areas of geological activity, he theorized that fusion must be taking place in the interior of the Earth; he set out to test this theory by passing an electric current through various combinations of elements. His cold fusion work produced neutrons, although on a much lower level than the Fleischmann-Pons apparatus.

Maitra toured Jones's lab in Utah, met with his colleagues there, and then interviewed Jones by telephone at Yale University. Jones was at Yale to help Dr. Moshe Gai set up a cold fusion experiment to measure neutrons.

* * *

Question: What is your view of the cold fusion results?

First of all, I think it is important to distinguish low-level cold fusion, in which we see neutrons at a rate of about a tenth of a neutron per second—that's a source rate—and contrast that with the excess heat claims. For the latter there is no correlation quantitatively, certainly by 13 orders of magnitude, with neutrons.

And even the tritium—the Texas A&M tritium, for example. They observed tritium but not in the same cells that produced heat. In other words, the cells that produced heat did not show tritium, and the cells that produced tritium did not show heat. That's very important. There's no correlation. . . .

Question: What do you make of this difference?

I think the excess heat may be real, but there is no evidence whatsoever that it's due to fusion. I think that's a very important point. There is still—and here we are five months since—there is no correlation. So, I think the excess heat is interesting, but not fusion.

Question: But how can one explain the formation of tritium?

Of course most of my work has been with neutrons at very low level, I think there is a low-level effect there. The tritium could be explained, of course, in terms of fusion, but there is a big problem with that. You ought to talk to Kevin Wolf at Texas A&M. The problem with interpreting it as a nuclear reaction of any kind is that tritium should then be produced with an MeV of energy—the triton.

For instance, in D-D fusion the triton has 1 MeV of energy. Now if it's got 1 MeV and then the proton that recoils opposite that has 3 MeV, that much energy coming out has to produce some effects in the material. If you dump MeV's of energy, you must get X-rays as the atoms are excited.

But there are no correlated X-rays. That has been checked. They've looked—it's not hard with detectors like a sodium iodide detector. I'm not sure which kind of detector they used, but I know that Kevin Wolf said that they had looked and had not seen any evidence of radiation that must be associated with a high-energy particle. So it's really a puzzle. It just doesn't fit. It can't be fusion if there is not the energy associated with it.

Question: But sometimes—I'm speaking of this particular D-D reaction—sometimes it could be tritium being formed and sometimes just neutrons formed. Is there such a possibility of branching?

If there is tritium formed with the energy associated with its formation, you know how much tritium and how much energy. Then you've got to see two things. You've got to see heat, which they don't see in the tritium-producing cells. But the main thing is, you've got to see radiation. It's not there, and these are sensitive counters

. . . of many orders of magnitude more sensitive than what is needed for the detection of tritium. Therefore it is not a fusion-produced triton.

So where does it come from? There are a lot of problems measuring tritium. As you may know, there is a problem of contamination. If there is no radiation, and it is really tritium—and there have been some places, I am sure, that have gotten tritium, because they have checked—where does it come from? If it came from fusion, *there has got to be the radiation and* the heat associated with fusion, but they aren't there.

Question: Didn't Dr. Wolf find heat?

In the cells that produced tritium, no. In the cells that produced heat, there was no tritium—or neutrons.

Question: But could it be that we are looking at some other interesting phenomenon that we cannot explain by what we now know about D-D reactions?

Yes, but first let's get the data solid. Then we can start worrying about [that]. . . .

Question: Are you acquainted with the work at the University of Hokkaido in Japan?

Yes. That was a good experiment. That showed neutrons of 2.5 MeV energy, and at almost precisely the same rate as we had observed. Well, it was a different size cathode, so it was within a factor of a few. . . .

Question: But later, July 31, the Hokkaido researchers reported at a conference in Japan of cold fusion researchers that at peak they had observed 1,150 neutrons per hour, which is pretty high.

Let's see—a source rate of 1,000 per hour. . . .

Question: And 600 on average.

. . .That's .3 per second—that's . . . exactly what we reported.

Question: And that is significantly above background, isn't it?

Yes. . . . For us it was, yes. Those rates are just what we reported in our *Nature* paper. Our average was .06 and the maximum .4 per second.

Question: It was about the same as what you got. But one interesting correlation is that at the time of neutron bursts, they would also get heat. That is difficult. . . .

The size of neutron bursts is extremely small. Unless you are getting a lot of tritium at the same time, it's miniscule. You wouldn't get any heat. Suppose you get a burst of a hundred neutrons: A hundred fusions would release 400 MeV. Now an MeV is a very tiny unit of energy in terms of heating something. It could not be seen.

Question: There's one report from India I can cite, although I haven't met Dr. Sinha. . . . At the Variable Energy Cyclotron Center in Calcutta, Sinha's team is seeing a 1° C rise in temperature. Sinha also says that every time this rise in temperature occurs, there is a burst of neutrons. Now there is no calculation—the numbers are not there.

That's funny. No one else has seen that.

Question: Yes. It is too much of a coincidence to think it is anything else. . .

You really need to know the num-

Cold Fusion Maverick: H. Tracy Hall, Jr.

Utah, and Salt Lake City in particular, have become a hotbed for cold fusion research since the Fleischmann-Pons announcement. Although most of this research work is confined to university laboratories, there is at least one privately operated lab in Provo.

This lab is part of Novatek, and the individual who runs the show is H. Tracy Hall, Jr. His father, now deceased, is famous in Utah for work in pioneering the manufacture of artificial diamonds. Like his father, Tracy, Jr. has also been involved in pioneering.

In a little laboratory attached to Novatek, Hall and a few colleagues have duplicated the Fleischmann-Pons experiment. In a paper they are circulating, Hall et al. report that they have witnessed heat production up to 16 percent more than the input energy, for a period of five hours.

The Hall team used an open cell with annealed palladium cathodes and a 0.1 molar lithium deuteroxide electrolyte. The palladium cathode was a 17-mm diameter loose coil annealed for 1 hour in argon at temperatures above 1,300° C and stored in air prior to the experiment and between consecutive experiments.

The anode consisted of 12 pairs of 0.127-mm diameter platinum wires, 5 cm long. Palladium wires were wound around a hollow, threaded polytetrafluoroethylene mandrel, which had six axial slits to permit circulation of fluid within the mandrel.

Although Hall et al. measured a significant generation of heat, they concluded: "It appears that the phenomenon of 'cold fusion' brought about by electrolysis of LiOD on palladium is a one time occurrence which begins abruptly only after sufficient charging or 'aging' of the palladium, and which can end just as abruptly if the system is driven too hard or if the palladium surface becomes poisoned with impurities."

Tracy Hall, Jr., an independent experimenter who has recorded excess heat from a Fleischmann-Pons setup.

bers. That's the scientific way of doing things. It's not just qualitative. And frankly, if the numbers are small, then it becomes very difficult—well, that's why I'm here [at Yale collaborating with Moshe Gai]—difficult to be sure.

Question: You are setting up experiments?

It is set up, yes. We just started running.

Question: And it's the same experiment that you published?

Pretty much. Right at the moment, we are doing deuterium [gas] under pressure. But what we demonstrated in our Los Alamos experiments is that the results are the same whether you use gas-charging or electrolytic-charging.

Question: Will you be counting tritium?

Not this time.

Question: So you are just measuring neutrons this time?

Yes.

Question: You have been giving me some of your thinking on which way this thing is going now. Without saying that it is or isn't fusion, what kind of research is now necessary to get to know these phenomena?

Things have to get to the point where they are reproducible. That's what we are trying to demonstrate here. We've worked pretty hard in the last few months to find a system that gives us very high reproducibility on the neutrons. That's a titanium-vanadium alloy that we expose to deuterium under pressure. And we get close to 100 percent reproducibility for neutrons—low-level.

Next we will look for tritium. We're doing things to look for heat as well, but again, you have to get things reproducible and believable before you can start changing parameters to see what's important.

Question: Do you think that at this point the physics should be looked into—or is there nothing to look into?

You mean, theoretically? Yes, I think it's time to start thinking about it, but really we need more constraints from experiments that have numbers to guide the theory.

Question: So it should take a little time. The impression I am getting here in the United States is that the results are not coming out, and it's getting late, and so the effort should be dumped. I think that approach is not helpful. It will take time to do these things.

Yes.

Question: Prof. Robert Huggins at Stanford University says that he has got the heat, but that these experiments are not easy to do, and that people are not succeeding in replicating them is not very surprising. . . . He is saying that we should continue with the work, and see if there are some interesting development possibilities.

Yes.

Coming in the January-February 1990

21st CENTURY
SCIENCE & TECHNOLOGY

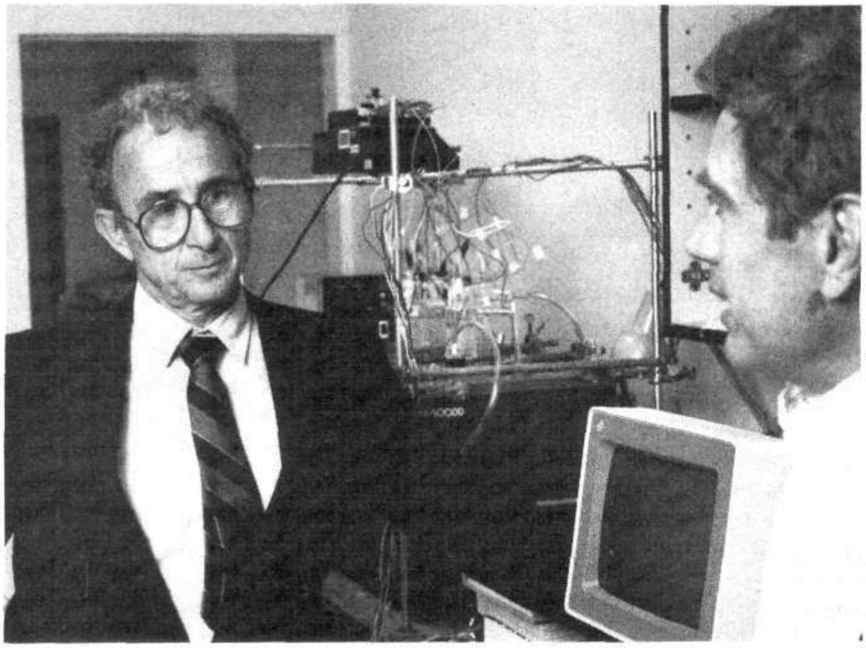
- Advanced Technology to Fight Drug Trafficking
- Roger Bacon and the Birth of Universal Science
- Cold Fusion: More Progress
- *21st Century*'s 1989 index by author and subject

AN INTERVIEW WITH DR. HUGO ROSSI

'The First-order Priority Is Reproducibility and Repeatability'

Ramtanu Maitra discussed cold fusion with Hugo Rossi, director of the University of Utah's National Cold Fusion Institute, Aug. 23. Also present was Karen Shepherd, the institute's administration director. What follows is a partial transcript of their conversation, with Maitra asking the questions and Rossi answering.

* * *



University of Utah

Dr. Hugo Rossi: "Ideally, what we would like to be able to do if a critic says, 'I'm skeptical,' is to put a cell in a box and send it to him; tell him to plug it into the wall. . . ."

Question: What kind of experiments do you have going and what are your plans for this new center?

This summer we have been in a state of transition. The Pons-Fleischmann laboratory has been primarily concerned with gathering more data on the calorimetry. The Wadsworth [Metallurgical] laboratory has essentially been waiting for funding, which has been a problem; the same is true also of our engineering laboratory.

They are going to have a dozen cells running in the Wadsworth Laboratory. We have 4 already up at the new place in Chemical Engineering, and we are going to have another 6 very shortly. We will have between 12 and 20 in the Electrochemistry Laboratory, depending on how the finances work out.

As of the moment the state appropriated the funds, we began to move one operation that we already had going into the new facility. The Pons-Fleischmann laboratory—the work that they are doing there—will not move. Instead, we will set up an electrochemistry laboratory run by someone who is in close collaboration with them, which will go on with another set of experiments.

Basically, Pons-Fleischmann have been continuing to gather data to support their "open system" calorimetry. It is a technique for measuring the heat balance, which in fact no one has ever tried before, and many people have been and are still quite skeptical. Their main purpose has been to gather data which demonstrate very convincingly the kinds of levels of power production that they have been finding, as well as energy production.

They have started up a flow calorimeter. . . . They are just finishing up their paper on calorimetry. It had originally been expected to be done by the middle of August, but they are still finishing up that paper, which will have all this data in it.

The Metallurgical Laboratory has a collection of experiments that will do several things in electrochemistry that use different materials; they'll try to solve the problem of the etching of the glass and the growth of silicates, which really disturbs and can even shut down the process.

They are trying to understand the problems of keeping the palladium useful. The palladium will degrade in some instances and it's not completely clear why this happens.

'Our General Program'

Let me talk about what our general program is, rather than specifically what is going on in that lab. Generally, our program is to try to resolve the problems of reproducibility, repeatability. Ideally, what we would like to be able to do if a critic says, "I'm skeptical," is to put a cell in a box and send it to him; tell him to plug it into the wall; hook it up in a specified way to a computer and watch what graph will appear.

If we can achieve that, I think we will really be on the road to developing a commercial product. That I think is the main thrust. From a scientific point of view, when I talk to my scientific colleagues, they find cold fusion frustrating; they want to understand the process. So at the same time, we have physicists working on the project who will be making measurements of nuclear by-products with very careful analyses of the electrolyte and the metallic materials themselves. We want to also do very careful analyses of the effluent gases.

We have not been gathering these gases for scientific data. In several experiments we have gathered them just to be able to monitor how much recombination could possibly be taking place. We have discovered to our satisfaction that this is not a factor. Every time we have attempted to make these measurements we find we account for all but 3 percent. . . .

So, reproducibility, repeatability is first and foremost; then understanding the process; then the materials—how the materials are involved: the gases that come off, the solid materials, and the electrolyte. We are trying some other electrolytes. We are also trying some other metals—zirconium and titanium are great candidates. In the Wadsworth laboratory, for two and a half months they have had a zirconium rod just doing electrolysis. . . .

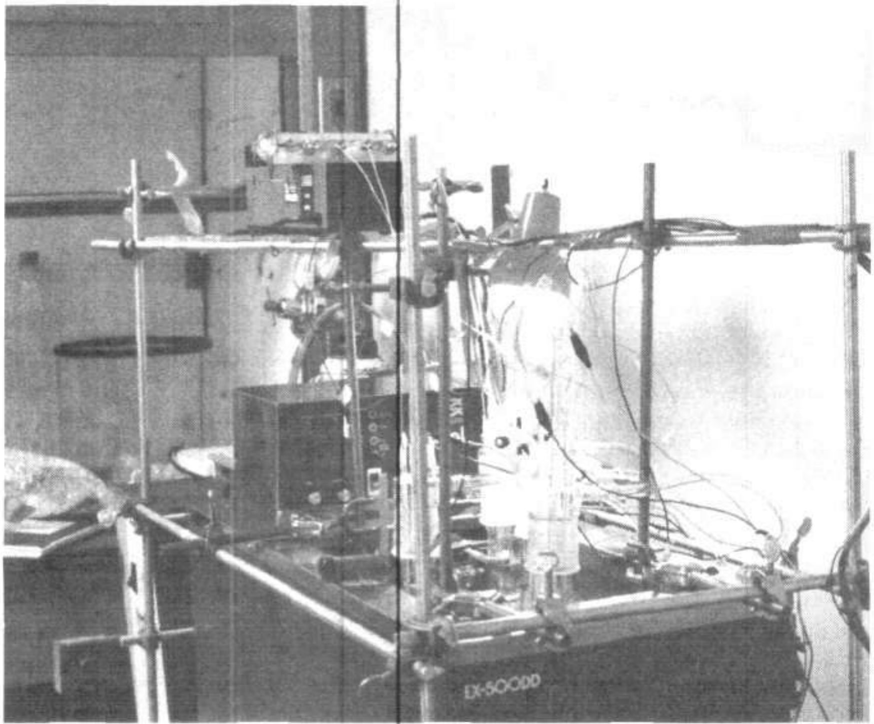
Question: Are they getting some surplus energy out of it?

They are getting no real energy out of it. And you can really pack in a lot of deuterium.

We also want to try other geometric designs. We are not really scaling up in the sense of making things bigger, but rather in the sense of increasing amperage and trying to make the design and materials more efficient.

Question: I think a lot of people in the United States are also working in these areas.

Yes. We have been in touch, at a moderate level, but now at a very substantial level, with the Huggins group and the groups at Texas A&M. There are other groups that, for reasons they understand better than we do, want our relationship with them kept to a minimum of public exposure. I think that the strongest interactions and the best prospect of collaboration is with the Huggins group and the Texas A&M group.



An electrolytic cell at the Metallurgy Laboratory at the University of Utah, where similar cells have generated a significant amount of heat.

In a way we are involved in a scientific controversy with the A&M group—which is a friendly controversy—over whether or not this is a surface or a volume phenomenon. If you forced me to guess, I would say, in fact, both processes and perhaps in both cases a variety of processes.

Another important question is to what extent the electrolyte is involved. By the way, I read a report at Santa Fe that excess heat had been found using sodium chloride as an electrolyte. This was in fact true. . . .

Question: With titanium as the . . .

—Titanium and sodium chloride. That is amazing, because the experiments that have been done at A&M have shown that sodium shuts down the reaction.

These may be consistent, however, because of the configuration of materials—they are using nickel and palladium here, whereas there they were using platinum and palladium and titanium in the other experiment. . . .

Question: So on the electrolyte question, you will be working with Texas A&M?

Yes. The collaboration is informal in the sense that our experiments complement each other. We are in communication constantly about how things are going. We are hoping to have it more formal in the sense that we will have an exchange of personnel and will really be running a group of experiments that have the same objective—that are parallel and complementary, with one consistent goal.

Question: Will you be publishing your progress reports in journal articles, or issuing a journal of your own?

We don't have any prospect of a journal of our own. We are now planning—it's not completely set in concrete, but almost—to have a conference in February, a scientific conference where papers are presented and we will publish proceedings, rather than a workshop or a get-together—a formal meeting where there are not preliminary data, but real data.

Question: Have you set any time limits on your research work?

A cycle of experiments is about three months. Although both Milt

Wadsworth and Stan Pons have had rods that have produced low levels of heat continually throughout the whole summer, the cycle of experiments really peters out after about three months because of degradation of the materials—too much silicate, and so on. You just have to clean things up and start over again.

Another task is to find a way to have it go on indefinitely, but that might be called a third-order priority. The first-order priority is reproducibility and repeatability, and second understanding the proper materials and roles of the materials and processes.

Question: Is there a time limit on your $5 million grant from the state of Utah?

There was no time limit specified, But we have essentially set one. What has actually been awarded to the University of Utah is $2.7 million for one year—the present fiscal year. The total amount appropriated is $5 million, a half million of which will be to support the legal effort, so we think that the $4.5 million will be expended in two years.

We anticipate a lot of corporate involvement developing within this period. We already have in process some involvement of other funding sources to proceed to the science applications. If things go well, we will get into the development phase, but we anticipate the bulk of the financing to be provided by consortia of participating corporations.

Question: Is Utah is the only state that has put money into cold fusion?

Yes. However, John Bockris at Texas A&M is a very shrewd man. . . . So I am sure that Texas A&M has figured out some way to proceed. They have in fact presented proposals. They did not go before the legislature because the governor said that he had sources available to provide the funds by executive order. He is waiting for the signal to go ahead from his science adviser, Norm Ackerman.

Question: Very good results have also been obtained at the University of Florida at Gainesville with Glen Schoessow. They are not meeting with anyone at this point; they are being cautious. But they have said enough to indicate that they have found something very substantial.

[This is Karen Shepherd] Yes. They got heat and also tritium in the same cell. That's what he told me.

Question: That will settle a lot of problems, because you can get tritium in one cell, heat in another cell, and neutrons in a third, but you don't get them in the same cell.

He is getting amounts of tritium comparable to what Bockris has been reporting in his electrolyte, not in his gas. And at the same time, from 10 to 30 watts of power per cubic centimeter. . . .

Question: Japan reported getting tritium. I don't think they looked for it in India, but they are looking for neutrons, heat, and gamma rays, and they got all three. The Japan Atomic Energy Research Institute has reported tritium. . . . There is a lot of misinformation going around, and I am going to set up with the people I know a fax or electronic mail newsletter to put out information on what people are doing.

What I would like to see happen—and it's hard to do because scientists have their own programs—I would like people who have had successful experiments to look at the papers from Harwell and Nate Lewis's laboratory [CalTech], which are now published, and to comment on what's wrong—why the experiments didn't work.

Stan Pons has told me that he did that with David Williams's article [Harwell Laboratory in England], and he said that of all the cells they ran, there was only one that had any chance of working, and in fact that one did work [laughs]. Of course this is completely informal; I would like to see a formal report.

Question: Dr. Huggins at Stanford is saying the same thing, that it is not an easy experiment to replicate.

No, it's not. I think that's clear. David Williams and Nate Lewis are very reputable scientists. If they are not replicating it, we have to pay attention, and we want to understand why that is.

Question: Huggins also said that the fact that it is not being replicated does not indicate that the effect does not exist.

That's correct. That is where, I think, that Harwell and Caltech are in peril. They announced that since *they* had not replicated it, there must not be anything happening. . . .

> **"We already have in process some involvement of other funding sources to proceed to the science applications. If things go well, we will get into the development phase."**

Question: *21st Century* wants to set up a visit to Yale, to Moshe Gai's laboratory. . . . We'll see what he says. But he is also going through this experiment now, maybe he'll get convinced.

Boy, if he gets convinced, call me up collect, and I'll send you a bottle of champagne!

Question: . . . Another report that came out in India just after I came to the United States was from Dr. Sinha in Calcutta. He said at a press conference that not only they found heat, but also a rise of 1 degree Celsius, and the neutron bursts happened so many times together that it was too much of a coincidence to think that it could be anything other than fusion.

Was this in an electrolytic cell. . . .

Question: In an electrolytic cell. I would like to find out what numbers and details he has got.

It seems to me that a country that should be very, very anxious to understand this is Israel. Have you heard any reports. . . .

Question: I have heard nothing from Israel, nothing from France, West Germany, from England. Italy, yes—Frascati.

Germany is mysterious, because Germany is really the strength of electrochemistry in the world.

Energy Department Sabotages Magnetic Fusion

For the first time in history, the director of this nation's fusion energy program went before the U.S. Congress to recommend that his budget be cut.

Dr. Robert O. Hunter, director of the Office of Energy Research for the U.S. Department of Energy, stated at congressional hearings June 14 that the planned next-step fusion experiment, the Compact Ignition Tokamak (CIT), should not be built. Fifty million dollars, he said, could thereby be cut from the magnetic fusion program.

According to Dr. Stephen Dean, former head of magnetic confinement systems for the DOE fusion program, Hunter is trying to resurrect an old ploy—to claim that the development of fusion power as a commercial energy source is so "iffy" that there must be competition within and between various approaches to this crucial, inexhaustible source of energy. Dean is now the executive director of Fusion Power Associates, an industry association.

This competition means that if the tokamak approach is ahead of all of the others—which is the case—then that research must be slowed down so other approaches can "catch up." Under Secretary of Energy James Schlesinger during the Carter administration, this meant an attempt to "compete" tokamak reactors against magnetic mirror devices.

DOE

Hunter: "The department does not believe that CIT is worth constructing if it will not ignite with high probability."

Dean: "CIT might not *ignite for $440 million. You might have to add some extra power."*

Guaranteed Failure

Today this competition is supposed to be between magnetic fusion machines and laser fusion devices. However many times the rules of this game are reformulated, the result is always the same: slow down the research that is farthest along and closest to commercial development.

WHERE HUNTER'S BUDGET FITS ON THE U.S. TIMETABLE FOR MAGNETIC FUSION

This 1976 government projection shows five possible funding paths, called logics, for the magnetic fusion program. The dots and dates on logics II through V indicate conservatively when fusion reactors would be achieved for each logic. The current budget proposal of the DOE is below these four logics; it falls on logic I, which illustrates the principle that continuous funding at a low level never *reaches the goal of a commercial reactor.*

The dashed curves represent optimistic and pessimistic projections of the scientific and technical progress required.

The $315 million for fiscal year 1990, now being recommended by Hunter, puts the fusion program on a budget line (see accompanying figure) that *never* leads to the achievement of a demonstration fusion reactor.

The timetable for fusion shown in the figure was developed by the DOE's predecessor, ERDA, in 1976, to counter the Carter administration's threat to slash fusion funding. Its purpose was to make the point that although money alone cannot *guarantee* scientific advance, the level of funding *does* determine how quickly breakthroughs can be expected to be made.

