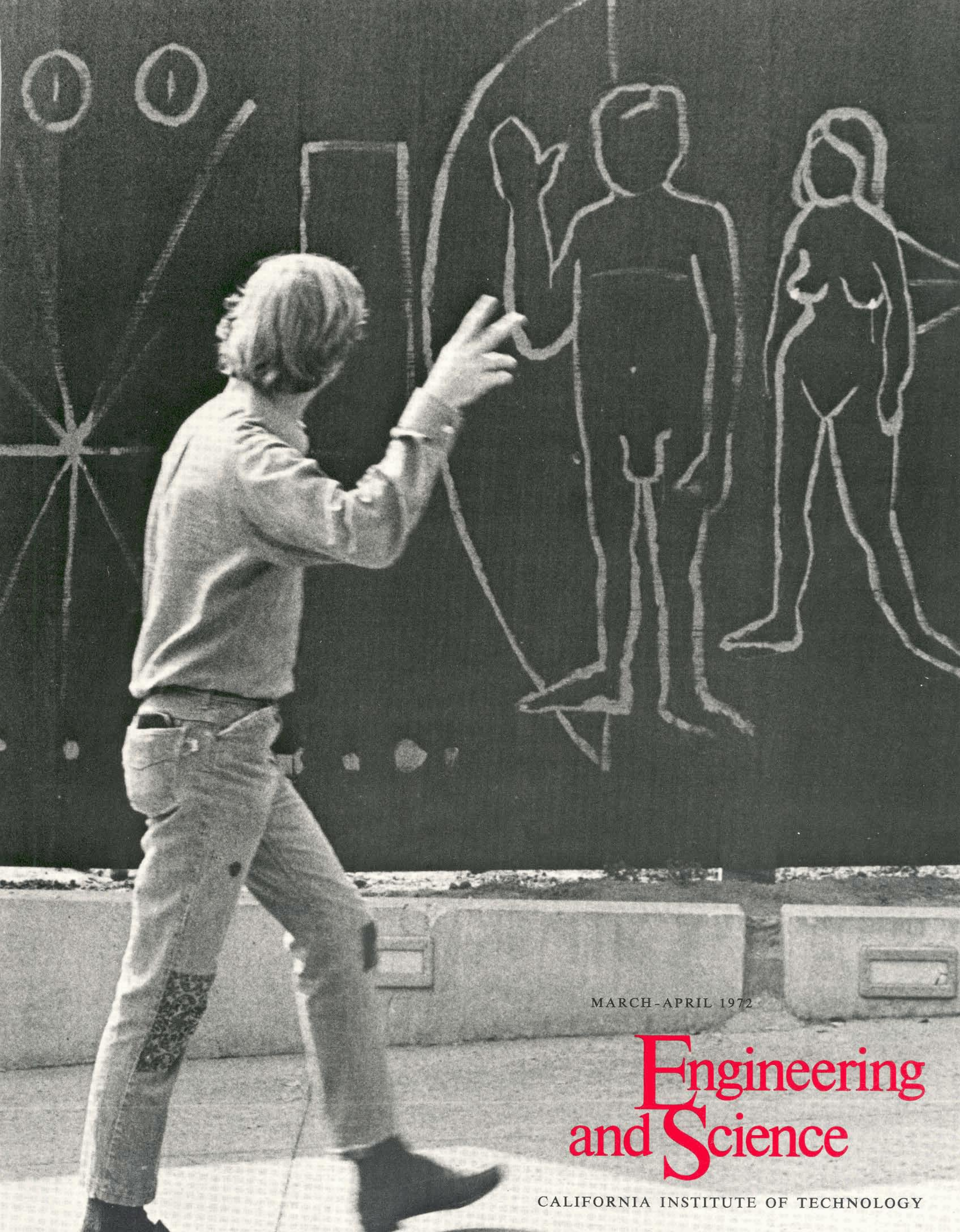

MARCH-APRIL 1972

Engineering and Science

CALIFORNIA INSTITUTE OF TECHNOLOGY

One U.S. airport has its own mini-subway system for passengers; another has its own "el."

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That well-known subway and el builder, Westinghouse.

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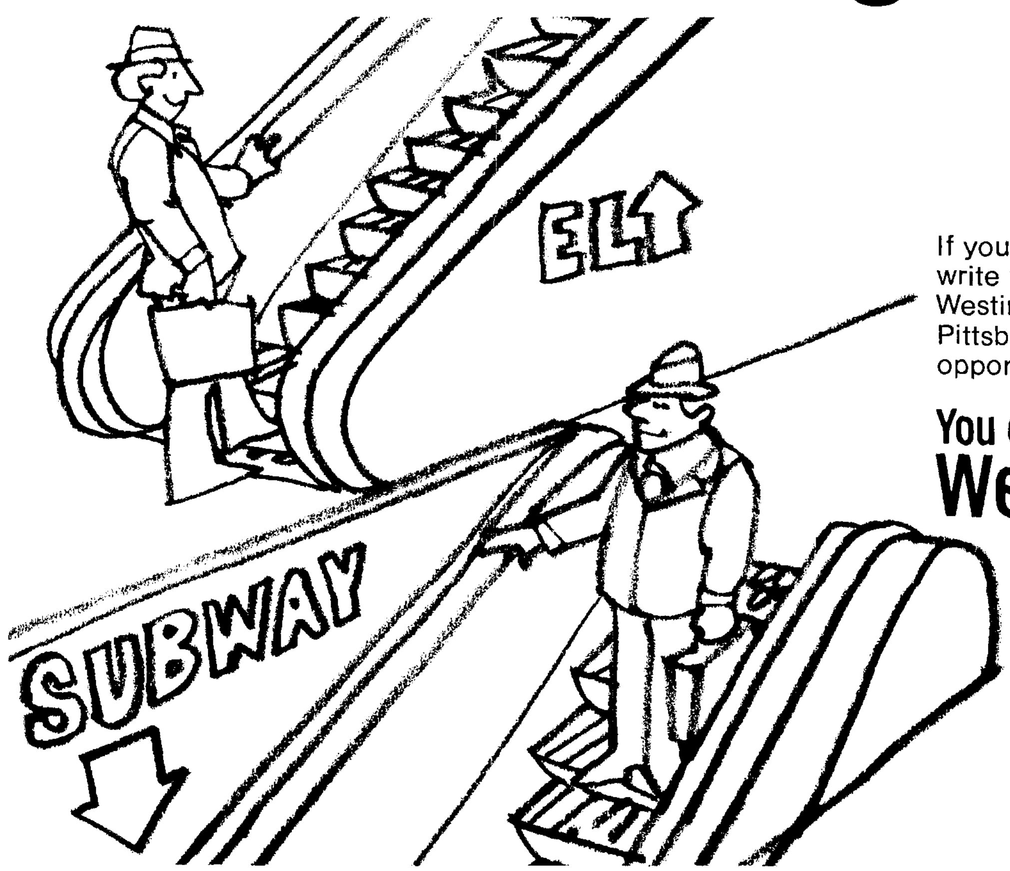

If you can't wait for the recruiter, write today to George Garvey, Westinghouse Education Center, Pittsburgh, Pa. 15221. An equal opportunity employer.

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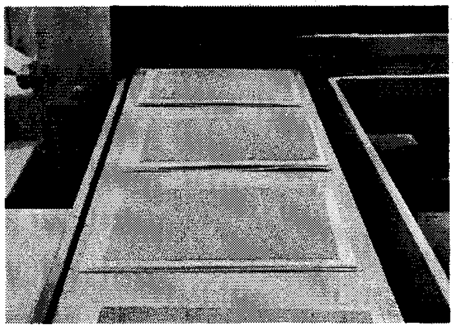
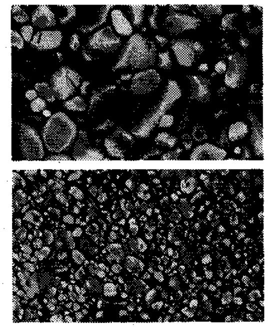
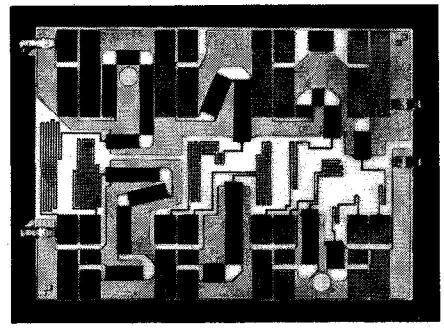
WESTERN ELECTRIC REPORTS



1500° C furnace was specially designed to fire these new substrates. The relatively low temperature results in smooth substrate surfaces for practically fault-free thin film bonding.



Electron micrographs show the great difference in grain size between new ceramic material (lower) and the previous material (upper).



Thin film integrated circuit shown here is part of a resistor network. It is one of many that benefit from the improved substrate. Metal leads on sides are bonded by thermocompression to tantalum nitride resistor film.

Smoothing the way for perfect thin film bonding.

Aluminum oxide, or alumina, is considered to have the best combination of properties for thin film circuit substrates. Until recently, however, the bonding of metal elements to gold-coated tantalum nitride resistor film on alumina was somewhat unpredictable.

Now, an advance at Western Electric has made it possible to get practically fault-free bonding of these materials.

This new perfection in bonding came through the development of finer grained alumina substrates.

The process has four basic steps: milling, casting, punching and firing.

During milling, alumina is combined with magnesium oxide, trichlorethylene, ethanol and a unique deflocculant. For 24 hours, this mixture is rotated in a ball mill. In a second 24-hour period, plasticizers and a binder are included.

The deflocculant plays a major role by dissipating the attraction forces that exist between the highly active alumina particles. This prevents thickening, which would ordinarily make an active alumina mixture unworkable.

The 48 hours of milling is followed by casting. When the material comes off the casting line, it is in the form of a flexible polymer/alumina tape, dry enough to be cut into easily handled sections.

After casting, a punch press cuts the material into the desired rectangles or other shapes. Holes can be punched at the same time.

Finally, because of the use of active alumina, the material is fired at an unusually low temperature which results in smooth substrate surfaces for reliable thin film bonding. The finished substrate is then ready for the various processes of thin film circuit production.

In developing this new process, engineers at Western Electric's Engineering Research Center worked together with engineers at the Allentown plant.

Conclusion: This new way to produce substrates is a truly significant contribution for thin film circuit production.

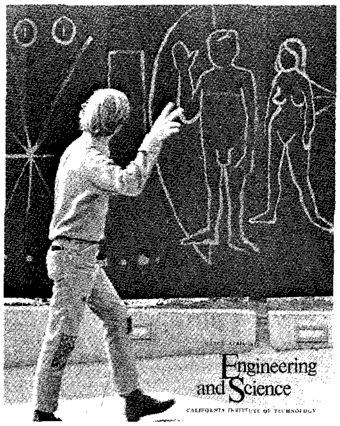
The ultimate gain from this smoother substrate is for communications itself. For through the achievement of nearly perfect bonding of metal leads to tantalum nitride, thin films can be produced with even greater reliability and economy.

Western Electric

We make things that bring people closer.

MARCH-APRIL 1972/VOLUME XXXV/NUMBER 5

Engineering and Science



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In this issue

Hello, Out There!

When Pioneer 10 took off for Jupiter on March 3, it carried an etched plate embedded in its side—a coded message to whomever it might concern, anywhere in the universe, about the nature and the location of the planet Earth. This intricate cryptogram was worked out, for the most part, by Carl Sagan, visiting associate in planetary science at Caltech. "Message for the Milky Way," on page 16 of this issue, tells something about what it means, and notes some of the more interesting reactions to it. ON THE COVER is one more reaction, from a Caltech undergraduate, to the version of the cryptogram that now decorates the construction fence around the site of Caltech's new behavioral biology building.

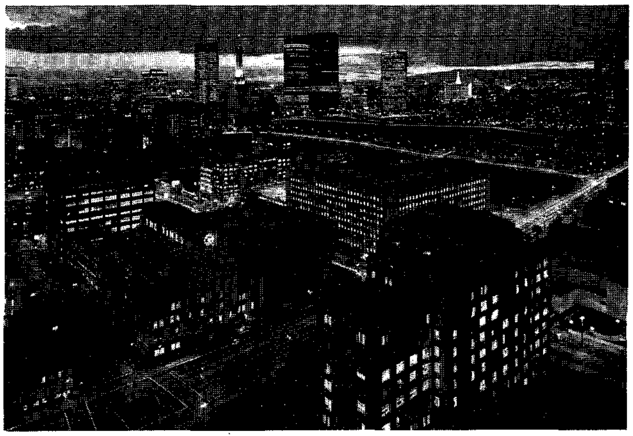
Power Problems and Possibilities

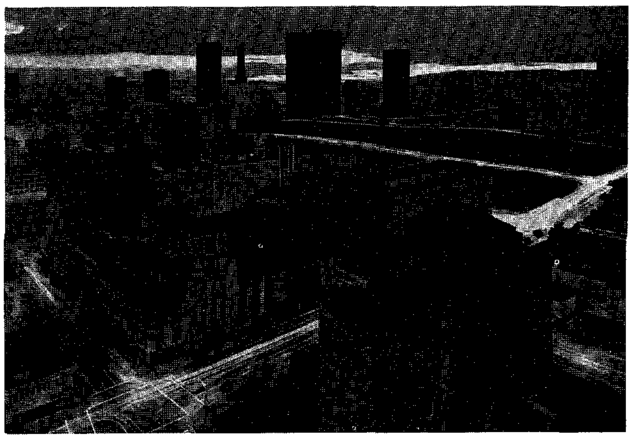
The future of technology—and indeed, of the quality of life on this planet—depends more and more on narrowing the gap between our consumption of energy and our sources of supply. This is a subject of continuing concern and discussion at Caltech, as are all the possible methods for ameliorating the situation. Geothermal, solar, and fusion energy are three of our most promising options; and on pages 4-9 are brief reports about each of them, abstracted from recent interviews, publications, and lectures by Martin Goldsmith, Jerome Weingart, and Roy Gould—all of the Institute staff.

"Energy, the Environment, and Thermonuclear Reactors" by John Holdren (page 10) is an analysis of the pros and cons of fission and fusion energy. Holdren is a senior research fellow with Caltech's population program and the Environmental Quality Laboratory.

PUBLISHED BY THE CALIFORNIA INSTITUTE OF TECHNOLOGY AND THE ALUMNI ASSOCIATION

ENERGY CRISIS





Today the United States uses more than a third of the world's energy. Throughout most of our history, energy consumption has increased continuously. Now there are signs that such rapid growth may no longer be possible. The gap between energy supply and demand in recent years has been widening dramatically, and major breakdowns, rationing, and other cutbacks have become commonplace in some parts of the country. These problems have created a concern about an impending energy crisis for both the short term—10 to 30 years—and the long term—100 years or more.