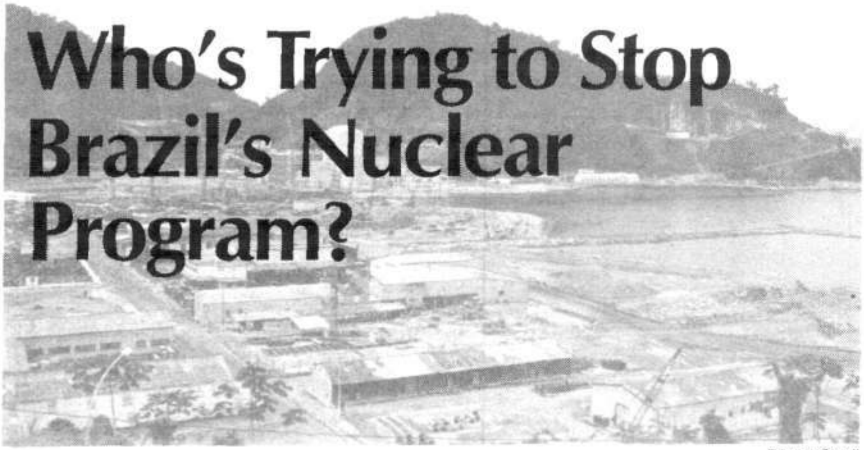
According to Dean, if inflation is taken into account, the level of actual resources going into fusion research today is about half that available 10 years ago. This "new" program proposed by Hunter actually represents nothing but a way of stopping the development of fusion, without cutting off all the funding and announcing that the United States is abandoning development of the only practical source of energy for the future.

Dean reports that reaction from foreign fusion research directors to Hunter's budget has been immediate. How can the U.S. commitment to agreements for international fusion projects be taken seriously, when the United States has *deliberately* slowed down its own effort?

As U.S. technological capabilities continue to erode, time is running out for magnetic fusion.

—Marsha Freeman

Who's Trying to Stop Brazil's Nuclear Program?



Dennis Small

Brazil's operating nuclear plant, Angra 1, shown here in construction in 1982. Angra 2 and 3, now in construction, are under attack by the Greens and their friends in the press and in the international financial community. Meanwhile, 60 million Brazilians have no electricity in their homes.

The Brazilian Nuclear Energy Society requested that we publish this editorial, translated from the Portuguese in the society's August 1989 Bulletin. *The history of the Brazilian nuclear program will be featured in a future issue of* 21st Century.

An international raid is under way against the nuclear development of Latin America, especially against the Brazilian nuclear energy program.

In June 1989, some of the leading newspapers of Rio de Janeiro and São Paulo sent a delegation of journalists to the Federal Republic of Germany. These journalists, apparently invited by the West German government, were in touch with several German institutions concerned with science, technology, and the environment. Afterwards they published almost identical texts, attributing to certain German authorities—mainly to two physicists of the Karlsruhe Nuclear Research Center—extremely damaging statements concerning the Brazilian nuclear program.

The statements alleged that Brazil's nuclear power plants Angra 2 and 3, built with German technology, do not fulfill the required safety standards.

Some days later, a vigorous denial was issued by the German Embassy in Brasilia. In a very objective text, both physicists—Horst Talarek and Claus Frischkorn—contradicted all the statements attributed to them by giving an almost opposite version of the interview.

Unfortunately, this denial was not published by the newspapers involved.

Distressing Alternatives

An accurate analysis of these facts leads us to just two equally distressing alternatives: Either the German physicists lied or three of the most important Brazilian newspapers lied in a concerted action. In any case, the incident caused considerable damage to the already fragile public image of nuclear power in Brazil.

But there are other indications of pressure. In West Germany, there is increasing political pressure to renounce the German-Brazilian Agreement on Nuclear Energy. Several news items in the international media report that the German-Brazilian Agreement is being used as a bridge to transfer "sensitive technology" to the Brazilian autonomous nuclear program, which is supposedly of "clear military inspiration."

It is interesting to note that many of these news items are published in the U.S. press, even in the respected *Wall Street Journal,* which covers international financial and business news.

At this moment, decisive for the future of our nation, the Brazilian Nuclear Energy Society cannot decline to react against these pressures.

All this international activity—supposedly motivated by antimilitarist concerns—aims at impeding Brazil's full access to nuclear technology. The critics have forgotten that the major achievement of our autonomous program until now has been the enrichment of uranium by the gas centrifuge process. It is well known that the industrial nations for several years have denied Brazil this gas centrifuge technology, which is certainly the most economical uranium enrichment process.

The critics do not mention that the Brazilian Constitution—unlike the majority of other nations' constitutions—strictly prohibits nonpeaceful uses of nuclear energy and attributes to the Brazilian Congress the responsibility for control of all nuclear activities within the national territory.

International Domination

The pressures mentioned here are not an isolated case. They are part of the machinery of international domination that operates today by means of two main instruments: the foreign debt and scientific and technological restraints.

These restraints do not apply only to nuclear power. We frequently read in the news about the restrictions imposed on the Brazilian Satellite Launching Vehicle (SLV), on supercomputers, and on microchip technology. We follow—with astonishment—the conspicuous attitude of the World Bank in refusing financial help to energy projects in Brazil, whether nuclear, hydroelectric, fossil fuel, or any other. Nearly 60 million people in Brazil have no electricity in their homes.

The Brazilian population must be made aware of these facts. Worldwide, nuclear energy is growing more rapidly than any other energy source. The percentage of electricity produced in nuclear power plants worldwide increased from 1.6 percent in 1970 to 17 percent in 1988, and it is still growing.

Brazil cannot miss the train of history. Energy means development. Nuclear energy is the future.

UNSCIENTIFIC AND UN-AMERICAN

Scientific American on 'Managing Planet Earth': A Review

The fold-out cover is a painting, "The Earth at Night," made with data from satellite photos of the U.S. Air Force. The light points reflect human activity.

by Hugh W. Ellsaesser

EDITOR'S NOTE

The widely advertised special issue of Scientific American, *September 1989, on "Managing Planet Earth" sounds the same alarm coming from the media, environmentalists, and political figures—that planet Earth is going under because of man's development. Rhetoric, not science, shapes the problem and also* Scientific American's *solution. Technology admittedly could solve any actual problems noted, but putting advanced technology to use is not what this special issue means by "managing." The aim seems to be to put the weight of "establishment" science behind various global proposals for policing the environment—and shutting down industry in the process.*

We asked veteran climatologist Ellsaesser to review "Managing Planet Earth" and to present his own views on the subject.

Last summer's drought, climatologist Jim Hansen's congressional testimony, and news on the ozone hole combined to tilt world sympathy toward Planet Earth as the underdog in the battle between man and his environment. Mother Earth became Man-of-the-Year on *Time*'s cover. And every other publication has felt compelled to declare sides, including *Scientific American,* which devoted its September issue to 11 articles by 16 distinguished scientists and environmentalists on the topic "Managing Planet Earth."

Never mind that Planet Earth has been around some 4.5 billion years while man can claim no more than one or two hours for each of those years: Earth has already been declared vanquished—unless. . . . It is the "unless" that has emerged as the common underlying theme of these latter-day environmentalists.

The Luxury of Environmentalism

Were it not for the affluence and free time which the free-market economic system and democracy have fostered, we would not now be worrying about the state of the environment—we would be too busy grubbing out a livelihood. Essentially every article in this special issue notes that the biggest threats to the environment are posed by the undeveloped countries.

Unmentioned, of course, are the international financial organizations that have forced underdevelopment and "appropriate technologies," rather than advanced technologies on these countries.

It is only in the release of carbon dioxide that may cause climate warming that the West predominates, and even here we are being rapidly overtaken. And it was not just the free-market economic system and democracy (anathematized though they be by the environmentalists and their friends) that got the West to where it is today; it was also the freedom to make a lot of individual and therefore small mistakes, from which the rest of us were able to work our way around the problems encountered. We were not forced lock-step into huge mistakes—like the brutal Chinese cultural revolution—from which there may be no recovery.

The biggest current obstacle to making the transition to a sustainable ecology is the holier-than-thou moralism of the environmentalists, which refuses to allow a balancing of costs against benefits. Also involved is the environmentalists' selective presentation of scientific data, overstating some facts and omitting others in an effort to justify the extremity of their solutions.

Here, in summary, is what *Scientific American*'s scientists had to say:

Competing for Management

In the words of **William C. Clark**, senior research associate at Harvard's Kennedy School of Government and author of the issue's lead article: "It is only as a global species pooling our knowledge, coordinating actions and sharing what the planet has to offer—that we have any prospect for managing the planet's transformation along pathways of sustainable development. Self-conscious, intelligent management of the Earth is one of the great challenges facing humanity as it approaches the 21st century."

As Clark sees it, a key requirement for "adaptive planetary management" is the construction of mechanisms at the national and international level to coordinate management activities"—that is, establishment of what Vernadsky (1945) dubbed the *noosphere*.

Clark cites as examples the Montreal Protocol to protect the ozone layer, proposals for an international law of the atmosphere, and a dozen or more global conventions for protection of the environment already in effect. But as befits one who has already spent several years studying sustainable development of the biosphere and who earlier had studied the witch-hunts of the 16th to 18th centuries, Clark (1986, 1979), the author revealed that he has encountered reasons for second thoughts.

In particular, Clark has found that beneath the orderly surface of the growing international environmental movement, "a large and rapidly growing number of nongovernmental bodies, governmental agencies, and international organizations are scrambling to play some part in the management of planet Earth." That is, the most active players are in it, not for the game, *but for a piece of the action*.

I am reminded of a term my mother used to use: "a political steam roller"—by which she meant a mob-like, emotionally driven movement designed to flatten all opposition before it knew what was coming.

A U.N. with Teeth?

In discussing "The Changing Atmosphere," **Tom Graedel** and **Paul Crutzen**, atmospheric chemists, appear most concerned over man's manufacture of nondegradable chemicals like PCBs, DDT, and freons—that is, chemicals that do not react with anything in our normal environment; with the burning of tropical forests and savannas—a practice that has been going on for thousands of years; for the weathering and corrosion of buildings and monuments; for the eye irritation and the aesthetic nuisance of reduced visibility from urban smog; for unexplained increases in atmospheric concentrations of methane and nitrous oxide; and for the Antarctic ozone hole.

Our environment has recovered from meteor falls, volcanic eruptions exceeding Krakatoa and Tambora, forest and prairie fires, and the excreta and decaying carcasses of all type of life forms for 4.5 billion years, but it can't cope with the impacts cited by Graedel and Crutzen without help from a United Nations with teeth? Come on, fellows.

Stephen Schneider—Again

Climatologist **Stephen H. Schneider**, one of the leading voices promoting the Greenhouse Effect, addresses "The Changing Climate"—again. First, he points out the uncertainties in climate models and all the things he can think of that *might* or *could* happen, such as sea level rise and increased releases of soil carbon and methane clathrates (molecular lattices of methane and water) as a result of a warmer Earth. Then he admits, "at this stage, it appears, no plausible policies are likely to prevent the world from warming by a degree or two."

Nevertheless, Schneider says: "it makes sense to take actions that will yield 'tie-in' benefits even if climatic changes do not materialize as forecast. . . . More efficient fossil-fuel use will slow the carbon dioxide buildup, but even if the sensitivity of climate to carbon dioxide has been overstated, what would be wasted by taking this step?"

In at least one instance, Schneider revealed his failure—or refusal—to apply his gray matter to the problem. In discussing ocean warming, he states that "high-latitude regions where deep water is mixed up to the surface might warm more slowly." He chooses to ignore the fact that ocean mixing is initiated by the cooling and sinking of surface water and that as soon as the surface water starts to warm, the overturning or mixing stops.

Overstating Water Pollution

"Threats to the World's Water" is addressed by **J.W. Maurits la Riviere**, secretary general of the International Council of Scientific Unions. He makes a slip. He admits that "in the

Uwe Henke von Parpart

"Sustainable development" to many environmentalists means the shutdown of developing-sector industry. Shown here is a Mexican oil refinery at Coatzacoalcos.

United Nations

Great Projects in Africa, Asia, and Latin America to prevent flooding and provide irrigation for agriculture have been in the blueprint stage for decades. What's necessary is the political will to get the job done. Here, a modern bridge under construction in Nigeria, 1961.

less developed countries where water pollution by organic wastes is widespread, millions of people—and children in particular—die each year from water-related diseases . . . eradicated in the West long ago."

Compared to this problem, which we in industrialized countries have already solved, the water pollution problems he cites do not look very serious, and la Riviere seems unaware of improvements in water quality achieved in many areas of the world in recent years.

One of his statements does ring of serious portent: "Contentious competition for the waters of such international rivers as the Nile, the Jordan, the Ganges and the Brahmaputra is a symptom of the increasing scarcity of water." This is the only statement I found in any of the articles that suggested realization of the fact that the greatest hazard to man—is man.

Pushing Back Biological Diversity

Edward Wilson's paper on "Threats to Biodiversity" is one with which it is difficult to find fault. As he says, "it is the one process that is wholly irreversible." Although we are unlikely to mourn the loss of the smallpox organism, we have to feel uneasy at irretrievable loss of any of the 1.4 million named—and estimated 4 million total—species now extant on Earth.

Wilson, a professor of science at Harvard University, estimates that man has already pushed biological diversity back to where it was 65 million years ago, with no end in sight. Our only hope appears to be Wilson's possession of "enough faith in human nature to believe that when people are both economically secure and aware of the value of biological wealth they will take the necessary measures to protect their environment."

Apparently, we have to reconcile ourselves to the loss of the elephant, rhino, and similar species with special attractions before this state of worldwide economic security arrives.

The Unpleasantness of Population

Demographer **Nathan Keyfitz** in "The Growing Human Population" handles the flip side of the threat to biological diversity. He sets the scale of the problem by noting that there are twice as many humans today as in 1950 and there are expected to be twice as many as now by about 2050. "Sooner or later growth has to stop," he concludes with certainty. He also says, as did Ellsaesser earlier (1971), that to wait for natural constraints to intervene and stop population growth will lead to all types of unpleasantness, including ecological destruction.

Keyfitz makes some points that should well be pondered by others concerned for the environment: "When people are concentrated in cities, they would seem to have less direct effect on the forests, the wildlife, the oceans—on the biosphere in general. . . . In spite of bad air [in Mexico City], city dwellers probably live longer than their country cousins."

Technology Not an Obstacle

In addressing "Strategies for Agriculture," Resources for the Future staffers **Pierre Crosson** and **Norman Rosenberg** ask the question: Will our species be able to feed itself when the world population stabilizes at about twice the present level? Their short answer is, "probably yes." For the past 20 years world food production has increased at an annual rate of 2.4 percent compared to a population growth around 2 percent. But meeting this goal will require the development of new technology. "We also believe that developing that technology is not the most difficult problem facing the world's agriculture; *society is* [emphasis added]," they state.

The most challenging problem, they say, is to devise institutional mechanisms that will reward individual farmers for valuing the resources they use at their true social value. Most needed are innovations to improve crop productivity per hectare. The authors also report on recent studies showing that previous estimates of loss of cropland to erosion, desertification, and salination were seriously exaggerated.

Little to Say About Energy

John Gibbons, Peter Blain and **Holly Gwin** have little to say about "Strategies for Energy Use" beyond their subtitle: "Energy efficiency can reconcile environmental concerns with economic development for all nations. It can stretch energy supplies, slow climatic changes, and buy time to develop alternative energy resources."

Industrial Ecology

Robert Frosch and **Nicholas Gallopoulos**, from General Motors Research

Laboratory, address "Strategies for Manufacturing." As with many others, these authors cannot visualize an Earth with 10 billion people living as people now live in the developed countries without running out of resources or being buried in garbage. They do believe it possible, however, with a more integrated "industrial ecosystem."

"In such a system the consumption of energy and materials is optimized, waste generation is minimized, and the effluents of one process . . . serve as the raw material for another process. . . . [B]oth manufacturers and consumers must change their habits. . . . Materials in an ideal industrial ecosystem are not depleted any more than those in a biological one are. . . ."

They suggest that financial incentives would be more effective than absolute rules in making the transition to such an ecosystem, but believe economic incentives alone are not enough. The concepts of industrial ecology must be taught more widely; they must be recognized and valued by public officials, industry leaders, and the media, the authors say.

Social, Not Technological Obstacles

In discussing "Strategies for Sustainable Economic Development," **Jim MacNeill**, secretary general of the World Commission on Environment and Development, addresses the question the United Nations posed to his commission (also known as the Gro Brundtland Commission): Can the needs and aspirations of the 5 billion people now living be met without compromising the ability of tomorrow's 8 to 10 billion to meet theirs?

While agreeing with the Commission's answer of a "yes" laden with conditions, MacNeill notes that the answer is not clear because the obstacles to sustainability are mainly social, institutional and political—that is, *not technological*.

MacNeill then cites the tendency of our present politicians to launch programs directly detrimental to the environment and counterproductive to the establishment of sustainable development. Specifically, he cites subsidies fostering depletion of ecological capital like forests, and agricultural subsidies in developed countries followed by dumping of surpluses in developing countries, which seriously damage the development of local self-sufficiency in agriculture.


United Nations

The authors of the article on agriculture admit that new technology could solve the problem of feeding the world. Here an Indonesian woman transplants rice shoots one by one.

What 'Global Ecological Crisis'?

William Ruckelshaus, chief executive of Browning Ferris Industries, authors the final article, "Toward a Sustainable World." As do some of the other authors, he states that "The previous articles . . . have documented the reality of the global ecological crisis."

I must have missed something!

Many of the papers indeed cite urban smog, acid rain, ozone depletion, climate change, soil erosion, desertification and salination, deforestation and crowding out of species—but not one of them cites any concrete supporting evidence of actual damages comparable to what is happening in Ethiopia and Lebanon, to the Kurds in Iraq, to the ethnic Turks in Bulgaria, to the Miskito Indians in Nicaragua, between the Jews and Palestinians in Israel, and between the Hindus and Sikhs in India.

The only natural hazard that rivals man's inhumanity to man is the organisms that cause parasitic diseases like malaria and schistosomiasis. Illnesses and early deaths from these diseases number in the hundreds of millions every year. None of the cited ecological problems is comparable to a crack in the dike—threatening a clear and certain catastrophe if remedial action is not taken at once.

The strongest argument that can be mustered on any of them is that we can't afford to wait until we really know what the danger is.

The more we learn of acid rain and the ozone hole the less likely they appear to be man-induced, and already both appear to be subsiding in importance. As Keyfitz points out, the peasants flocking to Mexico City would probably survive longer under urban smog than under the problems they fled. Graedel and Crutzen note that in the United States, sulfur dioxide leveled off and decreased in the 1960s and early 1970s—that is, before the formation of the Environmental Protection Agency.

The terrestrial climate we know today represents less than 10 percent of the past 2 million years and, at most, less than 1 percent of the 4.5-billion-year lifetime of Earth. It is by no means immutable or inviolate only because it is all we have ever known. Even during the 10,000 years of the current climatic era, the global mean temperature has varied by 1 to 2°C without any known changes in carbon dioxide and certainly with no help from *homo sapiens*.

Ruckelshaus makes the analogy of preventing the buildup of greenhouse gases to buying insurance: "As long as we are going to pay premiums, we might as well pay them in ways that will yield dividends in the form of greater efficiency, improved human health or more widely distributed prosperity. If we turn out to be wrong on greenhouse warming and ozone depletion, we still retain the dividend benefits. In any case, no one complains to the insurance company when disaster does not strike."

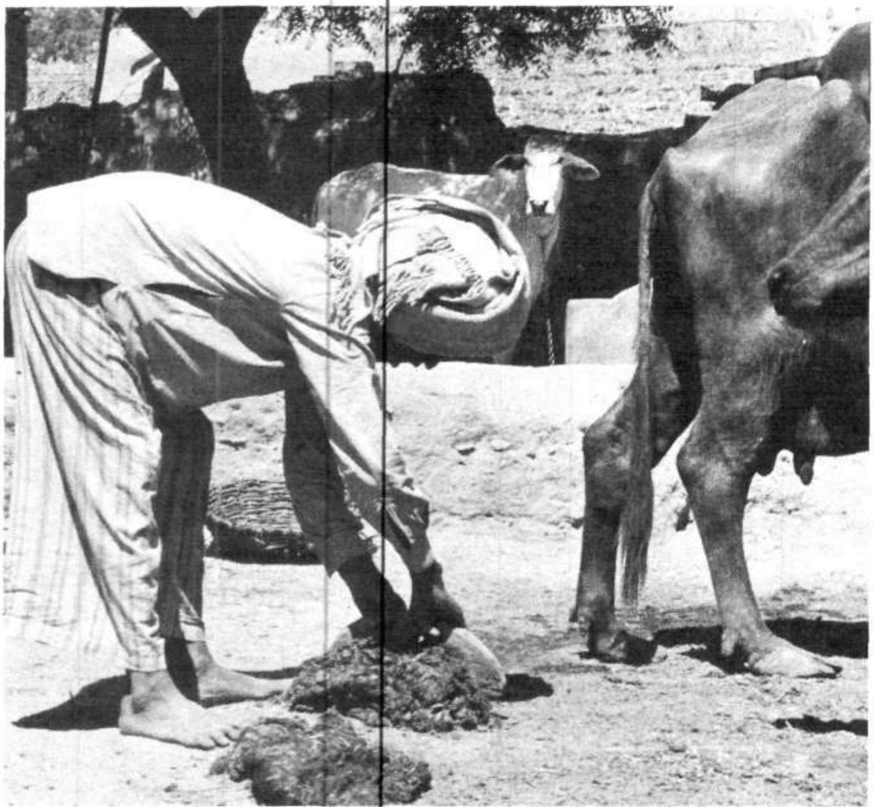
I get the impression that Ruckelshaus and Schneider, in particular, are not really worried about climatic warming but are using it to scare us into adopting their ideas as to how we should live.

Dictatorship of the Ecologists

Ruckelshaus says, "Taking control of the future therefore means tightening the connection between science and policy." But whose science?

(Ruckelshaus, it should be recalled, was the first administrator of the Environmental Protection Agency, and in that capacity banned DDT for what he admitted were "political" reasons, not scientific reasons. This was in 1972, after his own agency held seven months of hearings and concluded, based on the scientific evidence, that DDT should not be banned.)

Ruckelshaus cites industrial centers as also being centers of environmental pollution. This appears to directly contradict Keyfitz's statements that "where people are concentrated in cities, they would seem to have less direct effect on forests, wildlife, the oceans—on the biosphere in general," the peasants flocking to Mexico City being a case in point.



United Nations

"Integrating the ecosystem": Do environmentalists have a sensuous grasp of the way of life to which they are sentencing the world's population? Here, an Indian farmer collects cow dung to use as fertilizer.

"I get the impression that Ruckelshaus and Schneider are not really worried about climatic warming but are using it to scare us into adopting their ideas as to how we should live."

In any case, Ruckelshaus does not seem to think the advanced countries are going to accept this tightened connection between science and policy voluntarily: "institutions must be developed that will effectively apply the motivation." Instead of a "dictatorship of the protetariat" he is visualizing a dictatorship of the ecologists and environmentalists!

No wonder Clark had second thoughts about all those "scrambling to play some part" in the management of planet Earth. If we are going to be forced to live in such a dictatorship, I too would want to be a party member.

Suppose we establish institutions with sufficient power to "effectively apply the motivations" for worldwide adoption of policies based on sustainable development, where do we find the wizard saints to head them? How do we assure they will not be taken over by a Hitler, a Stalin, or an Idi Amin?

In Ruckelshaus's words, in the United States at present, "the appropriate motivations and environmental institutions are patently inadequate or nonexistent. . . . The difficulties, ironically, are inherent in the free-market economic system on the one hand and in democracy on the other." Obviously, he hasn't been paying any attention to what has been happening behind the Iron Curtain.

Ruckelshaus and those who agree with him are wrong. He notes that the transition to sustainability would be a modification of society comparable to the late Neolithic agricultural revolution and to the industrial revolution. While he admits those "were gradual, spontaneous, and largely unconscious," he claims that the transition to sustainability "will have to be a fully conscious operation."

Why? Apparently because he has little faith in humans other than himself. The fact that the shape of this transition "cannot be clearly seen from where we now stand" makes it no different from the earlier transitions.

Dr. Hugh Ellsaesser, an atmospheric scientist, retired from the USAF Air Weather Service after 21 years as a weather officer and from the Lawrence Livermore National Laboratory after 24 years in climate research. He is continuing his studies at LLNL as a Participating Guest Scientist.

References

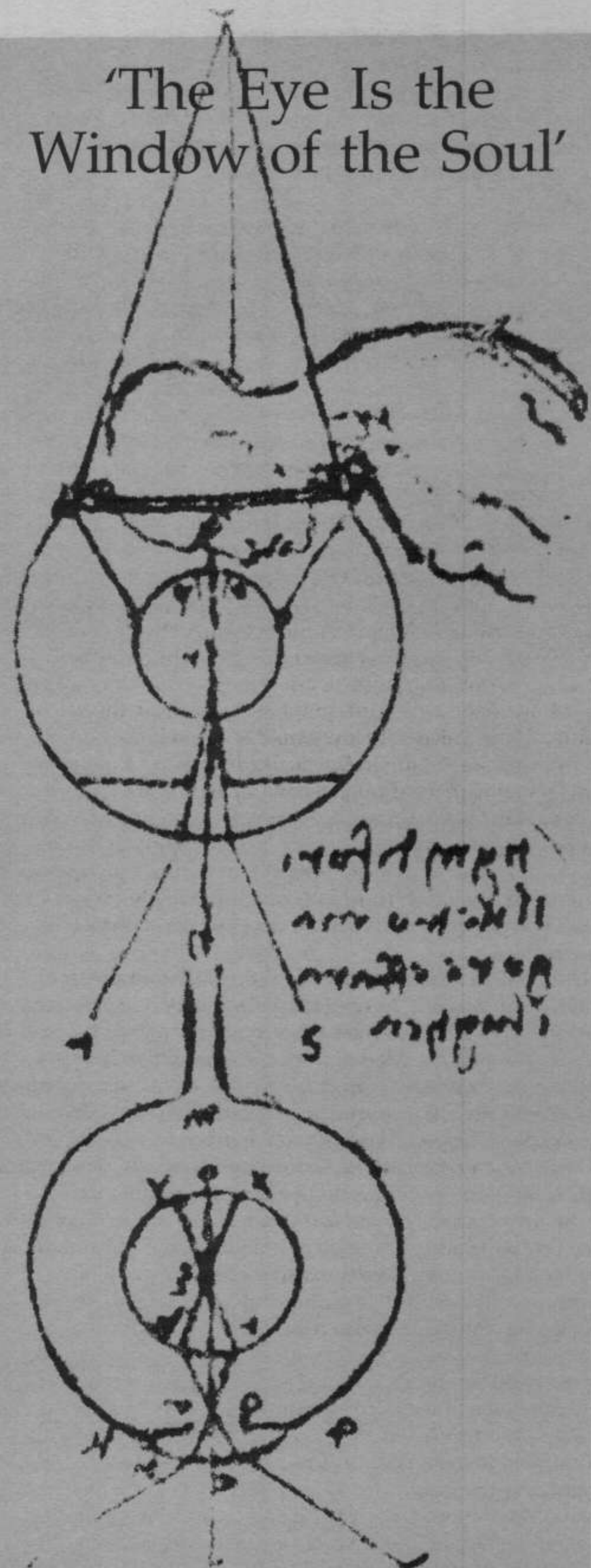
William C. Clark and R.E. Munn, eds., 1986. *Sustainable Development of the Biosphere* (Cambridge: Cambridge University Press).

William C. Clark, 1979. "Witches, Floods and Wonder Drugs: Historical Perspectives on Risk Management," in *GM Symposium on Societal Risk Assessment*, Warren, Mich., Oct. 7–9, 1979, p. 287.

Hugh W. Ellsaesser, 1971. "Air Pollution: Our Ecological Alarm and Blessing in Disguise," *EOS—Transactions of the American Geophysical Union* **52**:92.

W.I. Vernadsky, 1945. "The Biosphere and the Noosphere," *American Scientist* **33**:1.

'The Eye Is the Window of the Soul'



Leonardo da Vinci's Science of 'Prospettiva'

The ancient theory of human vision, based on the soul, is confirmed by Leonardo.

by Robert L. Gallagher

Leonardo da Vinci's advances in the science of perspective developed from his penetrating investigations into optics and human vision. In Leonardo's Italian, *prospettiva*, usually translated today as perspective, simply means optics, and by Leonardo's definition, optics or *prospettiva* "is nothing else than a thorough knowledge of the function of the eye." [A. 3a; Richter 50][1]

The theory of vision Leonardo adheres to and elaborates is very different from the modernist theory with which the reader may be familiar. Leonardo's *prospettiva* cannot be grasped unless it is approached from the theory of vision that guides his work.

From ancient times through the Renaissance, most thinkers held that perception is the result of an act of the soul outwards, to form the image seen or the sound heard out of a sensory continuum.[2] The eye is conceived of as an instrument of the soul, not a passive receiver of images. These views flow from the perspective that the soul is ontologically prior to all bodies that subsist in discrete time and space. While all things change with different temporal and spatial conditions, the soul undergoes change only in time, and because of that is prior to all bodies, writes St. Augustine in his *De Musica*: "The form changeable only in time is prior to that changeable both in time and place." [6,14,44][3] This Augustinian view of vision is part of the Renaissance culture that produces Leonardo and guides the work of his predecessors in optics, for example, John Pecham, whom he studied.

In contrast, the modernist theory of vision rejects the Christian view that the metaphysical nature of the soul is the basis of human vision. The modernists assume that objects imprint their images on the mind as though it were a blank slate, a Lockean *tabula rasa*. They make no distinction between sensation and perception, and deny there is a need for a judgmental process of the human mind to form complete images out of raw sense data. For the modernists, focused images arrive already formed on the surface of the retina by virtue of the optical characteristics of the atmosphere and of the eye. The retina serves only as a passive viewing screen for the brain, as in a *camera obscura*.

The modernists posit a point-for-point correspondence between images on the surface of the retina and the visual field, with the brain analyzing this digital image as a computer would. By this theory, the human mind and soul are at best mere epiphenomena of the mechanics of sensory stimulus and motor response.

The modernist view appeals to naive prejudice: We "see" only complete images; we are not conscious of a judgmental process. Vision appears self-evident. It seems plausible that images are formed on the retina and that we simply observe them.

Reflecting the modernist theory that the eye is a passive viewing instrument, M.H. Pirenne, one-time lecturer in physiology at the University of Oxford, writes in his *Vision and the Eye*: "The human eye acts like a *camera obscura,* an image of the objects outside being formed on the retina by the transparent refracting media of the eye. The essential principle is the same as a photographic camera. . . ."[4]

Pirenne's beliefs lead him to hypothesize a completely "objective" art, dissociated from human vision and the human mind. He concludes that "the perspective drawing made for a fly's eye will be the same as that for a man's eye."

A completely different attitude toward vision and the senses is expressed by the thinkers who played the greatest role in shaping the Renaissance, of which Leonardo's work is the most advanced expression in science. St. Augustine, for example, argues convincingly that hearing or vision could not exist without the judgmental processes of the soul.[5] Leonardo elaborates this viewpoint, contending that images are not presented to the mind preformed on the retina and that judgment is a necessary function of the human mind. In his "Treatise on the Eye" he writes:

> From this surface [of the retina] . . . the species are taken by the *imprensiva* and transmitted to the *senso commune* where they are judged [D. 2b; Strong 9].
>
> The soul seems to reside in the judgment, and the judgment would seem to be seated in that part where all the senses meet; and this is called *senso commune*. . . . The *senso commune* is the seat of the soul, and the memory is its ammunition [munitione] and the *imprensiva* is its standard of reference, since the sense waits on the soul and not the soul on the sense [W. An. IV 202a(B); Richter 838].

Source: D3b; Keele 206
A drawing from Leonardo's manuscripts of an experiment with a model of the human eye.

By this view, the visual image is not formed passively on the retina but rather is synthesized by the human judgmental faculty, which Leonardo situates in a specific ventricle of the brain.

The two views of perception, classical and modern, express fundamentally divergent attitudes toward aesthetics. The important question is: Do the harmonies we experience through the fine arts have their origin in the physical art object itself, that is, the painting seen, or the music heard, or do they have their origin in the soul of the viewer or hearer?

If sensory data act directly upon the mind, with no judgmental process intervening, we would be forced to conclude that the harmonies we experience originate in the art itself as an object or sense datum in discrete time and space. But sense data are ephemeral and have no lasting existence. They could be viewed as characterized by arbitrariness rather than harmoniousness. Under these conditions, how could art inspire us with any appreciation of the lawful nature of the universe? How would art even be possible?

Augustine raises this in *De musica* and resolves this problem by stating that although the world itself is fundamentally harmonic, we can know this only by reference to a standard of judgment that our souls receive from God. From this standpoint, Leonardo embarks on a thorough investigation of optics and vision and establishes anew a scientific basis for the relation of that sense to human knowledge.

On the Action of Light in the 'Luminous Atmosphere'

Leonardo's work on optics may be divided into several progressive levels of investigation: (1) how light acts in the atmosphere to produce the optical substrata required for vision: (2) how passive optical instruments like the *camera obscura,* lenses, and mirrors function; (3) how the eye functions; (4) Leonardo's *prospettiva naturale*; (5) Leonardo's *prospettiva divina*; and (6) his aesthetics. In the course of elaborating his *prospettiva,* Leonardo develops his critique of linear perspective. These headings are usually considered distinct subjects treated by Leonardo, but as this investigation shows, and like his work in anatomy and physiology, these are not self-standing "sciences" but rather subordinate parts of his *prospettiva*.

In the first part of his investigations Leonardo asks the question: Do objects themselves produce the images that we see with the eye? To the contrary, Leonardo says that images are produced by the action of light in the atmosphere. He begins by describing the optical activity continually taking place in the atmosphere, and he emphasizes that light is continuously interacting upon the surfaces of bodies around us. The same light by which you see this printed page scatters elsewhere in the room where you are sitting, interacts on other surfaces, and conveys, for example, an image of a picture on the wall.

Extending this thought, Leonardo writes that every object in the atmosphere could be said to be covered with the images of every other object in the atmosphere. We can imagine an eye or camera positioned anywhere on any surface, able to see or record images of all other objects. In this way, all surfaces are illuminated by the light that carries the images of other surfaces. In this continuous interaction, only two things about the light change—its color and the geometric form it conveys.

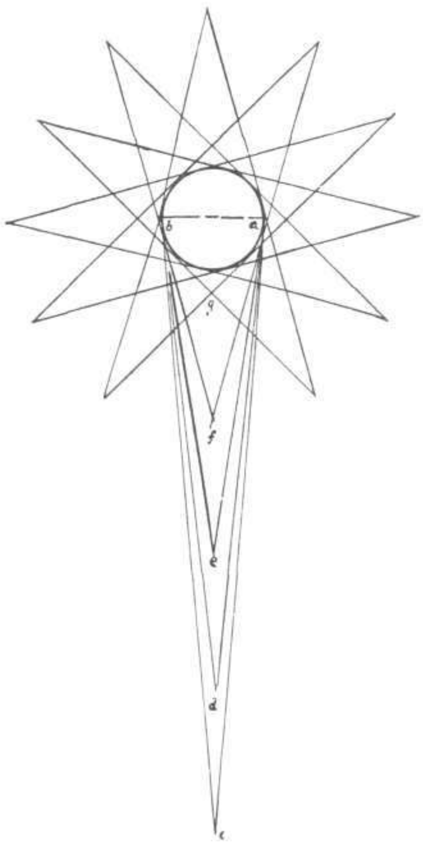


Figure 1
PYRAMIDS OF LIGHT RADIATE SPHERICALLY FROM ALL SURFACES

Leonardo describes the action of light using this figure, which shows pyramids of light radiating spherically from the surface of a sphere. He writes: "Every body in light and shade fills the surrounding air with infinite images of itself, and these by infinite pyramids infused in the air, represent this body throughout space and on every side. . . . A circle of equidistant pyramids of converging rays, gives to their object angles of equal size; and the eye at each point will see the object as of the same size. . . .

"The atmosphere is full of infinite pyramids composed of radiating straight lines which are produced by the boundaries of the surfaces of the bodies in light and shade placed in the air; and the farther they are from the body which produces them, the more acute they become. . ."

Source: Ash. I. 27 IIa; Richter 63

To characterize the action of light more precisely, Leonardo develops the construct *pyramid* of light. The interaction and scattering of light upon surfaces produce *pyramids* of light that propagate through the atmosphere and carry optical information on the surfaces at which they were formed. The surfaces of bodies form the bases of these pyramids, which emanate spherically in all directions from an object (Figure 1). Leonardo writes, "Every body in light and shade fills the surrounding air with infinite images of itself, and these by infinite pyramids infused in the air, represent this body throughout space and on every side" [Ash. I. 27 IIa; Richter 63].

At every point in the atmosphere, pyramids converge to an apex where the images they convey can be accepted by the eye or recorded by a camera. Leonardo proved this with the *camera obscura,* a device that admits pyramids of light through a pinhole that may be positioned anywhere in the atmosphere, and displays the images carried by the pyramids on a translucent screen.

Vision, Leonardo writes, is dependent on the formation of optical pyramids in the luminous atmosphere. These pyramids are formed by the scattering of light from "the boundaries of surfaces of bodies in light and shade." However, these boundaries and surfaces are not part of the bodies themselves, he writes. They are only the "medium"—or in modern scientific terminology *the surface of discontinuity*—separating bodies from each other and from the air. These surfaces have no independent material existence.

For example, what is the surface separating your hand from a table top on which it rests? Look at it where your hand meets the table. Is the surface part of your hand or part of the table? Now move your hand. What happened to the surface?

These surfaces seem to have only an illusory existence, yet they play an important role in optics. When light is reflected or refracted, it is turned in its direction of propagation "inside" the surface of discontinuity separating the air from objects or from water. Physicists speak of this surface as the "interface" separating two media of propagation. In reflection, for example, there is nothing to suggest that the bodies of objects themselves have anything to do with the phenomenon aside from being that which is enclosed by the surface of discontinuity that bounds the luminous atmosphere. Surfaces exist only incorporeally, Leonardo explains:

> The boundaries of bodies are the least of all things. The proposition is proved to be true, because the boundary of a thing is a surface, which is not part of the body contained within that surface; nor is it part of the air surrounding that body, but is the medium interposed between the air and the body. . . . The lateral boundaries of these bodies is the line forming the boundary of the surface, which line is of invisible thickness [G. 37a; Richter 49].

The surface is a limitation of a body and the limitation of a body is no part of that body and the limitation of one body is that which begins another. That which is not part of any body is nothing [Br. M. 131b; Richter 45].

From these remarks we may conclude that material bodies themselves are of discrete time and space but the surfaces by which we see them are not; they originate from the universal, timeless, and metaphysical nature of incorporeal *form*.

Leonardo elaborates this with respect to that part of a boundary which outlines a figure, from the standpoint of his wave theory of light. The wave nature of light allows us to see around this surface, to see around corners, so to speak. That is, the optical pyramid formed in the atmosphere from the surfaces of bodies—and by which we see objects—contains light reflected from surfaces that are not exposed to direct view and do not lie in a straight line with the eye or the apex of the pyramid. This is possible because every point of a light wave emanating from a surface becomes a point source for the spherical radiation of further light waves (the so-called Huygens principle). As a result, *light waves reflected from a surface that is not on a straight path to the eye can reach the eye though this secondary, spherical emanation of light along the fronts of waves reflected from that same surface.*

Consider the surface presented to the eye by the petals of a flower. Peonies present to the viewer a surface composed of a multiplicity of petals, one next to the other. The wave nature of light enables us to see far more of the surface of the petals than would be possible if light traveled only in straight line rays—perhaps as much as 10 percent more.

Because of the wave nature of light, the base of Leonardo's pyramid of vision encloses a greater surface than the surface that lies in a straight path to the eye. The eye is presented with information that enables it to *wrap around* the surface. From an optical standpoint, the pyramid of vision out of which an image is formed includes waves outside the rectilinear pyramid that embraces the light from the surfaces on a direct line to the eye; that is, light waves generated from wave fronts that originate from surfaces not in a direct line. As a result, Leonardo's pyramid extends asymptotically at its base. If it were drawn, it would appear more like a *caustic pyramid*—a surface produced by rotating a caustic about its axis—than a "normal" rectilinear pyramid, but one in which the asymptote wraps about a surface (Figure 2).

This asymptote produced from surfaces not in a direct line of sight constitutes the optical boundary surrounding an object and naturally intermingles with that of an immediately adjacent figure. Therefore, boundary simultaneously conveys *figure, depth, roundness, and connectedness.* Leonardo writes, "The boundary of one thing with another is of the nature of a mathematical line, because the end of one color is the beginning of another color and is not to be called [a physical] line . . . the boundary is a thing invisible" [Trat. 486; McMahon 506].

Many commentators have noted that Leonardo treats boundaries and form in general very differently and more gracefully than other artists, that he makes the boundary of one figure fade or blur into another. Here we have presented the philosophical and scientific basis of this feature of his "technique."

Leonardo regarded the sort of pyramid in Figure 2 to represent the *geometry of all fundamental physical processes.*

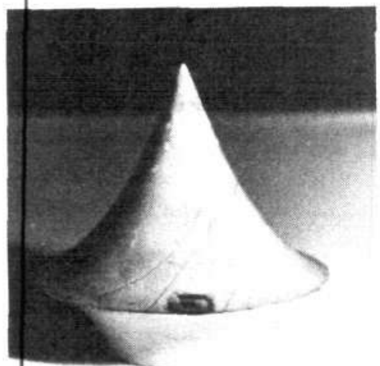
In summary, according to Leonardo, bodies themselves do not produce the optical pyramids that fill the atmosphere; rather, they are produced in the luminous atmo*sphere by the interaction of light with the surfaces that* envelop bodies. With this one investigation, he knocks the props out from under the theory of vision that assumes sight to consist of objects acting upon the human mind. As he writes, "Therefore we may rather believe it to be the nature and potency of our luminous atmosphere which absorbs the images of the objects existing in it, than the nature of the objects, to send their images through the air" [C.A. 133b; Richter 70].

Leonardo sets forth the continual optical activity taking place around us. "Our luminous atmosphere absorbs the images of objects, like a lodestone," he writes. The images are carried by nonlinear pyramids of light produced from the *interaction of light with the surface of discontinuity* separating objects from the air. Objects themselves do not produce images.

The Properties of a 'Passive Eye'

Leonardo analyzes an instrument that passively collects images from the atmosphere, in order to lay the basis for understanding what the eye and the judgment uniquely and *actively* contribute to vision. With this he completes his investigations of the optics of the luminous atmosphere.

Leonardo uses a *camera obscura* (dark chamber) to view



Dino de Paoli

Figure 2
THE CAUSTIC 'PYRAMID'

The wave nature of light transforms the shape of the "pyramid" of vision from a rectilinear pyramid of rays into a nonlinear caustic surface. A caustic is an optical surface produced by the action of a spherical lens or mirror. (See Figure 7.) The model in the photo was built by the 19th-century Italian physicist Eugenio Beltrami.

the images carried by the optical pyramids in the air. To construct a *camera obscura*, find a small room with a single window that faces north and seal it from all light; for example, using a frame of wood covered with light plywood. Attach a thin brass plate over a hole in the plywood and drill a hole in the plate "the size of a millet seed." (One photographer suggests using a drill bit 1/64 inch in diameter.) Place over the hole a small box about 6 inches deep and open in front, and replace the back of this box with a piece of white tracing paper.

Assuming there is light outside, the pinhole will serve as a guide for those pyramids of light that happen to converge to a point at the pinhole (that is, their apices coincide with the pinhole). These pyramids pass through the pinhole into the box and then diverge, opening up until they encounter the tracing paper. There they stop and "paint their images" on the screen (Figure 3). A person inside the room would be able to see a live color "movie" of activity and objects outside, displayed on the transparent screen by means of these pyramids of light.

The *camera obscura* is based on producing a one-to-one, point-for-point mapping onto the viewing screen of the optical surfaces on a direct line with the pinhole. Because the pyramids that carry the images come to a point at the pinhole and then diverge to the screen, they paint the images upside-down and reversed in orientation.

The images displayed inside the *camera obscura* have the following properties:

The images are harmonic. Harmonic proportion is a characteristic of optics. The action of light in the atmosphere composes an image into optical pyramids in such a way that the part is lawfully related to the whole. Optical harmonics will compose an indefinitely long sequence of equally spaced objects, such as an image of equally spaced railway ties, so that the closest part is in proportion to the next closest, as the whole is in proportion to the remainder.

The images are all in focus, but at the same time are all slightly out of focus. All images are in focus to the same extent; there is no differentiation in focus between center and periphery or foreground and background. There is no focal plane in the picture displayed by the *camera obscura*. Also, the focus cannot be changed or directed in any manner.

The images are somewhat distorted. If the screen on which the images are displayed is flat, the images directly opposite the pinhole will convey the shapes of the objects they are imaging correctly, while the images peripheral to this area will be *distorted*; the farther they are from the pinhole, the more they will be distorted.[6]

These distortions can be minimized by changing the shape of the surface on which they are displayed. A viewing screen that has a spherical surface with its center of curvature at the pinhole will minimize distortions, limiting them to some curving of linear structures. Other concave surfaces—a parabolic surface, for example—are useful as well.

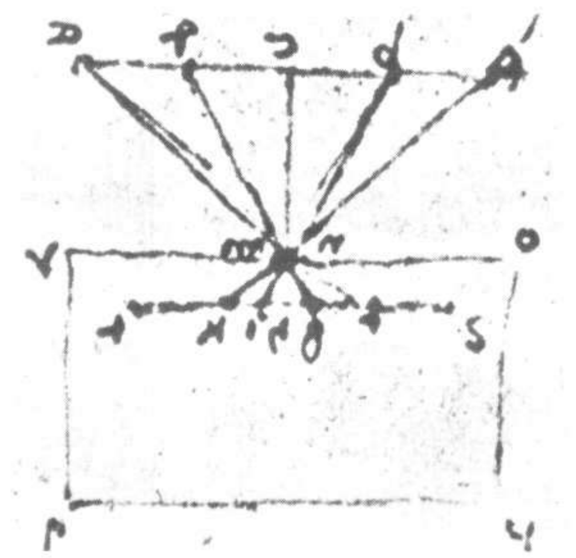


Figure 3
THE *CAMERA OBSCURA*

One of Leonardo's many drawings of his experiments with the camera obscura. The objects at top are illuminated and their images are reflected through a pinhole into the darkened chamber. Their images appear there upside down and transposed right to left.

Source: D.8a; Keele 56

The Human Eye

Unlike the *camera obscura*, the human eye displays a tremendous differentiation in visual acuity between the center and the periphery of vision. It produces and shapes a composite visual image by varying the distinctness with which objects appear in the field of vision. It sharply focuses the center of the visual field while deemphasizing the periphery. Leonardo stresses that this is the most important property of the human eye, and he places it first in his "Treatise on the Eye." As he writes, "Nature did not distribute power equally in the visual virtue, but gave this virtue increasingly greater power toward its center" [D. 1a; Strong 1].

Leonardo states that "the power of vision" is greatest at the center or *fovea* of the retina and progressively decreases away from the center, and he compares the shape of its variation to that of a "pyramid." The example in Figure 4(a) from Hochberg's book *Perception* shows this to be a caustic pyramid. The figure shows the rapid fall-off in the ability of a person to distinguish two objects as they are reflected onto the surface of the retina farther and farther away from the fovea. It shows just how differentiated human vision is—unlike the passive *camera obscura*. Rather than accepting the homogeneous visual field that is presented to it, the eye creates discontinuity by creating a focus for vision and organizing the entire visual field around that focus. Were the eye to passively rely on the optical properties of the atmosphere, we would not be able to "see" the way we are accustomed to.

The difference in visual acuity between the center of the retina and the periphery is very great. Leonardo also compares it to the sight of a gun, stating that surfaces directly opposite the center reflect light into the eye as "into the

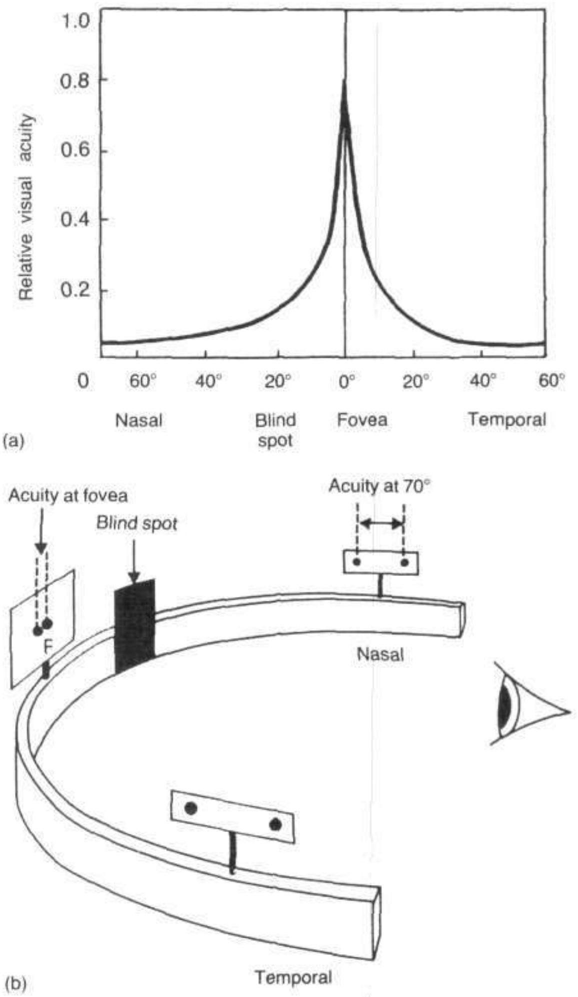


Figure 4
THE CAUSTIC PYRAMID OF VISUAL ACUITY

The variation in visual acuity over the surface of the retina has the shape of a nonlinear "pyramid" (a), as discussed by Leonardo in his "Treatise on the Eye." In the experiment shown in (b), the images of two dots are shone onto the surface of the retina from various positions along the curved bar while the subject maintains his focus on F. The spacing between the dots on the bar is increased from zero (where the subject may report that he sees only one dot) until the subject reports that he sees two.