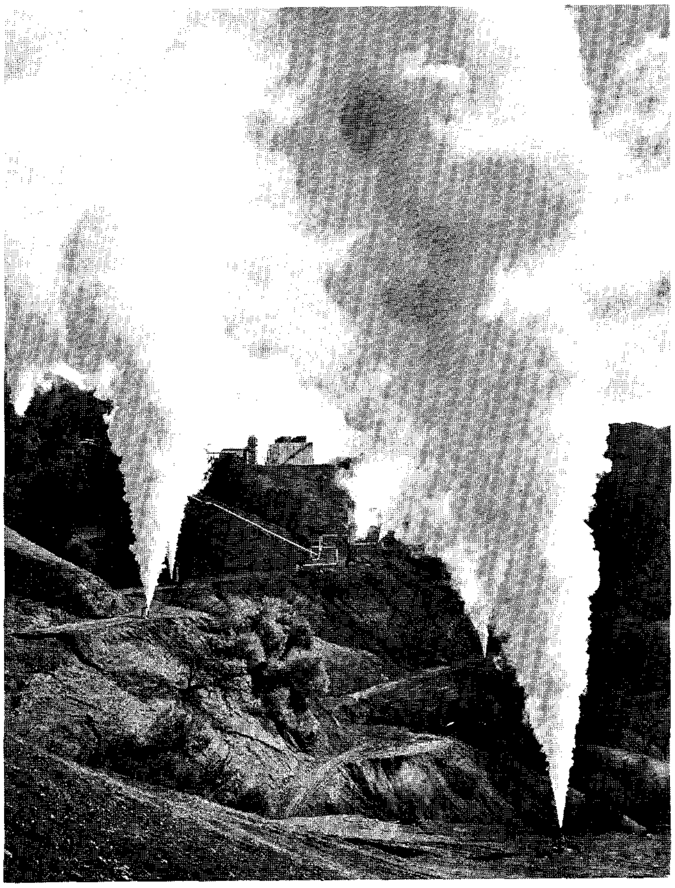
The immediate energy crisis comes from the anxiety that many people feel about the environment. Organized public resistance to nuclear power plants has slowed or stopped construction of these facilities in many areas. Tighter anti-pollution regulations have been imposed on conventional fossil-fueled (coal and oil) power plants, and have reduced their output.

The long-term energy crisis has its roots in a different kind of dilemma—the finite and dwindling sources of fuel for power purposes. If demands for energy continue to grow, this country's usable reserves of oil and coal will be exhausted within 30 years. Usable supplies from other parts of the world would give us another 30 years. But only on the unlikely assumption that the rest of the world is not going to raise its demands for energy. If populations and living standards around the world continue to increase, societies of the future are going to be faced with energy starvation if they have to rely on present sources of energy.

The answers to both the short- and long-term problems appear to be the development of alternative "clean" sources of power and of life-styles that do not demand so much energy. But these answers lead only to more questions. Which sources of power *should* be developed? Where should our money and research efforts be concentrated? How much time can we afford?

The three most promising new sources of energy are geothermal, solar, and fusion power. Each of these has been the subject of much concern and discussion at Caltech in recent months. Some of this discussion is reported in the four articles on the following pages.

Geothermal Resources—Potentials and Problems



The only geothermal power plant in the United States at present is the 11-year-old Pacific Gas and Electric Company facility, "The Geysers," located 85 miles north of San Francisco. The plant's four turbogenerators turn out 82,000 kilowatts, and two more generators are now being added. Plans call for expansion to produce up to 1 million kilowatts from the steam.

The margin between the supply of electrical power in the United States and the demand for it is rapidly narrowing. Major breakdowns, rationing, and other cutbacks have become commonplace in many parts of the country during the summer.

Over the long term, relief may come from the development of relatively "clean" sources of energy, such as fusion power. Accomplishing this would make limitless supplies of energy available. For the short term, however, there is little prospect of respite. Public resistance to nuclear-powered plants has slowed or stopped their construction, and tougher standards imposed on fossil-fueled plants has reduced their output. The result is that the ability of the utility companies to meet increasing energy demands is severely restricted.

As a temporary solution, utility companies have been urged to turn to an energy source that some believe is pollution-free, comparatively inexpensive, and plentiful enough to contribute as much as 4 to 5 percent of the total power generated in the U.S.—geothermal energy.

Geothermal energy is the scientific name for large underground reservoirs of steam and scalding water. Found at depths of from a few hundred to 30,000 feet beneath the surface, the water is heated by the molten matter that oozes up from the earth's core between the huge plates that make up the crust. Geothermal fields are found where two plates are trying to pull apart from each other. California, which some geologists believe may hold between 5 and 10 percent of the world's geothermal reserves, is one such spot.

However, Martin Goldsmith (PhD '55) visiting associate in environmental engineering, on leave from Aerospace Corporation to work with the Environmental Quality Laboratory, reports that such geothermal fields are not as pollution-free, inexpensive, or extensive as those who favor their development have claimed. In an EQL report, "Geothermal Resources in California, Potentials and Problems," Goldsmith points out that there is enough geothermal potential—at least in California—to enable us to squeeze through the predicted power crisis for the next few decades. But it will take technical solutions—often expensive—to solve the inherent environmental problems.

Goldsmith investigated two geothermal reservoirs, one near San Francisco and the other in the Imperial Valley.

The northern California site—The Geysers—is currently being exploited for power by Union Oil Company and Pacific Gas and Electric Company. It is now producing 193 megawatts of electrical energy. By 1979 it should be generating 1,000 megawatts, about the equivalent of a single modern nuclear power plant. The area of the steam reservoir under The Geysers is known to be greater than 10 square miles, and it may be as large as 20 square miles, which leads to some speculation that the field's capacity could be increased to 4,000 megawatts.

The Imperial Valley field is estimated to contain between one billion and five billion acre-feet of superheated water—which might produce 20,000 to 30,000 megawatts of electrical power. The field has been under exploration since about 1957, but so far it has not been developed commercially. Goldsmith attributes this delay both to the reluctance of companies to invest money and to foot-dragging by the federal government. At this time, one year after the federal geothermal leasing law was signed, no federal leases have been granted. Exploration companies, utilities, and local government agencies have pointed to this as a problem of procrastination because over half of the potentially productive wells appear to lie under federal lands.

If geothermal power is indeed to supply any portion of California's electricity in the near future, development of these fields must proceed as soon as possible because of the technical and environmental problems that must be overcome.

One of the most serious environmental problems involves the nature of the wastewater produced by a geothermal plant. In the Imperial Valley, the wells encounter very hot water at depth; this scalding water flashes into a mixture of steam and water as it flows up the well pipe. The salts and minerals in it amount to as much as 25 to 30 percent by weight in some areas. (By comparison, ocean water contains 3.3 percent salts.) These highly mineralized wastes cannot be discharged into surface waters. Even discharge into the ocean could lead to serious contamination if the plant waste differed substantially from ocean water—unless the two were very well mixed.

The most promising method of disposal appears to be injecting the wastewater into the ground. If large quantities of fluids are removed from an underground reservoir, the land surface may sink—sometimes with disastrous consequences. One method for coping with this problem in oil fields is to inject water into the reservoir. Similarly, disposal of geothermal wastes by injecting them into or near the reservoirs may be necessary to prevent subsidence.

Noxious gases are often a by-product of geothermal wells. At The Geysers, the odor of hydrogen sulfide is pervasive. It exists in the steam with other gases such as carbon dioxide, methane, hydrogen, and ammonia. In a 1,000-megawatt installation in some geothermal areas, 100,000 pounds of hydrogen sulfide might be released each day. This is about the same as the amount of sulfur released by a fossil fuel power plant of the same size, burning low-sulfur oil. The problem in eliminating these gases is not one of technical feasibility but of practicality and cost.

Another significant local environmental effect is heat rejection. If ten 1,000-megawatt geothermal plants were installed in the Imperial Valley, the total heat rejected from them, added to the 1,000-square-mile area, would be 5 percent of the total summer solar heat. What the effect of this added heat on the local weather would be is unknown.

Since drilling for geothermal steam involves high-pressure fluids, well blowouts are a major environmental problem. Standard oil-field methods have been used to bring such blowouts under control, but days were required to cap the wells, which meanwhile geysered steam and salt water. Such a release of salt water in an agricultural area, where many geothermal sites would be located, would cause irreparable damage. Means for effecting prompt blowout control must be employed.

While it is clear that geothermal development can have environmental impacts, Goldsmith urges that great caution be observed in passing protective legislation. If land subsidence seems likely to occur, irrigated portions of the Imperial Valley would have to be protected. But blanket prohibition of subsidence is not sensible, for it would not be a problem in many areas. Likewise, the escape of noxious odors must be carefully controlled, but residential standards need not be applied to industrial areas. The solutions are technical, as well as legal, and for this reason Goldsmith cautions against allowing a confusing mishmash of federal, state, and local regulations to evolve that would needlessly inhibit the development of this much needed energy source.

Harnessing the Sun

Of the three energy sources often touted as long-term solutions to the energy needs of man—solar energy, fission (breeder) reactors, and controlled fusion—the first may offer the most pollution-free option if it can be harnessed. But paradoxically, the funding priorities of the federal government do not reflect this fact. At the present time the United States is spending about $200 million a year on fission reactors, $30 million a year on development of controlled fusion power, and essentially nothing on the direct harnessing of solar energy.

There are those—among them Jerome Weingart, senior engineer at the Jet Propulsion Laboratory and senior research fellow in Caltech's Environmental Quality Laboratory—who believe these priorities should be modified.

Weingart was recently appointed to a joint National Aeronautics and Space Administration-National Science Foundation committee formed to create a national program in solar energy technology research and development. In February he was program director of a three-day working conference at Caltech on solar energy applications.

It is his opinion that with proper funding solar energy could generate 10 to 25 percent of this country's national energy budget. While solar energy conversion as a primary source of energy (more than 50 to 60 percent) would be feasible within 100 years, he feels that *no* single source of energy should be dominant, since such a situation is less stable than one in which there are a large number of energy options.

Almost all of our energy needs are currently supplied by some form of fossil fuels. As the ways we use them at present become less acceptable to society, the more acceptable or cleaner uses become expensive. The only alternate large-scale energy option we *now* have is the fission reactor, which has a number of unresolved technical issues associated with its use. Weingart feels that we must work out a large menu of energy alternatives for society, even though development and large-scale implementation of some of these options will require several decades. One of these options—solar energy—must be looked at from the point of view that we live in an energy-intensive, affluent, and high technology society. Keeping these factors in mind, we must develop solar energy to the point where it can be evaluated as a serious energy option.

Until the last few years interest and activity in the solar energy field has been confined to small-scale demonstration projects, such as solar-heated homes, small solar stills, and solar-powered steam engines. The conversion of sunlight to electricity has been confined to very special applications requiring only small amounts of power, or, more recently, for supplying power to spacecraft. But while future large-scale solar utilization systems on earth may employ some aspects of these developments, the economic, environmental, and ecological facets of the use of solar energy for terrestrial purposes have no counterparts in space endeavors.

One possible location for a solar energy reserve would be in the desert areas of California and Arizona near the Colorado River. Other lands suitable for large-scale conversion of the sun's energy to electricity are in Nevada, Texas, and New Mexico.

Residential dwellings and commercial buildings may be the first areas where solar energy can be effectively used. Already the technology for solar heating of houses is well developed and would be cheaper than all-electric heating in most of the country today. With the cost of electricity likely to double within a decade, and domestic supplies of natural gas running low, solar energy systems could provide practical and economical options for heating and cooling of homes and schools. While the solar cells developed for spacecraft are quite expensive, mass production techniques that would result in considerably less expensive photovoltaic converters for use on earth are being examined by NASA and the NSF.

Weingart estimates that if a 1,500-square-foot roof on a house in the Southwest were covered with solar cells that were 10 percent efficient, about 100 kilowatt hours of electricity would be provided on a typical spring day. The present daily use of electricity in residences in southern California is about 20 kilowatt hours. This leaves 80 kilowatt hours available for other uses. Some of this surplus could be used to charge batteries for a small electric-powered commuter vehicle that could travel up to 80 miles per day. If solar cells of the same efficiency—but able to operate at about 200 degrees— were developed, the heat collected by the rooftop array could provide the majority of heating, cooling, and hot water supply for residences in the Southwest. In other parts of the country, solar-generated electric thermal power could, in principle, significantly reduce the load on conventional fuels and conventional central electric power production.

The use of solar energy for large-scale production of electrical and chemical energy appears to be farther in the future. Virtually no substantial research and development have been supported in this area until very recently, and the current effort is of a small-scale, exploratory nature.

Some of the potential benefits of producing large amounts of power from solar energy rather than depending on fossil or atomic fuels have important implications for the United States and the rest of the world:

1. Solar energy conversion is inherently a low-impact technology. In principle it avoids some of the major areas of environmental impact such as air and water pollution, permanent land destruction, thermal effluent at the source, long-term storage of radioactive wastes, and addition of heat to the thermal budget of the earth.
2. The fuel is abundant and free.
3. If the total amount of power required in the U.S. can be limited to perhaps four times what is currently produced, the destructive exploitation of the natural resources of other nations (particularly the underdeveloped countries, which will need these resources for their own well-being) can be prevented—with a concurrent lessening of the dangers of political conflicts.
4. Availability of large amounts of solar-energy-produced power might eventually have a profound impact on the economic, environmental, and political conditions of the rest of the world. Supplying cheap and abundant power to low-technology nations, particularly those with very limited supplies of fossil fuels and limited nuclear technologies, may also prevent a world where every nation—large and small—has the materials to build nuclear weapons.

An area of 3,000 square miles in the deserts of the Southwest could hold enough solar energy collectors and converters to supply the total electrical needs of the U.S. today—if the equipment was 20 percent efficient in converting and delivering energy. An area 200 miles on a side could theoretically supply all the energy needs of the U.S. If this sounds somewhat grandiose, it nevertheless represents only 1 to 8 percent of the present farmland. Low quality land would be used for such installations. The federal government owns about 100,000 square miles of barren desert land in the Southwest, much of it used for gunnery ranges and testing of underground nuclear weapons. Much of this land is suited for solar-power generators.

Careful studies will have to be made to determine the ultimate technical and economic feasibility of various systems of conversion of solar energy (to produce electricity and chemical energy and to heat and cool buildings) and the various resources required for the development and implementation of this kind of energy on a meaningful scale. The best we can do at this early stage is to determine the economic range of the various solar energy conversion systems. If those ranges appear to approach the estimated costs for energy and power over the next several decades, we would do well to take a very serious engineering and economic look into the feasibility of such systems.

Controlling the Thermonuclear Fusion Reaction

Control of the thermonuclear fusion reaction that produced the hydrogen bomb has been the "holy grail" of applied physics since the early 1950's.

In a world where demands for electrical power are expected to multiply fivefold by the year 2000, development of a fusion reactor seems the answer to all energy deficiencies. Such a reactor would "burn" deuterium, a heavy isotope of hydrogen; and there is enough deuterium in the water of the oceans to meet the world's energy needs for more than 1 billion years. (The energy from the fusion of the deuterium in a gallon of water—less than an eighth of a gram—is equal to that from 300 gallons of gasoline.)

In the 1950's and early 1960's, after a series of tantalizing research approaches had turned sour, many scientists wondered if it would ever be possible to control the fusion process in the same way that atomic fission is controlled. Now, however, it is not a question of *if*, but *when*, according to Roy Gould, professor of electrical engineering and physics. On leave from Caltech to serve as director of the Atomic Energy Commission's fusion research division, he was on campus recently to address a joint Physics-Applied Physics Research Conference about progress in that field.

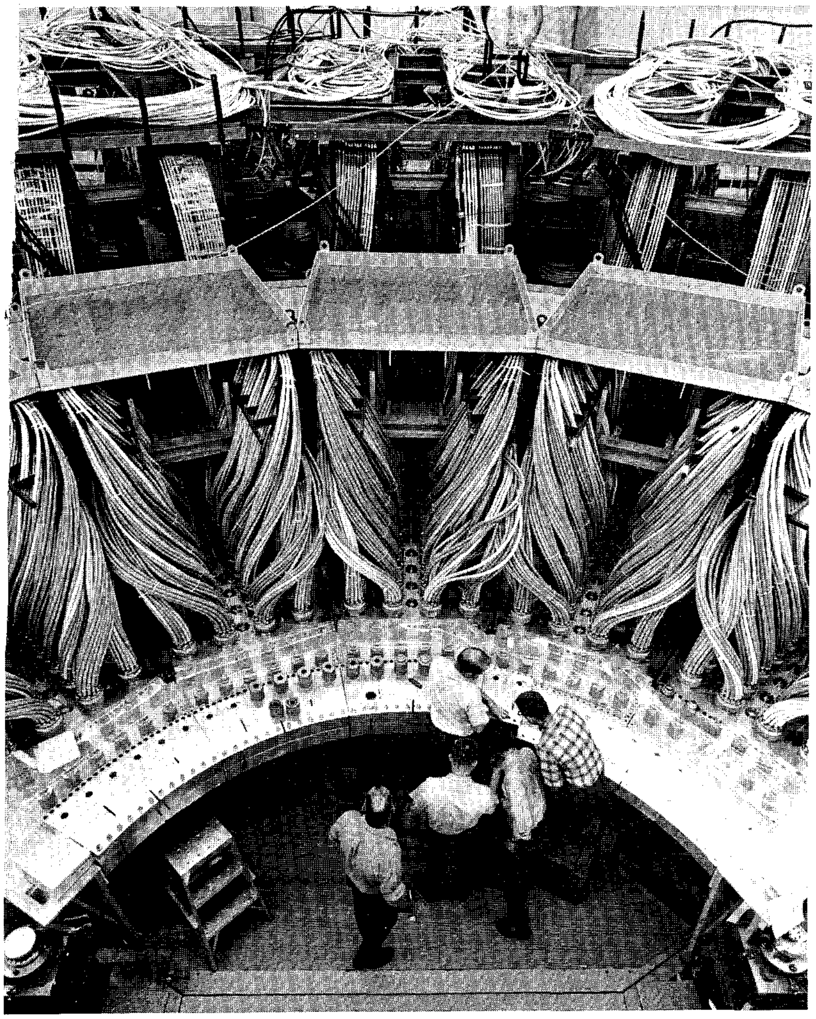
In Gould's opinion, the reason for the renewed optimism about controlling fusion processes has been the Russian success with their Tokomak-3 high-energy plasma machine, and subsequent good results in this country at the Lawrence Livermore, Los Alamos, Oak Ridge, and Princeton University fusion research centers.

To achieve useful power from controlled fusion reactions, it is necessary to heat dilute gas of fusion fuel to temperatures of hundreds of millions of degrees, until it is in the plasma state; then to contain it, free from any contact with material walls or from contamination by impurities, long enough for a significant fraction of the fuel to react; and finally, to extract the energy released and convert it to a useful form.

Progress toward this goal is dependent on what we know about the behavior of high-temperature plasmas, together with the means of heating and confining them. Using any material for a container to confine the plasma would lower the temperature of the plasma below the critical point, so scientists have made use of magnetic fields to "bottle" the electrically charged particles. Because of the interaction of magnetic and electrical fields, a particle—in theory—could not leak out of a properly shaped bottle.

Two basic magnetic bottle configurations have been developed to confine the plasma: the open-ended mirror machines and the toroid, or doughnut-shaped, machines. Mirror machines are straight tubes with magnetic fields that are stronger at the ends than in the center. The stronger fields act as mirrors, reflecting plasma particles back into the tube. In the toroid design the ends are eliminated, wrapping the tube—and also the magnetic field—around on themselves in the form of a doughnut.

These bottles are not perfect. A slow leakage occurs, due to collisions between plasma particles. For many years there has been a theory which predicted that the loss of plasma particles by diffusion out of the magnetic field would be low enough to allow a steady, energy-producing fusion reaction to go on. But experiments in the fifties and sixties repeatedly failed to confirm the prediction. In the last few years, results from a toroidal device called the Tokomak, developed in the Soviet Union, have shown that diffusion rates approaching the prediction can be achieved. Consequently, the Princeton plasma machine—the Stellarator—has since been converted to a Tokomak. In addition, two other magnetic confinement approaches are emerging—the steady state magnetic mirror and the pinch device, which operates in cycles, heating and constricting the plasma for only short periods.



Scyllac—with its complex twisted coils—is an example of one of the "new breed" of controlled thermonuclear research devices. Located at Los Alamos Scientific Laboratory, it represents one of four or five major efforts to come up with the correct configuration of magnetic fields to hold a plasma of excited atomic particles long enough for a fusion reaction to occur.

If any of these approaches can attain a plasma density of about 1,000 trillion particles per cubic centimeter for a tenth of a second at a temperature above 60 million degrees, a fusion reaction is assured. The Soviet Tokomak has attained temperatures of 10 million degrees at close to reactor densities for about one-hundredth of a second. The Princeton Tokomak has reproduced the Russian results and is now being used in a program to further extend these results and our understanding of them.

A second promising effort is the 2X mirror experiment at Lawrence Livermore, which has achieved temperatures of 100 million degrees at about the same density and a little less confinement time. A pinch device at Los Alamos —Scyllac—has reached temperatures of about 35 million degrees at the right plasma density but a very low confinement time.

Despite these promising results, Gould—even at his most optimistic—does not think fusion will do much to ease our power crisis until the year 2000. The scientific feasibility of a controlled fusion reaction could be demonstrated within five years—provided the resources for the research were available. With luck, break-even plasma conditions—the point at which a plasma creates more energy from the fusion reaction than is invested in producing the plasma—can be achieved by the end of this decade. Beyond that would lie an extensive, and expensive, engineering development period in which experimental fusion reactors would be built and operated. A demonstration fusion power plant would appear in about the mid-1990's at the earliest. Introduction of significant amounts of power into the economy would take even longer.

But it will take money. It is estimated that a modest program would require doubling the current budget of $32 million a year to $64 million by 1975, and more gradual increases to reach $89 million a year by 1980. A crash program would involve doubling and redoubling to $143 million in 1974 and more increases to $237 million a year in 1980.

Energy, the Environment, and Thermonuclear Reactors

by John Holdren

The rapid increase of energy use, electrical and otherwise, has intensified a long-standing dichotomy: On the one hand, energy is the prime mover of technology and an essential ingredient in fashioning a decent standard of living; and on the other hand, it is a major ingredient of man's growing detrimental impact on his environment.

Thus the nature of the "energy crisis" depends on whom one asks. Industry and many branches of government apparently regard the present rates of growth of energy use as inviolable. They view the crisis as one of logistics—how to mobilize resources and technology quickly enough (in the face of growing opposition from environmentalists) to maintain these rates well into the future. To the environmentalists, the crisis is the possibility that the growth rates will indeed be maintained, accompanied by a degree of environmental deterioration barely hinted at today. And thoughtful observers of many persuasions are concerned about bringing the costs of pollution and depletion into the balance sheets—and about how the resulting increase in the price of energy will affect the poor.

Short and Long Term

Even a cursory examination of present and probable future energy technologies leads to two inescapable conclusions. First, technologies of the future (such as controlled fusion) will not solve the logistics problem of maintaining present growth rates over the next two decades. They simply cannot be brought to bear quickly enough in sufficient quantity. Second, even in the longer term, technology cannot completely resolve the dichotomy between mankind's demands for energy and the adverse environmental effects of providing it. No means of providing energy is free from environmental liabilities. Thus, the question of distinguishing *demands* (as for comfort heating of poorly insulated buildings and fuel for overpowered automobiles) from *needs* (as for mass transit, recycling plants, and renovating the urban environment) must be frankly addressed. Sooner or later, the necessity to stabilize energy consumption will have to be confronted. In the U.S., which now accounts for 35 percent of the world's annual energy use, it is likely to be sooner.

At the same time, no amount of progress in dealing with these economic and social issues will eliminate the question of how best to provide energy in the long term. There are a number of possibilities, but those that appear today to have the potential to meet the bulk of civilization's energy requirements far into the future—for thousands of centuries—are only three: nuclear fission with breeder reactors, nuclear fusion, and direct harnessing of solar energy. I will not dwell on solar energy here, except to note that it is obviously feasible technically and almost certainly the best option we have environmentally. The questions are, in what locations, what sizes, and indeed in what roles (office building energy systems or central station electricity generation) will solar energy prove economically interesting. Fusion reactors and breeder reactors, on the other hand, are relatively easy to compare directly because they fill the same well-defined role: central station generation, with economic and technical factors pointing to very large sizes.

Fuel Considerations

Basically, fission breeder reactors operate by using excess neutrons from fissions taking place in the reactor to transmute Uranium-238 and Thorium-232 (called *fertile* materials) into Plutonium-239 and Uranium-233 (*fissile*, or fissionable, materials). Breeding is made possible because each fission yields an average of more than two neutrons; one sustains the chain reaction by initiating

The most extensive work on the radiological aspects of fusion reactors has been done by Dr. Don Steiner of the Oak Ridge National Laboratory and Dr. J. D. Lee of the Lawrence Livermore Laboratory. Their publications are the source of many of the numbers in this article.

FUEL SUPPLIES IN THE LONG TERM

		energy in Q*
U.S. electricity generation, 1970		.015
U.S. energy consumption, 1970		.06
World energy consumption, 1970		.17
Hypothetical annual world energy consumption (10 billion people at 1970 U.S. per capita rate)		3
Initial world supply of fossil fuels		250
Lithium (D-T fusion)	known on land	670
	probable on land	8300
	sea	21 million
Uranium and thorium		5 million
Deuterium (D-D fusion)		7.5 billion

*One Q is a unit of energy equal to 10^{18} B.T.U. or 2.93×10^{14} kwht (kilowatt-hours, thermal).

RAW FUEL CONTRIBUTION TO PRICE OF ELECTRICITY (33% plant efficiency)

	cents/kwhe
Coal ($6/metric ton)	0.2
Uranium ($8/lb. of U_3O_8, 1.5% utilization)	0.02
Uranium ($100/lb. of U_3O_8, 70% utilization)	0.004
Lithium (2¢/gram)	0.0002
Deuterium (30¢/gram)	0.0008
Delivered cost of electricity to residential consumers, 1970	2.0

another fission, one replaces the fuel atom by transmuting a fertile atom, and any others can either make extra fuel (breeding) or be lost by escape from the reactor core or by non-productive absorption.

Of the possible fusion reactions, that of deuterium with tritium is the least difficult to achieve and will almost certainly be the one employed in the first successful fusion reactor. (Deuterium and tritium are the heavy isotopes of hydrogen.) In such a system the tritium, which is almost nonexistent in nature, would be regenerated by neutron-lithium reactions in a "blanket" surrounding the thermonuclear plasma. Thus the raw materials for D-T fusion are effectively deuterium, which is easily extracted from seawater, and lithium. Reactions fueled by deuterium alone exist, but they are more difficult to exploit.

Given these possibilities, it quickly becomes apparent that both fission breeders and fusion reactors meet the requirements for long-term energy sources that the fuel be abundant. This point is illustrated in the table (top left), where current and projected energy consumption figures are compared with the energy content available in the fission and fusion fuels.

It is also clear that raw fuel costs will be very low with either option, as shown at the left. Even in today's light water reactors, only 1 or 2 percent of the energy potentially available in the uranium is extracted, and the cost of the raw uranium oxide accounts for only 1 percent of the delivered cost to residential consumers of nuclear-generated electricity. Enrichment, fabrication into fuel elements, and eventual reprocessing make the total fuel costs about 0.2¢ per kwhe (kilowatt-hour, electrical) in a light water reactor, but none of these expenses depend on the cost of raw uranium. This fact undercuts the Atomic Energy Commission's argument that we need the breeder reactor in order to hold the price of nuclear electricity down as high-grade uranium becomes scarce.

At this point, of course, it is not at all clear what construction costs for a reliable breeder will be. They could easily be high enough to offset the cheapness of the

Comparison between the breeder and the fusion reactor boils down to environmental aspects.

raw fuel. The same is true for fusion reactors: It is difficult to predict costs when no one yet knows what the successful device will look like. Even if the fuel were free (and .0008¢/kwhe is close to that), the electricity could be expensive.

Evidently, then, the breeder and the fusion reactor cannot meaningfully be distinguished at this point in time in respect to either abundance of fuel or to cost of the electricity. The comparison therefore boils down to environmental aspects. To focus on this issue, the table below lists the principal environmental liabilities of the breeder reactor—with no pretense of ranking by importance. For purposes of this discussion, "breeder reactor" will refer hereafter to the plutonium fueled liquid-metal fast breeder, which dominates the U. S. research program in this field. In evaluating a potential fusion system against the list in the table below, I will concentrate on the D-T reaction both because it is the easiest to achieve and because it is the worst case environmentally.

ENVIRONMENTAL LIABILITIES OF BREEDER REACTOR

Operation
- Routine emissions
- Thermal pollution
- Accidents
  - nuclear excursion
  - loss of coolant

Fuel Management
- Mining and refining
  - defacing landscape
  - workers' health
  - radioactive tailings
- Transportation
  - escape of spent fuel or concentrated waste
  - escape of plutonium
  - diversion of plutonium for clandestine purposes
- Emissions in reprocessing
- Storage of concentrated wastes

Fuel Management

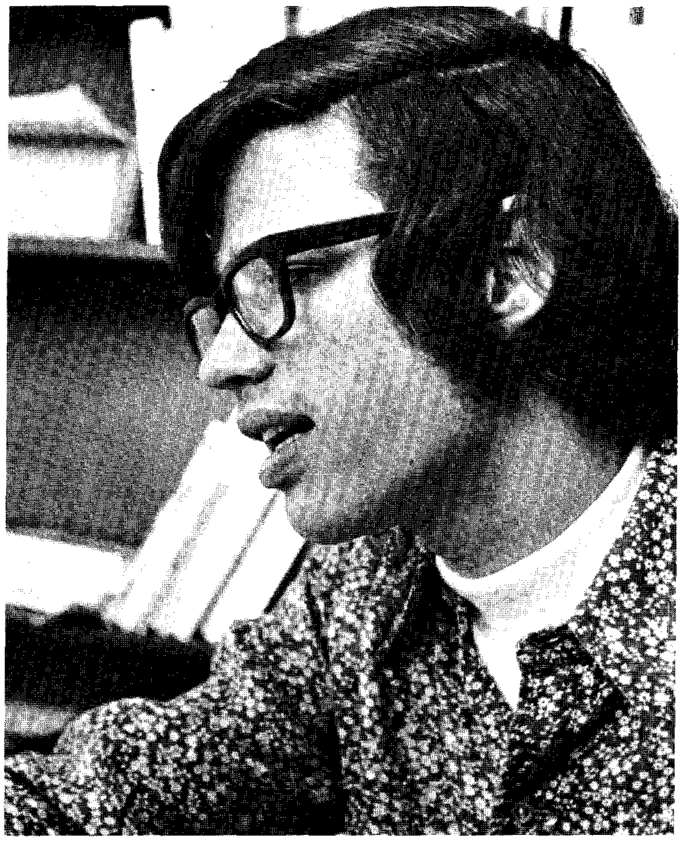
Deuterium is obtained from sea water by isotope separation, and water depleted of deuterium can be returned to its source without ill effect. The lithium from which tritium will be "bred" by neutron bombardment is now obtained principally from heavy brines found in Nevada and California. Eventually lithium may also be extracted from the oceans. Both deuterium and lithium are non-radioactive.