The spacing between the dots required for the subject to distinguish between them increases the farther into the periphery the dots appear; their spacing becomes a measure of relative visual acuity. When the dots are shone on the fovea, no spacing between them is required for the subject to tell them apart. Position on the retina is given in angular degrees from the fovea. Visual acuity is expressed on the vertical axis as a fraction of the visual acuity at the fovea.

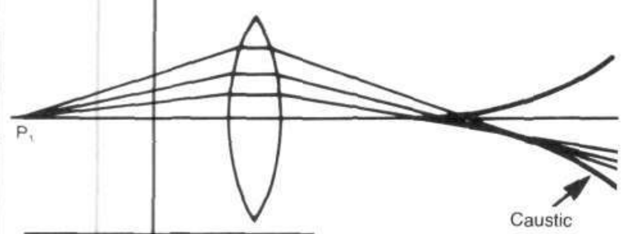
Source: Julian E. Hochberg, *Perception* (Englewood Cliffs, N.J.: 1964), p. 26

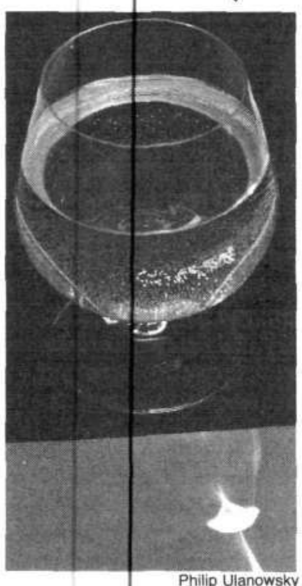
barrel of a carbine" [C.A. 220b; Keele 70].

Leonardo does not confine his investigations of the eye to an analysis of subjective acuity; he also investigates how the organ transforms the optical pyramid it finds at the pupil and presents it to the retina—the "visual virtu." He shows rather convincingly that no nicely focused images are formed on the surface of the retina; instead, the optics of the eye presents the retina with spatially differentiated light interference patterns formed from the light reflected from the surfaces of objects. These "are taken by the *imprensiva* and transmitted to the *senso commune* where they are judged"; that is, where the image we see is synthesized.

The light that conveys optical pyramids to the retina of the eye first passes through the lens of the eye. A normal "spherical" lens, like that of the eye, will form the light that passes through it from a "point source" not into a point, but into an interference pattern in the shape of a caustic pyramid or surface. This is a transformation of the surface of the spherical lens into a surface of negative curvature, as shown in Figure 5, from Max Born and Emil Wolf's *Principles of Optics*. Instead of focusing the light to concentrate its rays at a point, a spherical lens will direct it so that the light intersects itself at different points all along the caustic surface. There the light will interfere with itself, with the points of intersection/interference forming a caustic.

Leonardo shows this in the drawing in Figure 6, which illustrates how the lens of the eye forms the point light source *p*—a pinhole through which the image *mb* is constrained to pass—into an envelope of light. Figure 7 is





Philip Ulanowsky

Figure 5
A SPHERICAL LENS FORMS A POINT LIGHT SOURCE INTO A CAUSTIC SURFACE

The shape of the image of a point light source (P_1) formed by an "uncorrected" spherical lens is not a point, but a caustic surface. (The solid is shown in Figure 2.) As in the photograph, a caustic is produced when a beam of light is directed at a fluid in a glass.

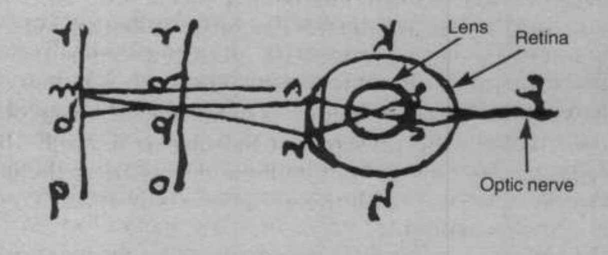


Figure 6
LEONARDO'S DRAWING OF THE ACTION OF THE LENS OF THE EYE

This drawing from Leonardo's "Treatise on the Eye" shows that the lens of the eye (the sphere in the center of the eye) forms the pyramid of light emanating from a point of light p *(shining through a hole in the screen* or*) and brought to a point again by the cornea, into another "pyramid" of light whose base is presented to the retina.*

Source: D. 2b; Strong 9

one of Leonardo's studies of how a spherical mirror forms a point source of light into a caustic surface.

All spherical lenses behave like the lens in Figure 5. They are the easiest lenses to make since they derive from the sphere, a least-action surface; a spherical lens is so composed that any section through its center produces a section of a sphere. Indeed, it is also suggested that the lens of the eye behaves like a spherical lens by the fact that when the lens is removed from the eye, it opens up into a sphere.[7]

A considerable amount of the labor of optical engineers over the centuries has been devoted to "correcting" spherical lenses for use in man-made optical instruments, so that they focus light from a "point source" to a point. This is accomplished by producing a lens with the optical characteristics of the central portion of the lens in Figure 5—the portion that produces the sharp point of the caustic. The process of producing a "corrected" lens can be seen as a geometrical transformation; the lens in Figure 5 is flattened so that it everywhere behaves only as its central portion. Figure 8 gives an example from Pirenne of a corrected lens focusing a point source of light to a point.

The fallacy of such endeavors is revealed by examining the fiction "point light source." In reality, no such thing exists in nature. Every light source takes up space and has geometrical shape. The light that any source reflects makes its shape knowable.

By forming the light from a source into a caustic surface, a spherical lens preserves the spatial variation in the light it reflects. Examine again Figure 5. The area around the point of the caustic is formed from light that passes through the center of the lens from that portion of the source directly opposite it. The surface that proceeds from the point, however, is composed of light that passes through the periphery of the lens from other regions of the source; the farther into the periphery of the lens, the farther along the surface is the light directed, coming from more distant regions of the surface of the source.

"Correcting" a lens destroys this spatial differentiation. Everything is jumbled together and the resulting image is flat and without true optical depth. The "correction" destroys the caustic, which carries the spatial differentiation of the light source.

This all suggests that the lens of the human eye—which is not flattened like a corrected lens and, more important, was made by God and not technicians—acts as a least-action-surface spherical lens and forms a point source of light into a caustic. Modern vision theorists like Pirenne, however, make the arbitrary assumption that the lens of the human eye behaves like a corrected lens, forming light from a "point source" into a point. With this, they maintain the erroneous view that the image we see is formed on the retina, that the eye is a passive instrument and functions like a *camera obscura*, and that the retina is like a movie screen.[8] But if the lens of the eye does not function like a corrected lens, then the eye does not form distinct images on the retina and a human judgmental faculty is required to synthesize the images we see.

Does the eye function "like a *camera obscura*," as Pirenne claims? Leonardo writes in his "Treatise on the Eye" that all the *camera obscura* shows us is how pyramids of light may enter the eye. It tells us nothing of how the eye transforms them.

Unlike the *camera obscura*, the eye does not produce a one-to-one, point-for-point mapping of the objects before it, onto the surface of the retina. The light emanating from a "point source" does not come to a point on the retina. Instead, the eye appears to spread over the surface of the retina an interference pattern of the light reflected from a "point source." Many points of the retina receive light from a single "point" on the surface of a luminous object. It is as though every point of the retina "sees" every point of an object or, as Leonardo writes: "Each point of the pupil sees the whole object and each point of the object is seen by the whole pupil" [D. 2b; Strong 15].

It is the transformation of each "point source" of light into a caustic surface that allows us to see as we do, for this preserves the wealth of sense data carried by the wave interaction of light. This wealth of optical information cannot be utilized by the *camera obscura* because, like any camera, it lacks a judgmental faculty and must present an image that is a mere point-for-point correspondence, a dead thing. The appropriate model for the way light from a "point source" is shaped by the eye is not that of modernist Pirenne in Figure 9, but may very well be that of Figure 6 from Leonardo's "Treatise on the Eye."

Physiological Vs. Engineering Optics

It is necessary to distinguish between physiological optics and engineering optics. The latter is concerned with the design of devices to produce sharp images for viewing by our eyes—for example, photography and television. These devices *do not reproduce the optical process of the eye*; if they did, they would be no use to us, since we already have eyes. What photography does provide is a means to reproduce for future reference and at lower fidelity the pyramids of light emanating from a scene at a specific time and place.

Physiological optics, on the other hand, is concerned with the study of how the eye transforms optical pyramids into an interference pattern and how the human judgmental faculty interprets this pattern. The difference between engineering optics and physiological optics is seen whenever we take a photograph of a beautiful sight. The photo never looks as good as the original scene did to the eye because the images produced by photography are formed without the intervention of the synthetic power of judgment.

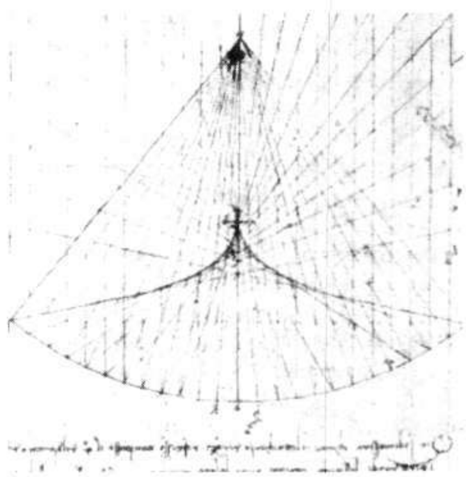


Figure 7
A DRAWING BY LEONARDO OF HOW A SPHERICAL MIRROR FORMS A CAUSTIC
Leonardo's drawing shows how a spherical mirror forms light from a "point source" (at top) into a caustic surface.

Source: Br. M. 87b; Nicodemi 423

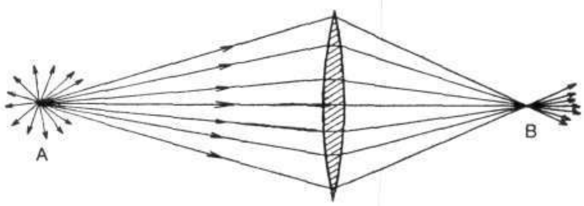


Figure 8
THE ACTION OF A 'CORRECTED' LENS
A spherical lens that has been "corrected" or flattened forms "a point source of light" into a point. This may be a useful lens for cameras or movie projectors, but if the lenses of our eyes were to behave like this, everything we see would be lacking in the quality Leonardo calls "roundness."

Source: Adapted from M.H. Pirenne, *Vision and the Eye* (London: Science Paperbacks, 1967), p. 7

The example of the modern hologram confirms much of Leonardo's optics. Holograms demonstrate that the optical pyramids, by which we see, are produced from surfaces rather than from the objects they surround. A hologram allows us to see a continuous "3-dimensional" image of a scene without the presence of the objects imaged. The image can be "seen" from multiple directions as though the bodies in it were truly there; their surfaces appear completely represented.

The hologram technique, a recording method invented in 1947 by Dennis Gabor, is based on reproducing the light pattern of the apical portions of the pyramids of rays emitted from a scene. The viewer of the hologram display synthesizes the remainder of the pyramids right down to their bases at the surfaces of the objects. He sees the surface without the objects being present—thus confirming that the judgmental faculty synthesizes the images we see.

In a hologram recording process, a light source irradiates the objects to be recorded and, independently, the film being exposed. The light reflected by the objects interferes at the surface of the film with the light that is irradiating the film directly. *This interference pattern is recorded on the* film. The developed film is then irradiated by the original light source, and the interaction of the light with the interference pattern recorded on the film re-creates the pyramids of light produced from the surfaces of the objects originally, to be seen by a viewer.

The hologram technique is consistent with the hypothesis that the optics of the eye forms the optical pyramids that enter the eye into interference patterns of light that are the raw sense data from which the human judgmental faculty synthesizes images. This hypothesis is also supported by the tremendous plasticity of human vision. An interference pattern carrying sense data of the wave interaction of light with surfaces provides a richer substrata for perception than a digital image. From the many optical pyramids that may enter the pupil, we synthesize a panoramic view of the world around us. The human mind resolves the ambiguities in the optical field in creating this "panorama" by which we

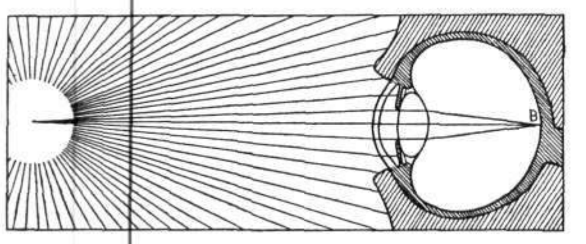


Figure 9
THE MODERNIST MODEL OF HOW THE EYE SHAPES LIGHT FROM A 'POINT SOURCE'
The modernist theory of vision holds that the optics of the atmosphere and of the eye forms light from a "point source" into a point on the surface of the retina. The modernists use this assumption to argue that images are formed on the retina as in a camera obscura.

Source: Adapted from M.H. Pirenne, *Vision and the Eye* (London: Science Paperbacks, 1967), p. 8

see in an outward, directional act, similar to aiming and firing a gun in an imperceptible instant. This is what occurs when we focus.

Our visual power extends from our eyes to the entirety of the world around us. The 19th century physicist Ernst H. Weber goes so far as to express the view that human vision is so finely developed that it is as if the entirety of the illuminated atmosphere were part of the visual apparatus. Unlike the considerably different sense of touch, in which something must touch or come within microns of the skin to be sensed, vision can sense anything in the luminous atmosphere. It is as if the entire atmosphere were part of our sense organ, Weber says.[9]

The skeptic may argue that we have not explained in detail how or where the visual image is formed, but only demonstrated the inadequacy of the modernist theory of vision. Therefore, the skeptic may say that the modernist model of vision stands unchallenged.

This reminds us of Gottfried Leibniz's marvelous reply to Samuel Clarke, when the latter protested that although Leibniz had raised valid criticisms of the Newtonian "system of the world," he had not developed an alternative explanation for why and how the planets remain in their orbits. Instead of replying at length by describing his and Kepler's vortical model of the solar system, Leibniz chose to make a methodological point about the practice of science and the study of that which we do not know. As far as he was concerned, he said, until some genuine understanding of the movements of the planets were acquired by man, he would have to describe them as "miraculous."[10]

The Negative Curvature of Human Vision

The curves in Figures 4 and 5 are caustics, cross sections of caustic surfaces that are generated by rotating a caustic about its central axis. In Figure 4, the caustic describes the shape of visual acuity over the surface of the retina. In Figure 5, the caustic is the shape of the interference pattern formed by a spherical lens. Caustic surfaces are surfaces of negative curvature; no matter how we view them they curve away from us in one direction but toward us in another.

The fact that vision, one of the most fundamental intellectual powers of man, is characterized by negative curvature says something not only about the nature of the human intellect but also about the nature of the universe. The negative curvature of vision creates discreteness and focus and organizes all else around it. It picks the forms of objects out of their optical context and highlights them so they appear separate and distinct; in this way, the mind creates discontinuity. However, the image of the object is not a discrete entity; it is the embodiment of incorporeal form that underlies all existence. For the soul, which partakes of incorporeal form as its natural language, the object as perceived is not an "it" or a "thing in itself"—it is nothing other than the embodiment of *plasticity*.

The soul creates discontinuities as the first necessary act preparatory to transforming nature from its present state to one that more closely conforms with the desire of the soul. In other words, the purpose of the negative curvature of vision is to help the soul take the present condition of the world to a higher order. In this way, the geometry of vision conforms to the principle of "negativity" that Nicholas of Cusa and others develop in Christian theology.

If man becomes obsessed with objects of sensual gratification, he reifies the *form* of bodies, freezing them in time and space; he degrades his original noetic fascination with form and refers all of its significance to mere corporeality. In this way he becomes encumbered with a perceptual instinct of "mass."

Readers may ask: If the human soul is required for human vision, what does this say about the vision of animals? Don't animals have souls?

No animal has been able to modify his relationship to nature and change his potential population density the way man has over millennia. This suggests a qualitative difference between the soul of man and the "soul" of animals. We conclude that there is likewise a qualitative difference between the vision of man and the mere sight of animals. Vision is such a fundamental action of the human intellect that it is unlikely that even the apes have anything comparable. This is borne out by Leonardo's further development of *prospettiva*.

Leonardo's *Prospettiva Naturale*

Leonardo develops his understanding of the special optical qualities of human vision at the same time that he elaborates an image of universal or absolute optics. While he places emphasis on the difference between central and peripheral vision in the human corporeal eye, he develops a notion of vision that transcends that distinction: "Every object sends its image to every spot whence the object itself can be seen; and the converse: The same object may receive in itself all the images of the objects that are in front of it" [C. A. 136a, 412a; Richter 65].

This statement describes the optical connectedness and action of the luminous atmosphere upon itself. It also describes the nature of our visual field. The eye "may receive in itself all the images of the objects that are in front of it." Through this concept of the mutual relatedness and dependency of the visual field, Leonardo begins to develop a concept of focused vision that is not limited to a particular direction or focal plane but can potentially encompass the entire visual field simultaneously and in full central clarity.

Leonardo develops the contrast between particular vision and such an "absolute" vision in the "Treatise on the Eye," where he hypothesizes how the image (*simulacrum*) of the Sun would be reflected in the biblical "sphere of water" that surrounds the heavens and the Sun. The sphere of water would behave as a huge mirror for all light emitted by the Sun; it would "see" and at the same time represent one single, huge, yet complete image of the Sun encompassing all possible vantage points. By contrast, the human eye sees no such universal image, but only an image of the Sun from a single vantage point. He writes:

> The simulacrum of the Sun appears as only one in the whole of the sphere of water, which sees and is seen by the Sun, but it appears divided into as many parts as there are eyes of animals which see [the Sun reflected in] the surface of the ocean from diverse places. This that is proposed, is proved because however

far the eyes of seafarers carried by ships may move through the universe, they behold simultaneously the simulacrum of the Sun through all the waters of their hemisphere in all the movements made in all the aspects. . . .

If the eye were as large as the sphere of water, such water, when seen by the Sun, would appear in its entirety as one single simulacrum of the Sun [D. 6a; Strong 49ff].

With these models Leonardo begins to free our concept of vision from our bodily sense organs. The effort to imagine his example of an "eye," which like the sphere of water could take in a complete spherical image of the Sun from all possible vantage points, suggests that vision is a faculty of the intellect independent in origin and operation from any bodily organs. *This is consistent with our discussion to this point.*

If the visual image is synthesized by the human faculty of judgment from indistinct sense data presented to the retina, then vision would seem to be a far more universal quality of the intellect than a mere sense that is limited by the capabilities of our bodily sense organs. If it is by the power of the intellectual soul that we organize our vision around a focus upon particular objects, then vision must be a general intellectual faculty and, like the soul itself, need not be tied down to individual objects or particular conditions of time and space, or even the physical presence of light. Vision is based on an *a priori* synthesizing capability of the human intellect that the blind have just as much as the seeing.

The human soul partakes of the metaphysics of form; it reflexively apprehends the world through a cognitive process that elaborates a synthetic geometry as its cognitive instrument. In its purest form, this power is totally spiritual. *Under particular conditions of time and space, it comprehends discreteness; it makes our ordinary vision possible.*

The task Leonardo undertakes is to concretize this universal concept of vision in a method of perspective in painting, to give the viewer by means of perspective some of the qualities of "an eye as big as the sphere of water"—able to look upon all things absolutely. Such an approach is entirely reasonable. Every theory of vision implies a theory of perspective. Just as the theory that the eye functions like a *camera obscura* underlies the theory of linear perspective, so a notion of universal sight dissociated from all eyes and bodily organs, necessarily produces its own *prospettiva*.

Leonardo begins by analyzing the *prospettiva* of the isolated human glance. He takes a case of vision that embraces a distant horizon as well as near objects as a paradigm for analyzing corporeal sight: "*Prospettiva*, in dealing with distances, makes use of two opposite pyramids, one of which has its apex in the eye and the base as distant as the horizon. The other has the base toward the eye and the apex on the horizon" [G. 53b; Richter 89]. [See Figure 10(a).]

The first pyramid, Leonardo explains, "includes the universe, embracing all the mass of objects that lie in front of the eye." This pyramid encompasses the panorama of our peripheral vision "and thus the pyramid is constructed with base on the horizon and the apex in the eye." The second pyramid represents our acutely focused vision, which converges to a small "spot" on the horizon. Figure 10(b) represents these "pyramids" as caustics.

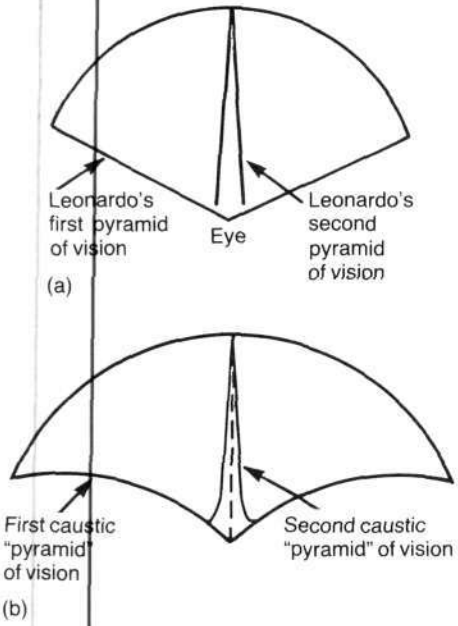


Figure 10
THE PYRAMIDS OF VISION
Leonardo writes that prospettiva makes use of "two opposite pyramids, one of which has its apex in the eye and the base at the distant horizon. The other has the base towards the eye and the apex on the horizon" [G.53b; Richter 89]. Both pyramids are shown in (a). The two pyramids of vision are shown in (b) as caustics.

Leonardo transforms the relationship of central to peripheral vision by introducing movement. He hypothesizes a *prospettiva* in which our eye and the apex of the second pyramid move along the horizon; that is, along the base of the first pyramid:

> If the eye remains stationary, the *prospettiva* terminates in the distance in a point. But if the eye moves in a straight line, the *prospettiva* terminates in a line, for it is proven that a line is generated by the motion of a point and our sight; therefore it follows that as we move our sight, the point moves, and as we move the point, the line is generated, etc. [E. 80b; Richter 223].

By *introducing movement into prospettiva* Leonardo immediately transcends the limited vision of the human glance. He transforms the geometry of vision from a focus around a spot into a focus simultaneous along the entire horizon. In the same way that the point of focus can move along the horizon, producing a *prospettiva* that terminates in a line, so it can move oblique or perpendicular to the horizon, with the result that the total *prospettiva* terminates in each point of a surface. This surface is nothing but the surface of discontinuity separating the objects, individuals, and landscape before us from the intervening luminous atmosphere. It is this surface that Leonardo and his student Raphael represent in their work.

Leonardo called his *prospettiva* "natural" and noted that this surface or nonlinear focal "plane" will cover the entire visual field and always intersect the pyramid from a particular object "at an equal distance from the eye," which "is our constant experience from the curved form of the pupil of the eye" [E. 16b; Richter 108].

With such a universal *prospettiva,* the painter paints as though his bodily eyes were able to look out in all directions so that he paints every thing as though he were looking directly at it. There is no single area of focus. Everything is painted in focus with complete depth and roundness. In such a perspective, the entire visual field is as elaborated and in focus as the center of vision normally is. This *prospettiva* has a powerful effect on the viewer because it confirms to him the intellectual priority of his soul over his mere senses.

As much as our own corporeal vision is superior to the images produced by a *camera obscura,* nonetheless, it is always limited to a single area of focus; and in the periphery of this area of focus, it is more and more out of focus the farther it is from the center. Outside of the focal area, our vision is not fully elaborated.

We have nonetheless an "intuition," a synthetic mental perception informed by our many individual views, of what our vision would look like if, instead of being limited to a single focus, it could look simultaneously at everything around us with "central" acuity. This is none other than the image of continuous vision of all around us, which our soul synthesizes in our daily visual experience.

A system of perspective based on this continuous vision synthesized by the soul would present to our bodily eyes, for the first time, a visual experience and a visual field of such a shape that we previously could enjoy only by means of the intellect. With this, Leonardo thus confirms our intuition, or "learned ignorance" (to use Augustine's expression), that the soul is prior to any particular experience in discrete time and space; he demonstrates that our "limited sight" is only possible by means of the soul.[11] In this way, Leonardo establishes Augustine's principle that the source for the harmonies experienced through art is the soul, which receives them from God.