Unfortunately, tritium is radioactive. Since it is a fuel rather than a waste product, it does not need to be shipped to remote storage sites, but some shipping would be involved in supplying new fusion reactors with their initial inventories of this substance. In a stable fusion-energy economy, no tritium would have to be shipped. "Reprocessing," in the sense of regenerating tritium from lithium, would take place on-site.

Thermal Pollution

Discharge of waste heat to the environment is a liability common to all forms of thermal electricity generation, and its biological and climatic effects have been widely discussed. A more general problem is that virtually all the electricity itself, as well as the energy wasted in generation, eventually appears in the environment as heat. This phenomenon already influences the climate of metropolitan areas and may ultimately be important on a larger scale.

First-generation fusion reactors will probably operate at thermal efficiencies between 40 and 50 percent, offering little or no improvement over the fossil and fission plants likely to be operating in the same time period. This is because most of the energy of the D-T reaction is carried by the neutrons and must therefore be converted in a more or less conventional thermal cycle. When the D-D reaction becomes exploitable, this situation may change. Here, most of the energy is carried by charged reaction



John Holdren

products, opening the possibility of direct conversion of this kinetic energy to electricity. Experimental and theoretical work on direct conversion at the University of California's Lawrence Livermore Laboratory suggests that plant efficiencies of perhaps 80 percent may eventually be possible. This would yield a sixfold reduction from today's best plants in respect to waste heat at the site per unit of electricity generated, and a twofold reduction of total thermal load per unit of electricity.

Tritium

A more bothersome issue is the inventory of tritium that would be associated with a D-T fusion reactor. Tritium decays to Helium-3, which is stable, with a half-life of 12.3 years. The accompanying radiation is a low-energy beta particle (electron), which is stopped by 7 millimeters of air and cannot penetrate the skin. The

PRINCIPAL VOLATILE ISOTOPES IN 2500 Mwt FISSION AND FUSION REACTORS

	fission (iodine-131)	D-T fusion (tritium)
Activity, curies	$8x10^7$	$3x10^7$
MPC, curies/meter^3	10^{-10} (respirated)	$2x10^{-5}$ (T_2)
	$1.4x10^{-13}$ (on crops)	$2x10^{-7}$ (HTO)
Relative hazard, meter^3	$8x10^{17}$—$6x10^{20}$	$1.5x10^{12}$—$1.5x10^{14}$

most serious aspect of the tritium problem is the tendency of tritium to replace one of the hydrogen atoms in a water molecule, forming HTO and giving tritium access from the inside to many of the cells of the body.

Preliminary engineering studies indicate that a 2,500 Mwt (megawatts, thermal) fusion reactor—1,000 megawatts, electrical, at 40 percent thermal efficiency—would require a tritium inventory of about 3 kilograms, or 30 million curies. (A curie of radioactivity equals 37 billion disintegrations per second of a radioactive material.) The table above compares this amount in quantity and in biological hazard with the dominant volatile fission product (Iodine-131) in a breeder reactor of the same size. Relative biological hazard can be thought of as the volume of air that could be contaminated to the maximum permissible concentration (MPC) if all the material escaped.

It is evident from the table that the potential hazard associated with the tritium in a fusion reactor is much smaller—by a factor of 10,000 to 1 million—than that associated with the Iodine-131 in a breeder reactor. At the same time, the tritium hazard is far from negligible. The sudden loss of only a thousandth of the tritium inventory under atmospheric inversion conditions would constitute an accident with serious public health implications. The application to fusion reactors of the Atomic

Breeder reactors and fusion reactors will both permit mankind to exploit nearly inexhaustible supplies of inexpensive fuel, but the costs are still uncertain.

Energy Commission's new emission standards for light water fission reactors would mean that routine releases could not exceed one part in ten million of the tritium inventory a day. Meeting this requirement will necessitate great care (and perhaps expense), but it can be done.

Accidents

It is not enough, of course, to ask what is inside the reactor—one should also try to examine the odds that the material will get out. Today, the possibility that a fission reactor might suffer a major accident leading to loss of containment is the subject of considerable speculation. Neither operating experience nor theoretical analysis is yet adequate to the task of assigning a numerical probability to such an event. However, the results of recent investigations into the performance of emergency core cooling systems for light water reactors suggest to some competent observers that the odds may be worse than had been supposed. Breeder reactors will certainly be even trickier to handle in this respect, owing to their higher power densities and operating temperatures.

A crude comparison of the hypothetical accident potential of breeder reactors and fusion reactors may be made by examining the magnitudes of the various forms of energy stored in these devices. Estimates are given in the table below. These figures are not the whole story, of course. One must also know whether the energy can be released suddenly. A fusion reactor will certainly be safe against a nuclear excursion (i.e., runaway), since any malfunction tends to quench the reaction by loss of confinement, loss of temperature, or both. Rather sudden releases of the magnetic and chemical energy in a fusion system are possible in principle, but there is no question that a structure sturdy enough to withstand the maximum event can be provided. In a breeder reactor, by contrast, excursions too extreme to be contained—involving sudden rearrangement of the nuclear core after extensive melting—cannot yet be ruled out.

STORED ENERGY IN 2500 Mwt FISSION AND FUSION REACTORS

	fission (breeder)	fusion
Nuclear	5×10^{18} joules	5×10^{11} joules
Chemical	5×10^{11} joules (sodium)	5×10^{11} joules (lithium)
Magnetic	0	5×10^{10} joules

(1 ton TNT=4×10^9 joules)

Long-lived Radioactivity

Tritium is not the only radiological problem of fusion reactors. Each D-T reaction produces energetic neutrons, and these particles bombard the vacuum wall separating the fusion plasma from the other components of the reactor. Unfortunately, neutron bombardment can transmute stable elements into unstable ones. Thus radioactivity is induced in the vacuum wall, the nature of the new isotopes depending on what the wall is made of. Moreover, the intense neutron flux erodes the structural integrity of materials, so that the entire wall will probably have to be replaced as often as every two or three years.

One does not have a wide choice of wall material, since it must meet many stringent requirements—operating temperature, resistance to corrosion, ability to withstand bombardment by plasma ions as well as by neutrons, and so on. From most points of view, niobium seems the ideal choice for this application, and almost all early engineering studies have assumed it will be used. However, some of the isotopes of niobium induced by neutron bombardment are so long-lived and so hazardous as to represent a waste-disposal problem only a hundredfold smaller than that associated with fission reactors. The table above right gives

LONG-LIVED ISOTOPES (2500 Mwt reactors)

	half-life (years)	generation rate (curies/yr)	accumulated activity after 1000 yr (curies)	relative hazard after 1000 yrs*
FUSION				
niobium-93m	13.6	2.2×10^7	4.3×10^8	1.1×10^{16}
niobium-94	20,000	7.3×10^3	7.3×10^6	7.3×10^{14}
FISSION				
strontium-90	28	1.7×10^6	6.8×10^7	6.8×10^{17}
cesium-137	30	2.3×10^6	10^8	2.0×10^{16}

*relative hazard=curies/MPC

the comparison. In view of this situation, it now seems likely that vanadium will be used instead of niobium in fusion reactors. Although use of this substance will entail some loss of thermal efficiency, it would reduce the long-lived waste burden by an additional factor of approximately 1,000—or 100,000 times less than that for fission reactors.

Afterheat

Another potential problem associated with the radioactive materials in fission and fusion reactors is afterheat—the energy released by radioactive decay of the accumulated isotopes even after the reactor itself has been shut down. This phenomenon is what makes an effective emergency cooling system absolutely essential in a fission reactor, even assuming that the reactor would be shut down at once if the main coolant were lost. The afterheat associated with the niobium in a fusion reactor would be small compared to that in a breeder reactor—so small that loss of coolant is unlikely to be a major problem. If vanadium is used instead of niobium, the afterheat will be smaller still.

ENVIRONMENTAL ASSETS OF FUSION

- volatile radioactivity 10^4—10^6 lower than breeder
- long lived waste 10^2—10^5 lower than breeder
- afterheat 20-30 lower than breeder
- nuclear excursion impossible; maximum internal energy release can be contained
- grinding up earth's crust to obtain fuel unnecessary
- potential reduction in thermal pollution

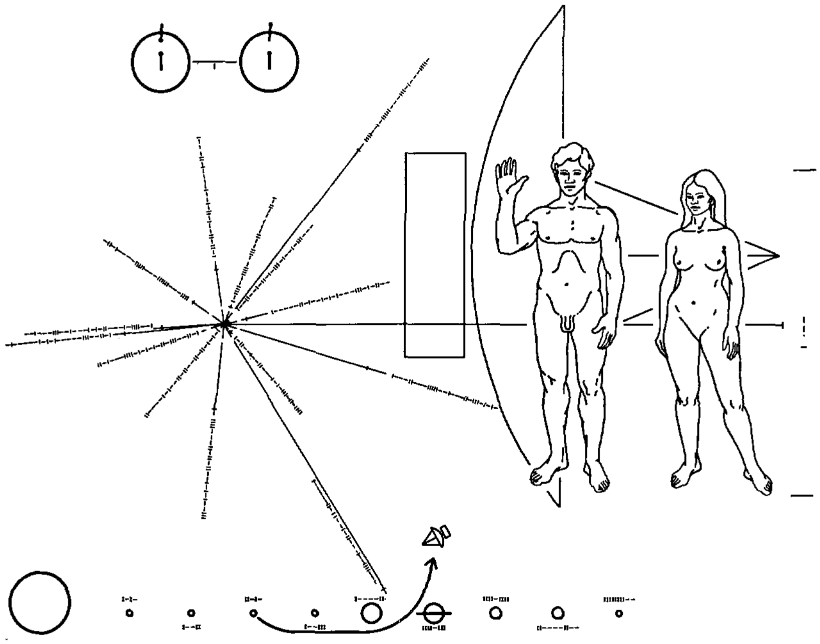
Advanced Fusion Reactors

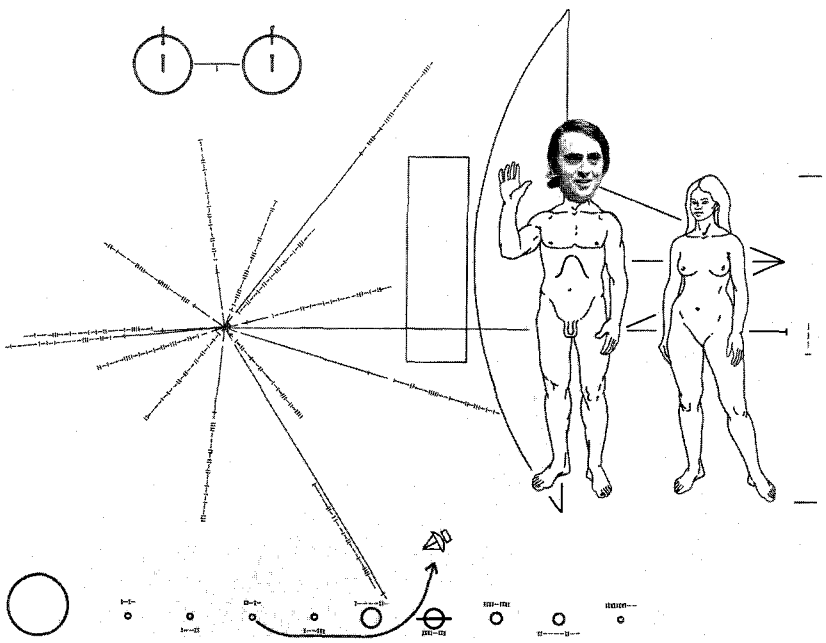
Although it is sometimes assumed that eventual success with the more difficult reactions (such as D-D and D-He^3) will eliminate the sort of problems described here, this is not the case. The D-D reaction produces both neutrons and tritium, and one cannot have D-He^3 reactions without D-D taking place too. Present evidence suggests that advanced reactors might get by with tritium inventories ten times smaller than those assumed here, and with neutron activation five times smaller. These are substantial improvements, but they do not eliminate the radiological hazards entirely.

Conclusion

Breeder reactors and fusion reactors will both permit mankind to exploit nearly inexhaustible supplies of inexpensive fuel, but the total system costs for both approaches are still uncertain. Present comparisons between them must therefore hinge mainly on environmental factors. The advantages of fusion are summarized in the table at the left. These assets are well worth striving for and, indeed, worth a good deal more research money than is currently being applied to the task. Nevertheless, fusion will not reduce the environmental impact of electricity generation to zero. Neither do any other alternatives available to us. Perhaps one moral of this story is the old dictum of economics, now being advertised as a law of ecology: There is no such thing as a free lunch.

Message to the Milky Way





The official drawing of Pioneer 10's message to outer space (top) differs in one significant detail from the version concocted by Caltech students for publication in the March 2 issue of The California Tech *(bottom).*

For the last month or so, Carl Sagan, visiting associate in planetary science at Caltech, has been rather secretive and vague about an innocuous looking six- by nine-inch etched aluminum plate in his office. He has put off curious visitors with a wave of the hand and the remark: "Oh, it's just something I am doing for publication."

Anyone with any knowledge of where Sagan's interests lie would have concluded he was writing something about the possibilities of contacting extraterrestrial civilizations. But the plate in Sagan's office had to do with more than an article about sending a message into space.

It *is* the message.

The etched plate was imbedded in the side of the Pioneer 10 Jupiter probe launched on March 3, and is intended to identify the Earth as the spacecraft's point of origin and to depict the nature of the beings that launched it. It is included aboard Pioneer 10 because, following a two-year flight to Jupiter and a brief flyby, it will loop out of the solar system toward the other stars in our Milky Way Galaxy—the first man-made object to do so.

Etched on the right side of the plate are two nude figures, a man and a woman, poised against a scale outline of the spacecraft's configuration to show their relative sizes, particularly with respect to the probe's nine-foot dish antenna.

On the left, lines radiate from what looks like an explosion. Circular forms float above and below this. The bottom row of variously sized circles represents our sun and its planets. A sketch of the spacecraft and its trajectory shows its origin from within the solar system. Two circular designs at the top represent the neutral hydrogen atom whose radio emission is one of the most characteristic natural "signals" in the universe. Supposedly, anyone who studies the universe would know this.

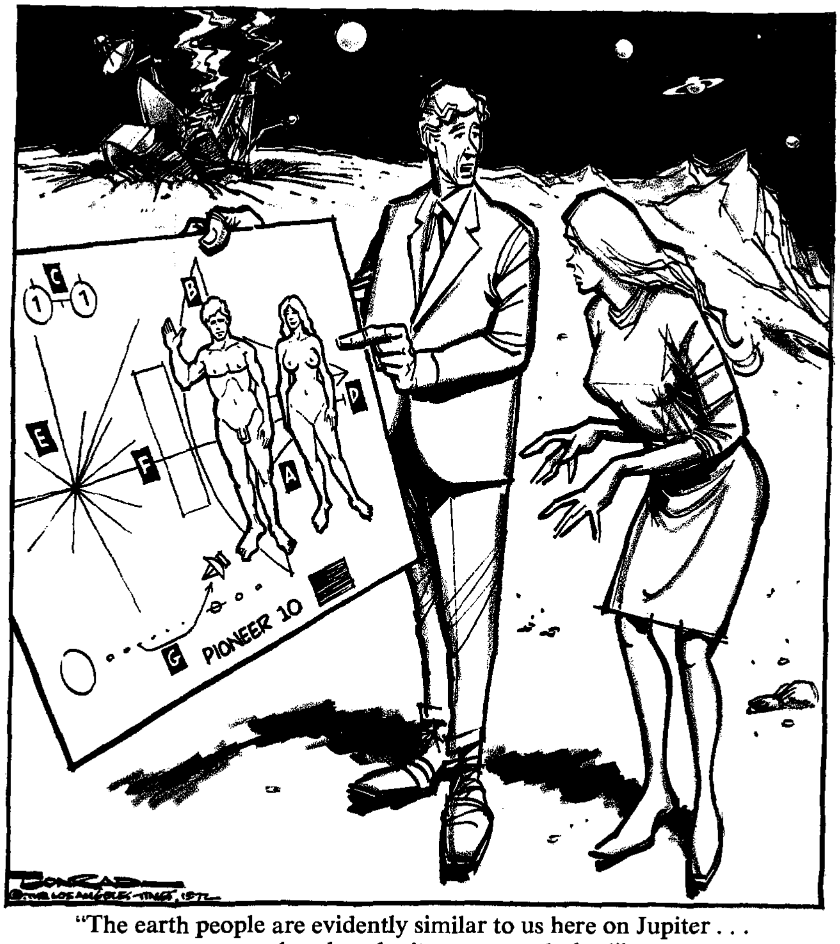
The lines radiating from the "explosion" actually mark the direction of 14 pulsars as seen from Earth. Pulsars are radio sources with very strong and accurately pulsed emissions. They too are a striking cosmic feature another advanced civilization should recognize. Each pulsar is identified by its characteristic pulse rate. A system of binary numbers encodes these rates in terms of their ratio to the hydrogen frequency. If any extraterrestrial beings ever discover Pioneer's message, presumably they will be able to identify each pulsar. From the relative distances of these pulsars from the Earth, they could locate our solar system. Since pulsar rates slow down at a known rate, the discoverers could also tell when the message was sent. The difference between pulsing rates at the time of discovery and those encoded in the message would measure the elapsed time.

The idea for a message originated with freelance writer Richard Hoagland and Eric Burgess, former West Coast science writer for the *Christian Science Monitor,* who were intrigued with the idea that Pioneer 10 will drift away among the stars. They raised the question with Sagan, director of Cornell University's Laboratory for Planetary Studies, and Frank Drake, director of the National Astronomy and Ionosphere Center at Cornell.

Sagan and Drake picked up the suggestion and—working with Sagan's artist wife, Linda—they produced the design, which the National Aeronautics and Space Administration then officially adopted.

This message is a first attempt to specify our position in the galaxy, our epoch, and something of our nature. The scientists admit that they don't know if it will ever be found or decoded, but its inclusion on Pioneer 10 seems to them a hopeful symbol of a vigorous civilization on Earth.

Courtesy of Paul Conrad and the Register and Tribune Syndicate



"The earth people are evidently similar to us here on Jupiter . . . except that they don't wear any clothes!"

Reader Reaction— two letters to the Los Angeles Times

"I must say I was shocked by the blatant display of both male and female sex organs on the front page of The Times (February 25). Surely this type of sexual exploitation is below the standards our community has come to expect from The Times.

Isn't it bad enough that we must tolerate the bombardment of pornography through the media of film and smut magazines? Isn't it bad enough that our own space agency officials have found it necessary to spread this filth even beyond our own solar system?"

"I certainly agree with those people who are protesting our sending those dirty pictures of naked people out into space. I think the way it should have been done would have been to visually bleep out the reproductive organs on the drawings of the man and the woman. Next to them, then, should have been a picture of a stork carrying a little bundle from heaven.

Then, if we really want our celestial neighbors to know how far we have progressed intellectually, we should have included pictures of Santa Claus, the Easter Bunny, and the Tooth Fairy."

Now, About That Steam Car, Howard—

You've read the Irving version
And the Phelan version . . .
Here's the Daugherty version.

The Irving Version

I owned a Stanley and I had a Doble. The Doble was a great machine, but they both had two big flaws . . . For one thing it took anywhere up to five minutes to get up a head of steam, and the goddam garage could burn down in that time. And also you couldn't get more than 70 or 80 miles to a tankful of water.

And so I went out one day to the California Institute of Technology and had a talk with Doctor Richard Millikan—he was President of the University and a Nobel Prizewinner—and I told him I . . . wanted two real bright boys to come and work for me and to develop the Hughes Steamer . . . He found two young kids, Lewis and Burns, and I told them what I wanted . . . a steamer that would get up a head of steam instantly, or as close as possible, and one that would give me four to five hundred miles without having to refill the boiler. I put them in a garage out near Caddo's headquarters on Romaine Street and I let them go . . .

Lewis and Burns came up with the machine all right. But in the first place, it would cost $30,000 to $50,000 to make each automobile . . . I figured I could sell 50 to 100 of them a year, and I still would have had a new car myself whenever I wanted one.

They came up with a flashy-looking five-passenger convertible, a real jazzy-looking machine . . . They told me it would go 400 miles on one tank of water and they had a flash-firing system worked out where they could get up steam in less than half a minute . . . I asked them how they solved the water problem and Burns said to me, "Well, we just made the whole body one big radiator, full of tubes."

I looked at them—these bright, eager Caltech kids—and I said, "You mean the whole body is a radiator—including the doors?" Burns said to me, "That's right, sir. You can go 400 miles on a tank of water." I looked at him again and I said, "So tell me what happens if a car runs into me? Into my door, for example. Won't I get cooked? Boiled? Burned to a crisp?"

Well, little by little they turned red . . . So I walked away and called Noah and said to him, "Turn that goddam thing into scrap metal. Close up the shop. Project's finished."

In the heat of the hassle over who *really* wrote Howard Hughes' autobiography, the prospective publishers of the material (Time-Life and McGraw-Hill) released a few selected passages from the Clifford Irving manuscript and some comparable passages from an earlier unpublished manuscript prepared for a former Hughes aide, Noah Dietrich, by writer James Phelan.

One critical passage concerned Hughes' $500,000 effort to develop a steam car, with the aid of a couple of Caltech graduates, Bruce Burns, '19, and Howard Lewis, '23—and the Irving version is indeed remarkably similar to the Phelan version. But neither one tells the *real* story. Herewith, our sensational, hitherto highly unpublished *third* version—which is probably much closer to the truth.

Our story comes from spry 86-year-old Robert L. Daugherty, professor emeritus of mechanical engineering. He was chairman of the department when Burns and Lewis were in school, taught them both, was instrumental in recruiting them for the Hughes steam car project, and kept an active interest in the project from its beginning in 1925 until it was dropped.

The Daugherty Version

Dr. Millikan had nothing to do with the Hughes steam car affair at all. He didn't know either of those boys. Burns graduated in June of 1919, but he stayed on an extra semester to make up some units. Millikan came to the Institute as chairman of the executive committee in 1920. Lewis graduated in 1923 and had no contact whatsoever with Millikan.

It all started one day in 1925—about 4 p.m.—when I received a call from somebody in the Hughes organization. Not Howard Hughes himself. This man said they were interested in developing the steam automobile. They wanted to know if I knew of a couple of young men who would be interested in such a project. I certainly did. As seniors in mechanical engineering here, Howard and Bruce had had single-track minds on the subject of steam automobiles. Whatever academic course either of them was taking, if it had some possible bearing on the steam engine, they were interested. If it didn't, they didn't want to bother with it.

Bruce had even built a small steam auto—a little fellow that held just one passenger. There was no body on it, no top, or anything. It was just a little flat thing that stood only a couple of feet off the ground. In addition to the boiler he had welded on an acetylene tank to supply the lights and a welding torch that he carried around on the car to put the thing back together when something fell off or it needed repairs around the frame.

Within a half hour of that first call to me I had reached Howard Lewis at Riverside High School where he was teaching physics. Later that day both he and Bruce were in touch with the Hughes company. A few days later the Hughes man called again and told me that they had been looking for two such men for two years.

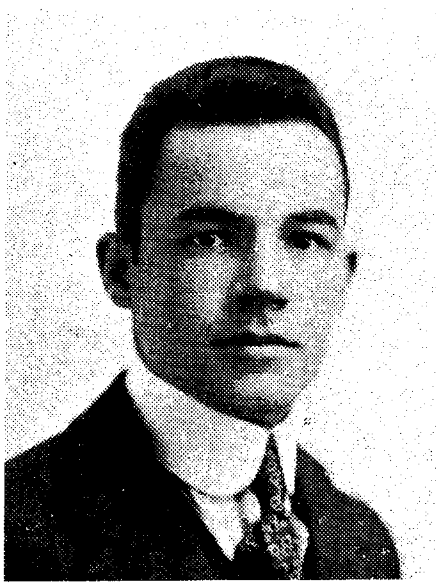
Hughes set up quarters for Burns and Lewis over in Hollywood. They worked on the steam car project for a year or two as employees of the Hughes Tool Company. I visited their machine shop several times. It was strewn with tools, equipment, and various components of steam engines—boilers, condensers, and so on. They said they were attempting to work on the components separately, improving each before they tried to build a complete engine. Months later Howard

Howard Lewis in 1923

Robert Daugherty in 1927

visited me at Caltech and took me riding in a Stanley Steamer in which they were trying out some of the different boilers they were making. He said they were trying to develop a flash boiler which could get up steam very quickly. Steamers at that time took several minutes to work up enough power. They were trying to reduce this to less than a minute. They were working on the condenser (radiator) system too.

Such development work takes time, since anything of this kind has to have a lot of automatic controls and takes a lot of work to make the various components mesh properly. But it turned out that Burns and Lewis didn't have the time,



Bruce Burns in 1919

because Hughes apparently lost interest in the whole project before they had really made any headway. It is my understanding that he had gotten interested in developing a "thief-proof" lock, and wanted them to work on that.

Both the Irving and Phelan stories talk about a radiator system that had tubes lining the entire car. This is nonsense. The radiator and boiler system were in the front of every version I saw, so there would have been no danger of being scalded to death. I don't think Hughes saw a complete prototype. Rather, he saw a standard Stanley or Doble with a lot of the components added.

Burns and Lewis were switched to work on the thief-proof lock and became the nucleus of the Hughes Development Company. Lewis was manager, with Burns as vice president and Mrs. Burns as secretary. They began to recruit a number of engineers as Hughes' interests diversified and he jumped from project to project. About 25 persons were employed at one time—with about 8 from Caltech. Russell Otis, of the class of 1920, a physicist, was one of the first. He was hired as research director. He died in 1960. Larry Grunder, a mechanical engineer who graduated in 1929, was another employee, as was Clarence Elliott, a graduate of Cornell, who was an instructor in engineering drawing at Caltech. The company was well funded by Hughes, but none of the projects they worked on got too far because he kept losing interest.

According to Grunder, the group worked at various times on such projects as wire recorders, hearing aids, high-speed color cameras, assorted aircraft ventures, and a multicolor process to compete with Technicolor.

When Hughes got interested in the technical side of making movies, it spelled the beginning of the end for the research group. That led him into producing movies, and there was no further need for Burns and Lewis and their group —so in 1931 Hughes abandoned the organization.

In 1930 Hughes produced his first motion picture, *Hell's Angels.* Lewis became general manager of one of Hughes' companies, Multicolor Ltd., but a year later left to set up his own company. In 1941 he became a partner in a consulting engineering firm. He died in 1957. Burns is now in semi-retirement in Yucca Valley, California. Grunder is a consulting engineer living in La Habra. Elliott now lives in Los Angeles. Otis went into practice as a consulting engineer and patent attorney. When he died in 1960, he was vice president of the Oil Shale Corporation of Beverly Hills.

The Phelan Version

Howard preferred his Doble over his Stanley . . . but he was critical of both because they took too much time to get up steam, and they had relatively short non-stop cruising ranges. They consumed water at what Howard considered an inordinate rate, and had to stop about every 60 or 70 miles for a refill.

"I can get better performance than that," he told me, and set out methodically to build the world's best steamer. He and I went to California Institute of Technology and conferred with Dr. Robert Millikan, its president and the 1923 Nobel Prizewinner in physics. Hughes told Dr. Millikan that he wanted to employ two of his brightest engineering graduates, men with creative imagination. Dr. Millikan recommended two young men named Burns and Lewis.

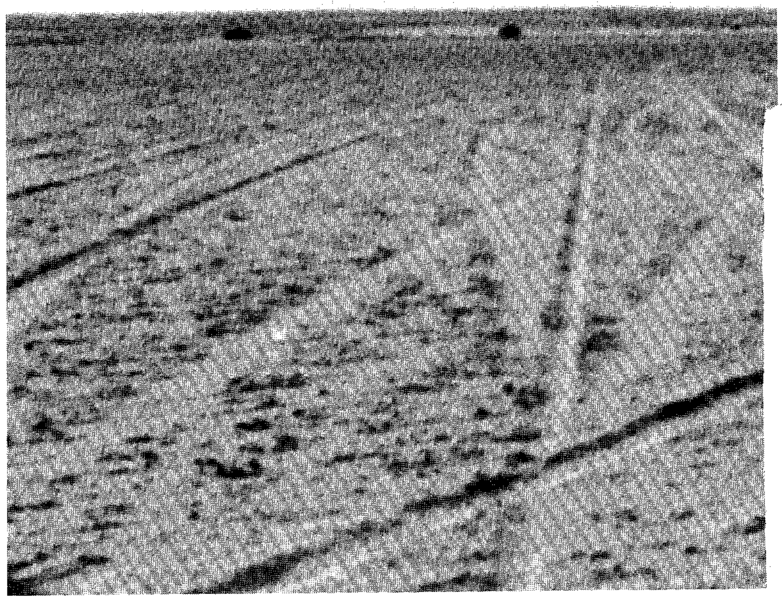
"I want a steamer that will get under way in 20 seconds, starting from a cold stop," he stipulated. "With the present steamer, it takes from two to five minutes to get up steam. If I had a fire, I wouldn't be able to get them out of the garage. Second, I want a steamer that will run from Los Angeles to San Francisco on one filling of water."

He installed the pair in rented quarters on Romaine Street out near the present Sunset Strip . . . I asked Hughes what he thought he could do with such a high-priced hand-made car if it proved feasible . . . "Well," he said defensively, "it's really just a sort of hobby for me. If we put it into production, we couldn't sell more than 25 to 50 cars a year, and we'll probably have to charge $25,000 or $30,000 each. I think some of my sportsmen friends would buy them at that price . . ."

Burns and Lewis were waiting for us at their workshop, eager to show off their masterpiece . . . The engineers assured him that it was fast starting and could run at least 400 miles on a single filling of water. "How did you manage that?" Hughes asked. The engineers proudly explained . . . "You mean the entire body contains radiators, including the doors?" Hughes asked . . . "Well tell me, then, if I'm driving along and somebody in another car broadsides me, what happens?" There was an embarrassing silence. "I'd get scalded to death, right?" Hughes said . . . Without ever firing up his $550,000 super-steamer . . . he ordered it junked. "Dismantle it, get some torches and cut it up into pieces," he said.