Compare the perspective of Leonardo's *Virgin of the Grotto* or Raphael's *Alba Madonna* with Botticelli's *Adoration of the Magi,* and see the contrast between an image of continuous vision in which the perspective terminates in a surface, and the fixed, limited sight of a single view that terminates in a point, reducing the Madonna and child in Botticelli's painting to secondary figures in an aggregate of discrete entities.

Leonardo's *Prospettiva Divina*

In further elaboration of his *prospettiva*, Leonardo concerns himself with the fine detail of execution of painting from nature, simultaneously from the most advanced standpoint of metaphysics and pedagogy. He addresses this topic in many locations in his notebooks. For example, in a reply to those who place little value on painting, he says that the representation of naturalistic detail through painting "brings philosophy and subtle speculation to bear on the nature of all forms—sea and land, plants and animals, grasses and flowers—which are enveloped in light and shade" [Trat. 12; Paragone 13].

From this standpoint, he takes the unusual step of criticizing another painter *by name*, his contemporary Sandro Botticelli, who avoids representing naturalistic detail. Leonardo says that Botticelli's view that the in-depth study of landscape painting is "vain" renders him unable "to finish any detail. The painter of whom I have spoken makes very dull landscapes," he writes [Trat. 60; McMahon 93].

This concern with detail of execution in the representation of nature flows from Leonardo's fundamental view of the task and nature of painting:

> The painter's mind must of necessity enter into nature's mind in order to act as an interpreter between nature and art; it must be able to expound the causes of the manifestations of nature's laws. . . [Trat. 40; Paragone 41].
>
> The divinity that resides in the science of the painter causes the mind of the painter to transform itself into a similitude of the divine mind [Trat. 68; McMahon 280].

Leonardo seems to call upon the painter to represent eternal and divine cause through his art. Is this mysticism? Or can the painter apply the powers of science so that through the painting, the viewer can see every creature not simply for its visual appearance but for what it in reality is: to see in every creature that which created it. St. Augustine speaks of this sort of vision in *The City of God,* where he writes that the soul may "by means of bodily substances behold God, though a spirit, ruling all things."[12]

How is it possible to see "God" through an optical representation? Cusa gives the classical Augustinian answer to this question in his 1440 work, *De Docta Ignorantia* [Of learned ignorance] :[13] "God is the form of being . . . the form of forms. . . . What is attributable to God is the fact that a creature has unity, separate existence, and is in harmony with the universe." Cusa's view is that the Trinity impresses on all of created nature the qualities of unity, individuality, and the order or harmony of all parts. This is the quality of life that exists in all creation. In this way, the Trinity can be *seen*, on one level, in every creature. This notion of vision is integral to the culture that produces Leonardo.

That Leonardo indeed seeks to represent all of nature as shaped by the action of God is shown by his explanation of why he works, in a reply to some who criticize him for working on his science of *prospettiva* on holy days:

> Let the reprovers be silent, for this is the way of knowing the Performer of so many wonderful works, and this is the way of loving so great an Inventor, because in truth a great love springs from a deep knowledge of the Being that one loves, and if you do not know Him, you may love Him but little or not at all [Trat. 74; Nicodemi 33].

Commenting on this, Giorgio Nicodemi says:

> In this profound passage wherein the meager and false religiousity of his contemporaries is contrasted to his own absolute purity of faith, Leonardo not only shows his conviction that God is the source from which the order of all things emanates, but also affirms his certainty of a continual, intimate contact with God. This is the source of his naturalistic aesthetic [Nicodemi 33].

Are there other possible explanations for Leonardo's devotion to the representation of naturalistic detail? For example, is there anything that prevents us from concluding that Leonardo was simply a pantheist? First, Leonardo holds that the human soul is superior to the human body and all corporeal nature. Second, he holds that human action is ultimately nothing but the expression—in whatever mysterious way—of the soul's desire to unite with God, the giver of life: "This desire is the very quintessence, the spirit of the elements, which finding itself imprisoned with the soul, is ever longing to return from the human body to its Giver" [Br.M. 156b; Richter 1162].

Leonardo begins to show man the nature of his "Giver" by representing naturalistic detail to reflect how the action of the Trinity shapes all creation. Having stirred his viewer's soul with his "absolute" *prospettiva* and his naturalistic aesthetic, he wants to direct its intellect more directly toward "its Giver" to satisfy its "longing," for ultimately it is only through recognition of God that man experiences beauty. For Leonardo, this "Giver" is knowable to man only through Christ, who made human spiritual progress, and thus the Renaissance, possible.

Leonardo presents this vision in the most startling way in his unfinished masterpiece, *Adoration of the Magi*, which dramatically portrays the complete overthrow of pagan history by the nativity of Christ. The painting captures the historic turning point for mankind, caught in the pagan domination of the Roman Empire, but offered the possibility of salvation with the coming of Christ. The figures in the painting approach the Virgin and Child scratching their heads, uncertain of the ground beneath their feet, and in this way call attention to the singular nature of the birth of Christ. The ruins of the pagan era already appear in the background—which seems dominated by chaos within its extreme linear order—as the birth of Christ makes its overthrow inevitable.

Approaching the same theme in a different way in the *Virgin of the Grotto*, Leonardo portrays, through the richness of the naturalistic detail and the entire setting of the composition, the metaphysical principle that the coming of Christ is a necessary event in the history of the universe, one without which the world would not exist; that Christ exists from the beginning of all time to the end of all time.

In depicting the Christ child ordaining the infant John the Baptist, Leonardo calls us all to view the purpose of our lives and of everything about us, to be nothing other than that which helps bring creation to its complete fulfillment. Thus Leonardo's *prospettiva divina* enters also into the content of his painting.

His last painting, *St. John the Baptist*—considered by some a last, enigmatic self-portrait—encapsulates this outlook with a simple portrayal of the Baptist pointing to the cross of Christ. Nicodemi comments that Leonardo believes "that human knowledge and effort would be most perfectly fulfilled in art, which in turn was so bound to faith that it must be regarded as the highest possible means of serving God. . . . Thus it was possible for Leonardo to unite in art . . . a fervent religiousity and philosophical speculation" [Nicodemi 19, 22].

Leonardo's Aesthetics

Leonardo holds the view that the purpose of science is to develop ways to educate the layman of the eternal, metaphysical truths that underlie the nature of the universe. He reasons that since all human beings are by nature conversant with the "languages" of the senses, the highest form of science is the development of means of communication that use these languages (such as painting and music) for the purpose of educating man of the eternal. Since vision is "the highest sense" and painting satisfies vision, it is "more noble than music, which only satisfies the ear" [Trat. 31b; Paragone 34a].

Unlike poetry or music, the presentation of painting does not require the passage of time; it is not dependent on the concentration span of its audience; and it gives the ego no span in which to defend itself. In painting, "The features react together and simultaneously, in order to produce that divine harmony which often so captivates the spectator that he loses his liberty" [Trat. 32; Paragone 35]. Painting is therefore the greatest science.

Because Leonardo holds that the primary purpose of science is to "communicate" ideas through painting, he considers the purpose of detailed scientific investigations—such as his work on anatomy—as nothing other than to develop the tools and knowledge required by painting. Nicodemi writes:

> By his contemporaries . . . Leonardo was considered an investigator who became so engrossed in each artistic problem confronting him that he made it a field of scientific research. In order to represent the human body, he studied its anatomy. . . . In order to paint plants, he delved into the laws of botany and geology; and so he was in turn geologist, physiologist, mechanical or hydraulic engineer, and astronomer [19].

In Leonardo's view, because the painter seeks to affect the mind through the sight, he must learn and make use of all that can be viewed and studied by the eye; this includes the entirety of science:

> The eye embraces the beauty of the whole world. It is the lord of astronomy and the maker of cosmography; it counsels and corrects all the arts of mankind; it leads men to the different parts of the world; it is the prince of mathematics, and the sciences founded on it are absolutely certain. It has measured the distances and sizes of the stars; it has found the elements and their locations; it divines the future from the course

Leonardo's Adoration of the Magi, *Uffizi*

Detail from Verocchio's The Baptism of Christ, *Uffizi Gallery, Florence*

Botticelli's Adoration of the Magi, *Uffizi*

Raphael's Alba Madonna, *National Gallery, Washington, D.C.*

These four paintings, plus the Virgin of the Grotto *on the cover of this issue, demonstrate the principles of optics discussed in this article. Leonardo's first work, the angel at left in the detail of* Verocchio's The Baptism of Christ, *was painted when he was only 17, and already shows Leonardo's unique* prospettiva. *Compared to Leonardo's angel, which appears in full roundness and elaboration of form, the angel at right, by his teacher Verocchio, appears almost flat.*

The contrast between Leonardo's and Botticelli's paintings of the Adoration of the Magi *illustrates the fundamental differences of method between Leonardo and his contemporaries. Leonardo's composition demonstrates the principle of "absolute sight": The entire composition emanates spherically from the figures of Christ and the Virgin. That the* prospettiva *is not resolved on the panel highlights the singular importance of the nativity. Botticelli's work, on the other hand, consists only of an aggregate of distinct figures; the* prospettiva *in his composition terminates at a point within the confines of the panel, as an isolated glance terminates at its focus.*

Leonardo's Virgin of the Grotto *(see cover) demonstrates the full development of his* prospettiva, *which terminates in a surface. The same optical principles and method of composition were applied by Raphael in his later works such as the* Alba Madonna.

of the stars; it has given birth to architecture, and to perspective, and to the divine art of painting [Trat. 28; Paragone 31].

Since all science begins with vision, and since painting is the greatest science because it educates man through his vision, Leonardo concludes that all the other arts and sciences owe their development to that characteristic of nature that leads to the development of painting.

Leonardo on Linear Perspective

Leonardo considered the carrying out of detailed investigations in optics, vision, and other areas essential for serious work in painting. He severely criticizes artists who do not carry out the detailed investigations required to understand the nature of light and vision in order to produce good art. He criticizes those who paint by eye or who merely insert figures into a grid, whether by linear perspective or some other method (like those who today paint by numbers):

> Many who have not studied the theory of shade and light and of *prospettiva* turn to nature and copy her; they thus acquire a certain practice simply by copying, without studying or analyzing nature further. There are some who look at the objects of nature through glass or transparent paper or veils and make tracings. . . .
>
> These practices . . . are reprehensible in whoever cannot portray without them, nor use his own mind in analyses, because through such laziness he destroys his own intelligence, and he will never be able to produce anything good without such contrivance. Men like this will always be poor and weak in imaginative work or historical composition, which is the aim of this science. . . [Trat. 39; Paragone 40].

Leonardo shows that the theory of linear perspective assumes that human vision functions like a *camera obscura*. This is shown in the practice of Leon Battista Alberti to require the viewer of a linear perspective painting to look at it with one eye, through a small hole in the side of a box in which the painting is situated. Alberti's viewing box is simply a *camera obscura* in which the viewer looks through the pinhole to observe a painting that has replaced the viewing screen of the *camera obscura*. The display is arranged in such a way that the viewer can see the painting only if he directs his sight at the vanishing point of the linear perspective representation.

Leonardo sums up the deficiences of linear perspective, as follows:

(1) Linear perspective requires that the observer view the painting with one eye from a determined spot, looking only in the direction of the linear perspective "vanishing point." Binocular vision is excluded and the viewer cannot move his eye about the painting.

These facts are shown by the nature of a linear perspective geometrical construction. The linear perspective construction freezes the *prospettiva* around the fixed vanishing point, and movement of the eye to another position, even along the horizon line, creates another "vanishing point" for vision that is inconsistent with the original construction (Figure 11).

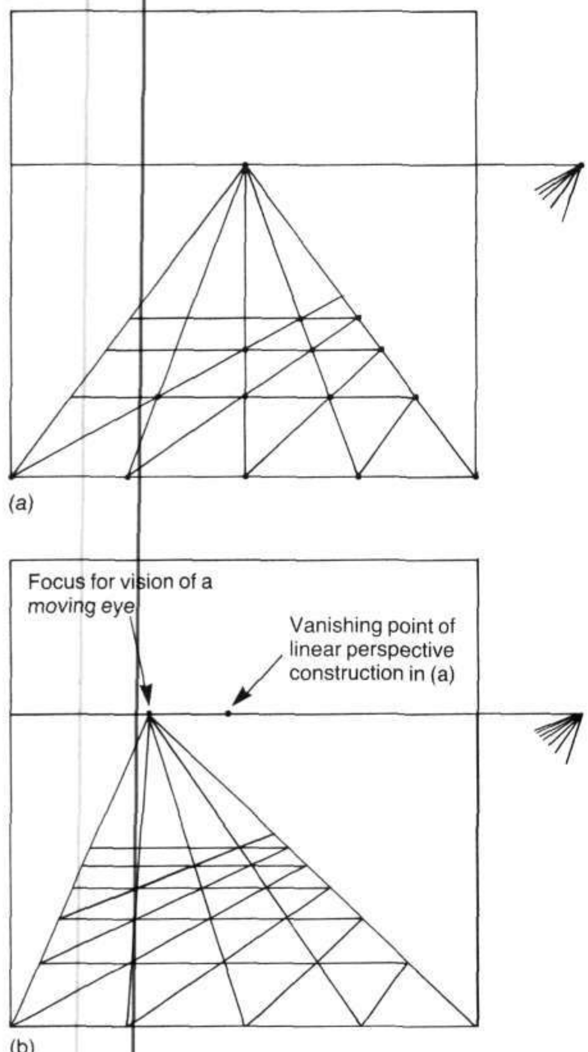
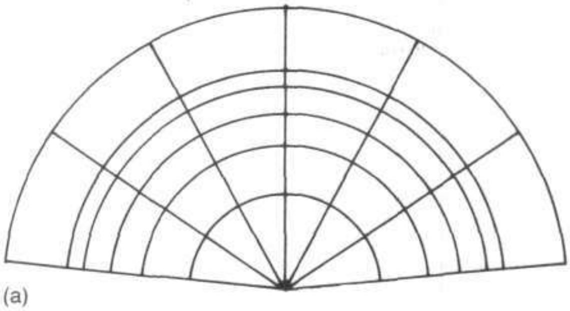


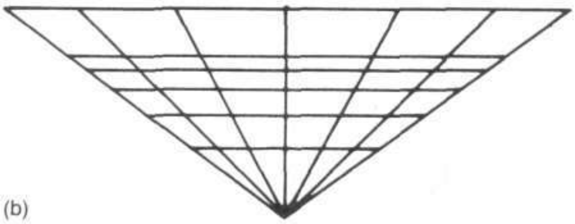
Figure 11
A LINEAR PERSPECTIVE CONSTRUCTION
The ground plan of a linear perspective construction freezes the perspective around a fixed direction for vision (a). If the viewer should move his eye, for example, to the left, his own vision assumes a perspective in that direction (b); however, linear perspective cannot subsume both directions simultaneously.

(2) Linear perspective assumes that all light entering the pupil of the eye intersects at one point, that the pupil does not accept a wider visual angle. This assumption is imposed on the pupil by requiring the observer to view the painting through a pinhole, truncating even that depth perception available to one eye. When viewed by the unhampered eye, the linear perspective representation is flat.

(3) Linear perspective produces the same distortions in the periphery that occur in a *camera obscura* with a flat viewing screen. (See, for example, the photo made with a



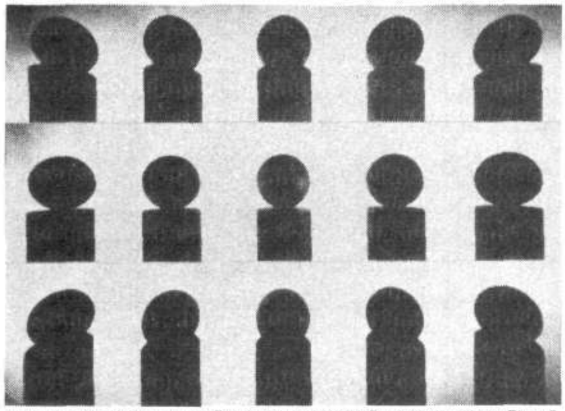
(a)



(b)

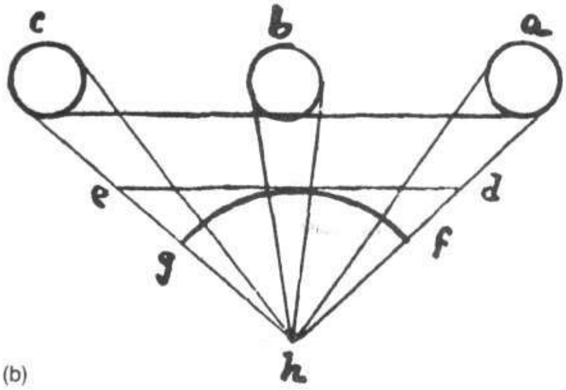
Figure 12
A PERSPECTIVE CONSTRUCTION THAT TERMINATES IN AN ARC OR A LINE

In (a), a hypothetical grid or ground plan of a system of perspective "terminates" in the arc of a circle; that is, the concentric arcs recede harmonically from the center toward the arc where the recession "terminates." A hypothetical ground plan for a system of perspective that terminates in a straight line is shown in (b). Leonardo, however, made no use of such grids.



M.H. Pirenne, *Vision and the Eye* (London: Science Paperbacks, 1967), Plate 5.

(a)



(b)

Figure 13
DISTORTION PRODUCED BY THE *CAMERA OBSCURA* AND IN LINEAR PERSPECTIVE

A photograph produced by a "pinhole camera," a camera obscura *whose viewing screen is replaced with photographic emulsion (a). The figures that are photographed are spheres on top of cylinders, but the pinhole camera distorts the ones that are farther from the pinhole into ellipsoids and ellipsoidal cylinders.*

Leonardo analyzed the circumstances of this distortion with a figure (b) that occurs frequently in his manuscripts. He shows that spheres like c, which is peripheral to the pinhole, are image distorted because the back of the pinhole camera or camera obscura, *represented by the plane ed, cuts the pyramids imaging the spheres obliquely, producing an ellipse instead of a circle.*

Source: E16a; Richter 108

camera obscura, Figure 13). The eye does not notice these distortions while it is viewing a linear perspective painting in a box, because it is constrained to direct its central vision at the vanishing point while its peripheral vision is too indistinct to notice the distortion.

For all these reasons, Leonardo labeled linear perspective *prospettiva accidentale*. Indeed, Filippo Brunelleschi and Leon Battista Alberti, the inventor and the popularizer of linear perspective, respectively, were acutely aware of its limitations: After producing a few paintings by that method, they concentrated their artistic energies on architecture.

Nonetheless, it is frequently asserted (for example, by Pirenne) that Leonardo used linear perspective in his paintings. Clearly, Leonardo's *prospettiva* is of a different order. Linear perspective recognizes only one of the two pyramids with which Leonardo analyzes vision; namely, the one with its base at the eye and its apex at the vanishing point—see Figures 10(a) and 11(a). In the linear perspective technique, the pyramid of vision with its base on the horizon does not play a role in the construction. If we were to construct a "ground plan" for a perspective that terminates in a line rather than in a point, it would look like Figure 12, not the linear perspective grid of Figure 11a.

Leonardo's method, however, is not formalized in any way; he makes use of no "grid" with which to slice up the space of a painting, as Alberti recommends, because the imposition of a grid hampers the eye's capacity for vision. There are no tricks or short cuts in Leonardo's method because it is concerned with nature, and nature cannot be forced into a formal schema.

Leonardo's method transcends all of his investigations. Although his technique is ultimately grounded in the results of his investigations, it is not dependent on them but rather is confirmed by them. Long before he conducted the many investigations into optics and vision that underlie his *most advanced reflection on aesthetics, he had already* formed in intuition the basis of his method.

This can be seen by looking at the similarity in method of composition between his first work, the angel he painted at the age of 17 for Verocchio's *The Baptism of Christ,* and his later work, such as the *Virgin of the Grotto.* How is it that the angels that Leonardo paints in both pictures are so different from those of other artists—and so similar to each other although they are produced so many years apart? What is the unique quality that unites his painting of the angel in *The Baptism* with his larger work?

Here formal, technical considerations necessarily merge with metaphysical and philosophical ones, so that the "how" of Leonardo's method is an expression of the "why" or purpose which he assigned to his art. This is Leonardo's *prospettiva divina.*

Robert Gallagher is an associate editor of 21st Century *magazine.*

Acknowledgements

This article is the result of an intensive collaboration with art historian D. Stephen Pepper. Discussions with Lyndon H. LaRouche, Jr., Dino de Paoli, Fred Tappert, and Jonathan Tennenbaum were also very helpful. It was de Paoli who suggested that negative curvature plays a role in Leonardo's *prospettiva.*

Notes and References

1. All excerpts from Leonardo's writings are referenced in two ways: (1) the manuscript collection where the original text can be found; (2) a reference to an English-language source. The translation sources are cited by paragraph or page number. The manuscripts are cited by the conventions followed in *The Notebooks of Leonardo da Vinci* edited by Jean Paul Richter. The specific translation sources used are:

   The Notebooks of Leonardo da Vinci, Jean Paul Richter, ed. (New York: Dover, 1970), cited as Richter and paragraph number.

   Leonardo da Vinci, *Paragone, A comparison of the arts,* trans. by Irma A. Richter (London: Oxford University Press, 1949), cited as Paragone and paragraph number.

   Kenneth D. Keele, *Leonardo da Vinci's Elements of the Science of Man* (New York: Academic Press, 1983), cited as Keele and page number.

   Giorgio Nicodemi et al., *Leonardo da Vinci,* (New York: Reynal & Co.), cited as Nicodemi and page number.

   Leonardo da Vinci, *Treatise on Painting,* trans. by Philip McMahon (Princeton, N.J.: Princeton Univ. Press, 1956), cited as McMahon and paragraph number.

   Donald S. Strong, *Leonardo on the Eye* (New York: Garland Publishing, Inc., 1979), cited as Strong and paragraph number.
2. We do not here refer principally to the theory of the Greeks that "in the act of seeing the eye *sends forth* toward the object a hail of small projectiles, the *species,* and when this jet of *species* arrives at the object, there is vision of the object. Leonardo overthrows this theory." (From "Leonardo's Optics" by Domenico Argentieri in Nicodemi et al.)

   Leonardo's point of view toward the fine senses, is best expressed in ancient times by St. Augustine in his *De musica.* Augustine holds that the soul is the seat of judgment, that it synthesizes images out of sense data presented to it by the world through the body. In developing his aesthetics, Augustine draws distinctions between the proportions or "numbers" sounded in music or represented in painting, those produced in the senses, and those that the soul receives from God by which it judges the others; he calls the first "sounding numbers," the second "corporeal numbers," and the third "judicial numbers." Augustine writes:

   > Why do we hesitate to prefer sounding and corporeal numbers? . . . Because the soul is made better through lack of those numbers it receives through the body, when it turns away from the carnal senses and is reformed by the divine numbers of wisdom. So it is truly said in the Holy Scriptures, "I have gone the rounds, to know and consider and seek wisdom and number (2 Eccle. 7.26)." And you are in no way to think this was said about those numbers shameful theaters resound with, but about those, I believe the soul does not receive from the body, but receiving from God on high, it rather impresses on the body.

3. St. Augustine, *On Music,* trans. Robert Catesby Taliaferro, Vol. 4, Fathers of the Church Series (Washington, D.C. Catholic University Press, 1947). Citations include the number of the book, chapter, and paragraph from this edition.
4. M. H. Pirenne, *Vision and the Eye,* 2nd ed., (London: Science Paperbacks, Chapman and Hall, 1967), p. 9.
5. In *De musica,* Augustine writes:

   > It must be carefully considered whether there is really anything called hearing, if something is produced in the soul by the body. It is very absurd to subordinate the soul like matter to the body as an artisan. For the soul is never inferior to the body, and all matter is inferior to the artisan. The soul, then, is in no way a matter subordinate to the body as an artisan. But it would be if the body worked numbers in it. Therefore, when we hear, numbers are not made in the soul by those we know in sounds [6,5,8].
   >
   > For each of these passes away with the time of its operation. But the judicial remain certain in the nature of man. [6,7,18].

6. Replacing the back wall of the box with a piece of photographic emulsion transforms the *camera obscura* viewing box into a pinhole camera that can record these distortions. See Figure 13.
7. Cited by Argentieri; see note 2.
8. Therefore, Pirenne says, "all the light originating in the point source and entering the eye is reunited in B, so that no other point of the retina receives light from this source." (See Figure 9.) This assumption is disproven by Leonardo.
9. Ernst H. Weber, *The Sense of Touch* (New York: Academic Press, 1978), p. 150.
10. "The Controversy Between Leibniz and Clarke" in Leroy E. Loemker, ed., *Gottfried Wilhelm von Leibniz: Philosophical Papers and Letters, Vol. II* (Chicago: University of Chicago Press, 1956), p. 1112.
11. There is a remarkable similarity between what Leonardo actually did and Cusa's prescriptions concerning vision and optics in his 1453 *De visione dei (On the Vision of God)* [(New York: Frederick Ungar, 1960). Keele is of the opinion that Cusa had a direct influence on Leonardo [Keele 103].

    In *De visione dei,* Cusanus contrasts "limited sight" with "absolute sight":

    > If I examine sight in the abstract, so that I have dissociated it in my mind from all eyes and bodily organs, and consider how abstract sight is in its limited state—that is, as is sight in seeing persons—how it is narrowed down to time and place, to particular objects, and to other life conditions, while sight in the abstract is, in the same way, without these conditions and absolute, then I well perceive that it is not of the essence of sight to behold one object more than another, although it inhers in sight in its limited state, to be unable to look on more than one thing at a time, or upon all things absolutely. . . .
    >
    > Sight that is freed from all limitation embraceth at one and the same time each and every mode of seeing, as being the most adequate measure of all sights, and their truest pattern. For without Absolute Sight there can be no limited sight; it embraces in itself all modes of seeing, all and each alike, and abides entirely freed from all variation. All limited modes of seeing, exist without limitation in Absolute Sight. . . .
    >
    > Absolute Sight exists in all sight, because through it, all limited sight exists, and without it, limited sight is utterly unable to exist.

    Cusa prompts our intuition of "absolute sight" in a meditation he presents on a painting. Using the image of the all-seeing eye of the painting, Cusa puts forth a perspective identical in form to Leonardo's:

    > This picture, brethren, you shall set up in some place, let us say, on a north wall, and shall stand round it, a little way off, and look upon it. And each of you shall find that, from whatsoever quarter he regards it, it looks on none other but you. And it shall seem to a brother standing to eastward as if that face looks toward the east, while one to southward shall think it looks toward the south, and one to westward, toward the west. First, then, you will marvel how it can be that the face should look on all and each at the same time. For the imagination of him standing to the eastward cannot conceive the gaze of the image to be turned unto any other quarter, such as west or south. Then let the brother who stood to eastward place himself to westward and he will find its gaze fastened on him in the west just as it was before in the east. And, as he knows the image to be fixed and unmoved, he will marvel at the motion of its immovable gaze.

12. St. Augustine, *The City of God* (New York: Modern Library, 1950), Book XXII, section 29.
13. Nicholas of Cusa, *Of Learned Ignorance* (New Haven: Yale University Press, 1954), book II, section 2.

Ominous Trends in U.S. Defense

Department of Defense

by Ryan Johnson

As the United States closes down its in-depth defense capabilities, the Soviets are in the middle of a war build-up plan that will give them military superiority in three to five years. New Soviet weapons based on new physical principles are ready for deployment.

The Soviet Union is now approaching the halfway mark in a military buildup designed to give the country military superiority in the next three to five years. The key pieces of evidence for this assessment are the undiminished production of war materiel, the accelerating potential for an Anti-Ballistic Missile system (ABM) breakout, and a new *offensive* doctrine for theater operations, incorporating greater deployment of spetsnaz and airborne units with new "emerging technology" weapons and a completely revamped military command.

The United States, rather than responding in kind to the Soviets, is doing just the opposite: Congress continues to curtail the development and testing of critically needed

While the United States has decimated the funding for the Strategic Defense Initiative, the Soviet Union is moving full speed ahead with its own SDI. Here, an artist's depiction of the operational Soviet antisatellite system, which maneuvers a conventional warhead within range and destroys the the satellite target in orbit with a multipellet blast.

weapon systems, and the President refuses to lead a charge to reverse the situation.

Senator John McCain, a member of the Armed Services Committee (R.-Ariz.), recently reported the results of a Defense Department study he requested that gives estimates of U.S. and Soviet military equipment production during each year of the Gorbachev era. The study shows that under General Secretary Gorbachev the Soviets have not slacked off on any major aspect of their military production. In *Defense News* July 24, 1989, McCain pointed out:

- The Soviets are producing tanks at a faster rate under Gorbachev than they were under Brezhnev. Soviet tank production has increased from 2,600 annually in 1983 to 3,500 in 1988. U.S. tank production dropped during the same period from 1,200 tanks to 775. The Soviet tanks have armor and guns distinctly superior to the U.S. M1 tank.
- The Soviets maintained a massive advantage in other armored vehicles, although production dropped slightly. In 1983 a total of 5,500 vehicles was produced compared to 5,250 in 1988. U.S. production was 1,000 vehicles in 1983 and 1,100 in 1988.
- In the important area of self-propelled artillery (rocket launchers, mortars, conventional missiles), Soviet production decreased from 1,600 weapons in 1983 to 1,550 in 1988. U.S. production went from 506 to 223.
- In the area of air weapons, the Soviets now deploy four fighter-bombers: the Su-24 Fencer, the Su-27 Flanker, the MiG-29 Fulcrum, and the MiG-31 Foxhound. The total payload delivery capability of this class of aircraft in missions within a combat radius of 500 km increased by 70 percent from 1980 to 1988. In missions up to 1,000 km the payload capability more than doubled in the same time-frame. In terms of production, the Soviets produced 950 fighters and fighter-bombers in 1983, and 700 in 1988. U.S. production rose from 400 aircraft to 550 in the same period.
- The trends in military helicopters are similar. The Soviets produced 600 in 1983 and 400 in 1988. U.S. production rose during the same period from 300 weapons to 375.
- Both U.S. fighter production and helicopter production will decrease radically in 1989 because of defense cutbacks. The Advanced Tactical Fighter is being stretched out, and the AH-64 helicopter and Army Helicopter Improvement Program are being canceled. This will leave the United States without any production of state-of-the-art fighters and helicopters well into the mid-1990s.
- The Soviets are widening their lead in fielded submarines; they produced 10 submarines in 1983 and 9 in 1988. U.S. submarine production averaged 5 per year during this time span. During the Gorbachev era, the Soviets have produced 34 submarines, the United States only 15.
- From 1983 to 1988, the Soviet production of surface warships decreased from 11 to 9. U.S. production fell from 11 ships to 3 during this period.
- The Soviets continue to outproduce the United States in other nuclear systems. Despite Gorbachev's image as an advocate of arms control, Soviet production of Inter-Continental Ballistic Missiles (ICBMs) rose from 75 weapons in 1986 to 150 in 1988. U.S. production of the MX ranged from 11 to 26 per annum during the same period. During Gorbachev's tenure, the Soviets have produced a total of 450 ICBMs, the United States only 56.
- The Soviets also produced greater numbers of nuclear bombers. They produced 35 aircraft in 1983 and increased this to 45 in 1988. U.S. production rose from 0 to 22, but U.S. production is now halted until the B-2 stealth bomber is ready for production.
- The advantage the United States once had in cruise missiles is fast disappearing. Soviet production of long-range sea-launched cruise missiles increased from 150 in 1983 to 300 in 1988. United States production rose from 40 to 280 in this same period. Soviet production of short-range sea-launched cruise missiles dropped slightly from 850 in 1983 to 800 in 1988, but improved in accuracy and performance. United States production dropped from 490 to 400 during this period. In conclusion, McCain said:

> . . . the Soviets have pursued a different course from the United States [during Gorbachev's tenure]. The United States is entering its fifth year of real cuts in defense spending. The disparity between Soviet and U.S. military equipment production in area after area is becoming so great that it raises serious questions about the long-term impact of the resulting gap on Western security.

ABM Breakout?

Bearing in mind the Soviets' greater total number of weapons and greater production rates relative to the United States, and therefore their greater surge potential (Figure 1), consider how the work they have been doing on their ABM system. The evidence supporting a Soviet ABM breakout sometime in the near future is compelling.

The Soviets maintain the world's only operational ABM system, the first phase of a Soviet SDI. A nearly completed construction program begun during the 1980s will yield an expanded and upgraded system comprising a two-layer defense of 100 launchers, the maximum permitted by the ABM treaty. The purpose of an ABM system is to intercept and neutralize ballistic missiles targeted for specific areas. The Soviet system is designed to defend Moscow from incoming nuclear warheads (also known as reentry vehicles).

Currently, the launchers launch missiles of two types: the GALOSH, a long-range missile designed to engage reentry vehicles outside the atmosphere, and the GAZELLE, a shorter range, high-acceleration missile designed to engage reentry vehicles after they have reentered the Earth's atmosphere. Both missiles destroy the reentry vehicles by exploding a nuclear device in their vicinity.

To provide targeting information to the GALOSH and GAZELLE, the Soviets began building a large phased-array radar network in the 1970s, and the number of radars has more than doubled since 1981. There are now nine radars in varying stages of completion, forming a nearly complete ring of detection and tracking coverage for the Soviet land mass. There is little doubt that the radars are intended to support an ABM system. The Krasnoyarsk radar, which clearly violates the ABM treaty, is located and pointed in such a way that it closes a major gap in the detection and tracking of reentry vehicles coming from the United States The entire network of ABM radars will be operational about 1994.

The ABM radar network can detect and track reentry vehicles over a vastly greater area than just Moscow, where the GALOSH and GAZELLE are based. In other words, most of the radars are not needed if only Moscow is to be protected from incoming reentry vehicles. This suggests only one thing—*that the ABM radars are located to support a future deployment of ABMs.* Recent Soviet activities have further violated the ABM treaty by moving components of an ABM site from a test range and initiating deployment outside an ABM deployment area permitted by the ABM treaty. These activities indicate new ABM sites can be established on the order of months.

If the Soviets decide to break out of the ABM treaty, how quickly can they produce and base additional GALOSHs and GAZELLEs? The Department of Defense estimates the Soviets produced 800 submarine-launched cruise missiles in 1988. Total annual strategic missile production has averaged 1,500 missiles per year for much of the 1980s. Since the GALOSH and GAZELLE are currently in production, a surge deployment of 2,000 to 3,000 of each type in a three-year span is not out of the question.

An ABM breakout in the near term would have devastating consequences for the balance of power. The United States currently can deliver to the Soviet Union 2,200 reentry vehicles via 1,000 ICBMs, and 5,400 reentry vehicles via 500 submarine-launched ballistic missiles (SLBMs). The United States can also deliver nuclear warheads via cruise missiles launched from the B-52, FB-111, and B-1B bombers and from ships and submarines. Ground-launched cruise missiles and intermediate-range ballistic missiles were banned by the Intermediate Nuclear Force (INF) treaty. The exact number of air- and sea-launched cruise missiles is strictly classified, but the total number of bombers is approximately 400 and the total number of major ships and submarines is approximately 200.

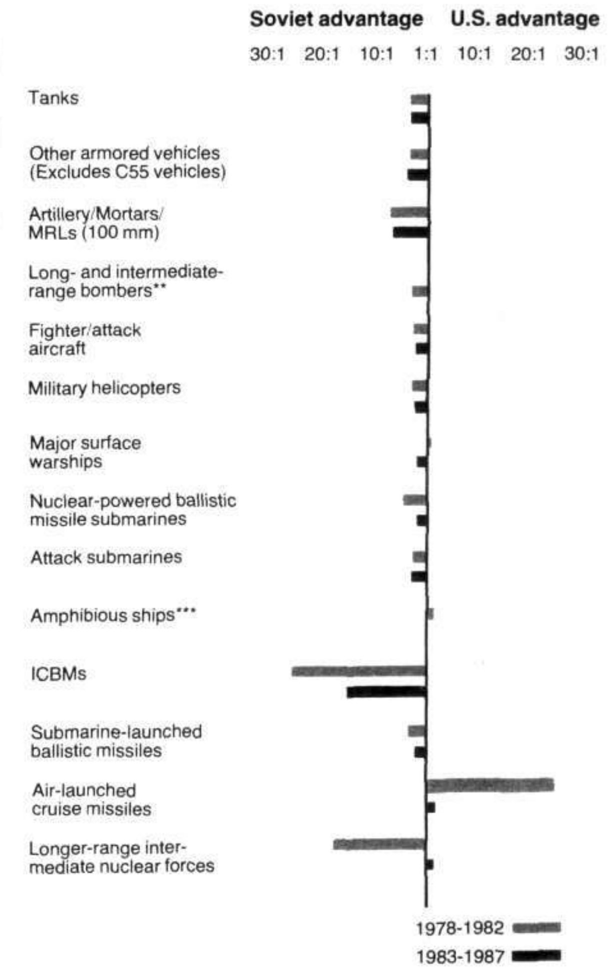


Figure 1
SOVIET/U.S. PRODUCTION OUTPUT RATIO (1978-1987)*

The Soviets still outproduce the West in most types of military equipment by a ratio of more than 2 to 1.

*Total military production, includes exports

**No U.S. production in 1978-1982

***No Soviet production in 1983-1987

Source: U.S. Department of Defense, *Soviet Military Power* (Washington, D.C., 1988), p. 37

Soviet Victory Scenario

Consider the following scenario: The Soviets break out of the ABM treaty and deploy 5,000 ABMs. A preemptive attack is launched against the United States. The first wave of Soviet reentry vehicles is targeted to U.S. command centers, ICBM silos, airfields, and surface ships. Except for some bombers, the majority of these targets is destroyed. (U.S. policy is *not* to launch on warning, but to absorb an attack before retaliating.) The surviving U.S. bombers head for the Soviet Union to deliver a retaliatory strike, but they are easily tracked and interdicted by Soviet attack aircraft and surface-to-air missiles. The problem-plagued radar countermeasures of the B-1B fail to fool Soviet radars.

Only the U.S. submarine fleet, consisting of 35 submarines, is left to retaliate. Of the 5,400 SLBM reentry vehicles, roughly are targeted to each of the 1,300 Soviet ICBM silos or expected mobile missile locations, for a total of 3,900; the remaining 1,500 go to Soviet cities. The Soviets use their 5,000 ABMs to defend the cities and a select number of their remaining ICBMs; the ABMs easily do the job.

Only the U.S. sea-launched cruise missiles remain and have a chance to inflict damage to Soviet cities. Admittedly, this is a tough threat for the Soviets to defend against, but given their civil defense capabilities, their extensive air- and space-based surveillance network, and their vast numbers of aircraft and air-to-air and surface-to-air missiles, the task is probably manageable. The defense need not be perfect, but merely limit the expected damage to acceptable levels.

Although the above scenario is extremely simplistic, it nonetheless shows how a capable ABM system in the hands of only one superpower can lead to a potentially war-winning capability and can turn the doctrine of mutually assured destruction on its ear. All the evidence suggests that the Soviets will soon be a position to do precisely this.

New Physical Principles

The impact of an ABM system on the balance of power is even more dramatic when coupled with an antisubmarine warfare (ASW) system capable of taking out cruise-missile-carrying submarines. The Soviets may have such a capability. There are multiple reports of Soviet breakthroughs in techniques for the detection and targeting of submarines. In January 1983, *Defense Electronics* reported: "the Soviets appear to have achieved a breakthrough by taking advantage of a natural phenomenon known as bioluminescence, an illuminating property exhibited by plankton (microscopic ocean life) when disrupted by ship movements that expose the sea life to rapid thermal changes."

The Salyut-7 orbital space laboratory was subsequently reported to be carrying sensors for this purpose. U.S. officials quoted in the *Defense Electronics* article said that they "do not completely understand" how this detection process works. In addition to this technique, the Soviets are also known to be investigating underwater detection systems using lasers of the blue-green range of the spectrum.

Lasers are but one type of system based on *new physical principles*. Other systems of this type are particle beams and radiofrequency or microwave systems (see box). The Soviets have been studying a vast array of technologies based on new physical principles for decades. As early as 1962, Marshal Sokolovsky, in the first edition of his book, *Military Strategy*, had this to say: "Possibilities are being studied for the use, against rockets, of a stream of high speed neutrons as small detonators for the nuclear charge of the rocket, and the use of electromagnetic energy to destroy the rocket in the descent phase of the trajectory or to deflect it from its target. Various radiation, antigravity, and antimatter systems, plasma (ball lightning) etc., are being studied as a means of destroying rockets."

More recently, on Nov. 30, 1987, in a dramatic departure from past assertions, Gorbachev confirmed that this research continues. "The Soviet Union is doing all that the United States is doing, and I guess we are engaging in research, basic research, which relates to these aspects which are covered by the SDI of the United States," Gorbachev said. As we know, most basic research under the U.S. SDI is concerned with systems based on new physical principles.

Without question, technologies based on new physical principles will have a greater revolutionary effect on the military balance, and thus on warfare, than did nuclear weapons in the late 1950s. At the turn of this century, they hold every promise of making nuclear-tipped missiles "impotent and obsolete." But what of the short term? In addition to providing new approaches to antisubmarine warfare, do they play a significant role in the Soviets' drive for military superiority by 1992-1995?

That question brings us to the revolution in military affairs that was occurring in the Soviet Union long before Gorbachev took power. The first indication of this military reorganization came in 1982, in a small book by Marshal Nikolai V. Ogarkov, then chief of the Soviet general staff, who wrote, "A profound revolution in the full meaning of the word is taking place in military affairs in our time. . . ." According to Ogarkov, the technological revolution in weapons based on new physical principles, as well as electronics and qualitative improvements in conventional weapons, have reached the point where they have begun to influence all "aspects of military affairs, particularly the development of military operations" and the "organizational structure of troops [forces]."

Two years after Ogarkov's book appeared, the Soviet high command was reorganized. The rank of marshal of tank troops was abolished, leaving only one chief marshal, that of artillery. Artillery was given precedence because it provides 80 percent of the firepower (although only 25 percent of combat manpower) in support of the theater strategic offensive, the operational concept of the revolution in military affairs. The theater strategic offensive concept, mentioned routinely in recent Soviet military writings, provides a framework for the integration of forces and strategy designed to wage a rapid nonnuclear—or if imposed by the enemy, nuclear—combined-arms campaign in a Soviet Theater of Military Operations, of which there are eight. The North Atlantic Treaty Organization (NATO) theater intersects five of the Soviets' Theaters of Military Operations.

The Soviets believe that in a future war, destruction of the enemy by integrated fire, deep in the enemy's own territory for the purpose of removing its nuclear option, will be the single most decisive factor in combat. Hence tank forces are deemphasized relative to airborne and air assault forces, spetsnaz (these are sabotage, agent provocateur, and terrorist personnel, many in place already in enemy territory) forces, and combined-arms forces. The airborne and spetsnaz forces, operating in the enemy rear and equipped with postnuclear emerging technology, radiofrequency, microwave, and other such weapons, are designed to secure victory at the outset of war. These elite units, equipped with the staggering firepower embodied in such weapons, have the mission to liquidate NATO's nuclear forces, air bases, vital command, logistics, and communications installations before Soviet ground forces advance.

The implementation of the theater strategic offensive could not have occurred at a more opportune time, given the crises enveloping the Soviet empire. If current trends continue, the Soviet Union will soon be in a position to seize portions of Western Europe, virtually intact, below the nuclear threshold, if that becomes imperative to solve the domestic shortages and bottlenecks of the Soviet economy. In the meantime, the KGB has never been as aggressive as under its current head, Kryuchkov.

In addition to radiofrequency weapons and others based on new physical principles, the Soviets are producing a plethora of less exotic, but nonetheless specialized weapons to support the theater strategic offensive. One such weapon is the new SS-21 short-range ballistic missile. This missile, which was not included in the INF Treaty, is extremely accurate and has a range of approximately 100 km. It is ideal for initiating hostilities with a preemptive strike as part of an air operation, which most analysts agree would begin any Soviet offensive in Europe.

Yet another system that meshes perfectly with the theater strategic offensive is the reactive armor on Soviet tanks produced after 1984. (Reactive armor consist of explosive charges placed on the outside of the tank that blow up shells or missiles that hit the tank surface.) Currently, almost every antitank guided missile in the NATO inventory is obsolete. As one military authority told the May 1987 *Armed Forces Journal International*, "reactive armor does not threaten a fundamental shift—it *is* a fundamental shift, and one which is extremely destabilizing in terms of the European military balance."

The West still has no counter to this threat. As of late 1987, the United States TOW IIA missile, specifically designed to defeat Soviet reactive armor, could not do so, according to *Jane's Defence Weekly* Aug. 1, 1987. The *Jane's* article said that missiles capable of countering reactive armor were years from becoming operational.

There are many other new systems the Soviets have developed for the theater strategic offensive—the BM-27 220-mm multiple rocket launcher, the T-64B and T-80 missile firing tanks, and significantly more effective cannon artillery systems. Obviously, the Soviets are working very hard to ensure that the theater strategic offensive is a success.

When viewed in the context of the theater strategic offensive, Gorbachev's announced reductions in troop strength and tanks are not at all surprising; they were to be expected. As military analyst Charles Q. Cutshaw, chief of the Foreign Systems Division, U.S. Army Foreign Science and Technology Center, wrote in the August 1989 issue of *Army*:

> The keynote of the current revolution, besides technology, is maneuver at the operational and tactical levels. The forces that provide the maneuver and force balance needed on the battlefield of the 1990s are smaller, highly mobile combined arms elements capable of functioning without benefit of the traditional second echelon.

Thus far, the tanks and other equipment withdrawn by the Soviets are not necessary for the prosecution of the theater strategic offensive; the T-64A and even most T-72 tanks are now superfluous. Older aircraft and towed artillery will also be withdrawn. The Soviets might even go so far as to withdraw a few T-64B or early T-80 tanks to prove their goodwill, but the mainstays of Soviet landpower, the T-64B and T-80 tanks, the 2S1, 2S3, 2S5, 2S7, and 2S9 artillery pieces and the new generation of attack aircraft and helicopters will almost surely remain.

Weapons Based on New Physical Principles

The capabilities of the next generation of weapons were described concisely by Lt. Gen. (ret.) G.C. Berkhof from the Netherlands at the Instead Conference in Amsterdam, Nov. 14-17, 1988. The conference brought together security experts from the countries of Western Europe and the Warsaw Pact to discuss disarmament questions. Here are excerpts from Berkhof's speech:

Weapons based on new principles in physics could have a revolutionary effect on warfare. . . . They include high-powered lasers, particle-beam weapons, and radiofrequency or microwave weapons. The latter consist of phased-array antennas or gyrotrons emitting nonlinear combinations of radio frequencies which, depending on the power output and the frequencies used, could disorient or kill people and damage or destroy electronics. Most high-energy lasers or HELs—the abbreviation used by American experts with their often macabre sense of humor—particle-beam weapons (PBWs), and radiofrequency weapons (RFWs) use large amounts of energy. They all project electromagnetic energy at or near the speed of light. But the beam ranges and the modes of interaction with both the target and the environment through which the beam is propagated differ considerably.

For instance, lasers might destroy a given target by depositing large amounts of energy on its surface. RFWs use complicated pulse shapes and pulse trains involving several electromagnetic frequencies and modulations with a wide spectrum ranging from extremely low frequencies to the hundred-gigahertz range. They can penetrate weapons systems and damage the electronics inside. On human beings, they induce an effect called "biological coupling," damaging or destroying the nerve synapses. In an antipersonnel mode, RFWs use relatively little energy as the power output needed for disorientation is low. Defenses against RFWs will be difficult, if not impossible, to devise.

PBWs, using electrons in the atmosphere or neutralized hydrogen atoms in space, possess an immense destructive force. On impact, the high-energy particles both irradiate the material and subject it to kinetic energy, causing rapid burn-through, damage to electronic components, and in some cases the ignition of fuels and explosives. Protective measures such as hardening, which is effective against lasers, are unlikely to be of assistance here. HELs are also more strongly affected by dust, smoke, rain, and atmospheric turbulence and require complex adaptive lenses which automatically compensate for the heat waves generated by the Earth's surface.

Although all beam weapons kill people, only RFWs and some lasers offer realistic prospects for use as antipersonnel weapons. One-shot, briefcase-size RFW devices can be used in operations of special forces, while larger de-

And what of the Soviet troop cuts? As it turns out, almost none of the 500,000 to be cut will be career officers, noncommissioned officers, and career enlisted men, and not one man from any of these groups now serving in "full readiness" units, will be touched. These details were revealed in a January interview with Radio Warsaw by Gen. Col. Nikolai Chervov, head of the Soviet General Staff's arms control directorate. The bulk of those to be cut, over two years, will be conscripts, who will depart when their two-year service ends. The conscripts who had served in "full readiness" units will enter, as they always have, the Ready Reserve. All that will change is that fewer men will be conscripted than previously, in accordance with the 12 percent reduction in armed forces personnel.

The advantages are obvious: 450,000 of the 500,000 troops to be cut will be troops based in the Soviet Union, and, broadly speaking, the reductions will eliminate the "lowest readiness" units. Getting rid of low-readiness units equipped mostly with outdated equipment eliminates the need to pour resources into equipping and maintaining them. Conversely, it permits the pouring of resources into upgrading the "middle readiness" units to "full readiness." In addition, the reduction of the annual draft call-ups by 25 percent will ensure a higher quality pool of conscripts.