To TIMBUKTU– The Hard Way

The Clausers take a quick trip to the ends of the earth.



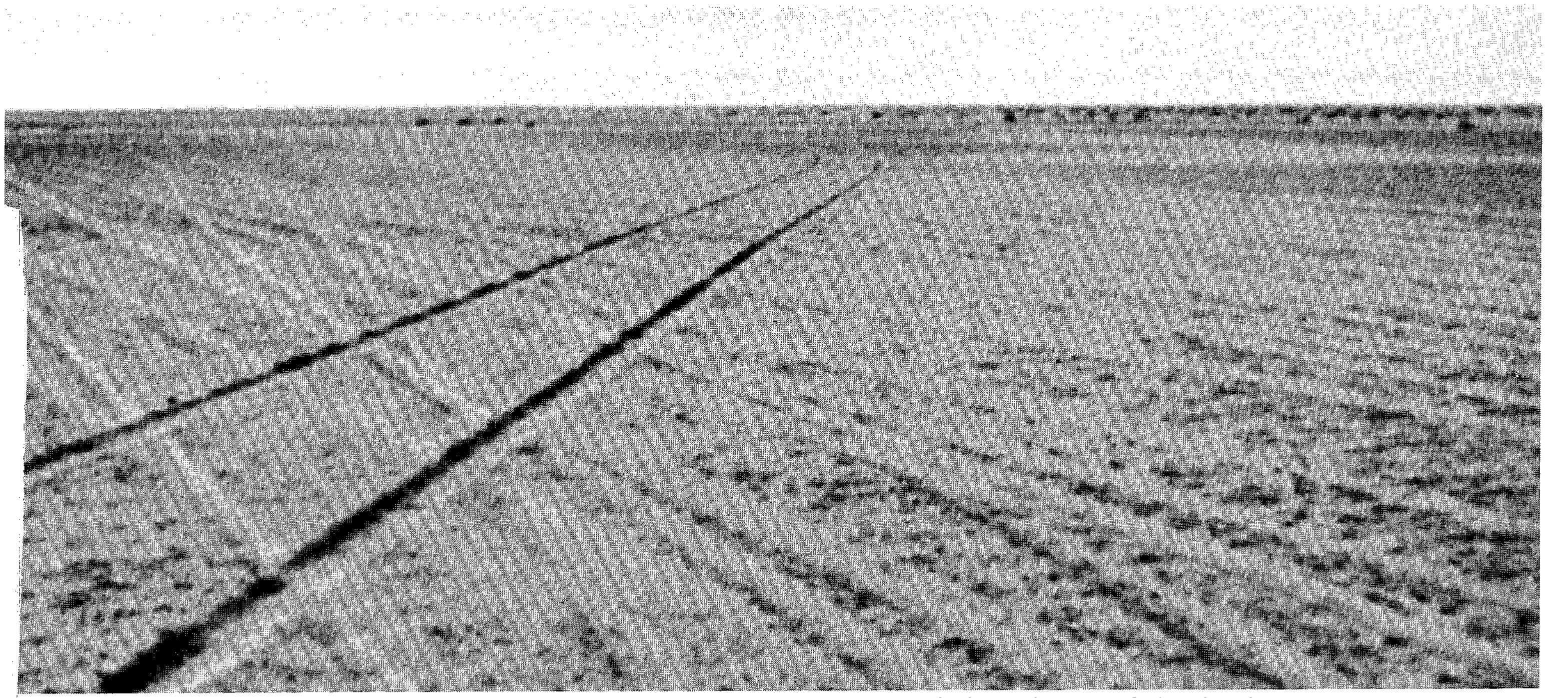
The Clausers and their Renault make a triumphal entry into Timbuktu.

Last December, Francis Clauser took time out from his chairman's duties in Caltech's division of engineering and applied science, and with his wife, Catharine, started out to spend Christmas vacation in, of all places, Timbuktu.

This was no sudden impulse. The Clausers may be adventuresome (twelve years ago they toured happily through Turkey, Iran, and Iraq in a VW) but they are not impulsive. From childhood they had both been fascinated with Timbuktu, as with all legendary far-off corners of the world. And the possibility of driving to the ancient outpost deep in the Sahara desert crystallized about a year ago when they read a travel story about the three motor routes over the desert. At least two of the routes, the story said, were "tracks of a sufficient quality that it is possible to drive across the Sahara with a sturdy vehicle." Daring travelers, it went on to say, could make the journey in Land Rovers traveling in pairs.

That was the kind of challenge that appealed to the Clausers. If it was possible to drive to Timbuktu *at all*, then they would do it on their own. Not in any convoy, and not in any Land Rover, but in a small car that would be easy to shove out of the sand if they should happen to get stuck.

The first omen of what their trip might be like came after their plane arrived in Tunis. The car rental people there, to whom they had written, were surprised to see them; in fact, they had considered their request for a car to drive to Timbuktu as a crazy American joke. It took a day, but the Clausers convinced the agency they were serious and drove off in a little Renault R4.



Over the last miles to Timbuktu the Clausers found the road wide open to them—except that they had to keep guessing where the road was.

It is 3,720 miles from Tunis to Timbuktu, and some of the stopping places are more than 700 miles apart, with *no* accommodations in between. The Clausers carried 25 extra gallons of gasoline, a plastic barrel of water, and simple food—mostly canned chicken, French bread, and bags of oranges. On six nights, when they were unable to reach one of the old French colonial hotels in desert oases, they slept, more or less, in the cramped quarters of the Renault. And they were never tempted to sleep late; by five o'clock in the morning they were usually so cold that they had to get up and move around to keep warm. One memorable night they heard a padding sound along the road and looked out to see, silhouetted against a rising moon, a great camel caravan as it passed within a few feet of them.

At the start of the trip, traveling south through Algeria to Tamanrasset, the road was well marked, and the traffic was fairly brisk—5 to 10 cars a day. On arriving at Tamanrasset, a typical sun-baked desert cluster of mud brick buildings, the Clausers found the place swarming with tourists. The reason was gasoline. The whole town had run out of it the week before, and everybody was waiting for the next tank truck to arrive. The Clausers' timing was exquisite; the truck showed up that day.

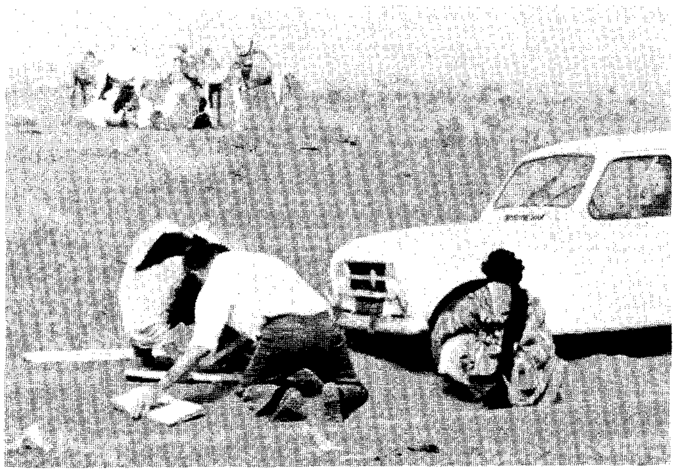
Another piece of luck—and foresight—was spotting a set of wooden planks on General De Gaulle's old atomic test site and taking them aboard. This was a precaution in case they got into deep sand somewhere up ahead. Sure enough, shortly after leaving Tamanrasset and heading south into Niger, the track became less and less distinct, traffic dropped off to about one or two cars a day, and they began running into long stretches of sand interspersed with stretches of harder material. They had to quickly work out a new driving technique.

"The trick," Clauser explains to anyone else who may ever need to know, "is to get up enough speed on the hard surfaces of the road to carry you through the alternating sandy parts."

Somewhere between 80 and 90 miles outside the town of Tahoua, the Renault's clutch began to slip. Francis went down one gear after another until finally he could make only five miles an hour full speed ahead. By 2 p.m. they had come to a dead halt.

Gasoline truck drivers are angels of mercy in this part of the world, and the Clausers hitched a ride into Tahoua with one of them. There were no new Renault clutches to be had in Tahoua, but the Clausers poked around until they found, in Francis' words, "a 52nd-hand car dealer who let us have an ancient clutch for $24. Then we rented a set of tools for $10 from a German mechanic and went out and sat by the road for two hours before we caught a 70-mile ride back to our car." Incidentally, the purchase of the clutch, along with other unforeseen expenses, had to be financed in local currency; and there turned out to be no banks or money changers in Tahoua. The Clausers were deeply touched by the trust of the local American Peace Corps young people who simply *gave* them $80 worth of CFA francs, to be returned later to the Peace Corps director when they arrived in Niamey.

They had been on the road 11 days at this point, and



Planking their way out of the sand was a routine occurrence, but on Christmas Day the Clausers had a special treat—taking the car engine apart.

it was Christmas Eve. On Christmas Day, while friends back home were gathering around their trees, the Clausers gathered around the Renault and took the engine apart, arranging the pieces in careful order on the sand. They did not work in solitude. From over the dunes appeared nomad Africans of all sizes to observe the process. For two days they sat and watched every nut and bolt come out and go back in.

The low point of the procedure came when Francis and Catharine were ready to try the new old clutch. They put it in. As they had half feared, it didn't fit.

The only salvation then lay in the *old* old clutch. Francis examined it and found that it was simply packed with sand which it had been scooping up through a hole in the clutch housing as they tobogganed over the desert. The clutch was so full of sand it wouldn't have held another grain.

They operated on it with a paring knife and a safety pin, laboriously working all of the sand out, and covered the hole with a boot made from one of the fender mud guards. Then they replaced all the engine parts and—*vive la Renault!*—it lurched forward, and ran all 70 miles into Tahoua. There they sold the ancient clutch back to the 52nd-hand car dealer for $20.

From Niamey north into Mali the track became sandier and more lonely. Over the last lap of the trip, from Goa into Timbuktu, the traffic thins out to about one car a month. Nearly all of the traffic in this area goes by boat along the Niger River or by air—all except the Clausers. So they found the road wide open to them—except that they had to keep guessing where the road *was*. Often it had been obliterated by the milling feet of goats and cattle, and much of the time it was too deep in sand for the small Renault, so that the Clausers had to follow alongside over the desert, dodging between thorn trees whose fallen branches punctured the tires until they began to look like eyelet embroidery.

Just as the last of the patches was used up, the Clausers planked their way up one last sand dune, and there, about a mile ahead, shimmering like an imaginary city in the noonday sun, lay Timbuktu.

Catching sight of their goal, the Clausers agree, was a highly emotional experience—"not only because of all our hardships," adds Clauser the realist, "but also because the two front tires were flat again."

So, they walked the last mile into Timbuktu.

Word of their arrival spread quickly, and a poignant image of the valiant Renault waiting for them outside the town stirred the hearts of a segment of the citizenry. Led by the official driver for the town's only hotel, approximately 20 people pushed the little car into Timbuktu in what the Clausers refer to as their triumphal entry.

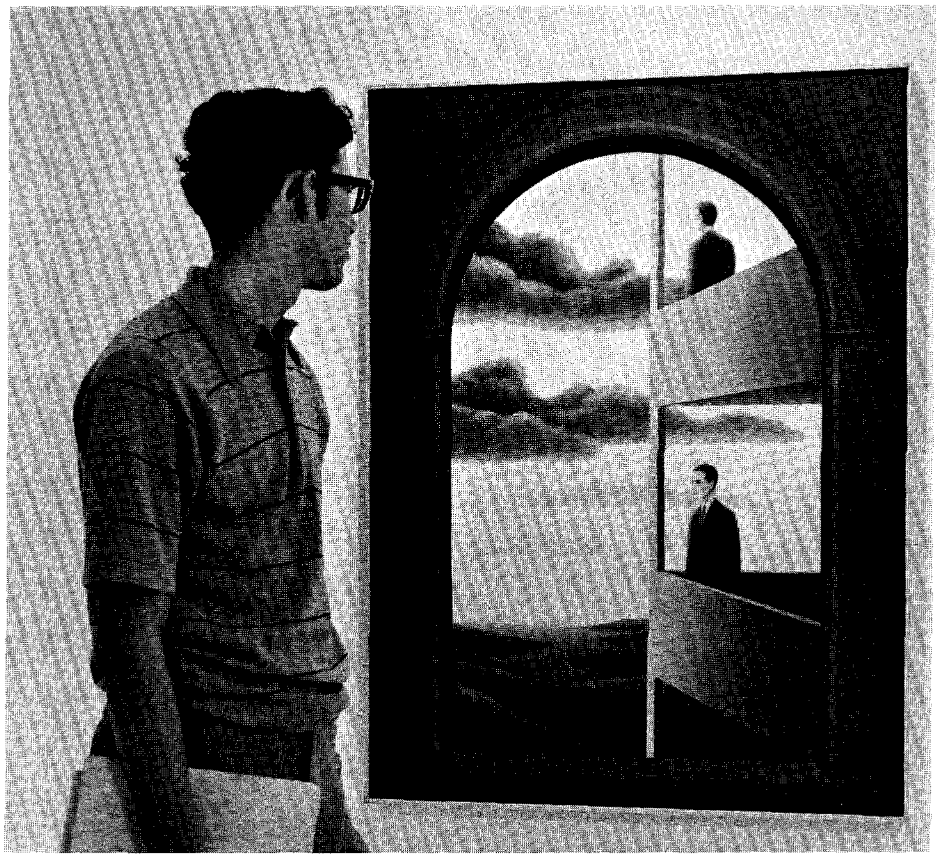
The Clausers' pilgrimage had consumed 21 days of their allotted 30, so they were running out of time. The five days they were able to spend in Timbuktu were largely devoted to trying to find a way to get the Renault back to Tunis and themselves back to Pasadena. In photo-finish style, two Peace Corps volunteers turned up—desperate for transportation to Tunis and in the nick of time for the Clausers.

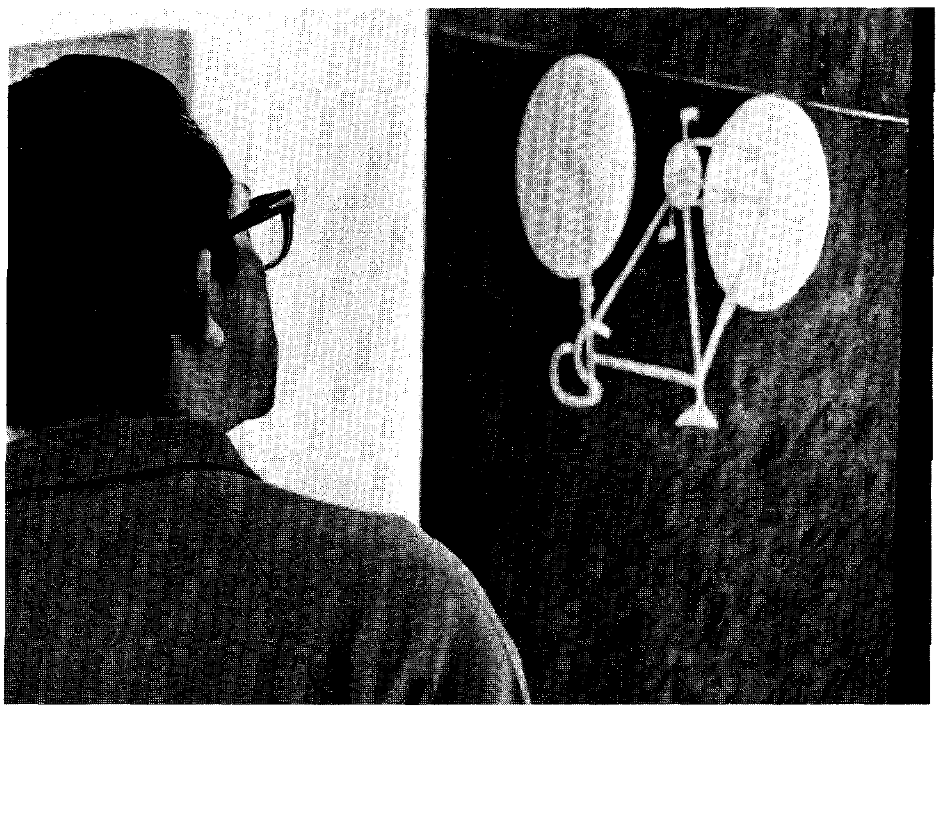
To those who say, "What a terrible experience!" the Clausers only smile. And Catharine adds: "We found it all intensely exciting. Everybody has different ideas of how he likes to travel and where he wants to go. We happen to like this kind of thing."