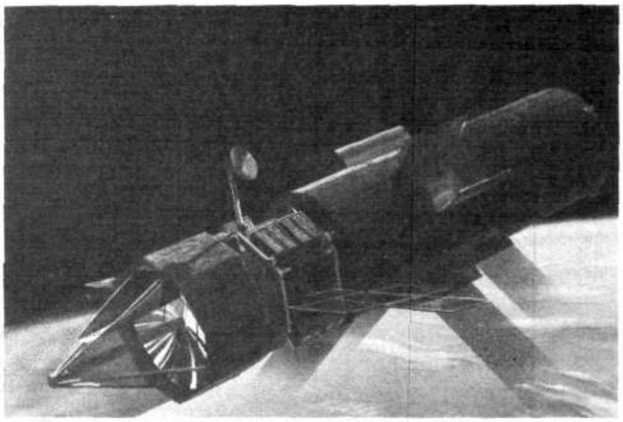
The new Soviet offensive doctrine is accurately summed up by Cutshaw: "Giving up weapons [and troops] which have a high 'fright factor' in the West, but have marginal utility for the Soviet military . . . builds political confidence for Gorbachev abroad, political clout for him at home and lulls the West into a false sense of security."

With its food supply collapsing, its entire economy in crisis, and the captive nations in revolt, the Soviet Union is preparing for war should its attempts—by combined intimidation and wooing—fail to secure whatever it needs by the "peaceful" submission of Western Europe, the Balkans, Turkey, or Iran.

U.S. Defense Five Years Hence

Given current Soviet military preparations, the response of the United States should be obvious: (1) move the B-2 stealth bomber into full production immediately and correct the B-1B electronic countermeasures at whatever cost and as soon as possible; (2) begin immediately deploying the railcar MX missile and the mobile Midgetman missile; and (3) accelerate the SDI to a crash program, both to deploy the first phase of a ballistic missile defense within the next five years and to rapidly develop and take advantage of new technologies based on "new physical principles." To do less than these three actions only invites the risk of war. The first two actions restore two of the three legs of the United States nuclear triad in the face of a Soviet preemptive attack. The third action attempts to keep the United States in the race with the Soviets to develop a ballistic missile defense.

Foolishly, the United States is pursuing none of the above three actions. Instead, the United States is in its fifth year



Department of Defense

Will the United States mobilize to develop weapons based on "new physical principles," as the Soviets are now doing? Not without a change in defense policy. Here, a Martin Marietta artist's depiction of a space-based medium-power chemical laser demonstration, Zenith Star.

vices with a range of several kilometers, carried by large trucks or transport aircraft, can be deployed against C^3I [Command, Control, Communications, and Intelligence] nodes, military and civilian electronic data banks, harbors, and other targets of opportunity. Both RFWs and lasers can function as air defense weapons by disorienting or blinding pilots. Indeed, Soviet low-energy-laser designators aboard ships illuminated American patrol aircraft, and temporarily blinded their pilots during missile tests on the Kwajalein missile range in the Pacific Marshall Islands. In addition to blinding, higher-energy lasers ignite plastics in the cockpit and render the canopy opaque. All types of beam weapons are suitable for a missile defense role.

RFWs and lasers are probably best for tactical operations. As early as 1978, tests with a static high-energy laser installation at California's San Juan Capistrano test range were highly successful. All 1.2-meter-long TOW antitank missiles flying at supersonic speeds were intercepted, even those flying at a high angular speed at a relatively close range. In some tests the missile exploded; in others the weapons were brought down as duds, demonstrating the tracker's uncanny accuracy. In the American Navy's Sea Lite laser test program, lasers were used to shoot down antiship missiles in a multimissile attack coming from different directions. The tests confirmed, however, that they are essentially "fair weather" weapons. The Army's Road Runner project with mobile laser pointing and tracking devices gave the same results.

Far less dependent on good weather conditions are the laser weapons used in the upper atmosphere. An Air Force project using a converted NKC-135 tanker aircraft as a laser test bed produced interesting results, though the first tests failed owing to excessive beam jitter. But after these failures, the airborne laser laboratory succeeded in May 1983 in deflecting five sidewinder missiles fired from Corsair attack aircraft at an 8-to-10 mile range.

of defense budget cuts, with greater cuts looming in the foreseeable future. The Bush administration is bringing disaster upon itself. By insisting, against all reality, that the Cold War has ended, that the Soviets truly want peace, that arms control is the wave of the future, the Bush administration has created an environment in which, as Wisconsin Democrat Rep. Les Aspin put it, "people see no downside risk anymore to voting against strategic programs. What would ordinarily prevent that would be a sense that there is a problem with the Soviets."

Syndicated columnists Evans and Novak, reporting on the 1990 budget fight in August 1989, noted that the White House had been sitting for six months on a Pentagon report that warned that the Soviet Union may achieve "a decisive military advantage" in the years ahead. Yet the White House released the report too late to affect the budget debates on Capitol Hill. Now rumors are flying in Washington that by 1994, the United States defense budget will be on 70 percent of its current level, dropping from approximately $300 billion to $200 billion.

In line with this, Massachusetts Democrat Rep. Nicholas Mavroules, chairman of the House Armed Services investigations subcommittee, commented in the June 19, 1989 *Defense News*: "I honestly believe that this year's $10 billion reduction [in the 1990 defense budget] could look like small potatoes next to the cuts that are likely to come out of the defense budget in the years to come." Mavroules's subcommittee is debating legislative proposals to help companies and workers hurt by defense budget cuts find alternative civilian work. Rep. Ted Weiss, a New York Democrat who is no friend of defense, argued before the subcommittee that "the potential hardship [from defense cuts] that will befall literally hundreds of thousands of workers in this country requires dramatic action," as reported in *Defense News*.

On average, the ratio of sales to employees for major defense contractors is about $100,000 per worker. Thus, the loss of "hundreds of thousands" of defense workers corresponds to tens of billions of dollars of defense cuts.

The mechanism for making these huge defense cuts is the Gramm-Rudman-Hollings Balanced Budget Act, which requires cuts of $36 billion annually from the U.S. budget until the deficit is reduced to zero, by 1993. Half of these cuts are to come out of defense.

In a June 30 analysis of the impact of the 1990-1991 defense budget on the Army, the Association of the U.S. Army claims that adherence to the 1986 Gramm-Rudman-Hollings law is forcing decision-makers to make budget cuts while ignoring their impact. As a result, the Army will suffer from an erosion of its ability to respond to a variety of conflicts. "The revised Army budget is not adequate to meet Army mission requirements," the report asserts. The Army had to make "very hard decisions . . . resulting in the reduction of force structure, support and the pace of modernization. The nation must provide the Army adequate resourcing and cannot afford to let it be eroded further."

Lack of adequate funding is, of course, only one of the major crises facing the armed forces in the years ahead. With national educational levels at all-time lows and drug and alcohol abuse at epidemic proportions among the recruitment pool, the ability of the armed forces to perform its missions—especially the development, testing and operation of new, highly sophisticated equipment—has been measurably degraded relative to previous years.

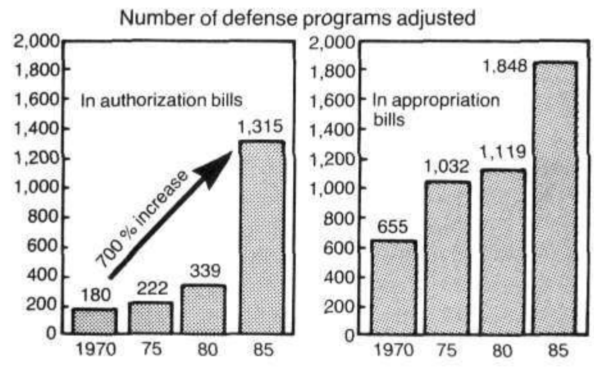


Figure 2
THE GROWTH OF CONGRESSIONAL INTERVENTION IN DEFENSE

Statistics compiled by the staff of the Senate Armed Services Committee in 1985 give a graphic idea of the growth of congressional intervention into the Department of Defense budget during the past 15 years. There is a sharp rise in the program funding changes ordered by Congress in the annual defense authorization and appropriation bills. This is a major cause of unstable funding levels for weapons programs, which prevent economical production rates and drive up procurement costs.

Source: *Aviation Week & Space Technology, July 4, 1988, p. 15*

Morale is understandably approaching an all-time low. To make matters worse, the procurement process is in a shambles. With the Department of Justice's Operation Ill Wind still in full swing prosecuting defense managers for a system run amok, and, with congressional intrusion into the management process at an all-time high (Figure 2), many defense contractors are having second thoughts about bidding for defense contracts, and some are getting out of the business altogether. Unisys Corporation, for example, is rumored to be contacting investment bankers about the sale of its defense business, which accounts for about a quarter of its annual revenues.

In addition, Eaton Corp., which makes the problem-plagued B1-B avionics system, has sold four of its five defense units since October 1987, and Honeywell Inc. recently announced that it may get out of the torpedo business.

The U.S. technology and industrial base continues to erode. John Swihart, president of the Washington-based National Center for Advanced Technologies, an arm of the Aerospace Industries Association, told a House Science, Space and Technology subcommittee on May 18, 1989, that the United States is "losing competitive momentum across a broad spectrum of industrial activities." There are fears, now that semiconductor technologies and electronics are led by the Japanese, that other defense-related segments of U.S. industry will be subject to foreign takeovers.

Department of Defense

The Soviet T-80 tank, with reactive armor mounted around the turret. So far, the United States has not successfully met the challenge in antiarmor technology.

A Losing Policy

To solve these problems, the Bush administration has embarked upon a policy of austerity combined with endless studies. Essentially this policy says that only a period of "doing without" can restore the United States economy, rejuvenate its tax base, and revitalize United States industry. While cutting the budget and waiting for this to happen, the problems will continue to be studied.

Such a policy did not work during the 1930s; it will not work today. The problem with the U.S. economy and its dwindling industrial and tax revenue base is that it has had to suffer 20 years of speculation and usury at the expense of capital-intensive and energy-intensive investments in scientific and technological progress.

Fundamentally, this is the explanation for the October 1987 financial crash that hit Wall Street, as well as the reason that another such crash is imminent. Few political figures have identified the problem, much less the solution, aside from economist Lyndon H. LaRouche, Jr.

Here we quote from 1988 Nobel Laureate in economics Maurice Allais. Allais, writing very much along the lines that LaRouche has argued, said in a front page June 27, 1989 article in the leading Paris daily *Le Monde:*

> It has been possible to avert a collapse up to this day, but it is becoming increasingly difficult to cope with disequilibria that no one is really able to control and command. In fact, the past shows no instance where so inconsiderate a development of credit and indebtedness, did not finally lead to major trouble. . . . My key conclusions are that, just as in 1987, in fundamental terms, the world economy is unstable; that its short-term evolution is essentially unpredictable; and that in order to do away with that potential instability, the international financial and monetary institutions ought to be thoroughly reformed. . . .
>
> The whole world economy rests upon gigantic debt pyramids that mutually sustain one another in a precarious balance. Never in past history had there been such an accumulation of promissory notes. Never had it been so difficult to honor such promises. . . . Whether it is currency or stock speculation, the world has become one vast casino where gambling tables are spread over all meridians and latitudes. . . .
>
> [There is a] disassociation between the parameters of the real economy and nominal values determined by speculation. The mechanism of credit as it presently operates . . . results in a massive amplification of disorders. All the major crises of the 19th and 20th centuries resulted from an excessive creation of credit, of promissory notes and their monetization, and the speculation they created and made possible. . . .

A Clear and Present Danger

We are faced with a clear and present danger; a superior (but unstable) military power and a global financial collapse loom before us. During the early 1940s, a policy of tax breaks and low-interest credit applied to the productive sectors of the U.S. economy—agriculture, manufacturing, infrastructure—and *not to speculation,* mobilized the American economy out of a depression and made it the most powerful economy on earth, allowing us to fight and win a terrible war. Those policies could have been adopted in the 1930s, prior to the war, but they were not. If they had, perhaps World War II would have been avoided.

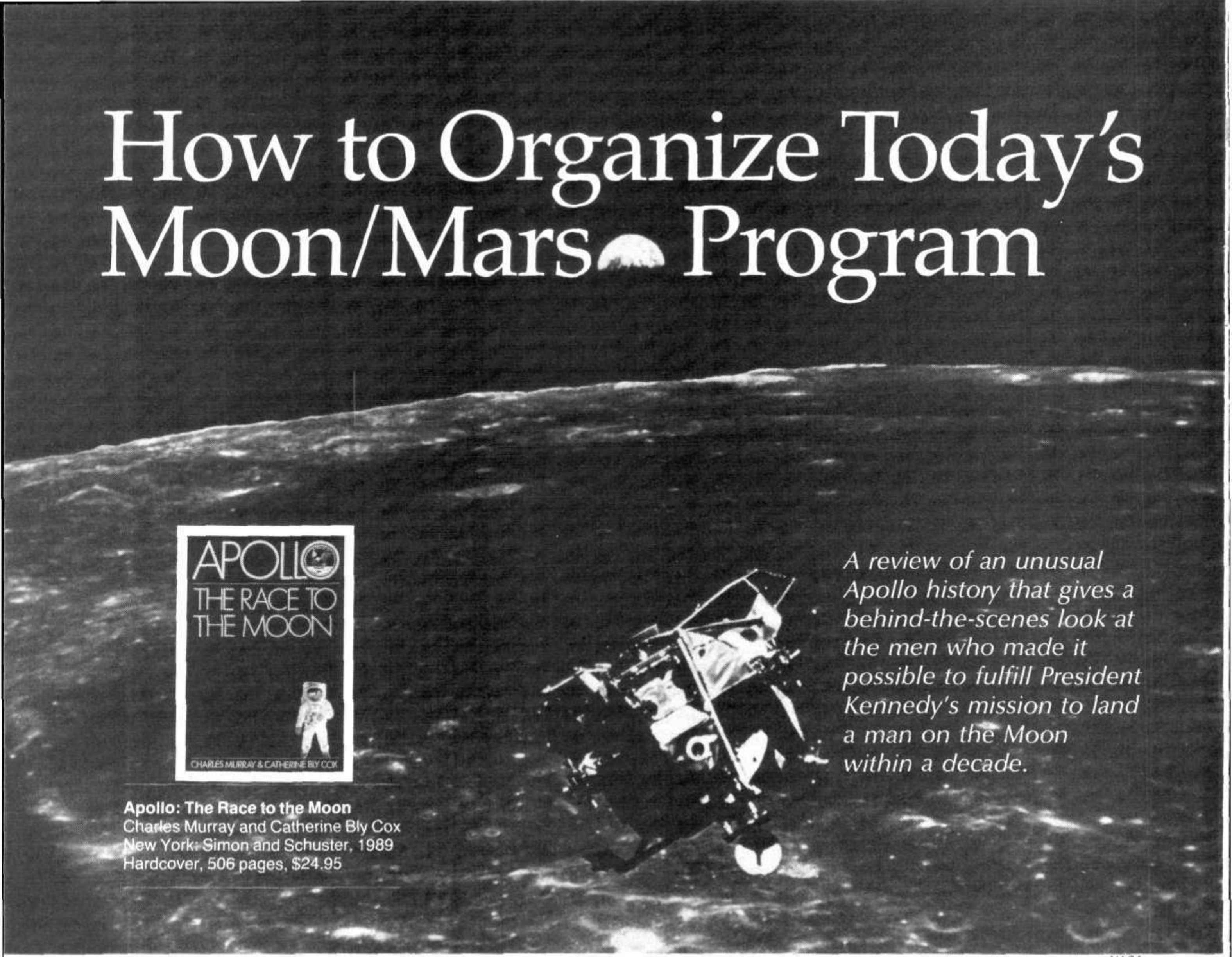
Such a policy option confronts us today in the form of the SDI. By transforming the SDI into a Manhattan Project and using it as a "science driver," the U.S. economy will begin to recover in depth and our military strength will be significantly enhanced. The type of technologies and scientific advances involved—high-energy lasers, laser welding, new materials, and new propulsion systems, to name a few—have the potential of improving average productivity in industrial production at least 10-fold. On the military side, a similar gain can be accrued in firepower and mobility. The economic process is similar to what occurred with the NASA Apollo program in the 1960s. Looking back and analyzing the moonshot's impact on the United States economy, Chase Econometric Associates in 1976 found that the Apollo program returned $14 of real, noninflationary wealth to the U.S. economy for every dollar spent on it.

Because the SDI program is much broader than the Apollo program was, and because it implies a much larger variety of different technologies, there is no question that the SDI will pay back to the United States economy 14 times what is spent on it, and most likely more. The more rapidly the SDI is advanced along a broad front, the more rapidly the U.S. economy will expand in depth.

We are on the verge of the greatest technological revolution known to mankind—and also one of the world's greatest crises. Let us throw off bad habits. By initiating scientific and technological crash programs in defense, with their implied spinoffs into the economy at large, we will solve not only our military problems, but a good portion of our economic problems as well. In fundamental terms, it cannot be otherwise.

Ryan Johnson is the pen name of a consultant for several major U.S. defense firms.

How to Organize Today's Moon/Mars Program



NASA

Apollo: The Race to the Moon
Charles Murray and Catherine Bly Cox
New York: Simon and Schuster, 1989
Hardcover, 506 pages, $24.95

A review of an unusual Apollo history that gives a behind-the-scenes look at the men who made it possible to fulfill President Kennedy's mission to land a man on the Moon within a decade.

by Marsha Freeman

On the 20th anniversary of man's first landing on the Moon, July 20, 1989, President George Bush announced that he would commit this nation to return men to the Moon, with manned missions to Mars to follow. On the same occasion, *Apollo: The Race to the Moon* was published recounting how such a visionary, long-range goal for the space program was achieved during the 1960s.

Unlike other efforts that have relied mainly on written materials, authors Charles Murray and Catherine Bly Cox prepared their history of this adventure by conducting more than 150 interviews over a three-year period. In this book, the people of the Apollo program tell the story.

Most people have little idea of how a program announced by President Kennedy on May 25, 1961, resulted in astronaut Neil Armstrong walking on the Moon less than nine years later. *Apollo* tells this story, recounting how this achievement required the triumph over stubborn and balky rocket engines, over the psychological shock and grief of the 1967 Apollo fire, over the naysayers and skeptics who did not think man should go to the Moon, and over a clock that was constantly running closer to Kennedy's deadline of a decade. Most of this story took place out of view of the cameras.

Today, even many scientists and engineers working in the National Aeronautics and Space Administration (NASA) cannot see how a Moon/Mars undertaking could be possible, after years of having to fight to maintain manned space flight with inadequate budgets, staff, facilities, and even spare parts. In private industry, which would have to build the hardware to take men to the Moon and Mars, those concerned might be less likely to voice their doubts publicly, but there is doubt about embarking on such aggressive, long-range goals.

As the Apollo 11 lunar module left lunar orbit in 1969, man's age-old dream of walking on another heavenly body was fulfilled. The full-time commitment and skills of hundreds of people were required to accomplish what most in 1961 doubted was possible.

How did we achieve the goals of the Apollo program? *Could we set the nation to the task of accelerating the* scientific and technological frontiers again? The book *Apollo* provides some of the answers.

Planning Before There's a Mission

Those who have spent years making plans for the kind of space program President Bush hinted we may have, but who have yet to see any fruit from their efforts, should take heart. The authors of *Apollo* provide a personal view of the intense planning for the manned mission to the Moon that began many years before the first human being had simply flown in space. As those principal players in the Apollo program tell the story, all those years were necessary—to do the thinking, technical research, and engineering studies and to build a constituency inside the space community itself even before there was a NASA—in order to allow a future president to make the decision to go to the Moon.

The German rocket team headed by Wernher von Braun had been working on rockets and dreaming of trips to the Moon for *40 years* before Neil Armstrong's first small step. Although this book does not cover this particular aspect of the Apollo story in detail, the first V-2 successfully tested at the German Army facility at Peenemünde in 1942 was decorated with a painting of a woman sitting on a crescent Moon, a reference to the 1929 film by Fritz Lang, "The Woman on the Moon," which had inspired the dreams of the young rocket pioneers.

The law creating NASA took effect Oct. 1, 1958. Just a month later, on Nov. 5, Robert Gilruth became the head of a Space Task Group at the Samuel P. Langley Memorial Aeronautical Laboratory in Hampton, Virginia—one of the facilities to be transferred to the new space agency. Its task was to study putting a man into space. The Langley group began its planning with 45 engineers, who were mostly in their 20s or early 30s. As the work of the group increased, so did its size. The fortuitous (for the United States) cancellation of an aerospace program in Canada added 30 more engineers.

By May 1959, after successful flights of the Soviet spacecraft Sputnik, everyone knew that sooner or later the Soviets would loft a man into space. NASA Administrator Keith Glennan established the Research Steering Committee on Manned Space Flight, which came up with a list of nine proposed steps in manned space. A lunar landing was only number seven on the list. However, two members of the group who would be key in shaping the future Apollo effort—spacecraft engineer/designer Maxime Faget and NASA's top man for manned space flight, George Low—were pushing for the lunar landing.

In November 1959, while engineers at Langley had already started a "Rendezvous Panel" to plan for space stations, President Eisenhower signed the executive order finally transferring von Braun's rocket team from the U.S. Army to NASA. As the authors of *Apollo* put it, "with the addition of the Germans, it became possible to go to the Moon."

In August 1960, still under an Eisenhower administration that would make no commitments beyond the brief Earth-orbital one-man Mercury flights, NASA announced that three contracts for $250,000 each would be awarded for design studies for the Apollo spacecraft. Said George Low: "...[W]e felt it would be most important to have something in the files, to be prepared to move out with a bigger program, should there be a sudden change of heart within the administration."

As what could certainly be seen as a vote of no confidence, the Eisenhower administration slashed NASA's budget request in fall 1960, canceling the development of the second stage of the Saturn rocket, without which man could not go to the Moon. But NASA persisted. In December 1960, when everyone was awaiting the new, young Kennedy presidency, the Space Task Group developed a Proposed Flight Schedule, which included circumlunar missions in 1967-1968 and manned lunar landings in 1969-1970. If the new president wanted to go to the Moon, NASA would be ready!

A lobbying campaign began within the agency to convince the top management that such a series of missions was possible, but a March 22 meeting of the top NASA leadership with the president—merely two months before the historical decision to go to the Moon—did not get the agency funds to go ahead with the design of the Apollo spacecraft. In close succession, however, the Bay of Pigs debacle and the flight of Soviet cosmonaut Yuri Gagarin would radically change Kennedy's ideas about space.

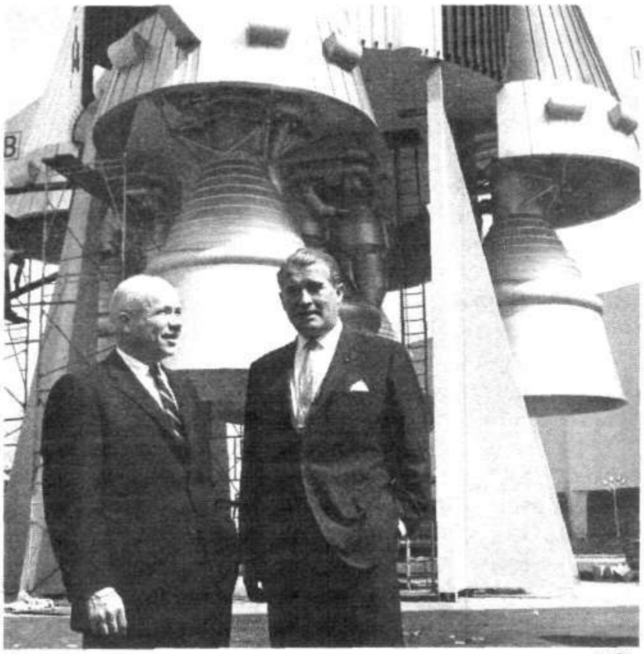
Under a forceful push from vice president (and space enthusiast) Lyndon Johnson, the new NASA head James Webb set up an Ad Hoc Task Group for a Manned Lunar Landing Study on May 2. Its job was to conduct a 30-day crash study to tell the president whether or not NASA could get the United States to the Moon and "how much money it would take."

The May 25, 1961 speech Kennedy made to a joint session of Congress was the public commitment by the man in the nation's highest office that this country would go to the Moon. All the years of dreaming and planning finally paid off. No one involved in the planning process prior to Apollo had any illusions about the need to have the president on board; it did not matter who else was behind the program if the president was not.

The planning that had been done until that time, although very preliminary, had created the possibility for Kennedy to announce that the United States would land a man on the Moon. Now all that NASA had to do was figure out how to get him there and back alive and to build the human and material infrastructure to accomplish the task virtually from scratch—all before Dec. 31, 1969.

The Men of Mission Control

Apollo recounts in wonderful detail how the heart of the manned space operations, Mission Control, was set up at the new Manned Spacecraft Center in Houston. The new facility, later to become the Johnson Space Center, would oversee the design, building, and man-rating of the spacecraft that would take men to the Moon as well as the training of the astronauts who would go. Most important, however, it would direct every step of each flight; it would run the mission. This meant that the lives of the astronauts were in the hands of that small group sitting in Mission Control.