Now that the drive to Timbuktu is behind them, they are beginning to think about the next trip. So if a travel story about Outer Mongolia turns up soon, two people in the Pasadena area will probably clip it out joyfully.

But . . . is . . . it . . .

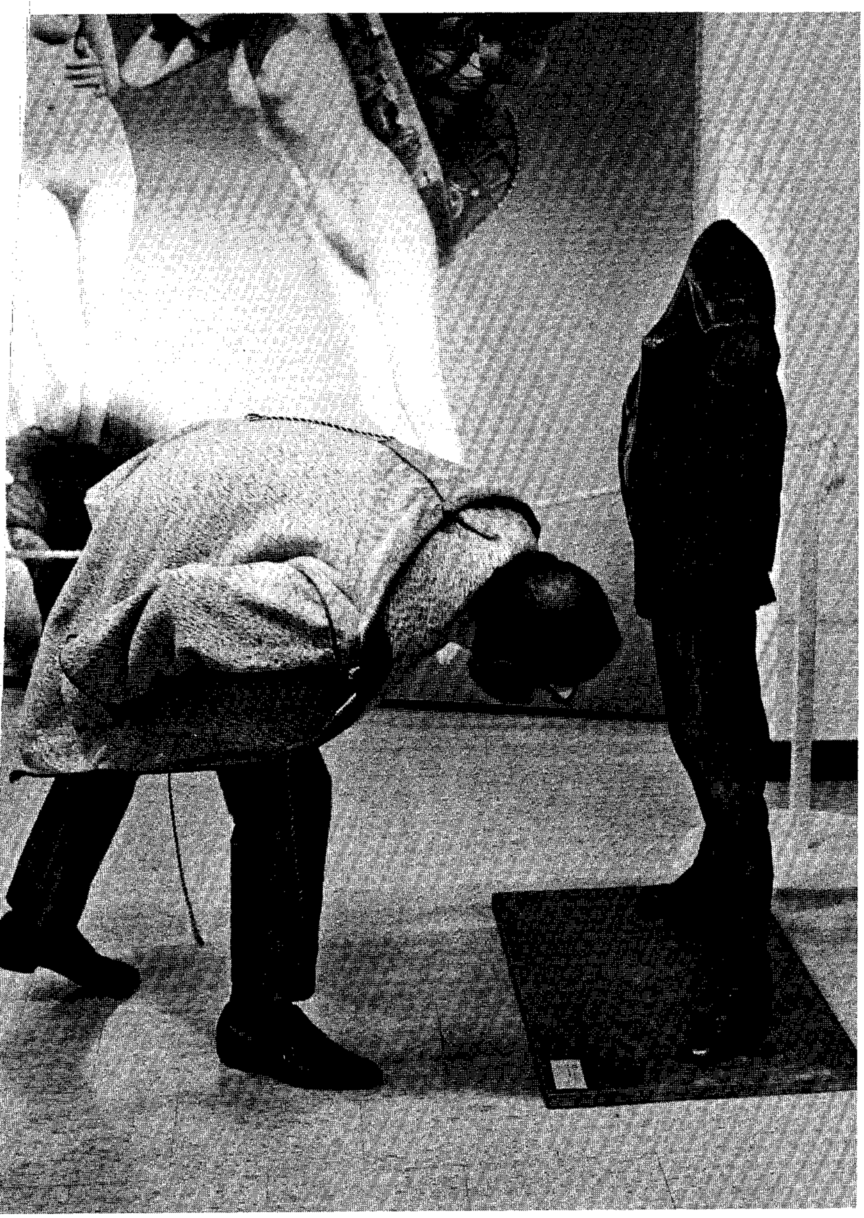
. . . Art?

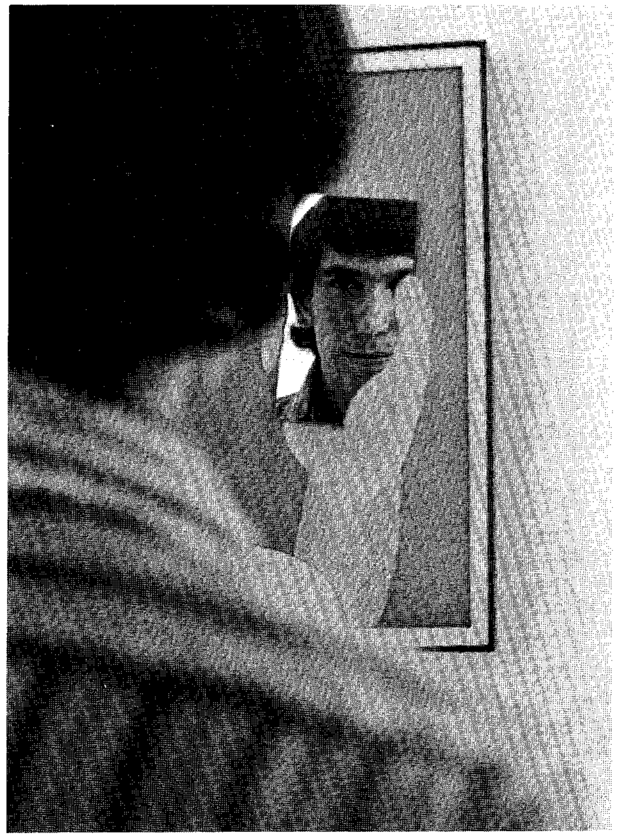




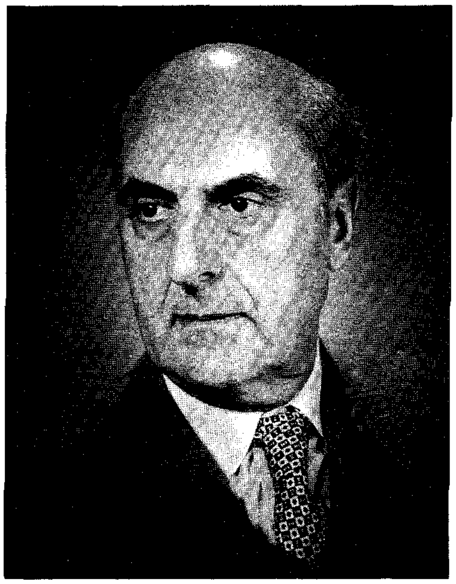
Well . . .

it's "Surrealism is Alive and Well in the West," the most recent exhibit in Caltech's Baxter Art Gallery—and no matter what your opinion of the art is, you must admit that the viewers put on a show of their own.





László Zechmeister
1890-1972



László Zechmeister, professor of organic chemistry emeritus, died in Pasadena on February 28 after an extended illness. He was 82.

A native of Hungary, Dr. Zechmeister received his education at the Eidgenössische Technische Hochschule in Zurich, Switzerland, where he was awarded his Dr. Ing. degree in 1913. From 1921 to 1923 he was an instructor in the Royal Danish Agriculture and Veterinary Academy, and from 1923 to 1940 was professor of medical chemistry and director of the chemistry laboratory of the medical school of The University of Pécs in Hungary. He joined the Caltech faculty in 1940 and became professor emeritus in 1959.

From 1912 to 1914 Dr. Zechmeister taught at the Kaiser Wilhelm Institute of Chemistry in Berlin. At the outbreak of World War I he was inducted into the army and sent to the front, where he was wounded twice and eventually taken prisoner by the Russians. During his subsequent two years of imprisonment, he taught himself English with the aid of one of the few books available to him—a Russian-English dictionary. Escaping once, he made his way to the Russian border before being recaptured and returned to prison. At the end of the war—with the complete collapse of the Russian army and government—he was able simply to walk away from the prison and home to Hungary.

After a period as a scientific leader in a pharmaceutical factory in Hungary, in 1921 Zechmeister was offered a teaching appointment in Denmark—contingent upon his learning Danish in three months. He succeeded, and spent two years in that country before returning to Hungary.

In 1940, at the invitation of Linus Pauling, then chairman of the division of chemistry and chemical engineering at the Institute, Zechmeister came to Caltech—barely avoiding internment in Hungary for the duration of World War II. The illness of his wife kept her from accompanying him, and she died in Hungary in 1941. In 1949 he married Elizabeth Sulzer of Zurich. She survives him, as do two sisters, a stepdaughter, and a nephew, who live in Budapest.

Zechmeister was widely known for his research in many areas of chemistry, among which were methods of chromatography and spectroscopy, and studies of polysaccharides, natural pigments, naturally occurring fluorescent compounds, and stereochemical phenomena. He was the author or co-author of more than 250 papers and of three textbooks. For nine years he was a member of the editorial board of the *Journal of the American Chemical Society*.

For many years he had a wide influence on international science through his founding and editing of the first 27 volumes of *Progress in the Chemistry of Organic Natural Products*, a review journal published annually in English, German, and French. Contributing authors were among the world's outstanding authorities in the field. He often referred to his wife as his associate in this work, because of her assistance in both editing and translating material.

In 1949 Zechmeister was awarded a Guggenheim fellowship in order to lecture in European universities. He was an honorary member of the Hungarian Academy of Sciences and holder of its Grand Prize; he was also a member of the Royal Danish Academy of Sciences. He received the Pasteur Medal of the French Biochemical Society in 1935 and the Claude Bernard Medal in 1949. In 1962 he received the Labline Award of the American Chemical Society for his work in chromatography and electrophoresis. Dr. Zechmeister's most recent honor arrived in Pasadena in January of this year: an honorary degree of Doctor of Medicine from The University of Pécs in recognition of his important contributions to chemistry and its relations to medicine.

One of Zechmeister's favorite nonacademic activities was tennis. Despite all his feelings about maintaining the dignity and comportment expected of a European professor, he regularly played Sunday morning tennis with Julian, the Athenaeum headwaiter. The Athenaeum served breakfast in those days, and also required that all men wear coat and tie. On Sunday mornings Zechmeister met this situation by putting on his white tennis shorts *and* a coat and tie—and startling the Athenaeum hostess the first time he appeared in this garb. "Good heavens," she moaned to the manager, "Professor Zechmeister has forgotten his pants!"

Though he became professor emeritus in 1959, Zechmeister remained active in reading and research at Caltech, and until he became ill last summer, he swam regularly at the Caltech pool. At his own request, no services were held.

The Month at Caltech

New Chairman for Geology Division

Barclay Kamb

Barclay Kamb, professor of geology and geophysics, will become chairman of the division of geological and planetary sciences on July 1. He succeeds Eugene Shoemaker, who has been head of the division since January 1969. Shoemaker, a Caltech alumnus (BS '47, MS '48), is resigning the chairmanship to devote full time to teaching and to his research on the origin and history of the moon, the geology of the Grand Canyon area, and paleomagnetic studies.

Kamb is also a Caltech alumnus (BS '52, PhD '56) and has been a member of the faculty ever since he received his doctorate. An authority on the structure of crystals and of glaciers, he is studying the flow properties of ice and the structures produced in ice by flow. From this study of ice Kamb hopes to learn more about the deformation of rocks at high temperatures and pressures deep in the earth.

His research also includes determination of the atomic structure of minerals and the relationships between these structures and the various forms of ice. He was awarded the Mineralogical Society of America award for work on minerals in 1968.

In addition to his teaching and research at Caltech, for the past five years Kamb has been a research collaborator at Brookhaven National Laboratory in New York, where he has used neutron diffraction to study forms of ice.

In 1960-61, Kamb held a Guggenheim fellowship in Switzerland where he did research on glaciers. He has directed Caltech's research program on the Blue Glacier on Mt. Olympus in Olympic National Park, Washington, since 1964. He is a fellow of the Geological Society of America and of the American Geophysical Union.

Ground Broken for New Mudd Building

Caltech's newest building is officially under way. Aided by a set of gilded shovels, the symbolic ground breaking for the Seeley G. Mudd Building of Geophysics and Planetary Science took place on March 7. The building should be finished in December 1973.

This Mudd building is the third campus structure to be financed by the Mudd family (the other two being the Seeley W. Mudd Laboratory of Geological Sciences and the Millikan Memorial Library). A grant from the Department of Health, Education and Welfare has also been provided to help defray the costs.

Speakers at the ground breaking ceremony included President Harold Brown; Arnold Beckman, chairman of the board of trustees; Eugene Shoemaker, chairman of the division of geological and planetary sciences; and Clarence Allen, professor of geology and geophysics.

Located on the site formerly occupied by Culbertson Auditorium, the new structure will have 71,000 square feet of floor space on its five floors—three above ground and two below. The Helen and Roland W. Lindhurst Laboratory of Experimental Geophysics will be a part of the building, which will also contain faculty offices, libraries, laboratories for research and teaching, special super-clean and shock-wave laboratories, shops, conference and seminar rooms, and a computer laboratory with direct ties to Caltech's southern California seismological network.

With this addition to the existing geology complex on campus, most of the geographically scattered activities of the division will be brought together. Faculty, staff, and students now located at the Donnelley Seismological Laboratory in the San Rafael Hills will move into the new building. Kresge Seismological Laboratory, which is near Donnelley and which has many of its instruments anchored to bedrock, will continue its operations.

Hans Liepmann

Director for GALCIT

Hans W. Liepmann, professor of aeronautics, has been appointed director of the Graduate Aeronautical Laboratories at Caltech (GALCIT). Liepmann, a native of Germany, has been on the faculty at Caltech since 1939. He is an authority on shock waves, plasmas, and flows of rarefied gases, and is currently occupied with research in the fluid mechanics of Helium-2.

Widely honored for his contributions to aeronautics, Liepmann is a member of both the National Academy of Sciences and the National Academy of Engineering, and is a recipient of the Ludwig Prandtl Ring—the highest honor conferred by the German Society for Aeronautics and Astronautics.

GALCIT, which was established in 1928, has had only two other directors: Theodore von Kármán, director from 1928 to 1949, and Clark B. Millikan, who directed it from 1949 until his death in 1966.

Graduate Degree in Social Science

There is—usually—nothing startling about the faculty voting a new degree program into existence at Caltech. But the agenda for the faculty meeting on February 21 called for a vote on a genuine innovation—the first qualitatively different program at the Institute in 50 years. And it was approved with only two dissenting votes.

Starting next fall, Caltech will offer a Graduate Degree Program in Social Science. This is not only a first for the Institute as a whole; it marks official recognition of the ability of the Division of Humanities and Social Sciences to offer graduate education leading to the doctor's degree as in the other divisions of the Institute.

The gestation period for the program was lengthy. In fact, says Robert Huttenback, chairman of the division, "I doubt if there has ever been any program at the Institute that has been subjected to such long-term, frequent, and minute scrutiny."

A graduate degree program in the general area of the social sciences has been under consideration within the division for several years. By two years ago, a group (the chief protagonists being economists Lance Davis, Roger Noll, and Burton Klein; anthropologist Thayer Scudder; and Frederick Thompson, professor of applied science and philosophy) had hammered out the basic outlines of a three-pronged program balanced between hard analytical social science; field work in real-life problem areas; and measurement and testing using econometrics techniques, gaming, and laboratory experiments as well as computer simulation. For another year this basic outline was discussed both within and outside the division, a process that honed it to a final statement of aims, requirements, and curriculum. In the fall of 1971, after preliminary study by the Institute Administrative Council, the proposal went to the Graduate Study Committee.

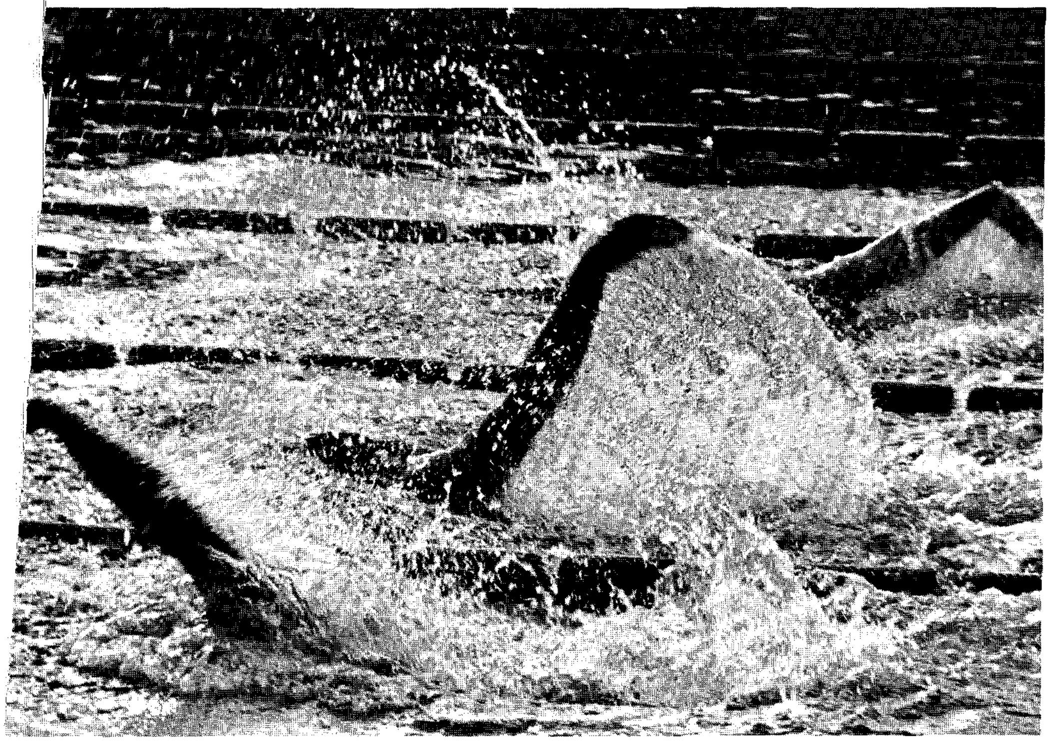
The Graduate Study Committee not only discussed the program at length but called in two outside consultants to evaluate it. Their report was favorable; the faculty board approved; and on February 21 the whole faculty voted the new PhD program into the Caltech curriculum.

Admission into the graduate degree program in social science will require, first of all, a thorough grounding in mathematics. Once a student is admitted, he or she will be expected to take about a year and a half of tightly structured course work in such subjects as micro economics, political science, psychology and organizational behavior, econometrics, and computer modeling and data analysis. This will be followed by another year and a half of research with emphasis on applications and testing of theory.

While the course work is similar to that of analytical economics majors in many graduate schools, the focus of the research for the Institute's students will be quite different. They will have to do it in areas like anthropology and political psychology, so that they will get some of their information about institutions outside the hard analytical areas. Specifically, they will be doing research with, for example, the Environmental Quality Laboratory, the environmental engineering science program, the social problems section of the Jet Propulsion Laboratory, and the population program.

"While some of them may come out looking not very different from economics majors elsewhere, others will come out looking very different indeed," says Lance Davis, professor of economics. "We'll turn out, for instance, some highly analytically trained graduates whose main interest will be in fields like political science or anthropology. We're going to try to use what theory we have to develop policies that make some sense in terms of social problems right now."

Once the program is under way, approximately five students will be admitted each year. Since the basic facilities and a 25-member faculty in the social sciences are already available, the division hopes that—late as it is to recruit graduate students for next fall—it may still be possible to bring in three for starters in October.



Here It Comes Again

The Loch Ness Monster hasn't been making much of a splash lately—but his little brother made this brief appearance in the Caltech pool recently, during the annual All-Conference Swimming Meet.

Some Faculty Honors

Fritz Zwicky

Fritz Zwicky, professor of astrophysics emeritus, has been awarded the Gold Medal of the Royal Astronomical Society for "his distinguished contributions to an understanding of the constituents of the galaxy and the universe." He will attend the November 10 meeting of the society in London to accept the medal in person.

Zwicky, 74, predicted and discovered compact galaxies, pioneered in the discovery and understanding of supernovae, and for many years has done research on the distribution of matter in the universe. He has just issued a catalog of 4,000 compact and post-eruptive galaxies; several years ago he supervised the production of a six-volume catalog of 40,000 galaxies and 10,000 clusters of galaxies.

Rochus Vogt

Rochus Vogt, professor of physics, has been appointed to serve on a 12-member panel on Alternative Approaches to Graduate Education. In the 18 months allotted for its studies, the panel will meet to discuss and make recommendations on such subjects as the growth of external degree plans, the trend toward non-graded study, the concept of part-time, self-paced study, innovations in graduate study, and the educational needs of disadvantaged groups and of potential graduate students among older persons. The panel is jointly sponsored by the Council of Graduate Schools in the United States and by the Graduate Record Examination Board.

George Housner

George Housner, professor of civil engineering and applied mechanics, has been appointed by Governor Ronald Reagan as a member of the governor's Earthquake Council. This council will coordinate research programs, recommend legislation, and work to develop an earthquake warning system. Clarence Allen, professor of geology and geophysics, will serve as Housner's alternate. Allen is a member of the State legislature's committee on earthquakes.

William Lear has ideas about eradicating air pollution—and will travel to explain them.

Betting on Steam

Seventy-year-old William Powell Lear, the industrialist-inventor of the first car radio and the first jet airplane autopilot, is known as "the man who not only invented the impossible but made it pay."

He now wants to be known as the man who eradicated air pollution.

Speaking to a capacity crowd at Ramo Auditorium on March 6, he said his goal is to "develop a smog-free automobile—even if it takes the last of my wife's millions."

He has placed his bets on the steam turbine as the most likely candidate and has gambled $8 million of his $30 million personal fortune on the engine. In addition, each month he pumps $250,000 into the Lear Motor Corporation factory, located—appropriately enough—near the gamblers' paradise of Reno, Nevada.

The results of this gamble are two prototype engines. One is installed in a Chevrolet sedan and is currently undergoing trials on a test track near the factory. The other is in a General Motors bus being road-tested before delivery to the city of San Francisco in April.

Lear's aim is to produce a steam car that not only pollutes less than an internal combustion engine automobile, but that costs less as well. He has come close to this ideal. The heart of his steam turbine design, which he calls a "vapor cycle power plant," is a 30-pound turbine that has only one moving part and turns out a healthy 125 horsepower. While the prototype Lear engines would cost $50,000 apiece as currently designed, he expects that mass production would reduce this to about $250 an engine.

A vapor generator (boiler) contains coiled stainless steel tubing and a kerosene-fed burner that heats the steam fluid within the tubing. A throttle valve controlled by the accelerator determines the amount of superheated steam that will flow into the turbine. Running at speeds up to 60,000 revolutions a minute, the turbine (through reduction gears) drives the accessories, such as the water feed pump, fans, and generator—and also an automatic transmission. The steam is exhausted and returned to a condenser where, through heat exchange, it is converted to fluid and recycled.

The key to the Lear design is the size of the turbine. Early concepts of the steam turbine were large and heavy and plagued with poor efficiency. A smaller, more efficient turbine could be built, but only if it were driven by a vaporized fluid of relatively high molecular weight. (Water is not used because it freezes in cold weather, takes too long to come to a boil, and has too low a molecular weight.) Lear specified that this fluid, called "Learium," must be chemically stable, non-toxic, non-corrosive, non-freezing, and possess good heat transfer characteristics. After analyzing and rejecting several hundred chemical compounds, his researchers have come across a form of fluorinated hydrocarbon which appears acceptable.

Lear's engineers are looking for ways to cut down the cost of the engine. The rotors in the prototype engines cost about $90 apiece. The engine design calls for two of them. By using a new manufacturing technique, costs of these particular components in a production engine may be reduced to 96 cents a pair. Also, by using air bearings at 50 cents each instead of ball bearings at about $4 each, Lear hopes to produce the engine's turbine for less than $30.

A considerable effort has been made to improve the efficiency of the engine. Every bit of efficiency gained in the engine means less horsepower used running auxiliaries and more horsepower delivered to the wheels. The turbine has an efficiency now of 74 percent, compared with 60 percent for more conventional designs. The condenser fan was redesigned to boost its efficiency from 40 to 65 percent.

For a brief period it appeared that the Lear engine would not be as pollution-free as its developer had hoped. If it were to meet the 1975 emission standards, it had to reduce hydrocarbons, oxides of nitrogen, and carbon dioxides simultaneously. But designs which minimized two of these pollutants caused the third to skyrocket. A few months ago Lear hit upon a scheme (which he is patenting) for burning the fuel below 2000 degrees Fahrenheit, which will enable the engine to meet not only the 1975 requirements but the more stringent standards anticipated for the future.

Books

GEOLOGY
Field Guide to Southern California
by Robert P. Sharp
William C. Brown Company
Publishers $2.95

Reviewed by Enid H. Bell
Editorial Assistant
Division of Geological and Planetary Sciences

This is a book for everyone who has an inherent interest in natural history and who enjoys travel. It is an authoritatively written layman's guide to geologic features in southern California. Robert P. Sharp, professor of geology at Caltech, has devoted most of his life to studying the processes that shape the earth's surface. He is especially interested in glaciers and in desert landscapes. "Among scientists," he says, "geologists are reputed to have as much fun as anybody because of their understanding and appreciation of the natural environment." His objective is to share that fun with others.

Southern California runs the gamut of scenic and geologic possibilities, and many of us, untrained in geology, drive high-speed highways unaware of the area's interesting features. Sharp's book stimulates the interest of the non-geologist, and is a helpful guide for those already acquainted with the field.

The book is divided into three parts, the first actually being a "mini" course in basic geology. The second section furnishes descriptions of geological features in the nine *natural* provinces of southern California. The third part, constituting more than half the book, is a series of self-guiding field trips which assist users to recognize geological features that can be seen while traveling by automobile.

The book is filled with interesting historical highlights and little-known facts. Are you aware that the basement relief of the Los Angeles Basin is 37,000 feet—exceeding by 7,000 feet that of Mt. Everest? And that over 20 million years ago the Los Angeles Basin was dotted with volcanoes spewing out smoke, fumes, and ash—Tertiary *smog*, I presume.

Southern California is laced with earthquake faults; many of our prominent landmarks are close to the San Andreas or one of its "friendly neighborhood branches." For example, the Huntington Hotel and the Huntington Library are on the scarp of the Raymond fault, as is the hillside stretch of the turf course at the Santa Anita racetrack. The San Jacinto fault passes directly under the principal buildings of the San Bernardino Valley College. We also learn that San Francisco (most of which lies east of the San Andreas fault) and Los Angeles (which lies west of it) are steadily drawing closer to one another by several inches per year.

Reading about geology is fine, but actually seeing some is much more satisfying. The trip guides and annotated sketch maps allow the users to make their own firsthand observations. The focus is upon two routes richly endowed with striking geological features. One trip is from the Los Angeles Basin to Death Valley and the other is from the Los Angeles Basin to Mammoth. The trips are divided into segments and the segments can be arranged in various combinations.

This book was written for out-of-doors people. As "aborigines" (according to Sharp, this includes anyone who has lived in the area for more than 10 years), my husband and I had travelled about southern California for longer than we care to admit. We had reached the point where we felt we had seen just about every place dozens of times and, frankly, our trips had become something less than exciting.

When we were privileged to review an early draft of Professor Sharp's book, we decided to try one segment of the field trip guide just to see if we could find the features he wanted his geologically untrained readers to see. Armed with nothing more than curiosity and the trip guide, we were delighted to find how easy he had made it for us. Marginal symbols and occasional mileage references in the guide, and correlated notations on the sketch maps, made the special geological attractions—even the subtle ones—easy to locate and identify.

We were more than a little excited when we found the roadcut just past Monte Cristo ranger station along the Angeles Crest Highway which exposes a huge mass of *anorthosite,* a type of rock which may be a major constituent of the lunar highlands. Professor Sharp tells us "anorthosite masses are rare, and we are fortunate to have one in our own backyard." Picking up samples of the same kind of rocks the astronauts went to the moon to find made our trip a memorable adventure.

Rock Creek and McGee Creek in the southern Sierras have often been sites for our family camping trips. We hadn't realized that the meadows where we pitched our tent were results of 10,000-year-old glacial deposits, and that the waterfalls and cascades we enjoyed were streams descending from *hanging* valleys carved by glaciers. We recognized other geological features as moraines and alluvial fans in this area.

Surely this book belongs in the map compartment of every automobile in the southern California area.

OSCAR MANDEL'S COLLECTED PLAYS
Volume Two
Unicorn Press .... Clothbound $7.50
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Volume Two of Oscar Mandel's plays is, like Volume One, a collection of six dramatic works—and of similar wit and wisdom. (Volume One was reviewed by J. Kent Clark, *E&S,* November 1971.) This volume includes "The Monk Who Wouldn't," "The Fatal French Dentist," "Professor Snaffle's Polypon," "The Sensible Man of Jerusalem," "Adam Adamson," and "Of Angels and Eskimos." Most of these plays have already been performed for live or television audiences. Mandel, a member of the Institute faculty in English since 1962, is the author of a number of other books, including works about drama, a collection of short fables, and two volumes of translations of French comedies.

Letter

Pasadena

EDITOR:

Your mention (*E&S,* February, page 21) of the "anatomical agonies from the slatted wood seats" of Culbertson evoked resonances in my caudal vertebrae, not to mention my gluteus maximus. But I am bemused by the second sentence of the article: "The demolition was not solely for the sake of progress but also to make room for a new laboratory of geophysics and planetary science." Are we to infer that the construction of such a laboratory is not considered to be progress?

CHARLES B. JORDAN, '36

The author of the Culbertson article assumed that use of the word "solely" could lead only to the inference that factors in addition to progress were part of the decision to raze Culbertson. Obviously, one writer's assumption is not necessarily every reader's inference.

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