NASA

When the head of the Marshall Space Flight Center, Wernher von Braun (right), posed for this picture at the 1964 World's Fair in New York, the Saturn V rocket had not yet been man-rated. But there was little doubt that the U.S. would go to the Moon, and the giant rocket was on display for the world to see. The man at left is unidentified.

Who were these men? Christopher Columbus Kraft had joined the Langley aeronautical group in 1945. According to *Apollo*: "[B]y 1958, Kraft was a quietly frustrated young man with an ulcer. Then that fall, [Chuck] Mathews recruited him into the Space Task Group as his assistant in the Operations Division. One day, as Mathews remembered it later, Kraft came to him and said, 'There needs to be someone in charge of the flights while they're actually going on, and I'd like to be that person.' "

Thus was born the concept of Mission Control, which to the American public became synonymous with the name Chris Kraft.

The people who tirelessly man the consoles and monitor every aspect of the performance of the craft, the crew, and the environment around both must be able to make split-second decisions that can mean the life or death of astronauts. As more than one interviewee remarks in the book, this is not a job for everyone.

What do you do when you have an instrument reading that tells you a critical failure has taken place? Is it a faulty instrument, or a real emergency? How many equipment failures can you tolerate on a mission before the risk is too high to keep the crew in space, knowing that the time of greatest risk is actually when they launch, and you will have to launch again if you abort this mission? Where do you find people who can calmly evaluate a massive amount of data and make decisions within seconds, while the lives of America's hero-astronauts hang in the balance?

To make these decisions, "Kraft looked for a particular kind of person. . . . Most of all, he looked for applicants who were fascinated by space flight and who couldn't believe their good fortune when they were given the opportunity to work 60-hour weeks at a Civil Service salary—as long as they were working for the space program." That is the key. An agency with a mission to go to the Moon did not have any difficulty finding young people who would consider no job too difficult or demanding if it were needed to complete the mission.

When Kraft was recruiting 20-year-olds to take charge of guidance, navigation, communications, life support, and all the other Mission Control responsibilities, he was making the mission rules at the same time. The rules are inviolable, as is the authority of the flight director and the mission control staff. There is no contradiction of the ground staff or breach of discipline tolerated in the behavior of the astronauts. "The ground had to be in charge," the authors explain. "Only one astronaut ever tried to question the ground's primacy, and not only did he never fly again, neither of his crewmates ever flew again either." If the ground had the primary responsibility for keeping the astronauts alive, it also had to have the authority to make decisions that were binding. The *Apollo* authors write:

> It is difficult to think of another role in the modern era that is the counterpart of flight director for an Apollo lunar mission. Many other jobs carry with them some measure of the same unrivaled power—the captain of a navy ship, for example. But even that comparison is inapt, for the captain of a modern naval vessel exercises his power under the orders of others who are in constant radio communication with him. The Apollo flight director experienced no such direction during the course of a flight. By explicit statement in the mission rules, the flight director's authority was sweeping.
>
> [In summary,] "the Flight Director may, after analysis of the flight, choose to take any necessary action required for the successful completion of the mission."
>
> Theoretically, either Flight's immediate boss, the director of Flight Operations, or the Mission Director could intervene. . . . But none of them, not even Chris Kraft, ever changed a flight director's decision, for all of them knew that they could not possibly read the technical situation during the course of a flight as well as he.
>
> Along with the power of command came breathtaking exposure in the event of error. . . . [T]he rewards for success and the penalties for failure were not symmetrical. With success, the flight director remained comparatively anonymous. On the other hand, if a crew were ever lost that could have been saved by the flight control team, a flight director had to be aware that he would be testifying before congressional committees and explaining his actions to boards of investigation, in addition to trying to live with himself. Formally or informally, he would be marked forever as the man who had failed to save the astronauts.

Kraft also set the tone for one of the most striking features of Flight Operations, unquestioning trust—not of superiors by subordinates, but the other way around. In the flight control business, where the consequences of mistakes could be irretrievable, this level of trust was sometimes an awesome thing to receive.

At times, the job took its toll. Not everyone in Mission Control could take the pressure and responsibility and those who could not, did not stay.

The Apollo program created a mission where people's lives could be lost in a matter of seconds a quarter of a million miles away from Earth. *Apollo* reports the observation by some that perhaps the flight controllers were so young that they did not realize the enormity of their responsibility. But if they did not understand this on the day they took their jobs, they did during the first mission they "flew."

When it was necessary for an experienced "old hand" in a senior-level position in NASA to step in to fix an important problem, management people "volunteered" for demotions without any question. In the epilogue, the *Apollo* authors rephrase a remark made by one such NASA manager when he came to Houston from industry: "[H]e'd never seen a place like it, where no one was jockeying for position, everyone was just trying to do his best. . . . [T]he people of Apollo seem to have retained those qualities since."

Could we find people now who would consider their salary, their house in the country, their career, and, if necessary, their time spent with family, secondary to contributing to the successful completion of a national goal?

The first requirement is leadership. Although Wernher von Braun and others are gone, many of the men of Apollo are fortunately still with us, in addition to the apt leadership in the space program today.

The second requirement is the mission itself. Today we may be closer than it appears to the threshold of an Apollo-style national commitment for manned space exploration. This depends largely upon the nearness of "Cuban-missile-style" crises the Bush administration may face. Much planning has been done and more detailed work is in progress. It may be that the core of a new crash space effort will be the "oldtimers" who created and lived through Apollo and the "kids" who saw their first manned space mission with the initial flights of the Space Shuttle.

The Guts to Take the Risk

If the fear of failure had been as prevalent during the Apollo program as it is today, we likely would still not have landed men on the Moon. As inherently risky as it was to send three men in a cramped spacecraft a quarter of a million miles from Earth, to be able to do it within the timetable set by President Kennedy required the guts to keep pushing the people and the hardware, even when no one was sure it would work. The first problem the Apollo team had was to figure out what risk could be considered acceptable. The *Apollo* authors write:

> In the months following Kennedy's speech, Bob Gilruth would occasionally remark to others in the Space Task Group that everything Kennedy had said in that speech was fine except for that one little word "safely," as in "and returning him safely to Earth."

NASA

Before a joint session of Congress on May 25, 1961, President Kennedy committed this nation to "achieving the goal before this decade is out, of landing a man on the Moon and returning him safely to Earth." It took two years for the Apollo program management simply to define what it meant to do the lunar mission "safely."

> Gilruth was confident that NASA could get a man to the Moon safely—eventually—or that they could get a man to the Moon within the decade if they were willing to take a pretty high chance of killing him. But as of 1961 they still didn't know how to do it both safely and within the decade.

This is no simple problem. First, what is an acceptable level of reliability for the Apollo spacecraft? While this question was being discussed one manager observed: "losing one crew out of a hundred was a reasonable goal but they couldn't afford to say so—it didn't put enough pressure on the contractors and the operators. The Range Safety people use one in a million . . . in deciding what chance they would accept of a rocket landing in a populated area. Why not use that?" In the end, "...they compromised. The probability of getting the crew back safely was set at three nines (.999), or 999 times in a thousand. The probability of completing the assigned mission was set at two nines, 99 times in a hundred."

One engineer later recalled, "We wrote those numbers down, and they had a most profound effect on the cost of the program. If you took one decimal point off that thing, in theory you could probably cut the program cost in half. If we'd added one more, there's no way in the world we could ever have done it—there's not enough money in the world to do it." In making that decision, all of the Task Force members accepted the fact that any one of the Apollo flights could be the one in a thousand where they would not be able to bring the crew back alive. The risk was not that far fetched, as Apollo 13 was almost that flight.

NASA

A jubilant Mission Operations Control Room on July 24, 1969, after the safe return to Earth of the Apollo 11 crew. Here are (from left): Associate Administrator for Manned Space Flight, Dr. George Mueller (with glasses, near flag); Apollo Program Director, Lt. Gen. Samuel Phillips (with glasses, looking down); Manned Spaceflight Center Director of Flight Operations, Dr. Christopher C. Kraft; Manager of the Apollo Spacecraft Program, George Low; and Director of the Manned Spaceflight Center, Dr. Robert Gilruth.

NASA

Mission Control—the most tense and exciting place in the space program. Flight Director Eugene Kranz watches astronaut Fred Haise, Jr. during the fourth television transmission from the ill-fated Apollo 13 mission, April 13, 1970.

The one incident during the Apollo program that gave people nightmares for years afterward was the 1967 fire that killed three astronauts. Immediately after the fire, however, a major concern of NASA managers was *to guard against overreaction*.

The top men entrusted with carrying out the Apollo mandate now had to make up for time that would inevitably be lost in the program as investigations and then redesigns of the spacecraft command module took place. Less than 24 hours after the fire, Apollo's top management was discussing how they could keep to the schedule.

It was certainly not easy for anyone to accept the fact that astronauts die in spacecraft as pilots do in experimental aircraft, and there was at least one management "casualty" after the fire. But on the whole, NASA picked up the pieces and made the changes while at the same time accelerating the schedule to meet the deadline.

Eighteen months after the Apollo fire, the Apollo leadership knew that "they needed to obtain deep-space experience in translunar navigation, lunar orbit, communications, and thermal conditions." George Low decided that the second manned Apollo flight, Apollo 8, should not only be the first manned flight of a Saturn V rocket and the first Saturn V to fly after a "failure-ridden" Apollo 6 unmanned test, but that it should also *go all the way to the Moon*. Additional preparatory Apollo test flights in Earth orbit were postponed. Americans were going to orbit the Moon during Christmas 1968.

This caused some shock and consternation among some people in NASA, as well as in industry. But if the mission were to be completed, risks would have to be taken.

Apollo 12, like all of the missions, had its share of mishaps but when it was struck by lightning 36 seconds after liftoff, the question of whether the crew should go to the Moon was on the table. After figuring out the problem and determining, as well as possible, that no critical system had apparently been permanently damaged, Mission Control made the nearly unbelievable decision that this spacecraft, which had temporarily lost all of its electrical systems, should go to the Moon.

Apollo summarizes remarks by an Apollo veteran, now a senior NASA manager, on how such a situation might be handled today:

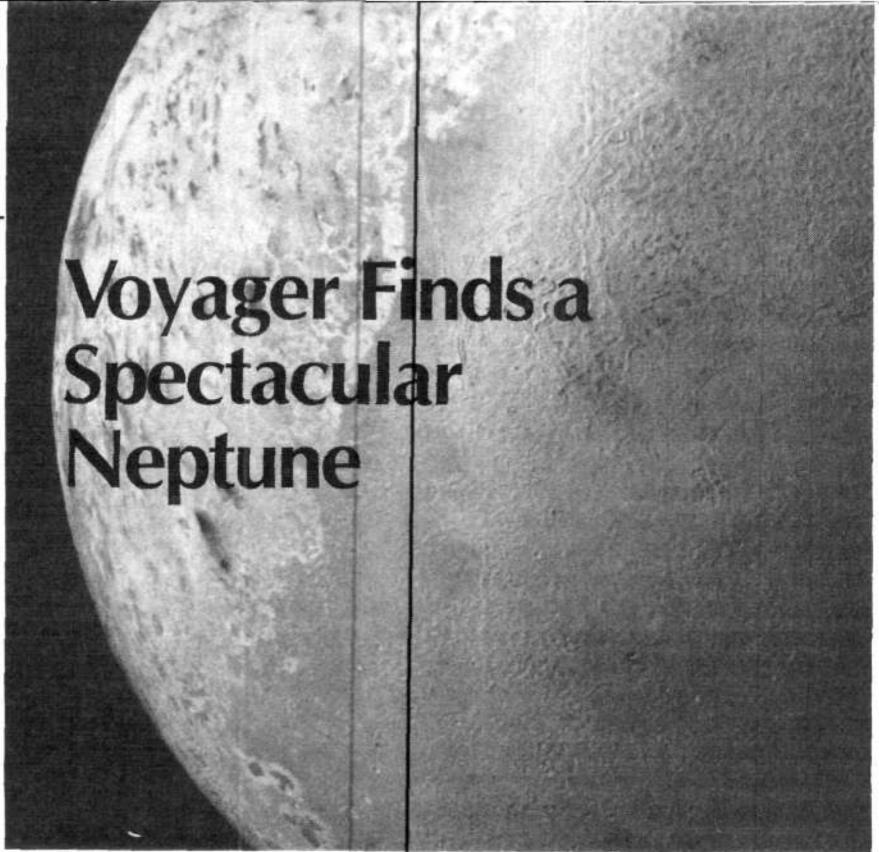
> . . .[S]uppose 20 years later, after the Challenger accident, that a comparable situation were to occur with the shuttle. Would NASA go ahead with the equivalent of a translunar injection? He laughed aloud at that one. Not a chance. But this is now, he said. That was then.

Apollo is an unusual history book. It makes you chuckle and brings tears to your eyes. It reminds you that this country, unlike many others, can mobilize the human and material resources to accomplish great projects, and that this nation was not always afraid to take risks. It presents a look at the past that is also a guide for the future.

Marsha Freeman is an associate editor of 21st Century.

Voyager Finds a Spectacular Neptune

by Marsha Freeman



Photos are courtesy of NASA

This photomosaic of Triton, assembled from 14 individual frames, was taken by Voyager 2 after its close flyby of Neptune. Visible in the mottled south polar cap are at least four distinct dark plumes, which scientists think may be nitrogen particles spewed out from cold volcanoes. North and west of the pole are long fractures that have apparently opened, allowing material to ooze up and form a central ridge. Also visible in the northeast region are flat areas flooded by fluid material that has smoothed them.

On its last stop in a 12-year journey, the remarkable Voyager 2 spacecraft made its close, 3,000-mile approach to Neptune on the night of Aug. 24. Five hours later it took close-up images of the Neptunian moon, Triton (some are shown here), and readings of the strange rings around the giant planet.

What Voyager found was similar to "Jupiter being orbited by Mars," in the words of geologist Larry Soderblom. Although Neptune receives only 5 percent as much energy from the Sun as Jupiter, it apparently has weather and storm systems just as active.

When Voyager was still millions of miles from Neptune, the images it returned to Earth showed the large dark spot, white cirrus-like clouds above it, and other atmospheric features that were constantly changing. Throughout the mission, members of the imaging team complained that cloud features changed so rapidly that they could not be used to track the rate of rotation or other features of the planet.

Radio emissions from Neptune, however, did indicate that the planet's rate of rotation (its day) is just over 16 hours, and not the nearly 17 hours scientists had formerly thought.

The radio emissions also indicated that Neptune has a magnetic field, which turned out to be very different from what anyone was expecting. Instead of being axisymmetric to its rotational poles, Neptune's magnetic field is inclined 50 degrees from its rotational axis.

This helped explain why, although scientists were searching for days, they did not find auroral activity. On Earth, these "northern lights" are seen near the poles, where a cusp in the Earth's magnetic field allows charged particles from the magnetosphere to precipitate through the atmosphere, causing a glow. But because Neptune's magnetic poles are at the planet's equator, that is where one would have to look for auroras. NASA will be continuing the search for evidence of both auroras and lightning.

Unique photographs of the shadow of the high-altitude white clouds on the lower, darker, methane dark spot cloud layer, allowed scientists to estimate that there is an approximately 30- to 60-mile difference in height between the two cloud systems.

Data from nonvisible-light measuring instruments on board Voyager revealed that the great dark spot is an anticyclonic storm, which means it rotates in a counterclockwise direction. It also rotates on its own axis every 10 days. The storm is likely a result of 700-mile-per-hour retrograde winds, which create a shear between various layers of the atmosphere. These are the strongest such winds in the solar system.

What enables such an active weather system on Neptune? Although the planet is radiating 2.8 times more energy than it receives from the Sun, this is such a small amount that it is still difficult to explain this Jupiter-like system. Perhaps the massive amount of data scientists are still analyzing will reveal more.

The 'Mars' Around Neptune

There is only one other moon in the solar system beside Saturn's moon Titan that has an atmosphere—Neptune's moon, Triton. However, when Voyager 2 went past Titan in 1981, the moon's haze prevented scientists from seeing its surface.

Earth-based observations of Triton had shown that there was methane there, but it was not possible to tell if it was in the atmosphere or on the surface. Voyager's instruments revealed that Triton's atmosphere is mainly nitrogen and that the methane is near the surface.

The most amazing revelations came when details of Triton's surface became visible. Like Mars, Triton has old cratered regions, but also areas where material that flowed on the surface filled in and smoothed over the craters.

There are 20 to 30 plumes of darker material in Triton's atmosphere in the south polar region, which could be

This detail of one of the darker plumes in Triton's south pole was taken Aug. 25, 1989, when Voyager was 118,000 miles from this moon. The dark streaks seem to be blown by winds in Triton's atmosphere. The white material may be frost on the surface.

material venting from volcanoes. On Triton, volcanoes could spew out liquid nitrogen that would change to ice crystals and vapor and then could form plumes. Because Triton is the coldest object yet seen in the solar system (30 degrees above absolute zero), the volcano would not be powered by heat.

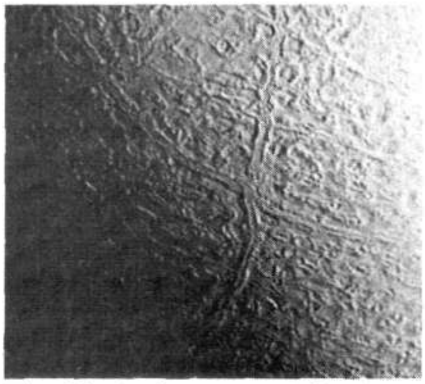
An Artesian volcano is one in which the eruption is created by a phase change in the subsurface material nonthermally. On Triton there may be higher pressure that liquefies the nitrogen beneath the surface. If a small opening in the surface exposes the liquid nitrogen to low pressure, it could explode and spew out like a volcano.

Only Jupiter's moon Io and Mars have any evidence of relatively (geologically) recent volcanic activity aside from Earth. Continued examination of the data from Triton may reveal whether or not these systems are still active.

Rings or Arcs?

Over the past 10 years, six solid observations (observed by more than two telescopes at the same time) have been made from Earth indicating that Neptune had partial rings, or ring arcs. This conclusion was reached when the rings were observed only on one side of the planet.

Voyager found, however, that there are three complete rings. The outer ring, which had been partially seen from Earth, is clumpy in parts, but very thin in others and hardly visible even up close. This unusual asymmetric structure in the outer ring reminded



The ridge in the center of this photograph, taken at a distance of 80,000 miles from Triton, is a close-up view of the feature in the upper right corner of the photo on p. 57. The long linear feature is about 20 miles across and appears to be a narrow down-dropped fault. The surrounding terrain is a relatively young icy surface with few impact craters.

The dramatic variety of geological features on Triton is clear from this close-up taken Aug. 25. Features between 18 to 30 miles across dominate the surface above the polar frost line, some resembling impact craters on Mars. There are also peculiar intersecting, doubled ridge lines 9 to 12 miles wide and hundreds of miles long.

scientists of the braided outer F ring of Saturn, which they are still trying to understand.

In addition, there is a sheet or plateau of ring-like material in between the rings, which might be more rings in formation or the remnants of rings that have dispersed.

Although there will be no missions to return to Neptune in the near future, scientists will be busy for the next few years trying to understand the wealth of information Voyager 2 has sent them.

BOOKS

A Complete Guide to CO_2

Carbon Dioxide and Global Change: *Earth in Transition*
Sherwood B. Idso
IBR Press (631 E. Laguna Dr., Tempe, Arizona 85282), 1989
Paperback, 292 pages, $19.95

Surrounded by the gloom and doom forecasts that prevail in the daily news—the Earth is warming, the ice caps are melting, the sea levels are rising, the sky has holes, and what not—it is extremely refreshing to read this new book by climate scientist Sherwood B. Idso. Idso is a research physicist with the U.S. Department of Agriculture's Agricultural Research Service and Adjunct Professor of Botany and Geography at Arizona State University.

In just 135 text pages, Idso demolishes the leading theorists of the "greenhouse effect" scenario. At the same time, he shows very systematically that an increase in the levels of carbon dioxide may be *beneficial* to humanity. Increased carbon dioxide levels could provide the basic "foodstock" used by plants to grow, thus lowering the amount of water required by plants.

The book examines every claim being made by the greenhouse propagandists, presents the evidence used by these propagandists, examines the validity of this material, and then cites the work of other scientists who have questioned this evidence and proposed alternative, usually more compelling, hypotheses.

What makes *Carbon Dioxide and Global Change* extraordinary is its thorough documentation—more than 2,000 literature citations and an extensive subject index. The references are current to mid-1989.

Anyone interested in the environment and climate change should definitely obtain this book.

—Rogelio A. Maduro

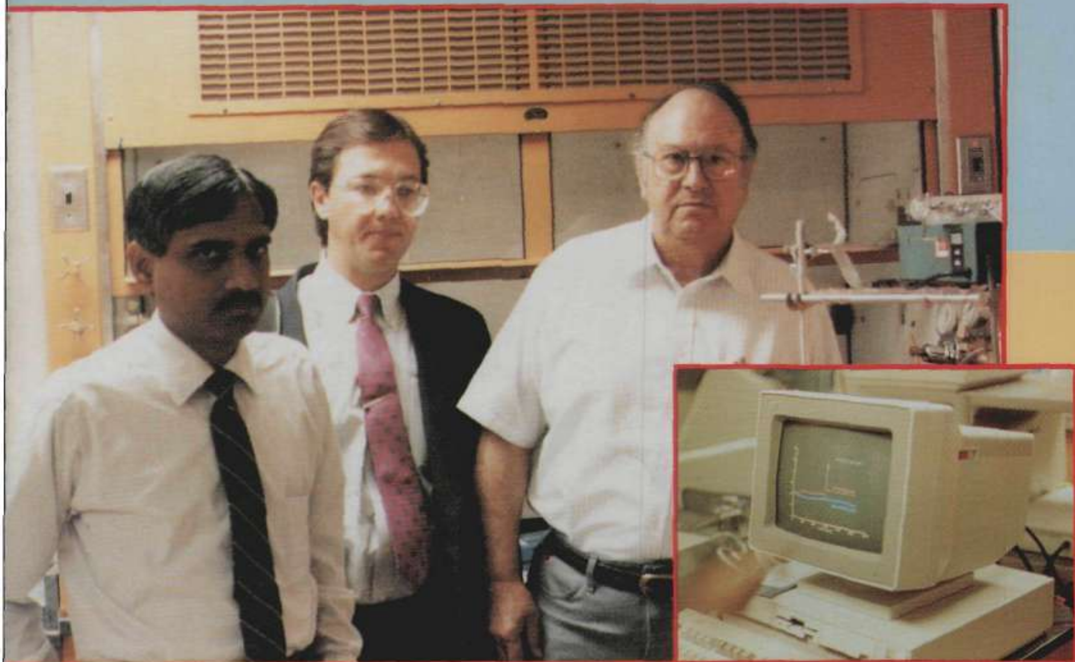
In This Issue:

NASA

Neptune as seen by Voyager 2 at a range of 14.8 million kilometers Aug. 14, 1989. Bright, wispy clouds are seen overlying the Great Dark Spot at its lower margin and over its upper left boundary.

NEPTUNE: LAST STOP ON VOYAGER'S GRAND TOUR OF THE SOLAR SYSTEM

Voyager's fabulous views of Neptune tell us much about the planet—and open up a new realm of planetary puzzles. We now know that Neptune has storms, quickly changing clouds, at least three rings, and a moon, Triton, which has nitrogen volcanoes, clouds, and dried-up river beds that are reminiscent of Mars. Neptune's magnetic fields are a real mystery; its magnetic poles are inclined 50 degrees from the axis of rotation, with the south pole stronger than the north, and the magnetic field nowhere going through the center of the planet. Marsha Freeman reviews the exciting scientific work in progress.



University of Utah scientists Sivaraman Guruswamy (left) and Milton E. Wadsworth (right) in the university's materials lab, where their cold fusion cells produce neutron bursts of 1 million joules. The orange spike on the computer screen (inset) depicts one such burst. At center in photo is Paul Prows of the Fusion Information Center.

COLD FUSION: SOMETHING'S PRODUCING NEUTRONS, HEAT, AND TRITIUM AT ROOM TEMPERATURE

***21st Century*'s Ramtanu Maitra reports on his visits to the Utah laboratories where cold fusion was discovered and to other laboratories that have replicated the initial experiments. He tells what these scientists are doing and why they think they have succeeded while others have failed. Variations of this seemingly simple electrolytic cell are producing neutrons, heat, and tritium far above background level, although not all at the same time. (One researcher, in fact, has powered a light bulb with cold fusion in a closed system.) A burning question remains: What process is causing these startling results?**

Ramtanu Maitra

Kevin L. Wolf at Texas A&M University in College Station has consistently produced tritium—2×10^6 ppm—in this cold fusion apparatus (inset).